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The Interplay of Dual Tasks, Sleep Quality and Load Carriage on Postural Stability in Young, Healthy Adults

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Abstract: Background/Objectives: To examine the combined effects of sleep quality, dual tasks, and load carriage on postural stability. **Methods**: Twenty-three university student participants (12 males, ages: 24.6 ± 6.1 year) completed the Pittsburgh Sleep Quality Index (PSQI), then performed quiet standing and a dual task while standing on force plates with and without load carriage. Correlations and repeated measures analysis of variances were used to assess relationships, main effects, and interaction effects of tasks on center of pressure (COP) to assess postural stability. Both a traditional PSQI global score and a sensitivity analysis of the PSQI cut-off were conducted. **Results**: With the traditional PSQI criteria, a main effect of sleep quality on 95% ellipse area was observed, with good sleepers outperforming bad sleepers (p = 0.016). Additionally, a significant interaction between sleep quality and task (p = 0.049) indicated that COP anterior–posterior velocity was lower during the dual task for good sleepers. No effects on sleep quality or interaction were found for other COP measures. The sensitivity analysis yielded no effect on sleep quality or interaction effects on any COP measure. There were no significant correlations between the PSQI global scores and COP variables. **Conclusions**: Overall, the results indicate that sleep quality alone had a limited effect and did not significantly interact with dual tasks or load carriage during quiet standing. Practitioners working with individuals who commonly experience poor sleep quality and perform load carriage and dual tasks should consider that common COP screens to assess postural stability may not detect differences due to self-reported sleep quality in healthy, young adults.

Keywords: fatigue; balance; sensorimotor control

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1. Introduction

Across the adult age spectrum, injuries resulting from falls pose a substantial challenge to health and safety [1]. Postural stability, defined as the ability to control body position in space to facilitate movement and balance [2,3], is essential for daily activities, inluding static balance [4], sit to stand transitions [5], and gait [6]. Maintaining stability during these actions helps prevent falls and reduces the risk of injury [7–9]. Postural stability is maintained by the sensorimotor system and requires the integration of visual, vestibular, and somatosensory input [4]. In order to be stable during quiet standing, the sensorimotor system must maintain the center of pressure (COP) within the base of support [10]. The measurement of objective COP-related variables is a common practice for evaluating postural stability processes, identifying dysfunction, and monitoring rehabilitation progress [11,12].

Although much of the literature focuses on chronic disease [13,14] and aging-related [12] factors contributing to decreased postural stability, there are a number of acute factors, such as injury [15,16], neuromuscular fatigue [17], load carriage [18], multi-tasking (e.g., dual tasks) [19], and sleep [20,21], that can impact postural stability. Importantly, poor sleep quality alone has been shown to significantly impair motor control and cognitive function [22], further complicating the ability to maintain postural stability under additional physical and cognitive loads.

Currently, it is recommended that adults sleep for 7 to 9 h per night [23]; however, a considerable proportion of adults fail to consistently meet this minimum threshold, leading to chronic poor sleep quality [24]. This chronic sleep deprivation not only hampers the ability to carry out daily tasks effectively but also exerts detrimental effects on overall health [25]. Generally, studies investigating acute sleep deprivation on postural stability reported impaired postural stability following acute sleep deprivation [26–28]. However, studies examining the effects of chronic poor sleep quality on postural stability among healthy adults is more limited [20,21,29]. In one such study by Furtado et al. [20], it was found that balance was impaired more by poor sleep quality when eyes were closed, but not in eyes-open conditions. Notably, the experimental group with poor sleep quality displayed performance similar to subjects who were completely sleep deprived for 24 h [20]. Similarly, Tanwar et al. [29] also found that postural stability decreased in bad sleepers compared to good sleepers when performing the Y-balance test. The assessment of balance using the Y-Balance Test warrants consideration because, compared to COP measures, the Y-Balance Test evaluates dynamic balance through reach distances in three directions, providing functional measures of stability [7]. However, Saraiva et al. [21] reported no difference in COP measures of postural stability between good and bad sleepers, but did find that dual-cognitive tasks impaired postural stability, independent of sleep quality.

