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Original article

The role of physiotherapy in the European Space Agency strategy for preparation and reconditioning of astronauts before and after long duration space flight

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ABSTRACT

Spaceflight and exposure to microgravity have wide-ranging effects on many systems of the human body. At the European Space Agency (ESA), a physiotherapist plays a key role in the multidisciplinary ESA team responsible for astronaut health, with a focus on the neuro-musculoskeletal system. In conjunction with a sports scientist, the physiotherapist prepares the astronaut for spaceflight, monitors their exercise performance whilst on the International Space Station (ISS), and reconditions the astronaut when they return to Earth. This clinical commentary outlines the physiotherapy programme, which was developed over nine long-duration missions. Principles of physiotherapy assessment, clinical reasoning, treatment programme design (tailored to the individual) and progression of the programme are outlined. Implications for rehabilitation of terrestrial populations are discussed. Evaluation of the reconditioning programme has begun and challenges anticipated after longer missions, e.g. to Mars, are considered.

1. Introduction

The requirements of the human body, in particular the neuro-musculoskeletal system, are very different in space than on Earth. Interestingly, physiological spaceflight data suggest that it is more difficult to return to gravity than to adapt to microgravity conditions (Payne et al., 2007). On Earth, the line of gravity normally passes through the ventral part of the L3 vertebral body (Richter and Hebgen, 2006), (ensuring optimal load transfer). In microgravity, musculoskeletal adaptations are appropriate to that environment but this has major effects on muscle function and posture. Astronauts move in a predominantly flexed position and the centre of mass shifts posteriorly (Baroni et al., 2001), with increased recruitment of flexor muscles and a loss of extensors (Fitts et al., 2000; 2001). A shift of muscle fibres types from tonic (type 1) to phasic (type 2) occurs (Fitts et al., 2001). Graviceptors, which are sensory receptors that contribute to providing a neural representation of the direction of gravity, with respect to the gravity vector (Binder, 2009), no longer function in microgravity. The astronaut therefore receives less information about his/her posture and has to rely on vision and feedback from dynamic receptors.

Prolonged microgravity has negative effects on muscle strength and endurance, motor control, coordination and balance (Layne et al., 2001), which may place the astronaut at higher risk of injury. In the spine, primarily lumbar, intervertebral discs absorb more water (hyperhydration) than on Earth (Belavy et al., 2016), which can be associated with low back pain (LBP) inflight but is short-lived and has been reported in 70% of astronauts without a history of LBP and 100% of those with a history of LBP (Pool-Goudzwaard et al., 2015). The effects of microgravity on the

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intervertebral disc must be considered to allow safe re-loading of the spine postflight, as the astronaut must readapt abruptly to gravity on return to Earth. The incidence of herniated nucleus pulposus is 4.3 times higher in astronauts than in terrestrial populations, predominantly in the period immediately following return to Earth (Johnston et al., 2010).

Since 2006, ESA has built its multidisciplinary team responsible for astronaut preparation, inflight management whilst on the International Space Station (ISS) and reconditioning after return to Earth. The physiotherapist and sports scientist are jointly responsible for the neuro-musculoskeletal health of astronauts. The ESA programme is based on specific principles and tailored to meet the needs of the individual astronaut. Evidence-based aspects central to physiotherapy practice (assessment, clinical reasoning and treatments) are integral to the management of astronauts.

The aim of this clinical commentary is to describe the ESA physiotherapy approach developed for astronauts who experience long-duration space flights.

2. The ESA astronaut programme

Members of the multidisciplinary team are involved throughout the three phases of the mission cycle of an astronaut in the ESA programme. The team includes flight surgeons, a psychologist, biomedical engineers, a nutrition specialist, a physiotherapist and sports scientist. Only the programme provided by the physiotherapist and sports scientist are discussed in this commentary. The sports science components are illustrated in a case report by Petersen et al. (2017).

2.1. Preflight training

The goals of preflight training are to a) familiarise the astronaut with the Inflight Training Programme; b) treat any pre-existing neuro-musculoskeletal conditions; c) prepare the astronaut for space; d) conduct preflight measures.

Flight preparation takes place over two years in three locations: The European Astronaut Centre (EAC) at the European Space Agency (ESA), Cologne, Germany; Johnson Space Center (NASA), Houston, USA; and Gagarin Cosmonaut Training Centre (RSA), Moscow, Russia. The ESA physiotherapist and sports scientist see the astronaut 10–20 times, depending on the astronaut's availability to educate them about the neuro-musculoskeletal changes that will occur and how these will be managed. This period is also crucial for building trusting relationships between the astronaut and training specialists, to maximise compliance.

