Surprise Payload Rack: A User Scenario of a Conceptual Novelty Intervention System for Isolated Crews on Extended Space Exploration Missions

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Abstract. Future space exploration missions to Near Earth Asteroids or Mars present unprecedented psychological challenges to the crew. One of these sets of factors includes long stretches of low workload, environmental monotony and confinement particularly during transfer phases of the trip. In previous orbital space missions, instances of isolation and monotony where remedied by audio or visual contact to ground, resupply of fresh cargo and visiting crews that provided diversion, variety and surprise. These powerful mitigation strategies will not be feasible in the autonomous setting of a deep space exploration mission. How can novelty be designed into a remote, virtually closed habitation system? Drawing on the historical experience of psychological support and countermeasures from orbital space missions and a series of related design studies, this paper addresses the need for the integration of variety as part of in-flight provisions. It describes the concept of a personalized 'surprise payload rack' (SPR) in the format of a fictional instruction manual, and discusses related R&D directions and organisational implications at the interface of non-invasive behavioural monitoring and smart, responsive vehicle environments.

Keywords. Human Space Exploration, Mars Mission Transfer, Habitats, Human Factors, Isolation, Monotony, Surprise, Vehicle Interaction, Autonomy

Introduction

Surprise has both positive and negative connotations in a spaceflight context. While some crewmembers in previous orbital missions might have experienced long stretches of low workload or perceived their scheduled work routines and habitat surroundings as monotonous [1], welcome instances of surprise or diversion were provided by real-time contact to friends and family on the ground, resupply of fresh cargo, visiting crews and crew changeovers, and a visual link to earth with its dynamic natural characteristics. Other 'surprising' unexpected events were less pleasant and often life threatening, such as system breakdowns, sudden structural damage or breakout of fire. Today, schedules in orbital missions such as on the International Space Station (ISS), are extremely busy and varied even in long duration missions.

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The provision of meaningful surprise in the form of variety, complexity and diversion will, however, be a vital component of psychological support for future missions that venture beyond orbit. The psychological challenges of isolated, remote deep space missions are acknowledged as critical [2] and the development of countermeasures highlighted as urgent research needs in biomedical roadmaps [3]. The means that appeared most effective in orbit in preventing or mitigating the phenomenon of monotony and isolation are infeasible in deep space missions to their extreme remoteness that do not afford real-time communication, visual contact, resupply or abort. In light of these constraints, particularly the need for autonomous support is pointed out [4]. In terms of monotony, this means that countermeasures need to be provided in situ to maintain crew morale [5].

The following paper addresses this design aspect. It outlines a set of studies conducted as part of a wider research project into designing countermeasures against monotony that exposed the need for designing-in surprise into existing habitat systems. The prototype of a 'surprise payload rack' is presented in the format of a user manual situated in a short narrative set in a fictional space agency. The paper concludes with a brief discussion of future research and development needs in the context of coupling non-invasive psychological monitoring technology with intelligent environmental systems in space habitats in view of integrating behavioural concerns into systems development.

1. Research Context

This prototype is part of a three-year study on psychological countermeasures to isolation and monotony funded by the Arts & Humanities Research Council, UK. Two sets of research questions addressed:

- Methodologically, how to design for unprecedented scenarios where the physical and behavioural user setting was inaccessible to the designer;
- Topically, how to address the experience of monotony and isolation during the cruising stages of deep space missions through the design of autonomous, onboard countermeasure.

1.1. Evidence & Speculation in a Space Systems Development Context

The first broad question addressed the relationship of evidence and speculation in design for future space systems. A human factors feasibility study was undertaken at the European Space Agency's astronaut training division that explored potential ways of harnessing evidence from empirical user experience with existing space hardware for the development of future systems [6]. A second study investigated the validity of speculative design in a space habitation context through the analysis of SF film production design – the area where speculative design is most tangibly embodied. This study first reconstructed the development of a particular habitability design aspect in Stanley Kubrick's 1968 film *2001: A Space Odyssey* (the food systems of the *Discovery*) [13], and then systematically sampled and reviewed a large group of SF films for their concepts addressing the interface of behaviour and habitat [7]. It was found that the activity of engaging with SF in that particular space context was not so much about identifying novel concepts that may be translated into actual technologies, as had been the focus of previous work in this context [8]. Rather, it was the richness of design insight embedded in manifested prototypes – models – that might enable scenario exercises in situations whose behavioural dimension could only be anticipated [9].

