**Effects of five days of bed rest with and without exercise countermeasure on postural stability and gait**

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### Abstract

**Objectives:** We tested whether intermittent standing or a combination of heel raising, squatting and hopping exercises was sufficient to prevent alteration in balance and gait following a 5-day bed rest. **Methods:** This cross-over design study was performed with 10 male subjects during 6° head down tilt: (a) with no countermeasure; (b) while standing 25 min per day; (c) during locomotion-like activities 25 min per day. Gait was evaluated by grading subjects’ performance during various locomotion tasks. Equilibrium scores were derived from peak-to-peak anterior-posterior sway while standing on a foam pad with the eyes open or closed or while making pitch head movements. **Results:** When no countermeasure was used, head movements led to decreased postural stability and increased incidence of falls immediately after bed rest compared to before. When upright standing or locomotion-like exercises were used, postural stability and the incidence of falls were not significantly different after the bed rest from the baseline. **Conclusion:** These results indicate that daily 25-min of standing or locomotion-like exercise proves useful against postural instability following a 5-day bed rest. The efficacy of these countermeasures on locomotion could not be evaluated, however, because gait was not found to be altered after a 5-day bed rest.

**Keywords:** Posturography, Balance, Gait, Bed Rest, Centrifugation, Artificial Gravity

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**Introduction**

The deconditioning of physiological function in human subjects during prolonged bed rest has been proposed as an analog to space flight¹. Indeed, countermeasures that minimize physiological deconditioning during bed rest, such as cycle ergometer exercise or compression garments, have proven to be useful with astronauts during space flight². However, until recently, these countermeasures have addressed the various physiological systems in a piece-meal fashion (e.g. cardiovascular system for exercise; musculoskeletal system for compression garments; etc.). On the other hand, artificial gravity generated by short-radius centrifugation has been proposed as a more general, multi-purpose countermeasure against sensory-motor, cardiovascular, and musculoskeletal deconditioning due to prolonged exposure to weightlessness³-⁵.

In a pioneering study, Vernikos et al.⁶ demonstrated that intermittent (real) gravity loading can effectively reduce the deconditioning associated with prolonged bed rest in healthy human males. She showed that intermittent standing or controlled walking during otherwise continuous bed rest prevented post-bed rest orthostatic intolerance and attenuated decrements in peak oxygen uptake, plasma volume, and urinary Ca⁺⁺ excretion. Other studies found that intermittent centrifugation supplemented or not with concurrent aerobic exercise during bed rest could completely protect respiratory and cardiovascular responses to upright exercise, improve G-tolerance, suppress plasma volume loss, prevent fluid volume shifts, and reduce the elevated heart rate, muscle sympathetic nerve activity, and exaggerated responses to head-up tilt after bed rest⁷-¹¹.

More recently, a study showed that human subjects centrifuged daily for one hour during a 21-day bed rest exhibited less physiological deconditioning than control subjects experiencing the same deconditioning stimulus without centrifuga-
tion. Beneficial effects were seen on muscle strength, volume, homeostasis, and cardiovascular performance. However, sensory-motor performance, including reflex function, spatial orientation, and balance control performance were unaffected by daily exposures to centrifugation, as were psychological and physiological stress, immune function, and cognitive performance.

In 2005 the European Space Agency (ESA) commissioned a multi-disciplinary Topical Team to advise the agency on artificial gravity research. The outcome of which was a book or a detailed set of recommendations for undertaking a program of ground-based research into the feasibility of using intermittent gravity loading plus supplemental exercise as a multi-system countermeasure. The first step of this program was very short-duration (5 days) bed rest studies to establish the effective ranges of intermittent gravity loading on sensory-motor, cardiovascular, and musculoskeletal systems, using either real gravity such as Vernikos et al. or short-radius centrifugation. These studies used a crossover design that required all subjects to experience each test condition. Thus, multiple campaigns were required, with each subject spending one week in the facility (under a different experimental condition) during each campaign and recovering for at least four weeks between campaigns. The full set of ESA standard bed rest dependent measures were collected on each subject before and after each campaign. As the 5-day campaigns are very short relative to the deconditioning time constants of some of the physiological systems (e.g., bone demineralization, muscle atrophy), a few longer duration campaigns (14–21 days) will be scheduled later in the program to validate the effects predicted in these systems and to develop optimal intermittent artificial gravity prescriptions.

