RECOVERY OF NEUROMECHANICAL PROPERTIES OF THE HUMAN PLANTARFLEXORS AFTER LONG-TERM SPACEFLIGHT

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Introduction

Exposure to μG is known to induce a decrease in muscle strength in animals as well as in humans, principally in postural muscles (Edgerton & Roy, 1996). This is due to atrophy and induces mechanical adaptations affecting contractile (Thomason & Booth, 1990) and elastic properties (Canon & Goubel, 1995). Recently, changes in contractile and elastic properties of the human plantarflexors immediately after spaceflight (3-6 months) were reported (Lambertz et al., 2001). In terms of neurophysiological adaptations, changes in neural drive are usually considered to be present after exposure to μG (Koryak, 1998; Antonutto et al., 1999). Moreover, changes in elastic properties should account for lower T reflexes despite an hypothesized increase in synaptic efficiency (Anderson et al., 1999).

The aim of the present study was to investigate changes in neuromechanical properties of the human plantarflexors when they return to a 1G environment just after long-term spaceflight and a few days after landing. For this purpose, a special ankle ergometer was designed to investigate both muscular contractile and elastic properties, as well as reflex excitability during a given experimental session. The determination of the muscular mechanical properties was made using isometric contractions, isokinetic movements and quick-release tests, respectively. Reflex excitability of pre-activated muscles was tested by sinusoidally evoked stretch reflexes at different frequencies.

Methods

The experiments were performed on 8 cosmonauts who spent 90 to 180 days aboard of the Mir Station. Cosmonauts performed two sets of muscular testing 28 to 40 days before flight [Baseline Data Collection (BDC)] and after spaceflight [Return (R)] on day R+2/+3 (postflight) and R+5/+6 (early recovery). Postflight was expressed in terms of gain values with respect to BDC and early recovery was expressed in terms of gain values with respect to R+2/+3.

Cosmonauts were placed on an adjustable seat with their left foot attached rigidly to the actuator of the ankle ergometer described elsewhere (Tognella et al., 1997). Electromyograms (EMG) were detected on each part of the triceps surae (TS). EMG signals were recorded differentially, amplified, band-pass filtered (1 Hz and 1 kHz) and expressed as the Root Mean Square ($RMS$).

Firstly, maximal voluntary contraction ($MVC$) was determined in plantarflexion under isometric conditions.

Secondly, isokinetic trials at different constant velocities ranging from 0.52 to 3.65 rad s$^{-1}$, in steps of 0.52 rad s$^{-1}$, were performed. Three cycles of alternated plantarflexion and dorsiflexion with the highest $RMS$ agonist activity were chosen to calculate a mean value in maximal plantarflexion torque and angular velocity. Plotting maximal torque ($T$) against angular velocity ($\Theta$) led to a torque-velocity relationship and angular shortening velocity at low torque ($T = 10\%$ of $MVC$) was chosen as an index of maximal shortening velocity ($V_{I\max}$) in plantarflexion.

Thirdly, elastic properties of the musculo-tendinous (MT) complex were determined by means of a quick-release technique. Quick-release movements were carried out while the cosmonaut maintained a voluntary isometric torque in plantarflexion corresponding to 25%, 50% and 75% of $MVC$. MT characteristics were measured at the beginning of the movement, i.e. when elastic elements are supposed to recoil. Thus, their stiffness was calculated as the ratio between variations in angular acceleration and angular displacement, multiplied by the corresponding inertia value. Then, MT stiffness was related to the isometric torque initially exerted by the cosmonaut. The slope of the linear stiffness-torque relationship so obtained was defined as a stiffness index of the MT complex ($SI_{MT}$).
Finally, trials of sinusoidal oscillations (3° peak-to-peak; 4-16 Hz) were imposed to the ankle joint in order to evoke stretch reflexes (SR). During such oscillations the cosmonaut had to maintain a constant level of torque equal to 50% of his MVC in plantarflexion. The EMG of the three muscles composing the TS were averaged, rectified and summed up to express the TS SR. Then, TS SR area was determined by integrating the averaged EMG over the time interval corresponding to the expected burst of reflex activity (35-60 ms). A mean SR amplitude value (SR) was calculated as the ratio between SR area and SR duration. Furthermore, supramaximal electrical stimulations were achieved in order to get the maximal motor direct response (M_max). The mean amplitude of the TS M_max (MT_max) expressed by the ratio between duration and area, was used to normalize SR. Then, TS excitability was expressed by the area under the normalized SR - frequency curve and it was defined as the “Frequency Distribution of the SR” (FD-SR).

Results & Discussion

In postflight conditions, a significant decrease in MVC was found (-17%), whereas VI_max and SI_MT increased (31% and 25%, respectively). However, no correlation was found between gains in SI_MT and VI_max (Fig. 1A). FD-SR was also found to increase (44%) but this increase was not correlated to gain in SI_MT (Fig. 2A).

