Superficial Lumbopelvic Muscle Overactivity and Decreased Cocontraction After 8 Weeks of Bed Rest

Daniel L. Belavy, BPhty,*† Carolyn A. Richardson, PhD,‡ Stephen J. Wilson, PhD,* Jörn Rittweger, PhD,‡ and Dieter Felsenberg, PhD§

It is not new to suggest that sedentary western lifestyle could be involved in lumbopelvic (LP) pain etiology. Dysfunction in the central nervous system (CNS) control of the LP musculature for stabilization is considered to be one risk factor for LP pain. Inactivity itself results in a number of changes in multiple body systems, but its association to change in LP motor control for stabilization and any potential link to LP pain etiology is poorly understood.

Changes in activity levels and cocontraction of the superficial LP musculature have been implicated in LP pain. In studies of activation levels, a common finding is that of increased activity (overactivity) in superficial muscles. Studies of LP antagonist cocontraction in LP pain find that it is increased and results in increased spinal loads. It has been argued that these changes in motor control reflect “splinting” of the trunk are maladaptive for LP stabilization.

While it is difficult to study LP motor control changes secondary to sedentary lifestyle, studies in “unloading” (microgravity, bed rest, and related environments) do provide insight. Leg and trunk muscle antagonist cocontraction has been observed to increase during and after exposure. Although postural instability after microgravity exposure has been documented, a component of motor control change must be involved in the increased cocontraction as the changes develop during unloading, rather than solely afterwards.

Activation levels of superficial muscles have also been studied in unloading. Generally, superficial muscles are either less active or show little change during unloading. After unloading, however, studies in animals have found superficial muscle activity to be increased. Human postural studies show similar pattern of increased superficial muscle activity after unloading. All of these studies have, however, been undertaken on the leg musculature, and no data are available on the LP region.

We hypothesized that similar changes of increased cocontraction and overactivity would occur in the superficial muscles of the LP region during inactivity (bed rest). The European Space Agency’s “Berlin Bed Rest Study” provided the opportunity to examine this hypothesis. This has not been studied before and also begins to address a large gap in the literature on the effects of unloading on the LP region.

Materials and Methods

Bed Rest Protocol. The Berlin Bed Rest Study (BBR) was undertaken at the Charité Benjamin Franklin Hospital in Berlin, Germany, and cocontraction and overactivity would occur in the superficial muscles of the LP region during inactivity (bed rest). The European Space Agency’s “Berlin Bed Rest Study” provided the opportunity to examine this hypothesis. This has not been studied before and also begins to address a large gap in the literature on the effects of unloading on the LP region.

Materials and Methods

Bed Rest Protocol. The Berlin Bed Rest Study (BBR) was undertaken at the Charité Benjamin Franklin Hospital in Berlin, Germany, and involved ten male subjects who underwent 8 weeks of bed rest. The study design was longitudinal, and the objective was to gain insight into the effects of inactivity on lumbopelvic stabilization. The Berlin Bed Rest Study (BBR) was supported by Grant No. 14431/02/NL/2006. Acceptance date: August 21, 2006. Acknowledgment date: August 2, 2006. First revision date: August 21, 2006. The Berlin Bed Rest Study was supported by Grant No. 14431/02/NL/SH2 from the European Space Agency.

The manuscript submitted does not contain information about medical device(s)/drug(s). Institutional funds were received in support of this work. No benefits in any form have or will be received from a commercial party related directly or indirectly to the subject of this manuscript. Address correspondence and reprint requests to Daniel L. Belavy, BPhty, Zentrum für Muskel- und Knochenforschung, Charité Campus Benjamin Franklin, Hindenburgdamm 30, 12200 Berlin, Germany; E-mail: belavy@gmail.com
lin, Germany, from February 2003 to May 2005. Ten male subjects underwent 8 weeks of bed rest with a 1-year follow-up. The bed rest protocol as well as inclusion and exclusion criteria are discussed in detail elsewhere.17 However, in brief, subjects were required to remain in bed at all times and were required to restrict activity in bed to the minimal required for hygiene and other necessary daily tasks. Adherence to this protocol was monitored by continuous video recordings and force transducers in the frame of the bed. The institutional ethics committee approved this study and subjects gave their informed consent.