1.2. Orbital Experience of Countermeasures to Monotony: A Review

A review was conducted on the monotony experience of users of historical space stations (Salyut, Skylab, Mir, ISS) and one ground-based space simulation (Mars500) through an analysis of published astronaut/cosmonaut diaries and logs. Instances of monotony or boredom, and related references to remedying these through provisions in the built or natural environment were noted on a taxonomy of monotony conceptualised as a model of sensory, social and spatio-temporal isolation.

The findings exposed emerging themes in of interacting with others (crew and ground) through designed artefacts (communications interfaces, leisure equipment); interacting with nature both outside the spacecraft (earth observation through windows, extravehicular activities, tending to plant-growth experiments); and receiving surprise packages through cargo or data transmissions (fresh fruit, letters; or greetings/ communication sessions with celebrities etc.). After translating these categories of provisions into the framework of constraints of a deep space mission, the need for 'designing-in' surprise into existing habitat systems was addressed through a series of design studies and conceptual design development.

1.3. Active and Passive Surprise: 4 Design Studies

Two collaborative design exercises were undertaken with regards to the integration of aspects of those themes that included the active pursuit of diversion through the crew (social interaction and interaction with nature). One study developed possible requirements for a non computer-based, tactile, modular game to be played socially in microgravity conditions [10], the second one addressed the integration of different set-ups of plant-growth facilities [11].

Another two studies addressed the conceptual application of induction of sensory variety in light of the orbital evidence on the preference for novel items sent through cargo packages. The potential acceptability of fragrance intervention was tested during a short-term Mars mission simulation at Mars Desert Research Station[2] [12]. Finally, the notion to utilise existing habitation systems as medium to instil variety was applied in form of recommendations for the crew's basic and active wear with the clothing provider of the ongoing Mars500 long duration isolation study at IMBP in Moscow[3] where clothing is changed and discarded in pre-determined intervals.

[2] As part of a broader study on sensory stimulation lead by Irene Lia Schlacht, Human-Machine-Systems Group, TU Berlin, Germany.

[3] In collaboration with Ralf Heckel, ISEI Leipzig, Germany.

1.4. Future Conceptual Requirements

The approach to implement a meaningful degree of variety across systems of fundamental provisions that already exist onboard can accommodate variety (such as clothing, food, or greenhouses) may be valid and feasible. Part of the 'surprise factor' of the historical care packages for orbital crews, however, was not only the novelty or variety within the different provisions that were included in them. It was also the fact that crew could place 'orders' (to a limited extent, at least) and that items were provided by friends and family from the ground and thus had a special meaning. Ideally, a potential autonomous system would facilitate inclusion of more serendipitous items, items that could be specifically requested according to personal preferences and moods, and those provided by loved ones on the ground.

Perhaps such a system could also blend into the existing infrastructure, but be coupled with monitoring for a more tailored, personal, timely and situational response to individual crew needs. One conceptual design response to this questions is outlined in the following user scenario of a 'surprise payload rack' (SPR) prototype. It is presented in the format of an email to the constituent parties involved in the psychological support of a fictional space agency, containing the first draft of a payload familiarisation manual.

