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Stokes M, Evetts S, Hides J.

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Guest Editorial for the *Musculoskeletal Science and Practice* Journal Supplement on:

"Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer"

[1,2]Maria Stokes, [3,4]Simon Evetts, [5,6]Julie Hides

1. Faculty of Health Sciences, University of Southampton, UK
2. Arthritis Research UK Centre for Sport, Exercise and Osteoarthritis
3. SeaSpace Research Limited, Colchester, UK
4. Faculty of Health and Life Sciences, Northumbria University, UK.
5. Centre for Musculoskeletal Research, Mary MacKillop Institute for Health Research, Australian Catholic University, Brisbane, Australia
6. Mater/ACU Back Stability Research Clinic, Mater Health Services, Brisbane, Australia

Corresponding author:

Prof Maria Stokes
Faculty of Health Sciences, Building 45,
University of Southampton
Highfield Campus, Southampton, SO17 1BJ
United Kingdom

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Highlights

- Astronaut reconditioning parallels many aspects of terrestrial physiotherapy
- Challenges to space research are similar in small population terrestrial research
- Self-motivation strategies needed to help astronauts adhere to exercise programmes
- Terrestrial therapists will need to manage deconditioning in space tourism industry

1. Introduction

Research on astronauts can benefit patients with conditions affecting the neuro-musculoskeletal systems and *vice versa*, as both face the challenge of managing the effects of disuse. Deconditioning in astronauts after spaceflight is a useful model for studying interventions for optimal recovery, as changes occur relatively rapidly and without the complication of underlying pathology seen in musculoskeletal and neurological disorders, where the effects of disuse are difficult to study in isolation. Physical inactivity is a major problem in the general population, despite well-known benefits, causing a public health concern worldwide (Kohl et al 2012; Lee et al 2012), so translating motivation strategies from astronauts would be very beneficial. Clinical conditions associated with disuse can also provide lessons for optimising exercise programmes to minimise deconditioning during spaceflight and reconditioning the astronaut on their return to Earth. The purpose of this Supplement is to highlight areas where space and terrestrial research and clinical management may have lessons for one another.

Astronauts typically spend six months on the International Space Station (ISS). The effects of microgravity (μG) on the cardiovascular, musculoskeletal and neurovestibular systems are well documented. Changes in the neuro-musculoskeletal system include: bone loss (Smith et al. 2012); muscle weakness, particularly postural muscles (Gopalakrishnan et al. 2010); reduced muscle mass (Belavy et al., 2011); impaired motor control and balance (Bloomberg & Mulavara, 2003; Buckey 2006; Cohen et al., 2012; Clément 2011) and increased risk of lumbar disc pathology (Belavy et al., 2016). Inflight exercise programmes, termed countermeasures (CM), have largely reduced these negative effects but despite exercising for two hours a day, some impairments are still present on return to earth, e.g. reduced knee extensor strength by 16% is evident after ISS missions, even with today's extensive countermeasure programmes (English et al. 2015). As space missions become longer and extend to unfamiliar environments beyond Low Earth Orbit (LEO), and involve excursions on planetary surfaces (Long Duration Exploration Missions; LDEM), such as on Mars, challenges to the human body and requirements for effective postflight reconditioning need to be better understood by learning from existing knowledge and further research. This Supplement arose from the work of a European Space Agency Topical Team on Post-mission Exercise (Reconditioning). The papers address ways that some of the future challenges faced by astronauts might be overcome and what research is needed to develop effective reconditioning programmes, which may also have implications for terrestrial rehabilitation.

2. The Way Forward for Optimal Reconditioning of Astronauts

The term reconditioning is used rather than rehabilitation, as astronauts are not patients with pathology but rather have made normal physiological adaptations due to neuromuscular plasticity in response to exposure to different environments (μG in space, then 1G on Earth).

Whilst the adaptation to space can be viewed as appropriate, on returning to Earth (or landing on the Moon or Mars), these changes could be seen as “maladaptation” and thus need to be minimized by inflight countermeasures. Postflight recovery requires reconditioning to enable the astronaut to readapt to gravity on Earth to return to preflight function as safely and as rapidly as possible.

For future exploration class missions to other planets, an additional phase of postflight reconditioning will be required following deep space cruise to the destination, to enable safe and effective exploration on a planet’s surface.

