

Upper trunk flexion versus whole trunk elevation in semi-Fowler's position: Effects on ventilation and heart rate responses

Research Article

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Abstract

Study aim: The semi-Fowler's position is widely used to support respiratory function and reduce cardiovascular stress. Despite the known cardiovascular benefits of upper trunk flexion in Fowler's position, its effects in the semi-Fowler's position remain uninvestigated. This study aimed to compare the effects of upper trunk flexion (UT30) and whole-trunk elevation (WT30) at 30° on ventilation and cardiac chronotropy in healthy young women.

Material and methods: Fourteen healthy young women (age: 20.6 ± 0.7 years; height: 162.1 ± 5.4 cm; weight: 53.1 ± 5.6 kg) participated in a randomized crossover design comparing supine, 30° whole-trunk elevation (WT30), and 30° upper trunk flexion at T10 (UT30). Tidal volume (TV), minute ventilation (MV), respiratory rate, and RR intervals were measured using a pneumotachograph and ECG (BIOPAC MP150) after 5-min equilibration. Data were analyzed using Linear Mixed Models (R version 4.3.3).

Results: Both UT30 and WT30 increased TV ($\Delta + 79$ and $+ 94$ mL) and MV ($\Delta + 0.89$ and $+ 1.18$ L/min) versus supine (all $p < 0.001$), with no UT30–WT30 differences. RR interval decreased in WT30 versus supine ($\Delta - 0.029$ s, $\approx +2.1$ bpm, $p = 0.038$) but not in UT30 ($p > 0.05$); the direct UT30–WT30 comparison was not significant.

Conclusions: These findings suggest that UT30 may be an efficient low-burden posture in healthy young women; applicability to populations with limited cardiovascular reserve requires direct clinical validation.

Keywords: Semi-Fowler's Position • Tidal Volume • Minute Ventilation • RR Interval • Patient Positioning

1. Introduction

Fowler's and semi-Fowler's positions, which involve raising the trunk from the supine position, are commonly used in clinical settings to improve respiratory function and reduce cardiovascular stress (Rauen et al., 2009; Kubota et al., 2015, 2017; Grap & Munro, 2005). Fowler's position typically raises the trunk by 45°–60°; the semi-Fowler's position involves a more moderate elevation of 30°–45°. Trunk elevation facilitates respiratory function by

displacing abdominal organs caudally through gravity, reducing diaphragmatic compression, and increasing functional residual capacity (Mezidi & Guérin, 2018), and is also recommended for preventing ventilator-associated pneumonia in critical care settings (Güner & Kutlutürkan, 2022). A recent scoping review confirmed that trunk inclination adjustment significantly affects respiratory mechanics, oxygenation, and ventilatory efficiency in patients with respiratory failure (Benites et al., 2024). However, trunk elevation also carries cardiovascular costs:

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progressive verticalization beyond 30° has been associated with decreased cardiac output and hemodynamic instability in ARDS patients (Bouchant et al., 2024), and trunk posture deviations can alter heart rate and autonomic balance even in healthy adults (Wang et al., 2022). Given this trade-off between respiratory benefit and cardiovascular burden, the semi-Fowler's position at approximately 30° is frequently employed for frail patients and those requiring gentle postural support (Rauen et al., 2009; Grap et al., 2005; Zhu et al., 2020).

