Journal of Aeronautic Dentistry, Medicine and Space Technology
Volume 2 Number 1 Jan-June 2010,

Risk of Compromised EVA Performance in MDRS: A personal views

Crew-78, MDRS, NASA, USA

ABSTRACT

Group program missions to the moon and Mars will include as many as 24 hours of EVA per crew member per week, which will involve the performance of exploration, science, construction, and maintenance tasks. The effectiveness and success of these missions is dependent on designing EVA systems and protocols that maximize human performance and efficiency while minimizing health and safety risks for crew members.It is very importantl to understand the effects of EVA system design variables such as suit pressure, weight/ mass, joint ranges of motion, and biomedical monitoring on the ability of astronauts to perform safe, efficient, and effective EVAs. This report describe the problems faced by MDRS health officer during two weeks MDRS mission.

INTRODUCTION

Fewer than 20 lunar EVAs were performed during the entire Apollo Program. Providing the capability for humans to work productively and safely while performing an EVA involves many

important, medically related considerations. Maintaining sufficient total pressure and oxygen, other survival enmity is vital not only to human health, but also to survival.

NASA report identifies and describes the various risks and associated evidence as follows:

*Risks to Crew Performance: EVA Suit Design Parameters

*Risks to Crew Performance, Health, and Safety: EVA Biomedical Monitoring and Consumables

MANAGEMENT

*Risks to Crew Health: EVA Suit Design Parameters

*Risks to Crew Health: Decompression Sickness

*Risk to Work Efficiency: EVA Suit Design Parameters

GROUND-BASED EVIDENCE

Physiologists and physicians are using various analog environments to study the effects of suit weight, mass, CG, pressure, biomechanics, and mobility on human performance. Test activities are designed to characterize performance during ambulation and exploration-type tasks such as ambulation on both level and inclined surfaces, ambulation while carrying a load, rock collecting, shoveling, and kneeling. Other studies examine recovering from a fall and simple exploration and construction tasks using hand tools and power tools. Data collected include metabolic rates, subject anthropometrics, time series motion capture, ground reaction forces (GRFs), subjective ratings of perceived exertion (RPEs) (1), and operator compensation using a relative subjective scale. The operator compensation scale, the gravity compensation and performance scale (GCPS), is modeled after the Cooper-Harper rating scale (2) and is described.

It has been suggested that EVA performance on the lunar surface may not provide sufficient loading to protect against bone loss, thus

Reprints Requests: Crew-78, MDRS, USA
Email address-raibalwant29@gmail.com

indicating the continued need for exercise countermeasures (3). Recognizing that not all ambulation on the moon will be similar to that on a level treadmill, EPSP personnel have initiated studies to characterize the effects of incline and terrain on metabolic rate. Inclined walking trials have shown that the metabolic cost of the suit that is due to factors other than suit weight goes to almost zero, indicating an energy recovery component of the suit that is currently not well understood (4). The studies assessed crew performance of representative planetary exploration tasks using a single EVA suit weight with six different CG locations. A reconfigurable backpack that has repositionable weight modules was used to simulate perfect, low, forward, high, aft, and NASA baseline CG locations under the assumption of a 60-lb. suit, a 135-lb. Portable Life Support System (PLSS), and a reference 6-ft, 180-lb subject. Subjects used the GCPS rating tool to evaluate the CG locations.

Thermal homeostasis of the crew member is crucial for safe and effective EVA performance. Heat storage above 480 Btu/hr leads to performance decrements, such as a loss of tracking skills and increased errors in judgment, and tissue damage begins at 800 Btu heat storage (1-3). The observations from the Gemini experience led to the development of a liquid cooling system that could accommodate high heat production in the suit from high EVA workloads. This liquid cooling garment (LCG) consists of a system of plastic cooling tubes that run along the inside of an undergarment that is worn inside the suit. The temperature of the coolant (water) running through the tubes regulates the amount of heat that is removed from the surface of the skin. The Apollo LCG had three temperature settings: minimum (69.8°F/21°C), intermediate (59°F/15°C), and maximum (44.6°F/7°C) (4). Astronaut energy expenditure rates during Apollo lunar surface EVAs ranged from 780 to 1,200 Btu/hr, as determined by three independent methods (5). The lowest metabolic rates occurred while the astronauts drove and rode in the lunar rover vehicle, while the highest metabolic rates were observed during egress/ingress through the tight-fitting hatch of the lunar module, offloading and setup of equipment, drilling, and stowage of lunar samples. It is estimated that 60% to 80% of the heat that was generated with these workloads was dissipated through the LCG. The minimum and intermediate LCG settings were most commonly used; however, the maximum setting was frequently used during the high workload periods that were experienced during Apollo 15 and Apollo 17 EVAs .

