Cardiac Electro-Mechanical Adaptations to 21-Day Head-Down Tilt Bed Rest and Gravitational Reinstatement

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Abstract

Head-down tilt (HDT) bed rest (BR) is a ground-based analogue of microgravity that induces cardiovascular deconditioning. While cardiac electrical adaptations have been extensively investigated, changes in cardiac mechanical activity remain less characterized. We investigated heart rate (HR) and seismocardiographic (SCG) biomarkers during a 21-day HDT BR campaign conducted by the Italian Space Agency. Twenty healthy volunteers (11 men, 9 women) underwent continuous Holter 24+ hours ECG (1024 Hz) and SCG (256 Hz) recordings at baseline (BDC), on bed-rest days 5 (BR5) and 19 (BR19), and on the first recovery day (R+1). HR was derived from the ECG and ECG-guided SCG processing identified isovolumetric contraction (IVC), aortic valve opening (AO), and aortic valve closure (AC), from which pre-ejection period (PEP), left ventricular ejection time (LVET), and IVC-AO amplitude were derived. Analyses were performed separately for day and night. The largest changes emerged at R+1: daytime HR increased by 31.9% in men and 22.3% in women compared to BDC, while nighttime HR increased by 14.6% and 21.7%, respectively. Daytime LVET increased by 14.1% in men and 13.3% in women. IVC-AO amplitude decreased during HDT BR, reaching reductions up to 28% in men and 39% in women at night, and generally reversed at R+1. These findings indicate that gravitational reinstatement elicits the most prominent cardiac electro-mechanical adjustments after 21 days of unloading.

1. Introduction

Exposure to microgravity removes the hydrostatic pressure gradient acting along the body axis and induces cardiovascular deconditioning. Head-down tilt (HDT) bed rest (BR) reproduces these effects on Earth and is widely used to investigate physiological adaptation to spaceflight and the response to the restoration of normal gravitational loading [1]. Cardiovascular deconditioning is particularly evident after reambulation, when orthostatic stress is suddenly re-established and the cardiovascular system must compensate for reduced central blood volume, lower stroke volume, and altered autonomic control [2].

Previous work showed that HDT BR modifies cardiac electrical regulation, heart rate variability, and cardiac circadian organization, with main alterations appearing immediately after bed-rest discontinuation [3,4].

Seismocardiography (SCG) provides a complementary non-invasive view of cardiac mechanics by measuring precordial micro-accelerations generated by myocardial contraction, valve motion, and blood ejection [5,6]. Fiducial points on the SCG can be associated with isovolumetric contraction (IVC), aortic valve opening (AO), and aortic valve closure (AC), allowing the derivation of systolic time intervals and morphology-based indices related to ventricular ejection and contractile dynamics [7]. Wearable inertial sensors have already shown sensitivity to bed-rest-induced cardiac electro-mechanical changes [8] and have recently enabled 24-h characterization of SCG parameters and their day-night variation [9].

The objective of this study is to characterize possible alterations in cardiac electro-mechanical (i.e., ECG-SCG) alterations induced by a 21-day HDT BR campaign.

2. Materials and Methods

2.1. Study population and design

Twenty healthy volunteers (11 men and 9 women) participated in the 21-day HDT BR campaign conducted within the Italian Space Agency SCIENCE FOR BEDREST programme. Participants completed a baseline data-collection period, 21 consecutive days of strict HDT BR, and a recovery phase. The study was conducted in accordance with the Declaration of Helsinki, and all participants provided written informed consent.

Combined ECG and SCG recordings were acquired at baseline (BDC, 36h), on the fifth day of bed rest (BR5, 24h), on the nineteenth day of bed rest (BR19, 24h), and on the first day after bed-rest discontinuation (R+1, 24h). The EcgMove4 wearable sensor (Movisens GmbH, Karlsruhe, Germany) was positioned on the left precordial region and recorded a single-lead ECG (1024 Hz) and SCG (256 Hz) signals. Sleep/wake information collected via a personal sleep diary was used to separate daytime and nighttime analyses.

2.2. ECG and SCG processing

ECG and SCG signals were pre-processed using zero-phase band-pass Butterworth filtering to attenuate baseline drift and motion-related artefacts. R peaks were detected from the ECG, from which HR was derived. SCG systolic complexes were identified by a template-matching procedure. Fiducial points of IVC, AO and AC were then identified beat-by-beat [8,9]. The pre-ejection period (PEP) was computed from the R peak to AO, while left ventricular ejection time (LVET) was computed as the AO-to-AC interval. Additionally, the IVC-AO amplitude and slope were calculated. Systolic time intervals are established non-invasive descriptors of left-ventricular performance [10], while SCG morphology and slope/amplitude features have been associated with myocardial contractility and stroke-volume-related changes [6,7].

2.3. Statistical analysis

The effect of HDT was assessed (Friedman, $p \leq 0.05$, Bonferroni corrected post-hoc Wilcoxon signed-rank), and comparisons between genders (Mann-Whitney U, $p \leq 0.05$).

3. Results

All 20 participants completed the HDT BR protocol and the scheduled 24-h acquisitions considered in this analysis. The overall temporal pattern was characterized by comparatively modest changes during sustained HDT BR and a larger electro-mechanical response at R+1, when orthostatic loading was restored.

Compared with BDC, daytime HR at R+1 increased by 31.9% in men and by 22.3% in women. The increase persisted during nighttime, although with a different sex-related magnitude: +14.6% in men and +21.7% in women.

Relative changes in SCG-derived systolic parameters throughout HDT BR and recovery are summarized in Figure 1. PEP remained comparatively stable throughout the protocol. Among the temporal SCG biomarkers, the most evident response involved LVET. Daytime LVET at R+1 increased by 14.1% in men and 13.3% in women relative to BDC.