Kubota et al. demonstrated that flexing the upper trunk in the Fowler's position resulted in less reduction in stroke volume and less increase in heart rate compared to the conventional Fowler's position, which raises the entire trunk (Kubota et al., 2015, 2017). Defining trunk posture in terms of finer segmental structures and considering their distinct physiological effects is consistent with the biomechanical perspective proposed by Dhahbi & Ben Saad (2024). During quiet breathing, tidal volume and minute ventilation increase when the trunk is raised (Agostoni & Hyatt, 2011; Romei et al., 2010). This is due to the gravitational effects on the diaphragm and abdominal organs. In the supine position, gravity causes the abdominal contents to compress the diaphragm cranially, restricting diaphragmatic excursion and reducing thoracic volume. Conversely, in upright positions, gravity displaces the abdominal organs caudally, allowing greater diaphragmatic descent and increased thoracic volume. Importantly, the upper trunk flexion posture proposed by Kubota et al. involves elevating the thoracic region while maintaining the abdomen in a relatively horizontal position. As the gravitational effects on the abdominal organs influence the respiratory mechanics, this differential positioning of the upper and lower trunk may produce distinct ventilatory responses. Additionally, abdominal wall tension affects respiratory function by modulating intra-abdominal pressure (Goldman et al., 1986; Novak et al., 2021). Upper trunk flexion may alter the abdominal wall tension through changes in trunk biomechanics, potentially affecting respiratory function. As this study did not directly measure abdominal wall tension, this mechanism should be regarded as an untested hypothesis rather than direct evidence explaining the observed ventilatory responses. However, the specific comparison of ventilation and hemodynamics between upper trunk flexion and whole-trunk elevation in the semi-Fowler's range has not been fully elucidated.

Although the semi-Fowler's position involves modest trunk elevation compared to the Fowler's position, it is frequently employed in clinical practice. Whether upper trunk flexion within this moderate elevation range affects cardiovascular

and respiratory functions remains unclear. Moreover, identifying trunk positions that enhance ventilatory efficiency while minimizing cardiovascular load may provide practical benefits for comfortable resting postures in daily life. This study aimed to examine the effects of upper trunk flexion versus conventional whole-trunk elevation in the semi-Fowler's position on ventilation volume and RR intervals in healthy young women. Based on the hypothesis that upper trunk flexion may reduce abdominal wall tension, we hypothesized that upper trunk flexion would improve respiratory function while maintaining cardiovascular stability by minimizing the hydrostatic gradients that drive orthostatic stress.

2. Material and methods

2.1 Participants

An *a priori* power analysis was not performed, as this study was designed as an exploratory physiological investigation rather than a confirmatory trial. The within-subject repeated-measures crossover design, in which each participant served as her own control across three conditions, substantially increases statistical efficiency by eliminating inter-individual variability from the error term, thereby requiring fewer participants than parallel-group designs to achieve comparable power (Wellek & Blettner, 2012).

Fourteen healthy young women were recruited using convenience sampling (age, 20.57 ± 0.73 years; height, 162.07 ± 5.4 cm; weight, 53.13 ± 5.57 kg; BMI, 20.19 ± 1.46 kg/m²). All participants were physically inactive and did not engage in regular sports activities. None of the participants had smoking or drinking habits. This study deliberately recruited healthy young women to establish baseline physiological responses in controlled conditions. Restricting participants to a homogeneous population minimized confounding factors, such as age-related vascular compliance changes and disease-related compensatory mechanisms. Women were specifically selected, given the documented sex differences in respiratory mechanics: females demonstrate a greater reliance on rib cage inspiratory muscles (Molgaat-Seon et al., 2018; Sheel et al., 2016), making them an appropriate model for investigating thoracic positioning interventions. The exclusion criteria were respiratory or cardiovascular diseases, low back pain, and obesity. Low back pain was excluded because individuals with chronic low back pain may exhibit altered neuromuscular strategies during postural tasks, potentially confounding respiratory mechanics (Tajik et al., 2026). Of the 15 participants initially measured,

one was excluded due to equipment malfunction, resulting in 14 participants for analysis. This study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the Ethics Committee of the authors' affiliated institution (Approval No. 21-Ig-16). Written informed consent was obtained from all participants before their inclusion in the study.