NUTRITION, HYDRATION, AND WASTE MANAGEMENT

The longer and work-intensive EVAs that are planned for future Exploration missions will also need to account for astronaut nutrition, hydration, and waste management. Specifically, dehydration is an issue that can lead to poor crew performance.

BIOMEDICAL MONITORING

Flight surgeons and biomedical engineers (BMEs) in the Mission Control Center monitor astronaut physical parameters during EVAs to assess workload and performance. Real-time medical monitoring can provide emergency medical assistance in response to off-nominal situations. However, bioinstrumentation systems that were used in the Apollo Program and are being used in the Space Shuttle Program have been problematic.

RISK IN CONTEXT OF EXPLORATION MISSION OPERATIONAL SCENARIOS IN MDRS

Current plans call for each crew member to perform up to 24 hours of EVA per week It is evident ce section of this chapter, the risks that are associated with any inadequacies that exist in current EVA suit designs - particularly with respect to suit-induced trauma - will be greatly amplified by such frequent EVAs.

Current CxAT-Lunar mission architectures include small pressurized rovers (SPRs) as a core element of the surface mobility system. The implications of SPRs on crew health, safety, productivity, and efficiency are potentially enormous. The availability of a pressurized safe-haven within 20 minutes at all times to provide DCS. Human Health and Performance Risks of Space Exploration Missions Chapter 14. Risk of Compromised EVA Performance and Crew Health. Due to Inadequate EVA Suit Systems 353 treatment, SPE protection, and on-site treatment of or medication for an injured crew member would significantly reduce many of the risks associated with planetary exploration. Furthermore, because crew members would be inside the SPRs during most surface translations, the overall number of in-suit EVA hours to achieve the same (or greater) science/ exploration return would be reduced. The possibility of performing single-person EVAs with a second crew member inside the SPR would further reduce total EVA hours during the lunar architecture to the same order of magnitude as during ISS construction. As a result, the number of cycles on the EVA suits would be decreased, thereby increasing the life of each EVA suit and reducing EVA risk for crew members.

CONCLUSION

The CxP will be more dependent on EVA excursions away from a pressurized habitat or vehicle than any program in the history of NASA. EVAs will be required to conduct planned scientific expeditions, assemble structures, perform nominal maintenance, and intervene and solve problems outside of the vehicle that cannot be solved either robotically or remotely. The ultimate success of future Exploration missions is dependent on the ability to perform EVA tasks efficiently and safely in these challenging environments.

With lunar missions planned for up to 30 times more EVA hours than during the Apollo era, exploration missions to the moon and Mars will present many new challenges with regard to crew health, safety, and performance. To date, our understanding of human health and performance parameters in partial-gravity environments is limited to observations of, and lessons learned from, Apollo-era astronauts who performed EV.

As on the lunar surface. Since the Apollo Program, and using lessons learned from microgravity EVAs aboard the space shuttle and ISS, new prototype suits have been in development for future space exploration activities. However, to date there has been limited quantification of the physiological and biomechanical variables associated with suited activities in unit and partial gravity. The integrated human testing program that is under way at NASA will help to better characterize the impacts to crew health and performance of the various parameters that are involved in EVA suit design.

Collaborative work is also under way to enable the development of suit technologies that enhance crew comfort and efficiency; provide for optimal nutrition, hydration, and waste management; and reduce suit-induced trauma and fatigue. These efforts will provide objective data to enable informed requirements and the design of Constellati on suit systems that will provide sufficient protection and life support for nominal zero-G and surface activities, as well as survival for contingency operations.

ACKNOWLEDGMENTS

The following individuals contributed to the preparation of this report:

1. Johnny Conkin, Ph.D.; Senior Scientist; Universities Space Research Association; Houston.
2. Nancy House, B.S.; NASA Constellation Program; Stinger Ghaffarian Technologies, Inc.; Houston.
3. Jennifer Jadwick, B.S.; Bioastronautics Contract Project Coordinator, EVA Physiology, Systems and Performance Project; Wyle Integrated Science and Engineering Group; Houston.
4. Lawrence H. Kuznetz, Ph.D.; Senior Scientist, Thermal Systems lead, EVA Physiology, Systems and Performance

Project; Universities Space Research Association; Houston.

