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Original article

Parallels between astronauts and terrestrial patients – Taking physiotherapy rehabilitation "To infinity and beyond"

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ABSTRACT

Exposure to the microgravity environment induces physiological changes in the cardiovascular, musculoskeletal and sensorimotor systems in healthy astronauts. As space agencies prepare for extended duration missions, it is difficult to predict the extent of the effects that prolonged exposure to microgravity will have on astronauts. Prolonged bed rest is a model used by space agencies to simulate the effects of spaceflight on the human body, and bed rest studies have provided some insights into the effects of immobilisation and inactivity. Whilst microgravity exposure is confined to a relatively small population, on return to Earth, the physiological changes seen in astronauts parallel many changes routinely seen by physiotherapists on Earth in people with low back pain (LBP), muscle wasting diseases, exposure to prolonged bed rest, elite athletes and critically ill patients in intensive care. The medical operations team at the European Space Agency are currently involved in preparing astronauts for spaceflight, advising on exercises whilst astronauts are on the International Space Station, and reconditioning astronauts following their return. There are a number of parallels between this role and contemporary roles performed by physiotherapists working with elite athletes and muscle wasting conditions. This clinical commentary will draw parallels between changes which occur to the neuromuscular system in the absence of gravity and conditions which occur on Earth. Implications for physiotherapy management of astronauts and terrestrial patients will be discussed.

1. Introduction

Physiotherapy is inextricably linked to the effects of gravity on the human body. In the early 1900's, "gravity tests" were developed (Hislop et al., 2013). In the 1940's, a system for recording muscle dysfunction in people with poliomyelitis was introduced (Hislop et al., 2013) whereby grading of muscle function was accomplished using gravity and manual resistance techniques. Manual muscle testing is still conducted today, and the principles involved underpin much of the theoretical basis of contemporary physiotherapy practice. Another area directly linked with the relationship to gravity on Earth is posture. The line of gravity normally passes through the ventral part of the L3 vertebral body (Richter and Hebgen, 2006), and biomechanical models have shown that the body is best able to withstand compressive forces when positioned in a cervical lordosis, thoracic kyphosis and lumbar lordosis (Kiefer et al., 1997). Specific muscles are required to maintain posture and

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the term “postural muscles” was used to describe antigravity muscles which are tonically active.

Neuromuscular plasticity refers to the ability of the nervous system to adapt and change the control and properties of skeletal muscle in response to both therapeutic input and environmental stimuli (Kidd et al., 1992). Rapid remodelling of the neuro-muscular system occurs in microgravity, with animal studies demonstrating that changes in gravitational or load related cues result in a biased recruitment away from antigravity muscles (Recktenwald et al., 1999). Healthy astronauts undergo specific physiologic changes in microgravity, which, on return to Earth, manifest as physical impairments requiring a period of rehabilitation (Payne et al., 2007). Interesting parallels can be drawn between the changes seen in the neuromuscular system induced by microgravity and those seen on Earth. Some changes due to unloading in microgravity are similar to those seen in terrestrial patient populations such as spinal cord, geriatric or deconditioned bed rest patients (Payne et al., 2007). In addition, conditions such a low back pain (LBP) and exposure to elite sports can also have specific effects on the neuromuscular system which bear some resemblance to changes seen in astronauts. The benefits of exchanging knowledge and expertise between the two environments are therefore reciprocal.

Space agencies are currently preparing for extended duration missions, including exploration of Mars. In addition, more members of the general public may be exposed to microgravity in the future due to increased availability of commercial human spaceflight. Current long duration missions to the International Space Station (ISS) are 6 months long on average. Ultra-long duration space travel, such as interplanetary space travel to Mars, would result in 3 years or more in microgravity. Physiologic adaptation to microgravity is dependent on exposure, with greater levels of disability anticipated on returning to Earth after longer missions (Payne et al., 2007). Combining the knowledge and understanding of the effects of microgravity with the expertise of those involved in rehabilitation is therefore required.

The aims of this clinical commentary are to:

1) Outline and discuss conditions on Earth and their physiotherapy management which could inform reconditioning of astronauts.
2) Draw parallels between changes which occur to the neuromuscular system in the absence of gravity in both astronauts and the terrestrial population, which could help physiotherapists better understand and prescribe interventions to the patient on Earth and the astronaut involved in spaceflight.

