Human Factors Ground Test Assessment and Protocol Development for Space Radiation Protection Concepts

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Human factors evaluations and procedures were developed in a series of ground tests in order to assess novel radiation protection concepts developed by industry leaders in aerospace. In addition, NASA's current prototype space radiation protection vest and storm shelter concept were tested using the newly drafted human factors assessment materials. Evaluation procedures and wearable garment technology were tested at Johnson Space Center (JSC) using a small sample of current NASA crewmembers for garment testing. Results for the garment analysis indicated that the current radiation vest ultimately did not hinder task performance or impede mobility. Results from the storm shelter analysis indicated that crew were able to construct the shelter within the time allotment without difficulty and limited reference to instruction materials. These data will be used to further develop wearable garment technology and storm shelter designs. Newly developed procedures will be used in future ground tests to further assess novel radiation protection concepts.

Introduction

The primary objective of this work was the preparation and execution of human factors evaluations to assess radiation protection concepts developed by NASA and private aerospace companies. A variety of NASA garments, blankets, and sleeping bags were previously developed in conjunction with private industry to provide astronauts with radiation protection against solar particle events (SPE) during space travel (Waterman et al., 2016). Most of these items utilize polyethylene, or a similar hydrogen rich material, as the primary shielding material (Ferl et al., 2010). During the 2012-2014 time period, this work was extended under NASA's Advanced Exploration Systems (AES) RadWorks Project. A new shielding garment concept was developed, which utilizes a water bladder, and new solar particle event storm shelter concepts were created (Baiocco et.al, 2018; Latorella and Hanson, 2014). One of the storm shelter concepts augmented the astronaut crew quarters with water walls and pantry type shelves, and another relied on the reconfiguration of onboard food, water, and supplies to create a safe haven. In 2014, an initial set of human factors tests was performed on those two storm shelter concepts, providing a better understanding of the set-up time required and astronaut training needs (Latorella and Hanson, 2014).

Under the Next Space Technologies for Exploration Partnerships (NextSTEP), NASA recently awarded contracts to several companies to develop human exploration habitation systems for a Lunar Orbital Platform-Gateway (LOP-G) habitat. This activity includes the development of prototypes for some vehicle systems, which will be utilized in future ground tests. In preparation for the testing of systems delivered by the NextSTEP contractors, the NASA NextSTEP team first performed internal ground tests, utilizing existing technology, with the goal of developing procedures that will be used in future assessments of novel systems delivered by contractors.

The secondary objective of this work was to use the newly drafted human factors assessment procedures to test the current version of NASA's prototype radiation vest and extend the 2014 storm shelter testing. The purpose of the vest assessment was twofold: Crewmember performance wearing the vest and the usability of the garment had not been previously examined. Additionally, human factors evaluations were not previously drafted to assess the multiple contractors expected to deliver radiation concepts to the NextSTEP ground tests. The purpose of the storm shelter analysis was to develop an effective human factors protocol to assess storm shelter concepts delivered by contractors, and also to gather additional data in order to extend the 2014 storm shelter assessments.

NASA's current radiation vest was developed in conjunction with ILC Dover and can be seen pictured in *Figure 1*. Weighing approximately 31.25 lbs., the garment was carefully designed with ideal anthropometric sizing and adjustability (Gordon et al., 1989). The fabric exterior is made from

Tecasafe® and the interior is composed of layered polyethylene sheets (Ferl et al., 2010).

Method

The protocols for these assessments were reviewed and accepted by the NASA Institutional Review Board at Langley Research Center (LaRC) and Johnson Space Center (JSC).

The first set of ground tests took place in October 2018. To prepare for the first ground test, the radiation vest repeatedly traveled from NASA LaRC to JSC in order to develop an effective human factors protocol to use in the ground test evaluations. JSC conducted several practice tests of the radiation vest in their mock habitat facility to prepare for the first ground test. A human factors protocol was drafted prior to the first practice session. The protocol was subsequently revised in additional practice sessions in order to have a finalized protocol to evaluate radiation protection garment prototypes delivered by contractors during the second set of ground tests in FY19.