A history of LP pain was not a specific exclusion criterion for the BBR. As LP suffers are known to exhibit differences in motor control, a qualified physiotherapist attained subjects’ subjective history of LP pain at the beginning of the study. During bed rest and the follow-up period also, subjects’ musculoskeletal health was monitored at regular intervals with pain questionnaires.37 Incidence of LP pain was defined as any report of pain or discomfort between the first lumbar vertebra and the gluteal fold.

Repetitive-Movement Model and Testing Protocol. To stimulate LP muscle activity for LP stabilization, a gravity-eliminated repetitive knee movement model was used. Subjects were positioned in prone lying with a spring attached to their right ankle and to the apparatus and were able to view a feedback-monitor under the apparatus. The setup was optimized such that, at rest (no activity in the hamstring musculature), the knee was held at 60° of flexion by the spring. This biomechanical configuration has been shown previously to eliminate the gravitational weight of the lower-leg during movement.38,39 Right knee movement was conducted between 0° and 45° of flexion at four movement speeds (50, 75, 100, and 125 cycles per minute). Three repetitions were conducted at each movement speed. Each movement repetition was performed for 11 seconds. Subjects paused their breathing during each movement repetition to remove the influence respiration on LP muscle activity.40 An electrogoniometer was placed at the right knee to monitor knee position.

Baseline data collection occurred on the first day of bed rest (BR1). Further testing was conducted on the fourth, 13th, 27th, 41st, and 53rd days of bed rest (BR4, BR13, BR27, BR41, and BR53) and 3rd, 7th, 14th, 28th, 90th, 180th, and 360th days of recovery (R + 3, R + 7, R + 14, R + 28, R + 90, R + 180, and R + 360).

Lumbopelvic Electromyography. Five superficial LP muscles were monitored. Bipolar Ag/AgCl surface electrodes were placed over the following right-sided muscles with an interelectrode distance of 35 mm: 1) lumbar erector spinae with multifidus (LES) positioned at the level of the fifth lumbar vertebra between the spinous process and a line drawn from the posterior superior iliac spine (PSIS) to the interspace between the first and second lumbar vertebrae;2 thoracic erector spinae (TES) at the level second and third lumbar interspace, 1 cm medial to a line drawn from PSIS to the lateral border of the erector spinae at the 12th rib;3) 3. internal oblique (IO): the superior electrode is placed 1 cm medial to the ASIS, the inferior electrode is placed parallel to the inguinal ligament with the standard interelectrode distance;4) external oblique (EO) at the most inferior point of the costal margin orientated along a line from that point to the contralateral pubic tubercle; and 5) inferior gluteus maximus (IGM) placed inferior and medial to a line drawn between the PSIS and posterior greater trochanter.44 Electrodes were also placed over the biceps femoris muscle to monitor leg muscle activity at rest. A ground electrode was placed at the right elbow. Standardized skin preparation was performed involving washing the skin, shaving and the application of an abrasive-conductive gel.

Data Acquisition. EMG and goniometer data were sampled simultaneously at 2000 Hz using a Powerlab system using Chart software (version 4.2, AD Instruments, Sydney, Australia) and were stored for offline processing. A second computer also sampled the goniometer signal and implemented custom written software in the Labview environment (version 6.1, National Instruments) to provide real-time feedback to the subject on position and movement speed.

Goniometer Signal Processing. Offline signal processing first examined the goniometer signal to find which “regions” of data fulfilled the criteria: 1) three consecutive movement cycles, starting at a minimum nearest 0°, 2) each cycle’s speed within ±5 cyc/min of target, and 3) peak flexion and extension angles within ±4° of their target (45° and 0°, respectively). This process limited the effect of extremes of performance/movement on observed EMG patterns and also provided data on movement accuracy: mean-squared-error (MSE) of movement speed (MSEspeed), maxima positions (MSE45°), and minima positions (MSE0°). MSE values were calculated both within each data “region” (to correlate with EMG variables) and also over the entire 11-second movement repetition at each speed (to examine motor skill acquisition over the course of the study).

EMG Signal Processing. Abdominal flexor-lumbar extensor antagonistic cocontraction (CoCon) was quantified using an “area-normalization” method adapted from prior work.45 The following algorithm was used: 1) generation of a “linear-envelope” of the EMG signals of the IO, EO, LES, and TES muscles (high-pass filtering at 100 Hz using a digital 10th order quasi-Butterworth filter, rectification, and then low-pass filtering using a 10 Hz digital 10th order Bessel filter) and partitioning into the appropriate data region; 2) normalization of the area of each linear-envelope region to “1” by dividing each value by the total area under the curve; 3) the greater value of the LES and TES signals was taken at each data point and the resulting signal renormalized as in step 2, which generates an “extensor linear-envelope”; 4) abdominal IO and EO signals are processed in the same fashion to yield a “flexor linear-envelope”; 5) the area of overlap of the flexor and extensor linear-envelopes is calculated; and 6), the overlap area ranges from 0 to 1 and generates the flexor and extensor cocontraction variable (CoCon).