The results reported here concern the effects of intermittent standing or a combination of heel raises, squats and hopping exercises during very short-duration (5-day) bed rest on sensory-motor performance. We focused on posture and gait because these responses have been extensively studied in astronauts returning from space flight and changes have been observed after only 5 days in weightlessness. Indeed, these functions are critical in case the crew needs to egress the vehicle in an emergency after landing.

Bed rest does not alter the otolith input in the same manner as space flight because gravity continues to exert a vertical force on the utricles in supine subjects during bed rest whereas this static stimulation is absent in weightlessness. However, bed rest does mimic aspects of the restricted visual environment of spacecraft and the reduced stimulation of proprioceptive reflexes of the lower limbs. Ground-based studies have shown that somatosensory loss increases vestibulospinal sensitivity and alters head movement control during locomotion. There is also ample evidence of interactions between the vestibular system and cardiovascular control. We therefore predicted that decrements in postural stability following bed rest would reflect altered proprioceptive function, and might also be affected by orthostatic deconditioning.

### Material and methods

#### General design

The present study was part of a series of bed rest studies organized by ESA, starting with a short-duration bed rest in preparation for more long-duration studies. Details of the experiment design have been presented elsewhere. In short, a total of three bed rest campaigns were scheduled. Each campaign consisted of 5 days of baseline data collection (BDC-5 through BDC-1), 5 days of bed rest in 6° head down tilt (HDT1 through HDT5), and 6 days of recovery (R+0 through R+5). Each subject randomly performed bed rest only (CON), bed rest with 25 min of daily upright standing (STA), or bed rest with 25 min of daily locomotion replacement training (LRT). In bed, the subjects maintained the 6° HDT for 24 h/day (except for 25 min in the LRT and STA interventions).

#### Subjects

Ten healthy male subjects (mean±SEM age: 29.4±5.9 years, height: 178.8±3.7 cm; weight: 77.7±4.1 kg) were used in this study. All participants received a comprehensive clinical assessment and gave their informed consent prior to the beginning of this study. The study design was approved by the Ethics Committee of the Northern Rhine medical association in Düsseldorf, Germany and was organized by the DLR Institute of Aerospace Medicine and sponsored by ESA.

#### Interventions and control condition

- **Locomotion replacement training (LRT)**. Subjects executed the upright 25-min LRT session daily during the HDT phase, which consisted of a combination of heel raises, squats and hopping exercises in the upright position (see Mulder et al., 2014 for details). A Smith Machine with fixed rails (PTS-1000 Dual Action Smith™ Cage, Hoist Fitness Systems, San Diego, USA) was used to guide the heel raise and squat exercises. Squats and heel raises were performed against body weight plus the additional weight of the barbell (15 kg). The heel raises were performed with straight knees and without ankle dorsiflexion. The shallow squats were performed continuously for 3 minutes. The reactive jumps and the cross-hopping (left-right-left-right etc.) exercises were performed without Smith Machine. The reactive jumps were performed with the ball of the foot (heels not touching the ground) at about 3 repetitions per second separated by 15 s of rest after 6 jumps. Cross hopping was performed continuously for 3 min at about 1.3 repetitions per second. The exercises had the same duration throughout the study, except for the duration of static squat that increased from 45 s at HDT1 to 70 s at HDT5.

- **Standing intervention (STA)**. Each subject stood upright for 25 min, directly next to the bed. Both feet were in contact with the floor during the entire standing phase and any type of physical activity (e.g. heel raise, squatting or walking) was prohibited.