The human factors protocol focuses on crewmembers' ability to move and perform simple movement tasks while wearing the radiation vest. The protocol requests crewmembers to bend forwards, backwards, side-to-side, and walk back and forth in the habitat. The protocol also asks crewmembers to walk past each other in the habitat while wearing the radiation vest, reach up and down to determine mobility limits, and requires crewmembers to fold and unfold the radiation vest in a specific manner. Crewmembers were asked to don the radiation vest by themselves and then to don the garment with help from a partner. Reaction time data were recorded for all of the aforementioned tasks and items, and preliminary results will be discussed briefly in the "Results" section, and will also be reported in detail in future manuscripts.

Questionnaires were also completed by crewmembers to gather additional data, and record comments and suggestions regarding the physical garment and the human factors protocol. From the assessments at JSC, a finalized human factors protocol was developed and used during the JSC ground tests in October. The human factors protocol will also be used to evaluate the contractor prototypes of radiation protection garments in the second set of ground tests in FY19.

In addition to garment analysis, a human factors protocol was also developed to assess radiation storm shelter prototypes, which are also expected to be delivered by contractors in FY19. To develop the protocol, reconfigurable logistics were acquired from various personnel at JSC and also shipped to JSC from LaRC. The reconfigurable logistics (including mid-deck locker trays, Cargo Transport Bags (CTBs), bungee cords, D-rings, and foam bricks) were used to build a radiation storm shelter in the mock habitat at JSC. The human factors protocol relayed instructions for constructing the storm shelter to crewmembers. Reaction time data and general observations were recorded as the crewmembers used the reconfigurable logistics and human factors protocol to construct the storm shelter. Crewmembers also completed questionnaires and provided feedback about the general storm shelter design and human factors protocol. The reconfigurable logistics assessment extended and improved previous tests by considering the time it takes astronauts to gather the logistics used from their stored locations within the habitat; the ability to create the shelter, put everything back, and repeat the process.

Participants

In total, eight crewmembers participated in the garment analysis and storm shelter assessments. There were three garment analysis assessments; two practice sessions and one official ground test assessment. Two crewmembers participated in each assessment, for a total of six. Additionally, two crewmembers participated in the standalone storm shelter assessment.

Test Objectives

The overall objective of these assessments was to develop human factors protocols that will be used to assess future radiation protection concepts. As upcoming ground tests will likely include either radiation protection garment prototypes or storm shelter designs, effective human factors protocols are necessary to fairly and accurately assess and compare concepts. Other objectives included assessing overall mobility, task performance, and reaction time while wearing the radiation vest. Reaction time, logistics selection and placement, and errors (committed and omitted) were assessed for the storm shelter standalone assessment.

Task

Radiation Vest Analysis

Crewmembers were welcomed and introduced to the experimental session. Crewmembers completed the Informed Consent form and preliminary questionnaires, and then were provided a brief demonstration from the researcher on how to properly put on and remove the radiation vest. The researcher also briefly explained the movement exercises. Once the experimental session started, the first crewmember was asked to put on the vest within the habitat. The crewmember then walked forwards, backwards, side-to-side, and rotated 90°. The crewmember then removed the vest, and put the vest back on with help from a partner. The crewmember was then asked to walk past the other crewmember in the habitat, and then reach to touch the top left and bottom right corners of a wall. The crewmember then walked through the habitat wearing the radiation vest multiple times, and then removed the vest. Following the assessment, crewmembers completed post-task questionnaires. Reaction time data and general observations were recorded for all tasks by the researcher. This session was repeated on three separate trips to JSC with six different crewmembers total.

Figure 1. (Image Credit: NASA) Radiation vest pictured on mannequin.