Dual-cognitive tasks are used to direct attention to a secondary task (e.g., talking, counting, etc.) while performing a primary motor task, such as quiet standing [19]. The dual task paradigm is frequently employed in research studies to assess the cognitive demands of postural control and to understand how varying degrees of dual-task complexity may disrupt stability in the young and healthy and in older adults, as well as in patients with neurological conditions [19]. A systematic review on the effect of cognitive task complexity on dual task postural stability indicated that for young, healthy adults, postural stability may only be impaired for more challenging postural tasks [19]. In other words, for simple quiet standing (e.g., eyes open, dual stance), even complex cognitive tasks may not disrupt postural stability in young, healthy adults. However, when additional physical demands are introduced, such as carrying loads, the dynamics of postural stability can change significantly [18].

When performing activities of daily living, recreational activities, and occupational duties, it is common for loads to be carried on the body [30]. A recent systematic review and meta-analysis found that COP measures were altered due to the effects of load carriage on postural stability [18]. Specifically, COP measures such as amplitude, sway area, and velocity were reported to increase under load carriage conditions in healthy-young adults [18]. These changes in COP indicate a greater challenge to maintaining balance and stability when carrying loads, which can increase the risk of falls and related injuries [31,32]. Furthermore, the added load can lead to increased muscular fatigue [33], which further compromises postural control [17]. This is particularly concerning in high-risk occupations where maintaining balance is critical for safety and performance.

Particularly for young, healthy adults, whom may be students or members of the military, poor sleep [34], dual-tasks [19], and load carriage [30] may be simultaneously experienced on a regular basis and understanding contributing factors to impaired postural stability [18,34,35]. Tactical athletes (e.g., military personnel, police officers, and firefighters) are typically required to carry an additional load on the body while working [30]. Poor sleep quality is also common amongst tactical athletes [36]. Considering that poor sleep quality is known to impair cognitive function and motor control, it may exacerbate the challenges posed by load carriage on postural stability. Given the prevalence of poor sleep quality in tactical athlete occupations and the need to carry an additional load while working and performing dual tasks, a greater understanding of the relationship between poor sleep quality, load carriage, and postural stability would be beneficial to prevent work-related injuries, often attributed to 'slips, trips, and falls' [31].

One similarity across tactical athlete occupations is an initial training period that is required to become a professional tactical athlete. Numerous studies have reported high injury rates during these initial training periods [37], with load carriage often cited as a contributing factor [32]. Studying the effects of load carriage on non-tactical athletes, such as young, healthy college students who are comparable to trainees in tactical occupations, can aid in identifying potential factors contributing to injuries in tactical populations. This approach avoids the barriers to conducting research on tactical athletes [38], and offers insights that can help mitigate injury risks during initial training periods.

In summary, sleep quality, load carriage, and dual-tasking have all been shown to negatively impact postural stability, and some populations may experience these factors simultaneously. However, there is a notable gap in the literature, as no studies to date have examined the combined effects of sleep quality, dual-tasking, and load carriage on postural stability. Furthermore, prior research on sleep quality [20,21,29] and dual-tasking [19] in young, healthy adults has yielded mixed findings. This highlights the need for further investigation to identify factors that may explain these inconsistencies. Thus, the purpose of this study was to examine the effects of sleep quality, dual tasks, and load carriage on postural stability assessed via clinically relevant COP measures. We hypothesized that poor sleep quality and the interaction of poor sleep quality with dual tasks and load carriage would reduce postural stability, which is evident by increases in COP measures. Importantly, the main effects of load and task were previously reported [39] from this data set and the results reported in the present manuscript will focus on the main effect of sleep and interaction effects of sleep quality, dual tasks, and load carriage as a secondary analysis of the published data. Previously, we found that dual tasks, but not load, had a negative impact on postural stability [39].

2. Materials and Methods

2.1. Experimental Design

This study utilized a repeated measures design, as each participant was assessed under multiple experimental conditions. Participants visited the laboratory for a single 120-min session. During the data collection session, participants completed a self-report survey instrument for sleep quality, and then postural stability was measured on force-plates under single and dual task conditions. To address the experimental hypothesis, a non-parametric 2 $\times$ 2 $\times$ 2 Aligned-ranks transformed repeated measures ANOVA was employed to analyze the effects of within-subject factors (e.g., sleep quality, dual task, and load carriage) while controlling for individual variability. The study adhered to the ethical principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the George Mason University Institutional Review Board with approval number 1455213. This study was not registered prior to commencement. The data presented are a subset from a larger study [39].