![Fig. 1](image1.png)

**Fig. 1** Paired changes in gain values between SI_MT and VI_max. In A, no correlation was found between gain values in SI_MT and VI_max when tested immediately after spaceflight (r = 0.26, P >0.05). In B the correlation coefficient r was found to be significantly improved when using recovery data (r = 0.73, P < 0.05).

In early recovery conditions, gain in MVC (4.4%) was found to be not significant, whereas VI_max decreased (-14%) and SI_MT increased (24%). Contrary to what appeared in R+2/+3, a correlation was found between gains in SI_MT and VI_max (Fig. 1B). On the other hand, concerning reflex excitability, FD-SR decreased significantly (41%). Interestingly, relating gains in SI_MT and FD-SR for each subject led to linear increase (Fig. 2B).

![Fig. 2](image2.png)

**Fig. 2** Paired changes in gain values between FD-SR and SI_MT. In A, no correlation was found between gain values in FD-SR and SI_MT when tested immediately after spaceflight (r = 0.32, P >0.05). In B a correlation found when using recovery data (r = 0.75, P ≤ 0.05).
The chronic unloading of the neuromuscular system during spaceflight has functional effects on the mechanical and the neurophysiological properties of antigravity muscles (Edgerton & Roy, 1996). Some insight has been gained from animal experiments, indicating a relative increase in fast fibers what led to an increase in shortening velocity (Thomason & Booth, 1990) and a decrease in the elastic properties (Canon & Goubel, 1995). The influence of μG on human mechanical properties due to long-term spaceflight has been undertaken in our laboratory and results obtained immediately after landing have been recently published (Lambertz el., 2001). The main findings from this part of the experiment were that: (1) the decrease in MVC could mainly be due to a failure in maximal activation capacities and (2) the increase in $V_{I_{\text{max}}}$ led to favor the hypothesis of a slow to fast fiber-type transition. The most unexpected finding from this study was an increase in MT stiffness, which is in general contradiction with other microgravity models. The increase in MT stiffness suggested an adaptative mechanism to counterbalance a decrease in stiffness of passive structures, notably tendon structures. The major factor to explain the increase in MT stiffness could be an abnormal muscular over-activation during submaximal isometric contractions. Thus, changes in neural drive could explain the lack of paired changes in shortening velocity and MT stiffness (Fig. 1A). As for reflex excitability, $SRA$ increased just after spaceflight despite the fact that the neuromuscular system was suspected to contain a higher number of fast, less excitable motor units. Such an increase in reflex excitability after simulated μG has been already reported when considering H reflexes (Duchateau, 1995; Anderson et al., 1999) due to an increase in synaptic efficiency (by a partial removal of a presynaptic inhibition) (Gallego et al., 1979) on the disused motoneurones. In other words, the $SR$ after spaceflight seems to be more influenced by this central adaptative phenomenon rather than by the mechanical properties of the MT elements in series with the muscles spindles. This hypothesis could explain the lack of relationships between $S_{\text{MT}}$ and $FD-SR$ gain values (Fig. 2A).

The fact that mean $MVC$ did not change from R+2/+3 to R+5/+6 seems to be wondering, since a lower atrophy and a partial recovery in activation capacities were expected. Recently, Antonutto et al. (1999) showed that peak force was still depressed by 12 to 22% after 26 days of recovery. Changes in torque-velocity relationships are usually interpreted in terms of differences in muscle fiber type distribution. The slowing in $V_{I_{\text{max}}}$ on recovery could be then attributed to a relative increase in slow type fibers. Furthermore, Fig. 1B revealed that a decrease in $V_{I_{\text{max}}}$ was associated with an increase in MT stiffness, compatible with a relative increase in slow type fibers. This should reflect the first step of a return of the postural muscle to its normal content in slow fibers. In other words, MT stiffness values measured on R+5/+6 could be dual in origin: (1) a recovery in the slow fiber muscle content and (2) a relative over activation of the muscles in order to maintain the submaximal torque to its preflight values, despite the muscles were still atrophied. Thus, it can be argued that the unexpected increase in MT stiffness on R+2/+3 resulted from a balance between two opposites mechanisms: a relative increase in motor drive to maintain the same instruction torque and a relative increase in fast fibers. As for reflex excitability, the decrease in $FD-SR$ could represent a return to a normal level of presynaptic inhibition during recovery. Such a supposed return to a normal synaptic efficiency should led to the improved correlation in $FD-SR$ vs. $S_{\text{MT}}$ gain relationships, showing that $SR$ was influenced by muscle stiffness what should illustrate a better solicitation of muscle spindles when MT stiffness is increased (Fig. 2B).

References