2.2 Experimental procedure

Participants were positioned in three postures: supine (SPIN) and two semi-Fowler's positions at 30° upper trunk flexion (UT30) and 30° whole trunk elevation (WT30) (Figure 1). This study employed 30° semi-Fowler's positions rather than Fowler's positions exceeding 30°, as lower-angle semi-Fowler's positions (approximately 30°) are commonly used for frail patients (Rauen *et al.*, 2009; Grap *et al.*, 2005; Grap & Munro, 2005; Zhu *et al.*, 2020). Postures were achieved using an electric hospital bed (KA-335, Paramount Bed, Tokyo, Japan), positioning cushions, and a mattress. The 30° angle was verified using a goniometer attached to the bed base. For the UT30, trunk flexion was adjusted at the tenth thoracic vertebra (T10). The T10 level was identified by palpating the spinous processes, and cushions were placed to ensure that the flexion fulcrum was accurately located, following the method described by Kubota *et al.* (2015). During both the UT30

and WT30 positions, the participants were instructed to maintain their knees in slight flexion.

A preliminary experiment was conducted on a separate day to allow the participants to become accustomed to breathing while wearing the ventilation measurement mask. Participants were instructed to avoid strenuous exercise, caffeine, alcohol consumption, and food intake after dinner the day before the experiment and to completely refrain from food and drink for 2 h before the experiment. The laboratory temperature was maintained at 28°C, within the thermoneutral zone, based on previous research (Kubota *et al.*, 2017, 2022). Participants were asked to wear sleeveless tops and shorts with properly fitted, non-constrictive bras to avoid chest compression.

All experiments were conducted between 11:00 and 15:00 to minimize the circadian influences. Measurements were taken after a 15-min rest in the supine position. Each position was measured for 5 min with 10-min rest periods between measurements. The measurement order was randomized to eliminate order effects.

Ventilation volumes were measured using a ventilation measurement mask and pneumotachograph (BIOPAC Systems, TSD117, USA). Electrocardiogram (ECG) data were collected using a three-lead ECG module (BIOPAC Systems, ECG100C, USA) with disposable Ag/AgCl electrodes (Vitrode M, Nihon Kohden, Tokyo, Japan) placed in the standard Lead II configuration. Data acquisition was performed using a BIOPAC MP150 data acquisition system (BIOPAC Systems, CA, USA), sampled at 1,000 Hz.

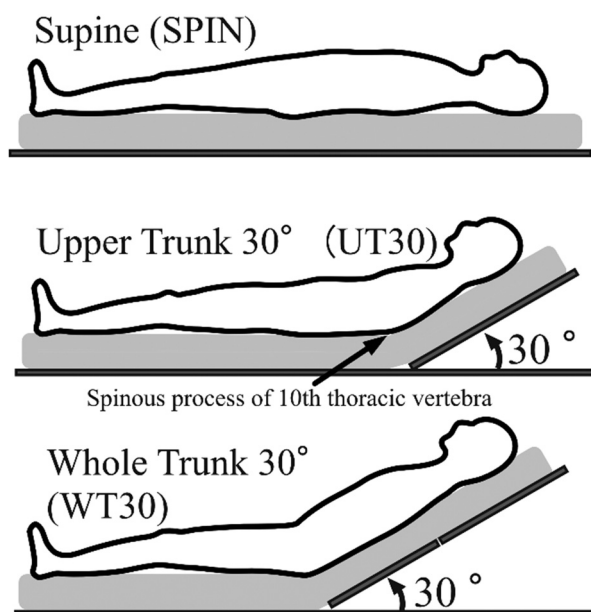


Figure 1. Bed positions for each condition. SPIN: Supine. UT30: Lower and upper trunk inclined at 0 and 30°. Segments were subdivided based on the spinous process of the 10th thoracic vertebra. WT30: Lower and upper trunk inclined at 30°

Source: Author's contribution.