2. Prototype: *'Surprise Payload Rack' Novelty Intervention System*

Vitaly cracked a green iced tea open and propped his legs up on the desk. It was quite late; the pine forest beyond the large windows was pitch-black. He'd been in the office far too long, and just spent the last hour free-diving in the pool at the Neutral Buoyancy Complex, trying to beat the Mandarin instructor's new record. He flicked through a bunch of emails he'd set aside earlier. New shots from the current asteroid sample return, BBQ invite for Minu's departure, a forward from Edezio…

FW: Re: Familiarisation Manual SPR-1.2

Hey, guess you've seen this already. Better not be another patch to wear… Lucki and Galina from C are down there this winter, wanna play a prank? The hardware is gone, but we can still do transmission, I had coffee with the comms guys from PPO earlier :)
Ed

>From: Behavioural Systems Integration Office CSF-BSI
>Sent: 29.01.2019 CPT 17:06
>To: Behavioural Training & Preparation CSF-BTP
>To: Astronaut Support & Administration CSF-ASA
>Cc: Crewed Spaceflight Headquarters CSF-HQ
>Cc: Payload Processing & Operations CSF-PPO
>Cc: Operational Ethics CSF-OE
>Cc: TG 6 Further Concepts BSI-TG6
>Cc: All Polar Programmes APP

>All,

>The recent meeting of TG 6, Ops Ethics and Heads approved the first version of the >familiarisation manual for SPR-1.2. The preliminary rack is currently in processing >and on its way to APP Region 1 for deployment and analogous trial in Acordia II for >the coming winter season. We expect first findings around March 2020, and will be >convening with the contractor to formulate final requirements documents based on >the overwinter debrief.

>TG 6 will convene again in April 2020 to review procedures documents. Payload >training for cruise segment in expedition SES-206 commences February 3rd, 2024 >(TBC) in Kutsuba. The preliminary familiarisation manual FM-SPR-1.3 (enclosed) >will also be issued to Class F who start fundamental training in October 2019.

>Please review the attached version for a last time and sign the WP macro. Any >changes at this stage should go to TG 6 for integration in FM-SPR-1.3.

>If the debriefs from trials and precursors turn out promising, SPR is foreseen to be >scaled up and implemented across CSF Extended Exploration and Commercial >Remote Duty partners. Note that the current version is operating with wristbands as >discussed earlier. A switch to smart garments is currently being assessed by BSI >Labs for potential flight certification.

>On behalf of BSI Steering, I would like to take this opportunity to thank you for >your input so far in tackling what has turned out a critical but manageable >operational issue in previous expeditions.

>Yours,
>\\\\\\ \\ \\\\\\\\\\\\\\-\\\\\\\\\\

>Head of Processing
>Behavioural Logistics & Deployment Unit
>Office for Behavioural Systems Integration CSF-BSI

>Attached documents:
>*Familiarisation Manual FM-SPR-1.2*

>Applicable documents:
>*SPR_1.0_REQ*
>*TG 6 BSI-FC Roadmap*
>*Work Package WP SPR-1.2*

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Vitaly flicked down to the same email he'd received directly earlier from BSI. The experimental group of the BLD unit was just across the road in a dull but spacious basement, more of a maze of industrial storage than a laboratory. Hundreds of products sat there stowed in large transfer bags, either waiting for flight certification, being tested, or had been abandoned and kept for reference. Although it was officially tied into training and systems integration, BLD was not a huge group. With the advent of commercial off-the-shelf procurement, it had moved from bespoke design to testing *and configuration. Led by a veteran flight surgeon with a background in psychiatry and four long duration missions under her belt, the small team consisted of a material scientist-cum-hygiene expert, a junior contracts officer, and a couple of biomedical interns, who were really tinkerers. Most of the concepts and requirements were conjured up by a pair of consultant anthropologists, who divided their time sifting through mountains of data from BTP and operations either in the lab, or travelling to tradeshows or obscure manufacturers to hunt down the most resilient, lightweight and ingenious products that could be used in long duration spaceflight. Together, they’d fast-tracked through development in the respective specialist human factors departments everything from antibacterial, lint-free merino jumpers, to extremely hot chilli-flavoured long-life chocolate that could be processed in the onboard food printer. They’d initiated a successful joint venture with the manufacturers of colour-changing surface coats for vehicle interior panelling, regularly liaised with PR to hook up famous mountaineers with crew in communications sessions, and had processed dozens of individual crew requests for especially patterned sleep station liners or extra databases on French cinema.*