The acceleration levels experienced by astronauts range from 0G (microgravity) in orbit, to 1Gz (9.81 m/s^2) on Earth (vertically feetward), up to 9Gx (felt briefly, horizontally through the chest) during Soyuz ballistic re-entry, with variable reduced gravity on planet surfaces, e.g. on the moon gravity is 0.17Gz (1.63 m/s^2) and on Mars 0.38Gz (3.71 m/s^2). Effective and safe performance during surface planetary excursions on Mars following long duration flights at 0G will require preparation through specific functional exercise programmes on board prior to landing. Hence, this aspect of conditioning is termed preconditioning (Figure 1). Optimal reconditioning and preconditioning programmes have yet to be established.

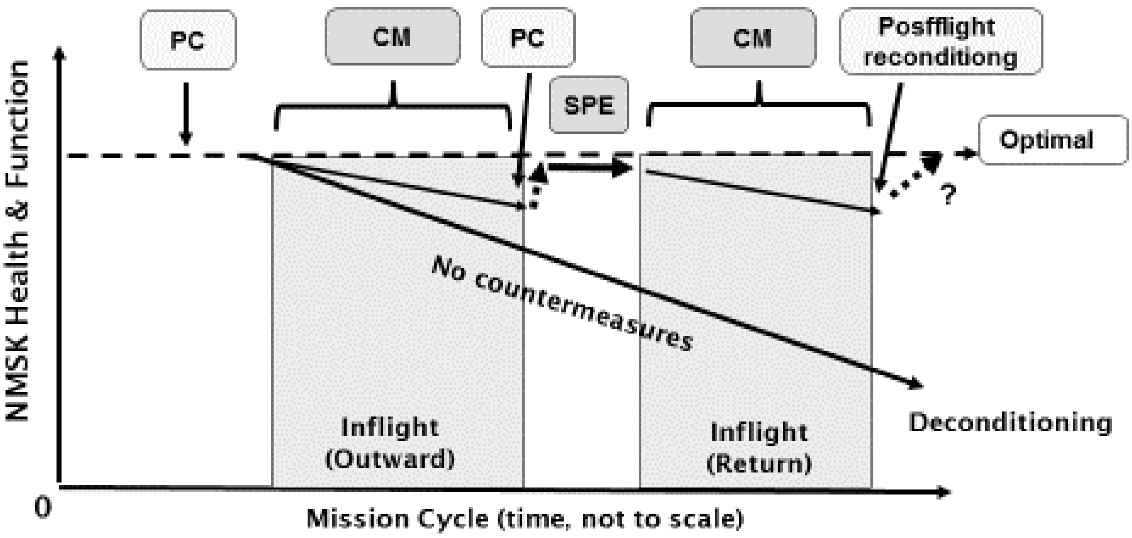

Figure 1: Maintenance of astronaut condition during one long duration mission cycle from Earth to a planet (e.g. Mars), with surface exploration, and back

NMSK = Neuro-musculoskeletal System

PC = Preconditioning; CM = Countermeasures (Inflight);

SPE = surface planetary excursion

Reconditioning needs to consider both the short-term requirements to return the astronaut to activities of daily living and readiness for future missions, as well as the astronaut's long-term health. The effects of repeated long-duration missions, and whether full recovery of all aspects of function between missions will be possible, are unknown, so research is needed to assess the risk and incidence of osteoporosis, osteoarthritis, and other neuro-musculoskeletal conditions related to deconditioning or premature ageing.

2.1 European Space Agency Post-mission Exercise (Reconditioning) Topical Team

The European Space Agency established a Topical Team for Post-mission Exercise (Reconditioning), which was tasked with setting research priorities to develop optimal postflight reconditioning programmes for astronauts in readiness for future longer duration exploration space missions.

The Reconditioning Topical Team report provided details of evidence-based postflight reconditioning programmes, identified knowledge gaps and proposed how terrestrial rehabilitation practices, and research and development, may have lessons for postflight reconditioning and *vice versa*. The report presented conclusions and recommendations for research activities that the European Space Agency and the wider space community might pursue.

The breadth of expertise of the Reconditioning Topical Team, and further experts recruited to author the report, spanned several scientific and clinical disciplines, including: physiotherapy, medicine, sport and exercise science, physiology, psychology, statistics and research methodology. As patient and public involvement is fundamental to the feasibility and success of terrestrial research, the Topical Team recognised the importance of including astronauts and Medical Operations specialists as members of the team.

The Topical Team report proposed recommendations for future research and practice for postflight reconditioning based on current knowledge from scientific literature on astronaut and bed rest studies, and relevant terrestrial populations, as well as insights from the perspectives of astronauts, space Medical Operations and terrestrial clinical experts.