The IVC-AO amplitude appeared reduced during HDT BR, indicating a modification in the morphology of the systolic SCG complex during prolonged unloading. During daytime, the largest reductions during bed rest reached approximately 16% in men and 22.2% in women at BR19. At night, the decrease was more pronounced, reaching 28% in men at BR19 and 39% in women at BR5. At R+1, this pattern generally reversed. In men, IVC-AO amplitude increased up to 22% relative to BDC, consistent with a rapid mechanical adjustment to renewed gravitational loading. Women showed the same general direction during daytime. However, nighttime amplitude remained reduced by about 16%. Similar results were observed in the IVC-AO slope.

4. Discussion

This study provides a 24-h characterization of cardiac electro-mechanical adaptation during and immediately after 21 days of HDT BR using a wearable platform combining long duration ECG and SCG recordings. The largest changes in electrical mechanical activity occurred on the first day after bed-rest discontinuation. During HDT BR, the most consistent mechanical alteration was instead a reduction in IVC-AO amplitude. The response was observed during both daytime and nighttime and showed some sex-related differences, particularly in the timing and persistence of the nocturnal amplitude changes.

The pronounced HR increase at R+1 is consistent with the well-established cardiovascular consequences of reintroducing orthostatic stress after prolonged unloading [2,11,12]. LVET also increased during daytime at R+1 in both sexes. Bed-rest studies in women have also demonstrated that prolonged unloading can alter PEP and the relationship between electrical activation and ventricular ejection [13]. Interestingly, alterations of the IVC-AO amplitude were already present during HDT BR, resulting specifically in a reduced amplitude. SCG amplitude is influenced by the acceleration transmitted to the chest by cardiac contraction, valve motion, and blood ejection, and previous studies have related SCG morphology to changes in myocardial contractility and stroke volume [6,7]. In our earlier 10-day bed-rest study, smartphone-derived SCG amplitude and slope features were sensitive to deconditioning and rapidly changed after reambulation [8]. The present results confirm that morphological SCG indices are responsive to prolonged unloading, while demonstrating that such alterations can be tracked continuously over 24 h with a wearable device. The inverse direction observed at R+1, with IVC-AO amplitude increasing up to 22% in men, may reflect the abrupt change in preload, afterload, body position, and sympathetic drive associated with renewed gravitational stress.

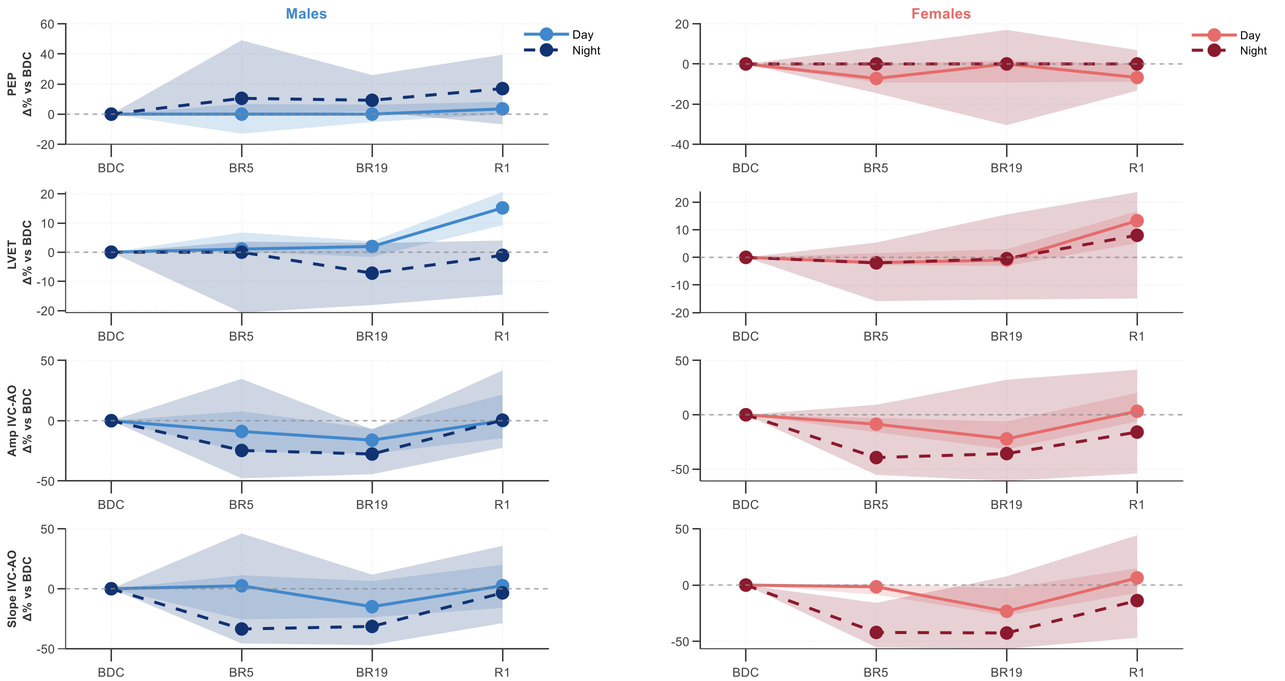

Figure 1. Relative changes in SCG parameters in males and females expressed as percentage variation from BDC.

5. Conclusion

Twenty-one days of HDT BR induced measurable changes in wearable-derived cardiac electro-mechanical biomarkers, with the strongest combined response occurring on the first day of gravitational reinstatement. HR increased markedly during both day and night, daytime LVET lengthened in men and women, and the reduction in IVC-AO amplitude observed during bed rest generally reversed after reambulation. These findings indicate that wearable SCG can complement ECG in the assessment of cardiovascular deconditioning and early readaptation.

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