Vitaly liked the atmosphere there – it was quiet, untidy, and a bit off-piste, with an underground shortcut to the canteen. When he didn’t have console duty and wanted to get away from the busy floor in Support, perhaps to finish paperwork or to revise for another Mandarin exam, he often spent his afternoons over there. His own grandfather had started out processing personal item packs during the 70s. This is how he met his grandmother, who nearly drove him mad with last-minute requests for lemons that she predictably – but dearly – missed in orbit. Both Vitaly and his father had then flown with or, later, been monitored by the lead of BLD. In short, Vitaly felt at home at BLD and knew that the efforts of this unit came in handy many months into a mission.

Familiarisation Manual FM-SPR-1.2
Version 1.0
Date: 16.01.2029
Work Package: WP SPR-1.2

Principle Author: \\\\\\\\\\\\\\ \\\\\\\\\, BSI-TG6
Approved by: \\\\\\\\ \\\\\\\\\\\\\\\\ \\\\\\\\\\\\\, CSF- BTP

To be distributed to: Class D, E, F

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“I do love a page intentionally left blank…”, Vitaly thought – for some reason, this always amused him. The document didn’t look too voluminous, but he remembered he expected a conference call later that night. He decided to take it at home and pushed the chair against the desk. While the beamer slowly shut down, Vitaly was already on the way down the concrete staircase to the underground garage.

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Once he’d driven past the night-guard and out of the gate, he asked for the SPR manual. The character of his Guidance Navigation & Control system started reading out the document. It always did that, so confusing. He shook the device, and it switched to reading voice.

This is the preliminary familiarisation manual for payload SPR-1.2 (Surprise Payload Rack 1.2). – *"What an apt name", Vitaly thought.* – This manual is to be used for preliminary study accompanying awareness training unit ATU 5 Autonomous Psychological Monitoring & Support … – *Vitaly, would you like to access ATU 5?* – *"Uh, no."* – … in conjunction with sample flight bag SPR-1.2 FB, which you will have received as part of your BTP induction. Please read the following information carefully, and refer back to your Fundamental Training manual or BTP instructor for further questions. In-depth training and simulation with SPR is foreseen in Specialist Training for your respective mission segment.

SPR, the novelty intervention system, is a hybrid system introduced for post SES-205 expeditions with cruising stages or overall remote duty mission durations of more than 30 days. It is part of the Psychological Countermeasure Programme (PCP). The aim of SPR is to mitigate the effects of prolonged stretches of low workload, environmental monotony and isolation by providing timely, meaningful and varied instances of novelty, surprise, reward and comfort.

SPR consists of an individual standard-size payload rack integrated into the personal storage and access section of the transfer habitat, an application on your Personal Digital Device (PDD), and an individual sensor wristband. The sensor wristband is worn on the left wrist next to the VS and monitors mood stages through a heart rate monitor, galvanised skin response meter and accelerometer. These data are transmitted to the app on the PDD. Depending on the operating modus chosen for the system, patterns in your mood, situational events, elapsed time segments or other input is matched against pre-determined personality profiles and preference codes. Based on these, the system releases a certain type of PL from the personal SPR rack, for which manual retrieval and access instructions are displayed on your app. (Future versions may send a signal directly to the payload rack Content Management System and trigger in-situ release of PL).

SPR App contains codes generated from data from mission selection (MS), BTP practical preference exercises (PPE), the individualised profiling questionnaire (IPQ), and the individualised profiling questionnaire of next of kin (IPQ-NoK). SPR does not contain codes from recruitment.

Documentation for set-up will be issued as procedures for your mission segment as part of BTP.

Access Modes. *Vitaly, would you like to proceed with Access Modes section? – "Yes, go on."*

Access Modes.