- **Control condition (CON)**. Subjects in the CON group remained in HDT 24 h/day for 5 days and refrained from any type of physical exercise and/or upright posture during the bed rest phase.
Posturography

This test utilized dynamic posturography to quantitatively assess both sensory and motor components of postural control. The subjects with their hands across the waist stood with the feet together, while looking straight ahead, for 30 s on a foam pad that rested on a force platform. The foam pad was made of a 12-cm thick medium-density foam (Sunmate, Dynamic Systems Inc., Leicester NC, USA). Standing on foam alters somatosensory inputs, and is a useful option for testing balance control when more expensive dynamic posturography testing equipment (e.g. EquiTest) is not available.

There is evidence that the diagnostic assessment of postural instability is more pronounced during unstable support conditions requiring active head movements. For this reason, in some trials, subjects were oscillating their head in pitch (frequency 0.33 Hz; amplitude ±20º) in phase with a sinusoidally varying auditory tone. These dynamic head tilts stimulate the vestibular system, which renders the maintenance of upright posture more challenging. This method improves the diagnostic sensitivity of posturography, as shown in healthy subjects and astronauts returning from space flight.

Consequently, three conditions were used to objectively evaluate the subject’s ability to make effective use of or suppress inappropriate) visual, vestibular, and proprioceptive in formation for balance control: (a) eyes open with the head erect (EO); (b) eyes closed with the head erect (EC); and (c) eyes closed with dynamic head tilts (ECDHT). Each condition was performed three times. The order of conditions was randomized. Between trials, subjects could rest and sit on a chair. Duration of the test was 15 minutes.

Center-of-mass sway angles were estimated from instantaneous anterior-posterior (AP) and medial-lateral center-of-force positions, which were computed from force transducers mounted within the force platform (Leonardo Mechanograph, Novotec Medical GmbH, Pforzheim, Germany). The AP peak-to-peak sway angle, Θ, (in degrees), was used to compute the equilibrium score (EQ): 

$$EQ = 100 \times (1 - \Theta/12.5)$$

where 12.5º is the maximum theoretical peak-to-peak sway in the sagittal plane. For Θ=12.5º, which is scored as a fall, the EQ score is zero.

Dynamic Gait Index

The Dynamic Gait Index (DGI) was developed as a clinical tool to assess gait, balance and fall risk. It evaluates not only usual steady state walking, but also walking during more challenging tasks. Eight functional walking tests are performed by the subject: (1) walk a distance of 6 m on a level surface at normal pace; (2) walk the same distance while changing gait speed at instructor’s command; (3) walk 6 m at normal pace while looking to the right or to the left upon instructor’s command; (4) walk 6 m at normal pace while looking up or down; (5) walk at normal pace, then turn as quickly as possible to face the opposite direction and stop; (6) walk at normal pace and step over an obstacle (shoebox); (7) walk at normal pace and step around the right side of a cone placed at 3 m, and around the left side of a cone placed at 6 m; and (8) walk up stairs, using the railing if necessary, and when arrived at the top, turn around and walk down. Duration of the test is 30 minutes.

Each of these 8 tasks was performed once, in random order. Performance of each task was rated by a trained observer on a scale of 0 to 3 (where 3 indicated the best score), based on the following criteria:

- 3 (normal): successful execution of task with no assistance, no evidence for imbalance, normal and smooth gait pattern.
- 2 (mild impairment): slow execution speed, may require verbal cueing, mild gait deviations, no signs of imbalance.
- 1 (moderate impairment): very slow execution speed, abnormal gait pattern, evidence for imbalance, must use rail, stagers but recovers before continuing the task.
- 0 (severe impairment): cannot safely complete the task, severe gait deviations or imbalance, unable to clear obstacles, subject stops and reaches for wall or requires physical assistance.

The Dynamic Gait Index (DGI) was obtained by summing scores for all 8 tasks. Twenty-four is the maximum individual DGI possible. Based on previous studies in older adults, DGI ranging from 22-24 are indicators of safe ambulators, whereas scores of 19 or less have been related to increased incidence of falls.