To quantify EMG amplitude, activity-ratios (ratio) across movement speeds were used. To obtain this data, root-mean-square (RMS) values of the raw EMG signal in each data region were first measured. Then, at each movement speed 75 cycles/min and above, the RMS value in each data region was divided by the median RMS value of the speed below. This resulted in three activity-ratios for each muscle (ratio15/50, ratio100/75, ratio125/100). Such relative measures of EMG amplitude have been used previously46 and have been shown to reduce inter-subject variability.47

Statistical Analyses. Linear mixed-effects models were used in statistical analysis.48 Analysis of variance of the EMG data
examined fixed effects for muscle, testing date, movement speed, interactions between each variable, as well as fixed effects for incidence of LP pain in the past or in the follow-up period. The goniometer MSE data for each repetition (MSE_{speed}, MSE_{45°}, and MSE_{0°}) were also analyzed to examine improvements in movement performance. A natural-log transformation was used for the ratio and MSE data to approximate normality. Where appropriate, allowances were made for heterogeneity of variance across different grouping levels (such as movement speed, muscle, or date). The “R” statistical environment (version 2.0.1, www.r-project.org) was used to implement these analyses. An \(/H_9251\) of 0.05 was taken for statistical significance. As multiple measurement sessions were undertaken on the same subjects, a Bonferroni adjustment was not performed; rather, we looked for consistent significant differences across time points.

To consider the association between motor control and movement accuracy changes, correlation analyses between CoCon, ratio and the goniometer MSE data (MSE_{speed}, MSE_{45°}, and MSE_{0°} values from each data “region”) were undertaken. SPSS for Windows (version 10.0.1, www.SPSS.com) was used to calculate Spearman’s rank correlation coefficient (\(\rho\)) between each of the variables.

### Results

Due, for example, to subject absence or technical difficulties, data from each subject on every scheduled testing day were not always available. Table 1 presents the number of subjects able to be included in statistical analysis on each testing day. Based on the classification used for low back pain occurrence, 6 subjects had a prior history of LP pain and 7 subjects experienced LP pain in the 1-year period after bed rest. Two of these represented “new” incidents of LP pain, the remaining being recurrences.

#### Abdominal and Lumbar Extensor Cocontraction

The measure of IO, EO, LES, and TES cocontraction (CoCon) showed a significant main effect for movement speed (\(F = 42.13, P < 0.001\)), with decreasing antagonistic cocontraction with increasing speed (50 cycles/min: 0.909 ± 0.012; 75 cycles/min: 0.858 ± 0.012; 100 cycles/min: 0.815 ± 0.012; 125 cycles/min: 0.801 ± 0.013). History of LP pain and occurrence of LP pain during follow-up showed no significant main effect in the CoCon data set (\(F = 0.06, P = 0.820\) and \(F = 0.20, P = 0.675\), respectively). Significant effects over testing date (\(F = 8.00, P < 0.001\)) and date \(\times\) speed (\(F = 8.34, P < 0.001\)) existed for the CoCon data.

Changes of the CoCon variable over testing date and each movement speed compared to baseline (BR1) data are presented in Figure 1. Strong effects can be seen at the 125 and 100 cycles/min movement speeds for decreased cocontraction over testing date. The effects appear to develop quickly in bed rest (by BR4) and persist until 1 year after bed rest at the 125 cycles/min speed and up to 6 months (R + 180) at the 100 cycles/min speed (with trend to persistence at R + 360). Weak effects for decreased cocontraction are seen at the 75 cycles/min speed.
during early to mid recovery (R to R). No significant changes in cocontraction are seen over time at the 50 cycles/min speed.