5. Lesley R. Lee, M.S.; Bioastronautics Contract Project Scientist, EVA Physiology, Systems and Performance Project; Wyle Integrated Science and Engineering Group; Houston.
6. Human Health and Performance Risks of Space Exploration Missions Chapter 14.
7. Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems 357.

APPENDIX A: GRAVITY COMPENSATION AND PERFORMANCE SCALE 24

The Cooper-Harper scale, which has been in wide use since the late 1960s, permits quantification of pilot perceptions of aircraft handling characteristics. Most of the participants in EPSP studies are astronauts, many of whom are pilots and familiar with the use of this scale; however, the scale itself assumes a certain level of consistency in both pilot skills and specifications of the desired aircraft performance. In the development of next-generation EVA suits for Exploration missions, NASA requires controlled evaluations of varied suit concepts across an ambitious range of activities. These evaluations must be performed by astronauts or test subjects whose skills are limited to microgravity and/or simulated partial-gravity environments - far from equivalent to the skilled pilot population for whom the Cooper-Harper scale was originally designed.

EVA suit development for lunar and martian surface operations will require a wide range of evaluationsencompassing tasks as varied as habitat building, traversing rocky terrain, core sampling, shoveling, and, potentially, rescuing an incapacitated crew member. In addition, suit concepts vary widely in mass, weight, CG, and pressure, and each must be evaluated across this range of tasks. NASA does not currently have rigorous performance measures for such tasks, and the EPSP Project personnel have begun the process of characterizing human-suit system performance under a variety of conditions and suit concepts using available analog facilities.

Due to the many limitations of using the Cooper-Harper scale under these circumstances, scientists in the EPSP Project adapted the Cooper-Harper scale to reflect handling/controllability characteristics of task performance in reduced-gravity environments when compared relative to one's own shirt-sleeved performance of the same task in 1g. This modified scale, the GCPS, is shown on the following page. Using this scale, a rating of 2 during a suited experimental trial is perceived by the subject to be equivalent to his/her unsuited performance of the same task in 1g, thereby providing a quantitative rating of desired task performance in the suit.

As an example, a subject who is performing a shoveling task while wearing a suit that has a high-and-aft CG may rate the task performance as a 5 because the selected CG setting requires considerable effort/ compensation compared to performing the same task unsuited with nominal CG. This new tool is useful for comparing multiple subjects' ratings of operator compensation that is required to perform a variety of simulated surface exploration tasks across a wide range of suit concepts, configurations, and gravity levels. 24 Modified from the Cooper-Harper scale.

Chapter 14 Human Health and Performance Risks of Space Exploration Missions 358 Risk of Compromised EVA Performance and Crew Health due to Inadequate EVA Suit Systems.

GRAVITY COMPENSATION AND PERFORMANCE SCALE (GCPS)

CONTROL

Risk of Operational Impact of Prolonged Daily Required Exercise 359.

CHAPTER 15

135. Risk of Operational Impact of Prolonged

DAILY REQUIRED EXERCISE

Jancy C. McPhee
Universities Space Research Association
John B. Charles
NASA Johnson Space Center

Muscle

REFERENCES

1. Abercromby AFJ, Gernhardt ML, Conkin, J.Potential benefit of intermittentrecompression in reducing decompression stress during lunar extravehicular activities. Aviat. Space Environ. Med, 2008; 79(3): 293.

3. Barer AS, Filipenkov SN. Decompression safety of EVA: the Soviet protocol. Acta Astronautica, 1994; 32(1): 73-74.

4. Borg GA. Psychophysical bases of perceived exertion. Med. Sci. Sports Exerc, 1982; 14(5): 377-381.

5. Conkin J, Waligora JM, Horrigan Jr DJ, Hadley III AT. The effect of exercise on venous gas emboli and decompression sickness in human subjects at 4.3 psia. TM-58278. NASA Johnson Space Center, Houston, 1987.

7. Chapter 14 Human Health and Performance Risks of Space Exploration Missions 354 Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems Cooper GE, Harper Jr. RP. The use of pilot rating in the evaluation of aircraft handling qualities. NASA, 1969.

10. TN D-5153. NASA Headquarters, Washington, D.C.

11. Davis JC, Sheffield PJ, Schuknecht L, Heibach RD, Dunn JM, Douglas G, Anderson GK. Altitude decompression sickness: hyperbaric therapy results in 145 cases. Aviat. Space Environ. Med, 1977; 48: 722-730.

