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Guest Editorial

Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: Reciprocal knowledge transfer

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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 public health and economic concerns 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 and 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 2 h 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 (Fig. 1). Optimal reconditioning and preconditioning programmes have yet to be established.

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

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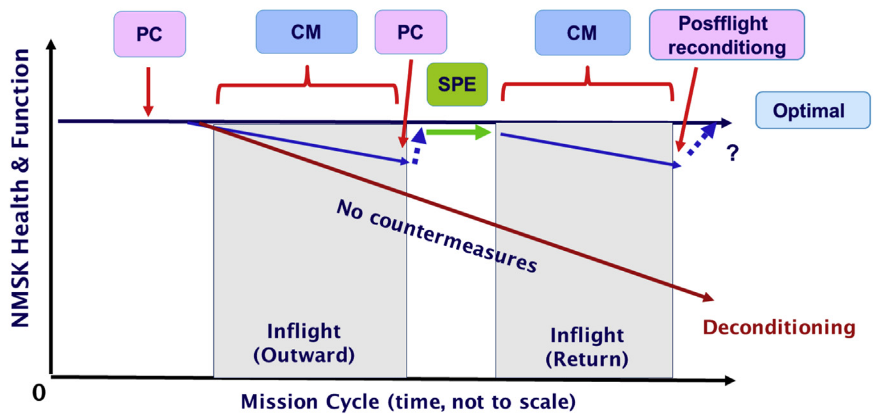

Fig. 1. Maintenance of astronaut condition during one long duration mission cycle from Earth to a planet (e.g. Mars), with surface exploration, and back
NMSK = Neuro-musculoskeletal System
PC = Preconditioning; CM = Countermeasures (Inflight);
SPE = surface planetary excursion.

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 post-flight 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 (see Acknowledgments for details of members of the Topical 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 Issue

The Reconditioning Topical Team produced a collection of papers for this Supplement of Musculoskeletal Science and Practice, 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 multidisciplinary 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,