2.2. Participants

Participants were asked to avoid strenuous exercise 12 h before data collection [39]. Participants were included if they were between 18 and 45 years of age, had a body mass index (BMI) below 30, and performed physical activity, at either a moderate or vigorous intensity level, at least three days a week. Individuals with a previous history of lower back or other lower extremity injuries within the past six months or the inability to deadlift a load equal to one's own body mass were excluded from the study. Participants were recruited with flyers and word of mouth from the university community. A total of 23 participants (male = 12, female = 11, age: 24.57 years ± 6.13, height: 169.17 cm ± 9.79, body mass: 74.3 kg ± 12.69, BMI: 25.85 kg/m^2 ± 3.07) completed data collection and were included in the analyses. The participants were all full-time students at the university. Notably, the number of males and females was approximately equal (52% male).

2.3. Protocol

Upon arrival, participants signed an informed consent form and completed the Physical Activity Readiness Questionnaire (PAR-Q) to confirm eligibility. The Pittsburgh Sleep Quality Index (PSQI) was then completed to assess sleep quality as part of a battery of survey instruments that were part of the larger study [39]. The total time to complete the survey instruments was approximately 15 min. Next, anthropometrics of height and mass were measured. At this point, participants performed a standardized warm-up. Without wearing a load, participants performed a body weight warm-up of 10 bird-dogs, 5 inch-worms, 12 body weight squats, and 12 body weight Romanian deadlifts two times. After warming up, a 5 min rest and transition period was provided before participants completed the dual task (serial 7's) and single task (quiet standing) trials for both loaded and unloaded conditions. All trials were performed with participants standing on dual force plates and a 60 s rest between trials was given. For the load carriage condition, participants wore a 7.2 kg loaded vest to simulate a law enforcement duty vest. The larger study aimed to compare the biomechanical effects of a law enforcement duty belt to those of a tactical vest. During the conceptualization stage, members of a local law enforcement department consulted on the project. In one of the meetings, a law enforcement officer provided a standard duty belt with full equipment, which weighed 7.2 kg. For the present study, we included only the vest condition as previous findings showed no difference in COP measures of postural stability between the duty belt and vest conditions. This decision was made to reduce the number of factors, thereby minimizing the desired sample size [39]. The load versus no load carriage condition order was randomized prior to participant arrival. A 5 min rest was provided between load conditions. Randomization was performed using an online tool (www.random.org, accessed on 10 June 2021) by a member of the research team prior to each data collection session.

2.4. Measurements

Anthropometrics: Prior to beginning conditions, participants' height was measured using a stadiometer (Detecto, Webb City, MO, USA) and was recorded to the nearest 0.01 cm. Also, participants' body mass, with shoes off, was measured using a digital scale and was recorded to the nearest 0.1 kg.

Sleep: The PSQI was used to assess self-reported sleep quality. The PSQI is a 19-item questionnaire that scores seven components: subjective sleep, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. A total sum is then reported as an overall PSQI global score. Participants were categorized as 'good' and 'bad' sleepers. Good sleep was quantified as a PSQI global score that is ≤5, while bad sleep was a PSQI global score of more than 5 [40]. In the original validation study by

Buysse et al., a PSQI global score cutoff of 5 effectively distinguished healthy controls (e.g., no sleep complaints) from patients reporting sleep issues (e.g., sought medical care), with a sensitivity of 89.6% and a specificity of 86.5% [40]. A more recent systematic review and meta-analysis (2016) reported that the PSQI survey has demonstrated acceptable test-retest reliability (r = 0.87), high sensitivity (98.7%), and specificity (84.4%) [41]. The Cronbach's alpha for the PSQI for the current study is 0.64, which can be interpreted as acceptable [42]. However, in prior studies comparing the effect of sleep quality on postural stability, Saraiva et al. [21] used a PSQI ≤ 5 to categorize good sleepers, while Furtado et al. [20] and Tanwar et al. [29] used a PSQI < 5 to categorize good sleepers. Thus, in the sensitivity analysis (see Statistical Analysis), the cut-off was changed to less than 5 to define good sleepers, which changed the number of good sleepers from 18 to 14.

Dual task: The Serial 7's (S7) test was utilized to simulate a dual task paradigm and assess how participant's COP varied while information processing [43]. Prior to data collection, numbers were randomly selected from 100 to 106. Participants stood on the force plates, faced the researcher, and counted backwards by 7 from the number that was randomly chosen (i.e., 106. . .99. . .92. . .85. . ., etc.) The quiet standing task was utilized as the single task paradigm. Participants crossed their arms across their chest and stood quietly, looking forward, for 30 s.