2.3 Data analysis and statistical analysis

Tidal Volume (TV), Minute Ventilation (MV), Respiratory Rate (RespiR), and RR intervals (RRi) were calculated. RRi represents the time required for one cardiac cycle and corresponds to the reciprocal of the heart rate. Subjective breathing difficulty was assessed using a Numerical Rating Scale (0 = easy, 10 = difficult). A Linear Mixed Model (LMM) was used to analyze the effects of postures on these parameters, with postural differences as fixed effects and individual differences as random intercepts, and *p*-values were calculated using the Kenward–Roger method. The estimated marginal means and confidence intervals were calculated, and comparisons between postures were performed using Tukey's method. Cohen's *d* was calculated as the effect size. The normality of residuals from the LMM was visually confirmed using Q–Q plots. Effect sizes were interpreted as small (*d* = 0.2), medium (*d* = 0.5), and large (*d* = 0.8) according to Cohen (1988). Statistical analyses were conducted using R version 4.3.3 (R Core Team) and the lme4 package. The significance level was set at less than 5%.

RR intervals were used as the primary variable for statistical hypothesis testing of cardiac chronotropy for the following reasons. First, under resting conditions, cardiac chronotropy is predominantly modulated by vagal tone, and vagal activity linearly modulates the cardiac cycle length (RR interval), whereas the relationship between vagal activity and heart rate is hyperbolic (Task Force, 1996; Lee et al., 2018; Heathers, 2014). Analyzing RR intervals, therefore, more accurately reflects the underlying autonomic control. Second, at the relatively low heart rates observed in the present cohort of healthy young women under resting conditions (approximately 65–67 bpm), the non-linear transformation compresses numerical variability, potentially reducing statistical power to detect posture-related changes (Sacha, 2013; Quigley et al., 2024; Berntson et al., 1995). Third, residual analysis confirmed that RR interval data better satisfied the normality assumptions required for the Linear Mixed Model compared to heart rate data. Heart rate values derived from RR intervals are additionally reported in Table 1 to facilitate clinical interpretation.

3. Results

Table 1 presents the estimated marginal means and 95% confidence intervals for the lung volume fractions and RRi in each posture, along with the *p*-values and effect sizes from between-group comparisons.

Table 1. Respiratory function values and RR interval (heart rate) in all positions

	Estimated marginal means (95% confidence intervals)				(p-value Cohen's <i>d</i>)	
	SPIN	UT30	WT30	SPIN vs UT30	SPIN vs WT30	UT30 vs WT30
Tidal volume (mL)	318.34 [251.26–385.42]	397.06 [329.98–464.14]	412.46 [345.37–479.54]	0.0002 [1.77]	<0.0001 [2.11]	ns
Minute ventilation (L/min)	4.61 [3.69–5.53]	5.5 [4.58–6.42]	5.79 [4.87–6.71]	0.0002 [1.81]	<0.0001 [2.39]	ns
Respiratory rate (times/min)	14.91 [13.68–16.13]	14.33 [13.11–15.55]	14.74 [13.52–15.97]	ns	ns	ns
RR interval (s)	0.929 [0.884–0.975]	0.908 [0.863–0.954]	0.9 [0.854–0.945]	ns	0.0384 [0.99]	ns
Heart rate (bpm)	64.6 [61.4–67.7]	66.1 [62.7–69.4]	66.7 [63.3–70.1]			

SPIN, Supine. UT30, Lower and upper trunk inclined at 0 and 30°. WT30, Lower and upper trunk inclined at 30°.

Heart rate (bpm) values were derived from the estimated marginal means (and 95% CIs) of RR interval (HR = 60/RR [s]).

CIs for HR were obtained by transforming the CI limits of the RR interval. All statistical tests were conducted on RR intervals; HR is provided for clinical interpretability. *p*-values represent pairwise comparisons of estimated marginal means from the Linear Mixed Model with Tukey's adjustment. ns, no significant difference for the indicated pairwise comparison.

Source: Author's contribution.