SPR automatically runs on the modes Mood, Time-based, Event, Nutrient, Buddy and Ground. Mood input allocates PL based on the data from the wristband. Time-based mode releases PL according to mission elapsed time and accounts for the 3rd quarter phenomenon, reconciling with Mood input. Event mode operates as Time-based and accounts for special occasions as reconciled by Time-based, but also for unscheduled events, such as Milestone Recreation & Reward or post-EVA. Nutrient mode remedies changes in your diet that cause mood or performance decrement. Buddy mode enables your designated crewmember peer or onboard flight surgeon to release countermeasures on an as-needed basis. Equally, Ground mode is triggered by designated next-of-kin, for instance after a communication session. Ground mode includes additional mode Friday Night Dinner (FND). FND enables next-of-kin to access your galley database and create a custom menu once a week. FND is reconciled with – and, in conflict, overridden by – Nutrient.

Mission Control cannot access or override SPR. Medical Console can access and override, and allow Mission Control to override. This feature is disabled in Pathology setting. The system is automatically disabled in off-nominal situations beyond Caution & Warning 1.

Please note that voice monitoring and email content analysis are not fed into SPR unless you enable the setting. All data logged on the SPR wristband is logged independently from medical remote monitoring, i.e. unlike standard issue VSPM. Logged data are disclosed after mission completion should you consent to the data being used for further research and development. Information on –

"Next."

For Remote Access Override, enable –

"Next."

Master Override.

Vitaly, would you li –

"Next."

Set-Up and Activation.

Vitaly, would you like to proceed with the Activation section? – *"No."*

Set-Up and Activation.

Extract – *"Stop."* – for datalogger – *"Stop."* – flight kit. Verify personal code. – *"Oh, stop it."* – should sit snugly on the inside of – *"Stop, stop, stop, stop." He smacked the device.* For reallocation – *It was kind of sticky* – by pressing firmly on yellow – *His 5 year old had probably* – do not swap bands. For swapping provisions –

Vitaly gave up. – for signal to register with SPR App. Verify signal against personal code. Input mode choice by accessing App settings. For default manual retrieval, slide the –

He shook the GNC again to make it stop. It changed back to the default voice.
Thank you for driving on the A2 today. We're looking forward to seeing you ag –

He had come to a halt, let the door slam shut and GNC, finally, fell silent.

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He called Ed at home. “Hey, ni hao, Ed, it’s Vitaly. … No, it’s a wristband. … [laughs], ouch. Serves you right, though, doesn’t it… Hey…. yes, yeah, definitely. Have you uh … [laughs]. … Well, actually, we can try hardware still, I think… Okay, yeah, but you can still hook it up to the 3D printer, right … yes, one of the interns still owes me a favour, remember from uh – I’ll go talk… No, regarding stowage plan. I thought then … yeah, we call Pilar … she’s already there. She can stow it in Lucki’s … [laughs] okay, great, Ed … yes, see you at 1. … Okay, ciao… Ciao.”