2.2 Papers in this Supplement

The Reconditioning Topical Team produced a collection of papers for this Supplement of *Manual Therapy*, in various formats: systematic review, commentary, case report and experimental study. These papers highlight the relevance of postflight reconditioning to the management of various clinical conditions seen on Earth, as well as challenges faced in research.

2.2.1 Exercise-based Countermeasures to Minimise Effects of Microgravity

To return the astronaut to preflight status rapidly postflight, inflight countermeasures help to maintain function and provide a good starting point for reconditioning, to enable it to be as effective as possible. Countermeasure studies have been conducted during bed rest (e.g. Belavy et al., 2010; Blottner et al 2006; Miokovic et al., 2011), which provides an analogue of microgravity; a useful tool given the methodological constraints of conducting studies inflight (see below regarding methodological challenges). Members of the Reconditioning Topical Team conducted a systematic review of countermeasures for lumbopelvic rehabilitation during bed rest (Winnard et al., 2017a), since the lumbopelvic muscles are particularly vulnerable after periods of microgravity. The review revealed inconsistencies in outcome measures between the seven studies included, which did not enable one form of exercise programme to be deemed more effective than another. Countermeasures included resistance exercise, resistive vibration exercise, lower body negative pressure, treadmill exercise, low magnitude mechanical signals, flywheel exercise, and spinal mobilisation exercise. The authors recommended that future studies include population-reported outcomes and functional measures relevant to astronauts. The authors also suggested that inflight studies of astronauts be conducted on the ISS, rather than rely solely on bed rest studies.

2,2,2 The European Space Agency Postflight Reconditioning Programme

The European Space Agency astronaut programme involves a multi-disciplinary team that takes care of the astronaut's health throughout the three phases of the mission cycle: preflight, inflight and postflight. The team includes specialists in medicine (flight surgeons), psychology, biomedical engineering, nutrition, physiotherapy and sports science. Aspects of the programme provided by the physiotherapist and sports scientist, which focus on neuro-musculoskeletal health, are discussed in the commentaries.

The physiotherapist and sports scientist work together closely to prepare the astronaut for spaceflight, monitor exercise performance whilst the astronaut is on the International Space Station (through, amongst other means, live audio/video link communication), and recondition the astronaut when they return to Earth. One clinical commentary focuses on the physiotherapy programme (Lambrecht et al., 2017), which has been developed over nine long-duration missions. Principles of physiotherapy assessment, clinical reasoning, treatment programme design and progression of the programme, tailored to the individual, are outlined. The reconditioning programme is based on the best evidence available from terrestrial research and requires evaluation.

Implications for rehabilitation of the terrestrial population are discussed and challenges anticipated after longer missions, e.g. to Mars, are considered. For example, remote feedback from the therapist to the astronaut on board the ISS is similar to telemedicine, which may need to become part of routine practice on Earth, with the growing population.

A case report of an astronaut focuses on the sports scientist's input to the exercise component of the reconditioning programme (Petersen et al 2017), demonstrating how it dove tails with the physiotherapist's input. The case report emphasises the tailored, personalised nature of the programme. The astronaut in the case report is an athlete and provides a useful illustration of how recovery of muscle strength is not sufficient, even in a highly trained athlete, to regain optimal functional performance and that motor control has a key role to play.

2.2.3 Learning from parallels with terrestrial populations and *vice versa*

Drawing on similarities with conditions seen in terrestrial populations may help inform postflight reconditioning, e.g. low back pain, where the distribution of trunk muscle atrophy is similar to that in microgravity (Hides et al. 2007; Pool-Goudzwaard et al. 2015). Comparisons have been drawn between the effects of microgravity and ageing (Biolo et al. 2003) but the greater challenges ahead resulting from longer missions and new environments may benefit from drawing on the challenges and rehabilitation strategies in other terrestrial clinical conditions involving deconditioning, such as neurological conditions and critically ill patients in intensive care. At the other end of the spectrum, reconditioning of astronauts may benefit from adopting physical and psychological strategies for achieving optimal performance in athletes in elite sports. Measures such as astronaut-specific performance testing and movement quality, and motor control strategies to improve these aspects of function, may be of value but require research. Reciprocal benefits of these parallels between astronaut and terrestrial populations are detailed in a clinical commentary by Hides et al. (2017).