The initial physical examination includes assessment of posture, motor control and functional movement, as well as in-depth assessment of joints/regions with pre-existing conditions. Physiotherapy modalities which may be appropriate at this stage include manual therapy, motor control training, elements from proprioceptive neuromuscular facilitation (PNF), fascial treatment, etc., as appropriate. If techniques such as kinesiotaping are required, the astronaut is taught self-application for use on the ISS. A home programme is given to the astronaut, which is monitored and progressed as necessary.

Ultrasound imaging was used for the last four missions to assess size and the ability to voluntarily contract antero-lateral abdominal and paraspinal muscles (Hides et al., 1995, 2007; Wallwork et al., 2007). This allows comparison of preflight measures with those taken postflight and post-reconditioning (Hides et al., 2016). Ultrasound imaging is also used to provide feedback of muscle contraction if retraining is required (Van et al., 2006).

The astronaut is familiarised with the Advanced Resistive Exercise Device (ARED), a strength training exercise countermeasure on the ISS (Fig. 1). The goal is to optimise and practise movement patterns that will be performed on the ISS, although exercising will feel very different on the ISS because of microgravity and lack of proprioception. The focus is on optimising postural control whilst performing exercises on the ARED, with attention paid to the position of the lumbo-sacral junction (avoiding posterior pelvic tilt), thoraco-lumbar junction (avoiding extension) and correct positioning of the cervico-thoracic junction.

2.2. In flight training on the ISS

Inflight, the astronaut is required to perform 2 h of training each day to mitigate the known negative effects of microgravity on the neuro-musculoskeletal system. For muscular and cardiovascular endurance, a cycle ergometer or treadmill is used. For strength training and loading of skeletal structures, the ARED is used. The ARED uses adjustable resistance piston-driven vacuum cylinders along with a flywheel system to simulate free-weight exercises in gravity, to work all the major muscle groups including squats, dead lifts, and calf raises (Fig. 2).

To optimise the positive effects of load on bones and muscles, and minimise stress on joints and passive structures for safety, the physiotherapist works to ensure that the astronaut's spines and legs are in optimal alignment (Fig. 3).

To optimise performance and safety, ARED exercises are monitored using real-time feedback via an audio and video conference link with the physiotherapist and sports scientist, located in the EAC in Cologne, they observe the astronaut performing the exercises and provide feedback. If additional feedback is needed, the astronaut can apply Kinesiotape to the lumbar region so they can feel a stretch on the skin if the lumbar spine flexes whilst performing exercises such as squats (Fig. 3). A flattened lumbar

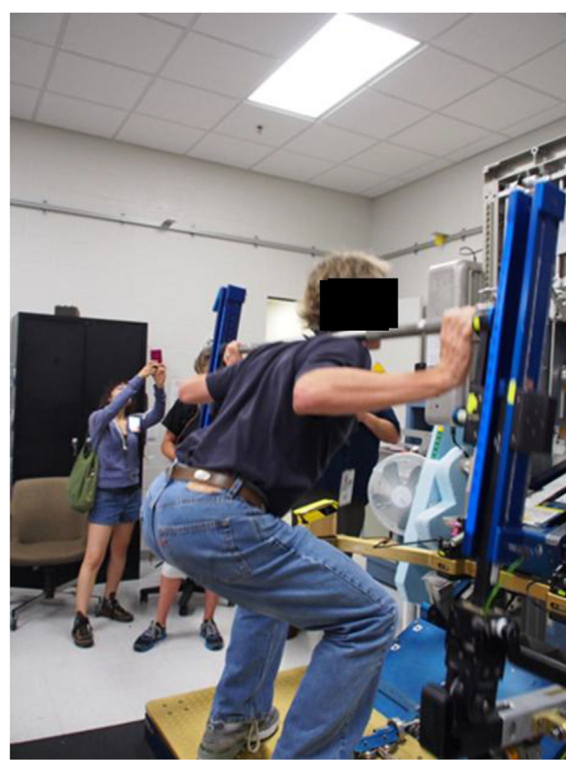

Fig. 1. Advanced Resistive Exercise Device (ARED) Training at the Johnson Space Centre, Houston. The Physiotherapist and Sports Scientist help the astronaut to optimise performance of exercises on the (ARED) device. (Photograph courtesy of ESA).