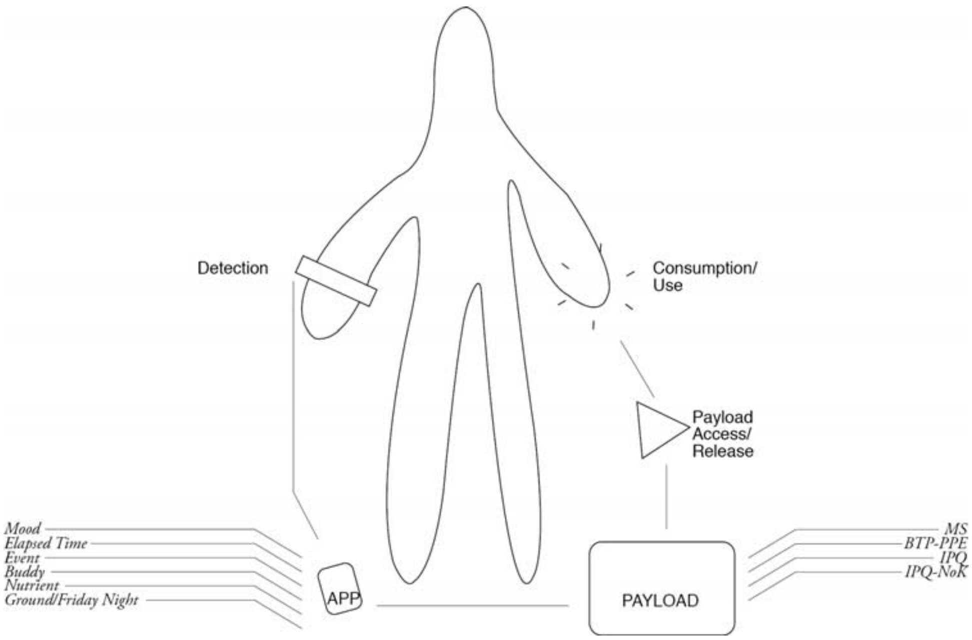

Figure 1. Diagramme of the SPR.

3. Future Research & Development Directions

This prototype aimed to give a snapshot of the rationale, functions, usability and integration of a conceptual ‘Surprise Payload Rack’ in an autonomous setting, seen through the perspective of an astronaut on the ground who receives routine documentation for this new system. The different aspects portrayed in the prototype hint towards areas that may benefit from targeted research and development efforts:

- Organisational integration to reflect the contemporary challenge to integrate ‘soft’ human factors concerns in a professional culture that does not necessarily facilitate the open discussion of personal behavioural needs;

- Potential subversion of the system through their users is incorporated through modifications, overrides, practical jokes or hacking that are reported in historical contemporary spaceflight;
- The potentially pervasive non-intuitiveness of devices in the scenario is represented through glitches in the GPS-like navigation system that reads the manual to the user while he is driving home, and through the relative dryness of instruction manuals in an operational setting that relies heavily on protocols and standards. This degree of non-intuitiveness makes seamless and meaningful interaction difficult in the fictional future setting, highlighting issues of system integration in the real contemporary industry.

Questions regarding profiling, coding, accuracy of measurement and privacy emerge in terms of collection of confidential data, but also its means of invasion or non-invasion. Some of these issues are interrelated: Would more intuitive handling lead to closer, more invasive monitoring and decreased control for the individual? Where on the spectrum of control and surprise, of privacy and invasiveness, should the interactive system be situated? These issues, seen in a contemporary context, present ethical issues both in research and operation. It is, therefore, perhaps not the technology aspect that primarily benefits from such a thought experiment, but issues of organisational integration implicit in the user scenario.

Finally, a methodological issue for the production of fictional prototypes and scenarios-of-use is highlighted. The angle and format of the prototype chosen in this paper focused on one of the several possible dimensions of user groups of a particular technology, and utilised in parts an industry-specific format to present the content of the story. The end-user may be crew on board an itinerant, remote vehicle; but in this case, additional user groups are involved in the day-to-day operation of the technology. In the context of discussing the leverage and properties of different fictional prototypes to elicit design-relevant insight [14], it would be of interest for further studies to assess the merits and shortcomings of different user perspectives and narrative formats.

4. Conclusion

The fictional prototype scenario presented in this paper re-interprets a particular type of 'surprise' provision (packs delivered through cargo) that historically worked effectively in an orbital setting for a future unprecedented deep space mission scenario. It points to further needs in research and development in the area of non-invasive monitoring and support, intuitive interfaces in relation to smart vehicle environments and organisational integration of related efforts in the space systems development and operations process.

While this prototype was specifically situated in the very particular setting of spaceflight, insights can be transferred to other contexts where users may rely on non-verbal or remote communication, are geographically isolated, or depend on in-situ variety in a very limited or confined environment. These include communities on remote duty stations in other extreme environments such as polar or marine, or isolated users living in long-term health care settings.

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