TV was significantly higher in both UT30 and WT30 than in SPIN ($p < 0.05$), with mean differences of 78.72 mL and 94.12 mL, respectively. MV was also significantly higher in both UT30 and WT30 than in SPIN ($p < 0.05$), with mean differences of 0.89 and 1.18 L/min, respectively. Respir remained consistent across all postures at approximately 14 breaths/min, and no significant differences were observed between the postures. The RRi analysis suggested potentially different hemodynamic profiles between the two elevated positions. The WT30 resulted in a significantly lower RRi compared to SPIN ($p < 0.05$), indicating a significant increase in heart rate. In contrast, UT30 showed no significant difference in RRi compared to SPIN ($p > 0.05$), suggesting that the resting heart rate was maintained. The direct comparison of RRi between UT30 and WT30 did not reach statistical significance ($p > 0.05$). The NRS showed no significant differences between any of the postures.

The Cohen's d effect sizes for significant between-group differences ranged approximately 1–2.4 (Table 1).

4. Discussion

This study revealed that upper trunk flexion (UT30) produced respiratory benefits comparable to whole-trunk elevation (WT30), with both positions significantly increasing TV compared to SPIN. Regarding cardiac chronotropy, WT30 showed a significant decrease in RR intervals relative to SPIN, whereas UT30 did not differ significantly from SPIN. Although the direct comparison between UT30 and WT30 did not reach statistical significance, this response pattern suggests that UT30 may preserve baseline RR intervals while maintaining the ventilatory benefits associated with trunk elevation under the present experimental conditions.

4.1 Ventilatory and cardiovascular functions

The significantly higher TV in WT30 than in SPIN was consistent with previous studies comparing the sitting and supine positions (Romei *et al.*, 2010; Agostoni & Hyatt, 2011; Takahashi *et al.*, 1998). This can be attributed to the gravitational effect, which causes the abdominal organs to move downward when the trunk is raised, resulting in a lowered diaphragm and increased thoracic volume (Agostoni & Hyatt, 2011; Mezidi & Guérin, 2018).

In contrast, while UT30 involves raising the thoracic region and head, the abdomen remains unraised. Therefore, the gravitational downward movement of the abdominal organs that occurs in WT30 is less likely to occur.

Nevertheless, UT30 showed an increased ventilation volume compared to SPIN. This pattern may reflect an altered thoracoabdominal configuration in UT30, which could reduce the cranial pressure of the abdominal contents on the diaphragm compared with the completely supine position. We further hypothesize that passive support of the upper trunk may modify abdominal wall tension; however, because abdominal muscle activity and intra-abdominal pressure were not measured, this possibility remains untested and should be interpreted cautiously.

Regarding MV, which is the product of TV and RR, considering that RR remained consistent at approximately 14 breaths/min across all postures with no significant differences, we conclude that the postural differences observed in TV influenced MV, resulting in differences between SPIN and the two Semi-Fowler's positions.

The cardiovascular responses differed markedly in their pattern relative to baseline. The significant shortening of RR intervals in WT30 reflects the expected orthostatic stress response, in which gravitational pooling reduces venous return, triggering a baroreceptor-mediated heart rate increase to maintain cardiac output. In contrast, UT30 preserved the supine RR interval values. This pattern is consistent with the possibility that UT30 imposes less hydrostatic challenge to venous return than WT30, but the direct statistical comparison between UT30 and WT30 did not reach significance ($p > 0.05$). These findings are consistent with previous reports that upper trunk flexion may lessen cardiovascular perturbation during trunk elevation (Kubota *et al.*, 2015, 2017). However, given the limited sample size and the possibility of a Type II error, the present data should not be interpreted as demonstrating a significant between-posture advantage. Rather, the current results show that WT30 differed significantly from SPIN, whereas UT30 did not.

Although no significant differences were observed in the NRS, this experiment was conducted under resting conditions and represented a low physical burden for healthy individuals. Therefore, we believe that the participants had difficulty perceiving the differences in breathing between the different postures.