Data analysis

Both posturography and DGI tests were repeated by the same subjects two days before bed rest (BDC-2), then on the last day of bed rest (R+0), i.e., approximately 20 min after the subjects first stood upright during a 5-30-min orthostatic tolerance test, and then three days later (R+3). EQ and DGI scores were compared across days (BDC-2, R+0, R+3) and bed rest countermeasures conditions (CON, STA, LRT). All statistical analyses were performed using SPSS (V20, IBM Corp, Armonk NY, USA). Since EQ scores cannot be treated as continuous, normally distributed data when falls are present, posture data were analyzed using the non-parametric repeated measures Friedman test. DGI scores were analyzed using the same procedure. When Friedman tests were significant, follow-up (post hoc) analyses between paired data were achieved using the Wilcoxon Signed Ranked test. Statistical significance was accepted at P<0.05 before appropriate Bonferroni correction was applied.

Results

To determine whether there were any effects of adaption/learning/familiarization to the test paradigm, we evaluated the temporal stability of the data for all BDC and R+3 data sessions across the three bed rest campaigns. Our null hypotheses were that: (a) no differences would be observed in BDC scores from campaign to campaign; and (b) recovery would always be complete by R+3, so that no differences would be observed between BDC and R+3 scores in any campaign.

All 30 EQ Scores (3 trials x 10 subjects) for each of the three posture conditions (EO, EC, and ECDHT) conducted at the BDC and R+3 test sessions for each of the three campaigns
were analyzed. Median values for each of the six sessions are presented in Table 1. These data are presented in the temporal order they were collected, so, owing to the randomization process, interventions (CON, STA, LRT) varied approximately equally among subjects between each of the three BDC and R+3 sessions.

Scores during the BDC session of the first campaign were lower than the other campaigns presumably because of the novelty of the testing paradigms. Had a familiarization session been provided prior to this first BDC, the scores on that session would likely have been similar to the scores in all of the remaining sessions.

The repeated-measures Friedman test on EQ scores from the EO, EC, and ECDHT conditions indicated a significant overall effect, i.e., all sessions were not the same. Removing the first session from consideration and repeating the Friedman test on the five remaining sessions resulted in a non-significant overall effect for the EO (P=0.241) and EC (P=0.04) conditions, suggesting that the first session was different from the others.

For the EQ scores from the ECDHT condition, removing the first session from consideration and repeating the Friedman test on the five remaining sessions still resulted in a significant (P<0.001) overall effect. Follow-up Wilcoxon tests showed a significant decrease in EQ scores from R+3 of campaign 2 to BDC of campaign 3 (P=0.002) (see also Table 1), and a significant increase from BDC of campaign 3 to R+3 of campaign 3 (P<0.001). These results suggest that the long delay between the second and the third campaign may have affected the performance of our subjects during BDC of campaign 3.

Because of the above observations, the effects of the interventions during bed rest were investigated using data where the results of the first condition for each subject were removed. For example, subject A received the LRT intervention first, so for subject A the first LRT data were removed from his data set. Similarly subject B received the STA intervention first, so the first STA data were removed, and so on.

When subjects were standing upright with no head movements, no significant differences in the EQ scores were observed between before and after bed rest (R+0 or R+3), neither with the eyes open (Figure 1) nor with the eyes closed (Figure 2).

However, a decrease in postural stability was observed when subjects had the eyes closed while pitching their head back and forth (Figure 3). When no countermeasures were used during bed rest (CON), the EQ score significantly decreased (Wilcoxon, P=0.003) immediately after the bed rest

<table>
<thead>
<tr>
<th>Campaign 1</th>
<th>Campaign 2</th>
<th>Campaign 3</th>
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<tbody>
<tr>
<td>BDC-2</td>
<td>R+3</td>
<td>BDC-2</td>
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<tr>
<td>EO</td>
<td>88.0±1.6</td>
<td>90.4±1.6</td>
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<tr>
<td>EC</td>
<td>76.0±4.0</td>
<td>79.6±2.8</td>
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<tr>
<td>ECDHT</td>
<td>43.6±24.0</td>
<td>64.8±5.6</td>
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Table 1. Median equilibrium scores (± median average deviation) in the three posture conditions (EO: eyes open; EC: eyes closed; ECDHT: eyes closed during dynamic head tilt) for the BDC and R+3 sessions of each bed rest campaign. *P<0.05 with respect to all other sessions; #P<0.05 with respect to preceding and succeeding sessions.