Activity Levels: Amplitude-Ratio Data
Significant effects existed for muscle and ratio (muscle: F = 4.91, P = 0.004; ratio: F = 9.22, P < 0.001; muscle × ratio: F = 3.09, P = 0.004) as well as testing date (F = 2.37, P = 0.005). Further interactions between testing date, ratio and muscle did not reach significance (testing date × ratio: F = 1.22, P = 0.209; muscle × testing date: F = 0.59, P = 0.989; testing date × ratio × muscle: F = 1.01, P = 0.456), suggesting the effect was generalized across muscles and movement speeds. History of LP pain was not significant in the ratio data set (F = 0.12, P = 0.745), nor was LP pain incidence in the follow-up period (F = 0.54, P = 0.493).

Table 2 gives the baseline values of ratio for each muscle. Changes in amplitude-ratio values over testing date are presented in Figure 2a. Increased activity levels are seen across the study period, and this is significant immediately after bed rest up to 3 months afterwards (R to R) with trend to significance 6 months afterwards (R + 180, P = 0.08). Although the testing date × ratio

<table>
<thead>
<tr>
<th>Table 2. First Day of Bed Rest (Baseline) Amplitude-Ratio Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>External oblique</td>
</tr>
<tr>
<td>Internal oblique</td>
</tr>
<tr>
<td>Inferior gluteus maximus</td>
</tr>
<tr>
<td>Thoracic erector spinae</td>
</tr>
<tr>
<td>Lumbar erector spinae</td>
</tr>
</tbody>
</table>

Values are mean ± SEM.

Figure 2. (A and B) Increases in activation levels during and after bed rest. Error bars represent standard error of the mean difference to baseline (BR1) values. *P < 0.05; †P < 0.01; ‡P < 0.001. BR, bed rest; R+, recovery.
interaction did not reach significance, Figure 2b indicates, similar to cocontraction, that the effect was predominantly localized to the highest movement speeds and was persistent up to 1 year after bed rest ($R_{H11001}/H11003$) despite low subject numbers at this time point.

**Movement Accuracy**

Analysis of the goniometer MSE data from each speed-repetition showed a significant effect for movement speed ($MSE_{speed}: F = 114.32, P < 0.001; MSE_{45°}: F = 56.73, P < 0.001; MSE_{0°}: F = 41.87, P < 0.001$) and testing date ($MSE_{speed}: F = 3.45, P < 0.001; MSE_{45°}: F = 2.91, P < 0.001; and MSE_{0°}: F = 3.84, P < 0.001$). Interactions of movement speed over testing date were nonsignificant ($MSE_{speed}: F = 0.70, P = 0.937; MSE_{45°}: F = 0.88, P = 0.692; MSE_{0°}: F = 0.85, P = 0.753$). At baseline (BR1) $MSE_{speed}$ was $3.81 \pm 0.42$ (cycles/min), $MSE_{45°}$ $2.15 \pm 0.20$ and $MSE_{0°}$ $0.51 \pm 0.09$. Figure 3 shows the change these variables over the study period. Accuracy increases (MSE decreases) though the bed rest and early-to-mid recovery testing dates. Later in the recovery period, with testing dates occurring at greater time separations, movement accuracy appears to in general decrease. At no time point is movement accuracy significantly less than at baseline testing.

**Correlation Analyses**

A significant negative correlation ($P < 0.001$) existed between the ratio and CoCon variables ($r = -0.48$); implying that as muscle activity levels increase, cocontraction levels decrease. Significant correlations ($P < 0.001$) existed between EMG and movement accuracy variables (Table 3).

These correlations imply that less accurate movement is associated with higher activity levels (amplitude-ratio) and lower antagonistic abdominal flexor-lumbar extensor antagonistic cocontraction (CoCon).

**Discussion**

We found long-term increases in muscle activity and decreased cocontraction during a repetitive-movement task in the superficial LP muscles after 8 weeks of bed rest. The increased activity appears to develop during bed rest at the highest movement speed, be generalized across all five superficial LP muscles and is significant up to 1 year after bed rest, despite low subject numbers at this time point. While consistent with other studies’ findings of increased superficial muscle activity after unloading,$^{20,21,24,34–36}$ the development of increased activity during bed rest is contrary to prior research conducted during unloading itself.$^{25–31}$ They are, however, similar

![Figure 3](image_url) Improvements in movement performance over the study period. Values represent mean difference to baseline (BR1) testing of each $MSE$ variable. Negative values imply greater accuracy. Error bars indicate the 95% confidence interval of the mean; hence, the difference to baseline is significant when the error bars to not cross x-axis (zero). BR, bed rest; R+, recovery.