Postural Stability: Force plate data were collected for 30 s during quiet standing and dual task trials. Participants stood on the force platform with an open base configuration. The preferred stance width for each participant was marked using tape during the initial trial to ensure consistency across subsequent trials. During the trials, participants were instructed to fix their gaze on a visual reference point, which was a mark on the wall located approximately 3 m directly in front of them [44]. The 30-s protocol for postural stability assessment was chosen to minimize participant fatigue, maintain the feasibility of the larger testing protocol, and because it is a common duration for postural stability assessments in young, healthy adults [45]. Force plates (Bertec Force Plate FP 4060-10, Bertec Corporation, Columbus, OH, USA) were warmed up at least 30 min prior to participant arrival and were zeroed prior to data collection. COP data were sampled at 2000 Hz, to be synchronized with surface electromyography data [39], then down sampled to 100 Hz for analysis. Data was low pass filtered with 5 Hz, 4th order Butterworth filter. The COP anterior–posterior (AP) range, AP mean velocity, medial–lateral (ML) range, ML mean velocity, total mean velocity, and 95% ellipses area were computed. Raw force plate data was filtered and processed in MatLab (MATLAB 2020a, MathWorks Inc., Natick, MA, USA), then exported to Microsoft Excel (version 16.78.3) for further analysis.

2.5. Statistical Analysis

Data were first visually inspected for outliers or erroneous data, and one participant was removed due to an extreme value of 95% ellipse area. The remaining participant COP data were then winsorized to the 1st and 99th percentiles [39]. This winsorizing approach allowed all of the participants to remain in the data set used for statistical analysis. Given the small sample size, retaining participants to reduce the risk of bias due to extreme values was desirable. After winsorization, data was found to not follow a normal distribution. Descriptive statistics were computed and differences in anthropometric variables between good and bad sleepers were assessed using a Mann–Whitney U test. Due to the failing normality, a non-parametric $2 \times 2 \times 2$ Aligned-ranks transformed repeated measures ANOVA was conducted to analyze the main and interaction effects of LOAD (2 levels: No Load, Load), TASK (2 levels: Single, Dual) and SLEEP (2 levels: Good, Bad) on each of the COP measures [46]. ART ANOVA was selected over alternative methods, such as the Friedman's test, because it enables the evaluation of interactions, which was critical to this study's objectives [46]. Partial eta-squared ($\eta_p{}^2$) was calculated to assess the effect size of the factors and the interactions, which can be interpreted as negligible ($\eta_p{}^2 < 0.01$), small ($0.01 \leq \eta_p{}^2 \leq 0.06$), medium ($0.06 < \eta_p{}^2 \leq 0.14$), and large ($\eta_p{}^2 > 0.14$) [47]. Post hoc pairwise comparisons with a Bonferroni correction were conducted as necessary. Cohen's d was used to interpret the post hoc pairwise comparisons as negligible (d < 0.2), small (0.2 ≤ d < 0.5), medium (0.5 ≤ d < 0.8), and large (d > 0.8) [47].

In the final stage of the analysis, the decision to use the PSQI global score of ≤5 as the cut-off for defining good sleepers was investigated in a sensitivity analysis. The 2 × 2 × 2 Aligned-ranks transformed repeated measures ANOVAs were rerun to assess whether the results would be altered. Lastly, although PSQI global scores are commonly used to categorize individuals as good and bad sleepers [41], a number of researchers have cautioned against creating categorical variables if not necessary [48–50]. Thus, Spearman rank correlations were computed between the PSQI global score with the COP measures to assess whether categorizing participants into good and bad sleepers influenced our findings. All statistical analyses and visualizations were conducted in the R environment (version 4.2.1, R Core Team, Vienna, Austria) utilizing ggplot2 (version 3.5.1), readr (version 2.1.2), dplyr (version 1.1.4), tidyr (version 1.3.0), and ARTool (version 0.11.1) packages. The statistical significance level was set a priori at $p \leq 0.05$.

3. Results

3.1. Participant Characteristics

Participant anthropometric data are provided in Table 1. Based on a PSQI cut off of less than or equal to five as good sleep, a majority of the participants were good sleepers with (e.g., 9 of the 12 males and 9 of the 11 females). No differences in age or anthropometry were found between the good and bad sleepers.