13. Fulton JF. Decompression sickness. Saunders, Philadelphia, PA, 1951.

14. Gernhardt ML. (1991) Development and evaluation of a decompression stress index based on tissue bubble dynamics [dissertation]. UMI #9211935. University of Pennsylvania, Philadelphia, PA, 1991.

16. Gernhardt ML, Norcross JR, Stroud LC, Hagan RD, Rajulu SL, Clowers KC, Morency RM, Whitmore M,

17. Vos JR, Patrick JA. (In preparation (a)) The effect of suit pressure, weight and inertial mass on ambulation.

18. Final report of Integrated Suit Test 1. NASA Johnson Space Center, Houston. Forthcoming NASA Technical Report.

19. Gernhardt ML, Norcross JR, Lee LR, Klein JS, Wessel III JH, Jones JA, Hagan RD, De Witt JK, Rajulu SL, Clowers KC, Morency RM, Whitmore M, Desantis L, Vos JR, Patrick JA. (In preparation (b)) Feasibility of performing a suited 10 km ambulation on the moon. Final Report of the EVA Walkback Test. NASA. Johnson Space Center, Houston. Forthcoming NASA Technical Report.

23. Gernhardt ML, Norcross JR, Stroud LC, Hagan RD, Rajulu SL, Clowers KC, Morency RM, Harvill LR, Clark TS, Whitmore M, Vos JR, Patrick JA. (In preparation (c)) The effect of suit pressure, weight and inertial mass on EVA task performance and inclined ambulation. Final report of Integrated Suit Test 2. NASA Johnson Space Center, Houston. Forthcoming NASA Technical Report.

27. Horrigan DG, Waligora JM, Beck B, Trevino RK. Space biology and medicine. In: Antipov VV, Grigoriev ?I, Lich-Khantun K (Eds.), Manned spaceflight: extravehicular activity. Moscow, Vol. 3, Book 2, Chapter 24. Nauka, Moscow, 1997; 448-469.

30. Jadwick JM, Rullman K, Skytland NG, Gernhardt ML. Influence of center of gravity on human performance in partial gravity. Aviat. Space Environ. Med, 2008; 79(3): 293.

32. Jones JA, Ansari R, Das H, Dewitt JK, Gernhardt ML, Garcia YL, Hagan RD, Harvey C, Lee SMC, Reid M, Parazynski SE, Rajulu SL, Smith SM, Soller BR, Strauss S, Warmflash DM, Welch J, Williams DR. Zwart S. Medical issues for extravehicular activity (EVA). Presentation at the National Space Biomedical Research Institute Retreat. Houston, Feb 27 - Mar 1, 2006.

36. Jones JA. Medical issues for lunar surface activity and EVA. Presentation at the Lunar Atmospheric Dust Toxicity Advisory Group Meeting. League City, Texas, Nov 6, 2007.

38. Jones JA, DeWitt J, Velasquez LE, Warmflash DM, Gernhardt, ML, Schaffner G, et.al. (In review, Internal harness as a countermeasure to shoulder injury during underwater extravehicular activity training. ActaAstronautica, 2009.

40. Kelley GF, Coons DO, Carpentier WR. Medical aspects of Gemini extravehicular activities.

Aerosp. Med, 1968; 39: 611-615.