2. Lessons from prolonged bed rest studies

Prolonged bed rest is a model used to simulate the effects of spaceflight on the human body (Nicogossian and Dietlein, 1982). Subjects follow a strict protocol of lying down in bed at a 6° head down tilt for days to months.

A 60 day bed rest study (2nd Berlin Bed Rest study- BBR-2) assessed lower limb muscles and showed that the response to bed rest was not uniform (Miokovic et al., 2012). In the lumbopelvic region, increases in disc volume, spinal length, loss of the lower lumbar lordosis, and changes in muscle size occur (Belavy et al., 2011). The rate of muscle atrophy was greatest in the multifidus muscle (L4 and L5 vertebral levels) (see Fig. 1) and the lumbar erector spinae (at L1 and L2). In contrast, the size of the psoas muscle at the trunk increased (Belavy et al., 2011; Hides et al., 2007).

Bed rest studies constitute a direct link between space research and rehabilitation medicine (Payne et al., 2007). In the BBR-2, two physiotherapists were provided with a unique opportunity. The European Space Agency (ESA) physiotherapist (Lambrecht et al., 2017) and a physiotherapist experienced in motor control training designed and delivered a reconditioning program. Magnetic resonance imaging (MRI) of the lumbo-pelvic region was conducted at the start and end of bed rest and during the recovery period. After bed rest, participants underwent either trunk flexor and general strength (TFS) training or specific motor control training (MCT). MCT was based on combining the approaches used by the two physiotherapists (Hides et al., 2011a,b). Both exercise programs restored the multifidus muscle but further increases in psoas muscle size were seen in the TFS group up to 14 days after bed rest. Results suggest that incorporation of weight bearing exercises in good spinal alignment increased the atrophied multifidus muscles, and decreased the size of the increased psoas muscles (see Fig. 2).

3. Motor control training for astronauts and terrestrial populations

The ESA approach to post space mission lumbo-pelvic reconditioning has been published (Evetts et al., 2014; Lambrecht et al., 2017; Petersen et al., 2017). Whilst the physiotherapy programme encompassed much more than rehabilitation of the lumbo-pelvic region, a recent case history documented changes in lumbopelvic muscles associated with spaceflight (Hides et al., 2016a,b). Results showed that reconditioning post spaceflight restored the sizes of the multifidus and anterolateral abdominal muscles. Data from other astronauts pre and post spaceflight are currently being collected by the ESA medical operations team.

4. Lessons from the patient with low back pain and elite athletes

A similar MCT approach has been used on Earth for people with acute LBP, chronic LBP, elite cricketers and elite Australian Football League players (Hides et al., 1996, 2008; Hides et al., 2012). The programme has been shown to decrease LBP, was commensurate with decreased games missed due to injury and was predictive of injury (Hides and Stanton, 2016; Hides et al., 2011a,b; Hides et al., 2016a,b; Hides et al., 2014). The program also restored the size of hip muscles such as the gluteus medius, most likely due to performance of weight bearing exercises in good femoropelvic alignment (Mendis and Hides, 2016). The FIFA 11 + used as a warm-up by football (soccer) players is perhaps the most widely implemented neuromuscular exercise injury prevention programme currently used (Soligard et al., 2010). More targeted preventive training programmes are now being developed for specific sports and occupational cohorts (Padua et al., 2014).

Movement screening in the elite athlete comprises two types of tests: physical performance tests, which assess function and provide objective (quantitative) data, e.g. Triple Single Leg Hop, Star Excursion Balance Test (Hegedus et al., 2014, 2015), and movement control tests, which assess quality of movement and provide qualitative observation data. Movement control tests identify and rate functional compensations, asymmetries, impairments or efficiency of movement control through transitional (e.g. single knee bend, squat, sit-stand, lunge) or dynamic (hopping, walking, landing, cutting) movements tasks. Several movement control screening tools exist, e.g. the functional movement screen or FMS (Kiesel et al., 2007) the Nine Test Screening Battery (Frohm et al., 2012) and the Performance Matrix (Mottram and Comerford, 2008). However, consensus is needed to harmonise terminology and definitions used (Teyhen et al., 2014; Hegedus et al., 2015) and further research required for movement tests to be implemented in pre- and post-spaceflight screening.

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