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The performance of field scientists undertaking observations of early life fossils while in simulated space suit

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ABSTRACT

We conducted simulated Apollo Extravehicular Activity's (EVA) at the 3.45 Ga Australian 'Pilbara Dawn of life' (Western Australia) trail with field and non-field scientists using the University of North Dakota's NDX-1 pressurizable space suit to overview the effectiveness of scientist astronauts employing their field observation skills while looking for stromatolite fossil evidence. Off-world scientist astronauts will be faced with space suit limitations in vision, human sense perception, mobility, dexterity, the space suit fit, time limitations, and the psychological fear of death from accidents, causing physical fatigue reducing field science performance. Finding evidence of visible biosignatures for past life such as stromatolite fossils, on Mars, is a very significant discovery. Our preliminary overview trials showed that when in simulated EVAs, 25% stromatolite fossil evidence is missed with more incorrect identifications compared to ground truth surveys but providing quality characterization descriptions becomes less affected by simulated EVA limitations as the science importance of the features increases. Field scientists focused more on capturing high value characterization detail from the rock features whereas non-field scientists focused more on finding many features. We identified technologies and training to improve off-world field science performance. The data collected is also useful for NASA's "EVA performance and crew health" research program requirements but further work will be required to confirm the conclusions.

1. Introduction

1.1. Off-world field science

A Mars mission crew, as described by NASA's "Design Reference Architecture 5.0" [1], is expected to include scientist astronauts such as geologists and astrobiologists with one objective being, as suggested by the Mars Exploration Program Analysis Group [2], "To determine whether life ever arose on Mars". Human exploration will include scientist astronauts surveying geological formations on the Martian surface looking for evidence of present and past life. The evidence could be in the form of biologically-derived organic molecules buried in the subsurface soil horizons, or within surface rock. The evidence could also be visible fossils or other biologically-meditated sedimentary

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structures (geological biosignatures) located on the visible surface of rock units, or slightly within the rock fabric accessed by breaking open the rock during the exploration.

When field scientists such as geologists and astrobiologists explore rock units on Earth they typically first survey the site, and then photograph and document the general features characterizing the geology by identifying rock types and fabrics, reading the layer sequences and then interpreting the environmental and geological history. They select specific samples, break them open, inspect with hand lenses and if of science interest label and store them for future analysis. Equipment such as hammers, core drills, cameras, and portable geochemical sensors like X-ray diffractometers (XRD), X-Ray florescence spectrometers (XRF), and Raman instruments can be used to obtain further information while in the field. Astrobiologists have a further complication in ensuring samples are not contaminated with external organic material. Furthermore, the field scientist's 'field observation skills' use the senses of vision, including color interpretation, sound (different rocks may emit different sounds when struck with a geological hammer), touch when examining surface textures and even taste for confirmation of grain size of fine sediments, pH, and chemistry. Field scientists also require body dexterity to gain access to locations, hand–eye dexterity and coordination for sample collection and manipulation during inspection as well as physical techniques to operate the equipment.

The first off-world field science exploration experience, the Apollo manned lunar exploration program, showed that there are big differences in doing terrestrial field science and off-world field science on EVA. Schmitt [3] in a "Field Exploration Analysis Team White Paper" summarized this as

> "Terrestrial field geology is usually a slow, deliberate, iterative process. Field geology in a space suit is physically an even slower process, however, the very difficulty of that process in space and the inherent constraints of time, requires that the practitioner be able to deliberate and iterate at a much more rapid rate than normally expected on Earth."…and…"a lunar field geologist must always be aware that time is relentless, that consumables are limited, that fatigue can be fatal, and usually, returning to a location is unlikely."

The Apollo experience showed that future scientist astronauts doing off-world field science will have their performance challenged by a combination of: the psychological pressure of exploring unfamiliar terrain, working to strict time bound periods governed by space suit consumables and mission schedules, and knowledge of a fatal outcome if the space suit is damaged or consumables are depleted. In addition, operating in a space suit puts limitations on the senses including vision, color changes due to the helmet visor coatings, a lack of sense of sound, touch and smell as well as dexterity restrictions that slow mobility causing physical fatigue. Schmitt [3] argued these challenges demand scientist astronauts to have a greater than normal field experience background and faster scientific decision making ability to achieve results that match terrestrial field science exploration.

Since Apollo, improvements have been made to space suit dexterity, weight reduction, durability and better field equipment design as tested by the NASA Desert-RATS program [4] where space suit hardware integrated with rovers and habitats using, for example, 'suit port' technology, will make donning and removing a space suit easier. However the scientist astronaut's ability to employ 'field observation skills' will still have limitations due to restricted senses. The questions we initially considered for assessing the effectiveness of scientist astronauts ability to employ his or her field observation skills were:

- "Which field observation skills are most used while in a space suit?"
- "Can we quantify what is seen and what is missed?"
- "Can we identify and characterize early life fossils?"
- "What level of effort is needed to survey rock units?"
- "Can a scientist astronaut's field observation skills be augmented or improved through technology or training?"

These issues were investigated from a global perspective by Schmitt [3] and Lim [5]. Schmitt [3] noted that during the Apollo missions, from Apollo 13 onwards, astronaut geological training using simulated lunar analog landscapes, resulted in a significantly better science return. Similarly, Lim [5] emphasized the need for extensive scientific science classroom and field training for astronauts in the areas of field observation and data collection methodology. Lim [5] provided astronaut field science training as part of the 'Pavilion Lake Research Project' at Pavilion Lake, British Columbia, Canada, using single person submersibles to investigate lake floor microbialite formations. The training provided field science experience in which according to Lim [5] the scientist astronaut was:

- 100% reliant on technology for his or her safety;
- Operating in a lethal environment;
- Restricted mobility and human senses; and,
- Interfacing with the submersible technology and scientific instruments to achieve a science outcome.

In addition, Groemer [6] investigated an aspect of off-world field science, looking at reducing biological forward contamination by a space suited subject using the space suit simulator AoudaX. Groemer [6] tested a laser induced fluorescent emission technique to monitor micospherules simulating microbial life transported into Habs on space suits.

In mid-2011, NASA Spaceward Bound and Mars Society Australia undertook an expedition to 3.45 Ga "The Dawn of life Trail" which includes stromatolites and microbalites near Nullagine in the Pilbara region, Western Australia, to investigate early life on Earth [7,8]. Participants included field scientists and teachers specializing in geology, earth sciences, astrobiology and engineering. A space suit field trial at the site was conducted using the University of North Dakota's NDX-1 pressurizable space suit with the aim to undertake a preliminary overview study, assessing