41. Kumar KV, Powell MR, Waligora JM. Epidemiology of decompression sickness under simulated space extravehicular activities. Aviat. Space Environ. Med, 1993; 64: 1032-1039.
43. Human Health and Performance Risks of Space Exploration Missions Chapter 14.
44. Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems 355.
45. Kuznetz, LH. Thermoregulatory models in the management of safety-for-flight issues related to space shuttle and space station operations. Presentation at the Universities Space Research Association, Division of Space Life Sciences, Brown Bag Seminars. Houston, 2004; Jun 24, 2004.
48. Malkin VB. The habitability of space flight vehicles: barometric pressure and the atmospheric gas mixture. In: Genin AM, Salzman FM (Eds.), Space biology and medicine, Vol. II, Part 1, Chapter 1. Nauka, Moscow, 1994; 9-66.
49. NASA Mission Operations Directorate (MOD) Summary of Apollo G mission lunar surface EMU post flight thermal analysis results, Table E1. Unpublished Internal Report. NASA Johnson Space Center, Houston.
52. Norcross JR, Stroud LC, Schaffner G, Glass BJ, Lee PC, Jones JA, Gernhardt ML. The effects of terrain and navigation on human extravehicular activity walkback performance on the moon. Aviat. Space Environ. Med., 2008; 79(3): 292.
54. Powell MR, Horrigan DJ. Jr., Waligora JM, Norfleet WT. Extravehicular activities. In: Nicogossian A, Huntoon C, Pool SL (Eds.), Space physiology and medicine. 3rd Ed., Chapter 6. Lea and Febiger, Philadelphia, 1993; 128-140.
56. Scheuring RA, Jones JA, Polk JD, Gillis DB, Schmid JF, Duncan JM, Davis JR. The Apollo Medical Operations Project: recommendations to improve crew health and performance for future exploration missions and lunar surface operations. TM-2007-214755. NASA Johnson Space Center, Houston, 2007.
59. Scheuring RA, Mathers CH, Jones JA, Wear ML, Djojonegoro BM. In-flight musculoskeletal injuries and minor trauma in the U.S. space program: a comprehensive summary of occurrence and injury mechanism. Aviat. Space Environ. Med, 2009; 80(2): 117-124.
62. Strauss S. Extravehicular mobility unit training suit symptom study report. TP-2004-212075. NASA Johnson Space Center, Houston, 2004.
63. Viegas SF, Williams D, Jones JA, Strauss S, Clark JB. Physical demands and injuries to the upper extremity associated with the space program. J. Hand Surg. (Am.), 2004; 29(3): 359-366.
64. Waligora JM, Hawkins WR, Humbert GF, Nelson LJ, Vogel SJ, Kuznetz LH. Apollo experience report assessment of metabolic expenditures. TN D-7883. NASA Johnson Space Center, Houston, 1975.
66. Waligora JM, Horrigan DJ. Metabolism and heat dissipation during Apollo EVA periods. In: Biomedical results of Apollo, Section II, Chapter 4. SP-368. NASA Headquarters, Washington, D.C, 1975.
68. Waligora JM, Pepper LJ. Physiological experience during Shuttle EVA. SAE Technical Series. No. 951592. 25th International Conference on Environmental Systems. San Diego, Calif, 1995; Jul 10-13, 1995.
70. Williams DR, Johnson BJ. (2003) EMU shoulder injury tiger team report. TM-2003-212058. NASA Johnson Space Center, Houston.

REFERENCES FOR ADDITIONAL INFORMATION

71. Barer AS. (1991) EVA medical problems. Acta Astronautica, 1991; 23: 187-193.
72. Barer AS. Physiological and medical aspects of EVA. Russian experience. SAE Technical Series. No.73. 951591. 25th International Conference on Environmental Systems. San Diego, Calif, 1995; Jul 10-13.
74. Chapter 14 Human Health and Performance Risks of Space Exploration Missions 356 Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems Biomedical results of Apollo, 1975; SP-368.
75. NASA Headquarters, Washington, D.C. Flight rules: Section 15 - Extravehicular activity (EVA). Available at the following Website: http://mod.jsc.nasa.gov/for/fordn/124_1J_FOR/Books/FR/124sec15.doc.
76. Jones JA, et.al. Inflight and NBL training musculoskeletal and extremity injuries: mechanisms and potential countermeasures. Available at the following Website: http://www.dsls.usra.edu/meetings/hrp2007/pdf/

SmartMed/3130Jones.pdf, 2007.

81. Katuntsev VP, Osipov YY, Barer AS, Gnoevaya NK, Tarasenkov GG. The main results of EVA medical support on the Mir space station. Acta Astronautica, 2004; 54:577-583.

83. Maida JC, Gonzalez LJ, Rajulu SL, Miles E. Predicting fatigue for isolated joints while wearing an extravehicular mobility unit (EMU). Available at the following Website: http://sd.jsc.nasa.gov/doclib/sa/sf/Human_Factors/predictingfatigue.pdf.

86. Morgenthaler GW, Fester DA, Coolfy CG. An assessment of habitat pressure, oxygen fraction, and EVA suit design for space operations. Acta Astronautica, 1994; 32(1): 39-49.

88. Portree DSF, Trevino RC. Walking to Olympus: an EVA chronology. Monographs in aerospace history series, 1997; 7: 89-91.

89. Powell MR, Norfleet WT, Waligora JM, Kumar KV, Robinson R, Butler ?. Modification of physiological processes concerning extravehicular activity in microgravity. SAE Technical Series No. 941334. 24th International Conference on Environmental Systems and the 5th European Symposium on Space Environmental Control Systems. Friedrichshafen, Germany, 1994; Jun 20-23.

93. Thomas KS, McMann HJ. (2006) US spacesuits. Springer-Praxis Publications, N.Y, 2006; 85-86, 51-52.