Future long-duration missions will pose new challenges for the maintenance of exercise levels inflight to limit deconditioning on return to earth but there has been limited research on astronaut adherence to prescribed exercise programmes. Self-motivation will be imperative during the prolonged isolation, particularly during preconditioning in preparation for conducting exploratory missions on planet surfaces, when live contact with ground support will not be possible. A commentary by McKay & Standage (2017) on psychological strategies discusses adherence predictors in analogous terrestrial populations (sport, clinical rehabilitation, general exercise) that may translate to spaceflight environments. The importance of intrinsic motivation, realistic outcome expectancies, self-regulation skills, and strong therapeutic alliances are stressed to promote ongoing exercise adherence. Research is needed to understand spaceflight-specific barriers and facilitators to adherence, and to develop appropriate strategies to promote ongoing exercise behaviours. Such strategies may in turn help the general population maintain an active lifestyle long-term, particularly those without support systems who need to rely on self-motivation.

2.2.4 Methodological challenges for space and terrestrial research

Definitive studies of postflight reconditioning using conventional research designs, such as randomised controlled trials, are restricted by factors such as insufficient numbers, the availability of astronauts and non-standardised exercise programmes between space agencies. A commentary by Beard & Cook (2017) explores methodologies for optimal designs and outcome measures. It also suggests how some evidence based terrestrial findings might be adopted directly for postflight reconditioning practice, given that some research questions are not possible to test in the astronaut population, due to the difficulty in employing complex designs in the spaceflight circumstance. The authors of the commentary propose that multi-space agency collaboration will be critical to pool data from small groups of astronauts using standardised outcome measures. The messages from this commentary are particularly relevant for researching conditions on Earth that pose challenges for study design, e.g. varying experimental conditions, or small sample sizes, such as rare diseases.

2.2.5 Potential technology for postflight reconditioning and back pain rehabilitation

This series of papers concludes with an example of an exercise device for lumbopelvic muscle training described in an experimental paper. The effects of exercise using the Functional Re-adaptive Exercise Device (FRED) on lumbopelvic kinematics was examined in people with and without low back pain (Winnard et al., 2017b). The findings indicate that FRED exercise promotes a lumbopelvic posture which is more conducive to automatic lumbar multifidus and deep abdominal muscle training than walking, in both asymptomatic people and those with back pain, so this device may be potentially useful in postflight reconditioning and in back pain rehabilitation on Earth.

3. Concluding Remarks

We hope this Supplement will spark further interest in space research, and mutually beneficial collaboration between rehabilitation and space reconditioning experts. Optimal exercise programmes are needed for reconditioning of astronauts and rehabilitation in terrestrial musculoskeletal and neurological conditions. Effective adherence strategies are needed by both populations; for astronauts as their missions to space enter more extreme environments and on Earth due to limited health care resources. Translation of knowledge from spaceflight research and practice has implications for several areas of rehabilitation. Insights into space medicine will have more direct relevance, and even become a necessity for some terrestrial clinicians, as space tourism is set to become a reality.

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Topical Team Members:

Maria Stokes (Co-Chair & Co-editor of Topical Team Report, University of Southampton, UK); Simon Evetts (Co-editor of Report), SeaSpace Research Ltd Colchester, UK; Joern Rittweger (Co-Chair of TT; German Aerospace Center (DLR) and University of Cologne, Germany; Tobias Weber (TT Secretary), Space Medicine Office European Space Agency (ESA), Cologne; Nick Caplan, Northumbria University, UK; Lieven Danneels Ghent University, Belgium; Dorothee Debuse, Northumbria University, UK; Julie Hides Australian Catholic University, Australia; André Kuipers (Astronaut ESA corps, non-active); Gunda Lambrecht ESA Physiotherapist, Cologne; Nora Petersen ESA Sports Scientist, Cologne; Jonathan Scott Space Medicine Office, ESA, Cologne); Andrew Winnard Northumbria University, UK; Jochen Zange DLR, Cologne, Germany.

Additional Expert Authors of Topical Team Report:

Daniel Barry (former NASA Astronaut, USA); David Beard (University of Oxford, UK); Jacob Bloomberg (NASA/Johnson Space Center, Texas, USA); Dieter Blottner (Charité University Medicine Berlin and Berlin Center of Space Medicine and Extreme Environments, Germany); Filippo Castrucci (Flight Surgeon, ESA, Cologne); Jonathan Cook (University of Oxford); Rebecca Cusack (University Hospital Southampton NHS Foundation Trust and University of Southampton, UK); Anna-Maria Liphardt (Friedrich-Alexander-Universität Erlangen-Nürnberg, German Sport University Cologne and University of Cologne); Carly McKay (University of Bath, UK); Anja Niehoff (German Sport University Cologne and University of Cologne); Gita Ramdharry (Kingston University and St George's University of London, UK).

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