Storm Shelter Assessment

Similar to the radiation vest assessment, crewmembers were welcomed and introduced to the experimental session. Crewmembers completed the Informed Consent and filled out preliminary questionnaires. The instructions were explained to the crewmembers, and they were shown the logistics placed outside of the habitat. The logistics included: mid-deck locker trays, CTBs, bungee cords, D-rings, and foam bricks. Crewmembers were instructed to use the reconfigurable logistics to construct two storm shelter walls, encapsulating themselves within the habitat to prepare for a mock solar particle event. The crewmembers first used the mid-deck locker trays, CTBs, and foam bricks to construct the rear storm shelter wall. The requirements were that the logistics used to construct the wall needed to be flush with the floor, ceiling, and habitat walls. The crewmembers stacked the locker trays and other logistics and created the rear storm shelter wall with minimal gaps and spaces. They then used the remaining logistics to construct the front wall and complete the storm shelter. Crewmembers were given specific instructions detailing how many logistics to use for each wall, and they were able to construct both walls quickly and with minimal difficulty. The researcher recorded reaction time data, deviation from instructions, and how many times the instructions were referenced during the assessment. Following the completion of the storm shelter, crewmembers were instructed to return all logistics to their original modules located outside the habitat, and to complete post-task questionnaires.

Figure 2. (Image Credit: NASA) Constructed rear wall of storm shelter in JSC habitat.

Results

Radiation Vest Analysis

Initial data analyses indicated that the vest caused no significant mobility hindrance or task performance interference. Reaction time analyses indicated that it was significantly faster to put on and remove the vest with help from a partner; M = 18.76 s (mean time to remove the vest with help from a partner), M = 32.64 s (mean time to remove vest without help from a partner). Reaction time analyses indicated that the time to walk across the habitat while wearing the vest was approximately equal to the time to walk across the habitat without wearing the vest; M = 40.61 s (mean time to walk across habitat wearing vest), M = 33.76 s (mean time to walk across habitat not wearing vest). Crewmembers commented that the weight of the vest (≈31.25 lbs.) was not uncomfortable or degrading to task performance.

Storm Shelter Assessment

The overall goal for the storm shelter was that crewmembers were able to completely construct both storm shelter walls in under 20 minutes. Even with a mistake regarding the orientation of a column of locker trays, both walls were easily completed within the 20-minute goal. The time to complete the rear wall = 4.30 s. The time to complete the front wall = 8.10 s. The total time to construct the storm shelter = 12.40 s. Crewmembers referenced the instructions five times during the assessment. Both crewmembers were able to carry three locker trays at a time from the logistics module to the habitat.

Following the construction of the storm shelter, crewmembers completed a post-run questionnaire. Participants were asked to rate (on a seven-point scale, with anchors: 1= Not at all, 7=Perfectly acceptable) their agreement with the statements "How acceptable is it to complete the shelter in 20 minutes?" and "How acceptable is it to complete the shelter in 10 minutes?" Only run number had a significant effect on acceptability ratings for completion within 20 minutes ($p < 0.001$). Although means were not significantly different (all $p > 0.17$), acceptability generally increased with run number, but was greater than moderately acceptable for even run 1 {instructed (mean) =5.75, discretionary (mean) = 6}. When assessing the acceptability of completing the shelter in 10 minutes, neither run number ($p = 0.621$) nor instruction type ($p = 0.589$) were significant factors, and means were appreciably lower than ratings associated with the acceptability of completing in 20 minutes.

Discussion

This section summarizes results from above and presents recommendations for improving components and process for future assessments of the radiation vest and reconfigurable logistics storm shelter sheltering concepts.

Summary of Results

The overall goal of both the radiation vest and storm shelter assessments was to develop effective human factors protocols for use in evaluating delivered contractor prototypes during the next set of ground tests. This goal was accomplished, as human factors protocols were finalized for both the radiation vest and storm shelter. Other important and applicable results were observed, however. It was learned that the current radiation vest does not impede crewmember mobility, and the weight is not degrading to task performance. It is faster to put on and remove the radiation vest with help from a partner, and the time it takes to walk across the habitat was approximately equal regardless of whether the crewmember was wearing the radiation vest. Concerning the storm shelter, both shelter walls were easily constructed within 20 minutes, and the instructions were appropriate and useful in the overall construction of the storm shelter. Both human factors protocols will be instrumental in evaluating contractor prototypes in the FY19 ground tests.

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