4.2 Clinical implications

Upper trunk flexion in the semi-Fowler's position represents a simple, non-pharmacological approach without specialized equipment, requiring only strategic pillow placement or adjustable bed positioning. These findings also suggest that upper trunk flexion may serve as a comfortable and physiologically efficient resting posture in daily

life, providing adequate ventilation without imposing additional cardiovascular strain. Although the present findings are derived exclusively from healthy young women, this favorable physiological profile raises the possibility that UT30 could offer advantages for populations with limited cardiovascular reserve; however, this extrapolation remains speculative and requires direct validation in clinical samples. Notably, healthy hearts readily compensate for orthostatic changes in venous return, whereas a failing heart may respond differently to the hemodynamic alterations induced by trunk positioning; therefore, direct clinical application should be approached with caution. For patients with conditions such as heart failure, recent myocardial infarction, or hemodynamic instability, avoiding additional cardiovascular stress is a primary therapeutic goal. Supporting the clinical relevance of positioning interventions, Zhu et al. (2020) demonstrated that the semi-Fowler's position can improve comfort and reduce adverse symptoms during extubation after abdominal surgery. If the ventilatory enhancement without concurrent tachycardia observed in healthy participants is replicated in clinical populations, UT30 could represent a useful positioning strategy for individuals requiring respiratory support or for whom circulatory stability is a concern. Future studies in patients with compromised cardiovascular reserve are necessary to test this hypothesis.

4.3 Limitations

This study has several limitations. First, the sample consisted exclusively of healthy young women with intact autonomic function and cardiovascular reserve, limiting generalizability to men, older adults, or clinical populations. Patients with impaired autonomic reflexes, reduced cardiac reserve, or altered vascular compliance may exhibit qualitatively different hemodynamic responses to postural changes; therefore, the clinical implications discussed above should be regarded as hypothesis-generating. Second, while we hypothesized that reduced abdominal wall tension drives ventilatory improvement in UT30, we did not directly measure abdominal muscle activity (EMG) or intra-abdominal/gastric pressures. Future mechanistic studies should incorporate these measures to confirm the proposed pathways. Third, we measured RR intervals as a surrogate for cardiac chronotropy but did not directly assess stroke volume or cardiac output. Finally, the lack of a statistically significant difference in the direct comparison of the RRI between UT30 and WT30 warrants caution; larger studies are needed to determine whether a between-posture hemodynamic

difference exists. Furthermore, the Numerical Rating Scale for breathing difficulty may lack sufficient sensitivity to detect subtle differences under resting conditions in healthy individuals, potentially contributing to the absence of significant NRS differences between postures. Additionally, an *a priori* power analysis was not conducted. While the sample size of 14 participants is consistent with recommendations for exploratory investigations (Julious, 2005; Kunselman, 2024) and is supported by the statistical efficiency of the within-subject crossover design (Wellek & Blettner, 2012), it may have been insufficient to detect a significant difference in the direct UT30–WT30 comparison for RR intervals. Larger confirmatory studies with prospective sample size calculations are needed to evaluate between-posture cardiovascular differences.

5. Conclusion

This study demonstrated that the semi-Fowler's position with upper trunk flexion (UT30) improves ventilation volume comparably to whole-trunk elevation (WT30) in healthy young women. WT30 induced a significant elevation in heart rate (reduced RR intervals) relative to the supine position, whereas UT30 maintained RR intervals at baseline levels. However, the direct comparison between UT30 and WT30 did not reach statistical significance. These findings indicate that both positions improved ventilation, whereas only WT30 differed significantly from baseline in cardiac chronotropy. Further investigation in larger and clinical samples is needed to determine whether these response patterns persist in other populations.

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Author contributions

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Furudate; Formal analysis: Satoshi Kubota, Takuya Furudate; Funding acquisition: Satoshi Kubota, Takuya Furudate; Investigation: Sayuki Miyashita, Satoshi Kubota, Takuya Furudate; Methodology: Satoshi Kubota, Sayuki Miyashita; Project administration: Sayuki Miyashita, Satoshi Kubota; Supervision: Satoshi Kubota; Writing – original draft: Satoshi Kubota; Writing – review & editing: Sayuki Miyashita, Takuya Furudate.

Conflicts of interest statement

The authors declare no conflict of interest.

Data availability statement

The authors will make the data supporting the conclusions of this article available upon reasonable request.

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