| Table 3. Correlations Between Electromyographic and Movement Accuracy Variables |
|----------------|-------------------|-------------------|-------------------|
| EMG Variable   | $MSE_{speed}$     | $MSE_{45°}$       | $MSE_{0°}$        |
| Activity-ratio | 0.11              | 0.11              | 0.20              |
| Cocontraction   | -0.16             | -0.17             | -0.27             |

Values represent Spearman’s rank correlation coefficient ($r$). All correlations are significant ($P < 0.001$). $MSE_{speed}$ movement speed accuracy; $MSE_{45°}$ accuracy of peak knee flexion position; $MSE_{0°}$ accuracy of terminal knee extension position. A positive correlation coefficient implies less accurate movement is associated with higher EMG variable values.
to those in LP pain, which commonly observe superficial LP muscle overactivity.4–11

Some authors have suggested that superficial LP muscle overactivity in the pain population is a CNS strategy to “splint” the trunk in response to deep muscle dysfunction.13 The repetitive-movement task employed in the current study requires the development of muscle stiffness at the LP region to allow efficient knee movement. During bed rest, the same subjects show significant atrophy of the deep multifidus muscle, while this is not seen in the lumbar erector spinae or abdominal muscles (Hides JA, Belavý DL, Wilson SJ, Rittweger J, Felsenberg D, Richardson CA, unpublished observations). We suggest that due to this deep muscle atrophy, in order to maintain the necessary amount of LP stiffness for the knee movement task, the CNS increased the recruitment of the superficial LP muscle systems.

Abdominal flexor and lumbar extensor cocontraction decreases over the study period at the higher movement speeds. These changes are significant early in bed rest and persist up to 1 year afterwards. These findings of decreased cocontraction are contrary to findings of both prior unloading studies18–21 and those in LP pain,12–14 where an increase in LP antagonist cocontraction are observed. The prior research into cocontraction used static tasks, such as load-release or postural perturbation, but also active movements of the trunk. In such tasks, antagonist cocontraction typically increases with load, exertion, or speed of movement.49–52 Cocontraction is, however, both muscle and task specific. In the current study, we used a repetitive limb movement task requiring the antagonist LP muscles to stabilize the pelvis for efficient knee movement. Although the findings of overactivity suggest “splinting” of the trunk, reduction in flexor-extensor cocontraction over time could suggest reduced stabilization of the LP region. Further work is necessary to resolve these differences.

Importantly, the observed changes in superficial LP muscle motor control are unrelated to skill acquisition. The subjects’ movement skill improves over the course of the study, while activation levels increase and cocontraction decreases. The correlation analyses show, however, that greater movement accuracy correlates with lower amplitude-ratios and higher levels of cocontraction. It is highly unlikely, therefore, that improvement in accuracy of movement is involved in the observed motor control changes.

In the current study, no link could be made between incidence of LP pain and motor control changes during the study. Studies in bed rest, such as the BBR, typically comprise a limited number of subjects. Prospective studies of LP pain typically employ larger subject pools53–55 for sufficient statistical power. Furthermore, 6 of the 10 subjects in this study reported prior LP pain. Past LP pain is a significant risk factor for future incidence.55,56 It becomes more difficult, therefore, in a limited subject pool to accurately test whether inactivity leads to a greater risk of LP pain. Future bed rest studies attempting to address the same question should exclude subjects with a prior history of LP pain. Also, statistical assessment of whether risk of LP pain increases after bed rest may require pooling of data from a series of studies.

### Conclusion

The results suggest that long-term inactivity (bed rest) results in motor control change in the superficial LP muscles. In the current study, we observed this to be a generalized increase in superficial LP muscle activity and decreased cocontraction for stabilization of the LP region during a repetitive-movement task. In light of known motor control dysfunction in LP pain, these adaptations could be maladaptive for normal LP function, though further work in larger populations is required.

### Key Points

- Superficial lumbopelvic muscle activity increases during and after bed rest.
- Abdominal flexor and lumbar extensor cocontraction during a repetitive-movement task decreases during and after bed rest.
- These changes likely reflect alterations in lumbopelvic motor control for stabilization.
- Inactivity may result in maladaptive motor control patterns for lumbopelvic stabilization.

### Acknowledgments

The authors thank the subjects who participated in the study and the staff of ward 18A in the Charité Campus Benjamin Franklin Hospital, Berlin, Germany for their expert assistance, as well as Mr. Benny Elmann-Larsen of the European Space Agency.

### References

11. Ng JKF, Richardson CA, Parnianpour M, et al. EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a compar-