SIMONS JC, WALK DE, SEARS CW. *Motion performance of pressure-suited subjects under zero and lunar gravity conditions.* Aerospace Med. 1965; 36(5):406–14.

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This Classic study used parabolic flight to assess how weightlessness (0-G) or lunar gravity (0.17-G) while wearing a pressurized space suit might affect human locomotion from one module to another in space. Ten subjects propelled themselves from one seat through an adjustable iris to another seat wearing coveralls or an inflated pressure suit. Variables under study included iris diameter, maneuvering style (head- or feet-first) and the location of hand-holds. Each subject completed 48 trials in a partially counterbalanced fixed factorial design over the course of two flights in the same C-131B aircraft that was used for training Project Mercury astronauts. No 1-G comparison was possible due to the completely different nature of the required motion.

The authors analyzed motion from film in three movie cameras, augmented by timers triggered by departure and arrival at the seats and breaking a light beam across the iris. Accuracy of movement was measured by the number of contacts with the iris. The movements were segmented into "lunge" (seat to iris), "egress" (period the iris was blocked) and "landing" (iris to seat).

Wearing a suit added about 30% to the time required to complete the exercise, and weightlessness caused slowing compared to lunar gravity. These effects were additive, so that the suited-weightless condition required 70% longer than the unsuited-lunar condition. Of the styles tested, the headfirst, bottom-handhold method was the fastest. Increasing the iris size from a minimal 1-in clearance to 5 in shortened times by 30%, with little additional gain for more generous diameters. For all iris sizes, subjects in suits contacted the iris about twice as often as those in coveralls. The feet-first approach, while slower than headfirst, cut the number of contacts in half.

The authors concluded that accuracy was a sensitive measure of motion performance. They also noted that, while "zero gravity" increased subject mobility, it also decreased accuracy, likely due to the loss of control associated with the added degrees of freedom. They suggested that there might be an intermediate G-level at which egress time would reach a minimum by allowing a balance between controllability and the effort required to carry out the task.

Background

Astronauts routinely operate under "shirt-sleeve" conditions but don pressure suits during critical phases of flight such as launch and re-entry and to carry out extravehicular activities. Previous studies had derived the detailed requirements for space suits that used a closed system with inflation to a relatively low pressure with 100% O_2 (2, 7,12). Such suits had been extensively tested in hypobaric chambers (4), thermal chambers (6), and in centrifuge runs simulating launch and re-entry profiles (3). These experiments resulted in a Navy Mark IV suit modified to allow for bioinstrumentation and increased thermal loads, which was used during the Mercury Program with great success. Studies had also shown that the accuracy and reaction times of the Mercury astronauts performing tasks on the Mercury capsule panel were decreased in the full pressure suit at 5 psi (1).

This classic study assessed movement under conditions that simulated working and living on a space station or on the Moon and were unlike anything that had been encountered in the U.S. space program to that time. Astronauts in Project Mercury (1959-63) were said to have "worn" rather than "ridden" the Mercury capsule because of its small size, and the Gemini capsule (1965-66) allowed little more mobility. However, the study of human movement was critical for Project Apollo (1966-1975), whose Command and Lunar Modules offered more maneuvering room for astronauts wearing either shirt sleeves or space suits. Plans for lunar-surface activity added to the urgency. In a paper published a year earlier, Margaria and Cavagna had theorized that astronauts in lunar gravity would adapt their gaits to minimize energy expenditure (10). They predicted that traction would be low, the natural transition from walk to run would occur at a much lower speed, and that jumping or hopping would often be utilized, all of which came true. In this Classic, Simons et al. went beyond theory to the study of motion under altered-gravity conditions, a critical step in preparing for the first Moon landing 4 years later.

Commentary

A problem in this Classic study was that the authors used suits pressurized to only 2.5 psi, which is much lower than the 3.7 psi actually employed for Apollo. Because suits stiffen as pressure increases, worse performance could be expected in higher-pressure suits, although this has been mitigated by improving the design of suit joints, allowing a further increase to 4.3 psi for NASA's current Extravehicular Mobility Unit. The study can also be criticized for its statistical methods: Simons et al. used simple averages to compare results across widely different conditions. However, this is understandable given the limited computer facilities of the time, with data input only by means of hand-typed punch-cards.

The technique for analyzing movement in this study originated in the photographic-sequence analysis of animal and human movement by Marey and Muybridge in the late 19^{th} century, and similar methods were used in subsequent time and motion studies of Apollo astronauts on the Moon (8,9). Videos of lunar surface locomotion revealed a variety of alternative gaits including loping, a type of skipping without support-foot exchange, as well as running with an extended aerial phase, and occasional odd gaits such as a two-footed bunny hop. Later bioastronautics researchers have used movies combined with force plates to produce more sophisticated analyses. For instance, it was demonstrated on the Mir space station that astronauts can learn to minimize the force of their movements to avoid disturbing load-sensitive experiments in space (11). Inverse-dynamics models have also allowed estimation of musculoskeletal joint torques in addition to quantifying motion accuracy. The loads imposed by space suits have been quantified and used to engineer further improvements (5). Working in the much larger spaces aboard the Shuttle and the space stations, astronauts have learned how to rotate their bodies without any external torques, an act that appears to violate conservation of momentum (it does not).

The authors of this Classic provided the first answers to practical questions about human movement in reduced gravity. For example, is motion in weightlessness controllable? How big must the port be between modules? Will suited astronauts be able to move accurately within a spacecraft?

Motion in altered gravity is now taking on new importance with NASA's planning for new spacecraft and its emphasis on exploration-class missions, including habitation on the Moon. As was predicted in this Classic, humans "will choose many new motions for performing… tasks in low gravity environments." Future explorers of near-Earth asteroids or the surface of Mars will surely find such studies as this an important part of their knowledge base.

Classics in Space Medicine are selected from among more than 250 space medicine articles published prior to 1965 in this journal under its previous title, *Journal of Aviation Medicine*. The series is edited by Mark R. Campbell, M.D.

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