Figure 1. Equilibrium scores for 10 subjects trying to stand upright for 30 s on a 12-cm thick foam pad with the eyes open. Measurements were made two days before (BDC-2), and then immediately (R+0) and three days (R+3) after 5-day bed rests with no countermeasure (CON), standing 25 min per day (STA), and locomotion replacement training (LRT) 25 min per day.
(R+0) relative to before (BDC-2). This decrease was still statistically significant after applying Bonferroni adjustment ($P<0.017$). Also, the number of falls increased from 6 to 18 after the bed rest.

By comparison, when STA and LRT were used, there was no significant change in EQ score between R+0 and BDC (Freidman, $P=0.069$ for STA; Wilcoxon, $P=0.234$ for LRT). The incidence of falls after STA and LRT still increased on R+0 relative to BDC. Three days after the bed rest, EQ scores were significantly larger than on R+0 (Wilcoxon, $P=0.002$ for LRT), but not significantly different from BDC.

Most subjects got nearly perfect DGI scores (24/24) when tests were performed two days before and three days after bed rest. Immediately after bed rest though, DGI scores were lower by one point in half of the subjects (Figure 4). This occurred for the tasks where they were instructed to look sideways or up or down when walking on a level surface, or when they walked up and down the stairs. However, this difference was not statistically significant. In addition, there was no significantly difference in the DGI before and after the bed rest between CON, STA, and LRT.

**Discussion**

Our results showed that the standard Romberg conditions with the eyes open or closed were the least sensitive to bed rest. By contrast, pitching the head back and forth while standing with the eyes closed increased postural instability and the inci-
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Figure 4. Frequency of Dynamic Gait Index scores obtained in 10 subjects two days before (BDC-2), and then immediately (R+0) and three days (R+3) after 5-day bed rests with no countermeasure (CON), standing 25 min per day (STA), and locomotion replacement training (LRT) 25 min per day. None of the subjects scored 20 or lower.

Figure 4
and might also be affected by orthostatic deconditioning. Postural and gait disturbances have significant implications for performance of operational tasks that require ambulation immediately following landing on a planetary surface including rapid emergency egress from a landing vehicle. Consequently, bed rest could be a useful analog for evaluating potential flight countermeasures to body unloading.

Acknowledgements

The authors are grateful to the subjects for their participation in this experiment, the staff of the DLR Institute of Aerospace Medicine for conducting all the tests, and to Mr. Rahul Goel of the University of Houston for performing the statistical analysis. This study was supported by ESA, DLR, and CNES.

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The purpose for this 30-day bed rest study was to investigate the effects of short-term, high intensity isotonic and isokinetic exercise training on maintenance of working capacity (peak oxygen uptake), muscular strength and endurance, and on orthostatic tolerance, posture and gait. Other data were collected on muscle atrophy, bone mineralization and density, endocrine analyses concerning vasoactivity and fluid-electrolyte balance, muscle intermediary metabolism, and on performance and mood of the subjects. Bed rest resulted in significant decreases of postural stability and self-selected step length, stride length, and walking velocity, which were not influenced by either exercise training regimen. Most pre-bed rest responses were restored by the fourth day of recovery. Background: Spaceflight has been associated with changes in gait and balance; it is unclear whether it affects cognition. Head down tilt bed rest (HDBR) is a microgravity analog that mimics cephalad fluid shifts and body unloading. We also repeatedly assessed an outside-of-bed rest control group to examine metric stability. Results: Small practice effects were observed in the control group for some tasks; these were taken into account when analyzing effects of HDBR. Aerobic and resistance exercise partially mitigated the effects of HDBR on FMT and accelerated the recovery time course post-HDBR. Discussion: HDBR did not significantly affect cognitive performance but did adversely affect FMT and standing balance performance.