Table 1. Participant characteristics and comparison of good to bad sleepers.

Variable	All Participants (n = 23)	Good Sleepers (n = 18)	Bad Sleepers (n = 5)	p-Value
Age (years)	23.0 (20, 26.5)	22.5 (20, 27.8)	23.5 (20.8, 24.8)	0.453
Height (cm)	168.5 (161.5, 175.3)	168.8 (162.5, 175.5)	166.3 (161.8, 173.0)	0.684
Mass (kg)	73.3 (68.1, 83.8)	74.1 (68.0, 82.7)	75.6 (70.2, 84.2)	0.489
BMI (kg/m^2)	25.8 (24.1, 27.4)	25.1 (23.8, 27.2)	27.2 (25.4, 29.6)	0.160
PSQI	4.0 (3.0, 5.0)	4 (3, 4.0)	6 (6, 6.75)	<0.001

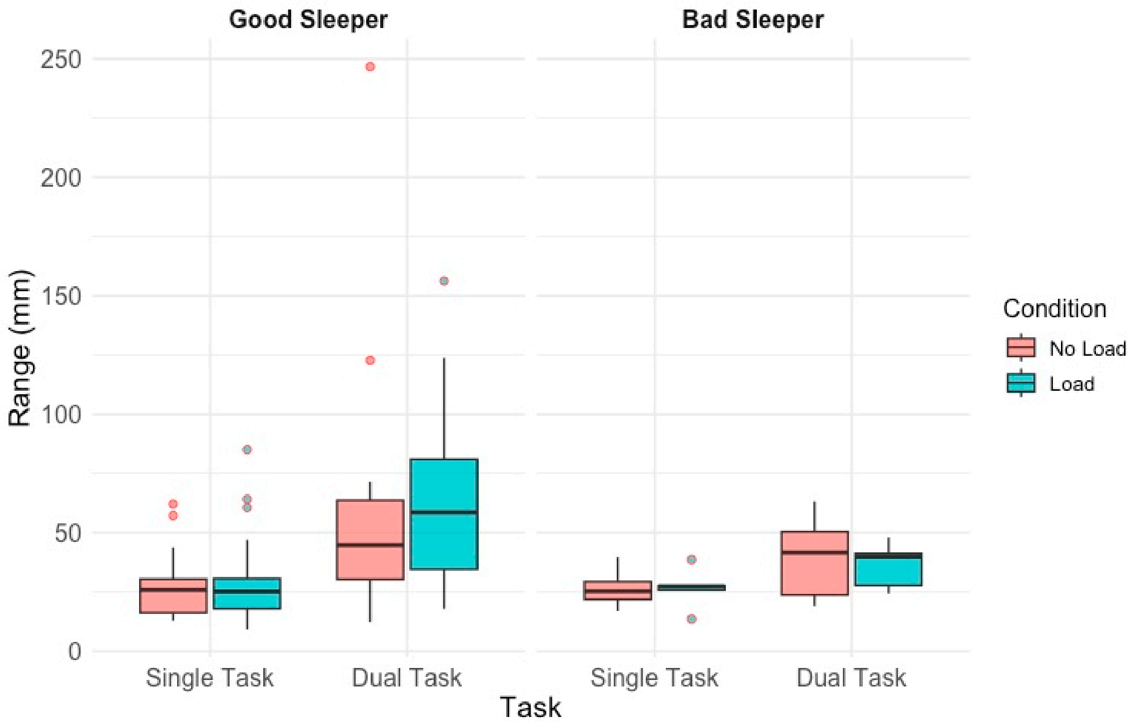
Notes: (1) Values are presented as median (interquartile range). (2) Differences between good and bad sleepers were assessed with a Mann–Whitney-U tests. (3) Good sleepers were defined as having a PSQI global score ≤ 5. (4) Abbreviations: BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index.

3.2. Main Analyses

Box plots for all COP variables are presented in Figure 1, and the results from the repeated measures ANOVA are presented in Table 2 There was a significant main effect of SLEEP on 95% ellipse area ($F(1,21) = 6.92$, $p = 0.016$, $\eta_p{}^2 = 0.248$) such that 95% ellipse area was significantly greater in good sleepers than bad sleepers. Regarding interaction effects, there was a significant LOAD × TASK interaction on 95% ellipse area ($F(1,63) = 4.14$, $p = 0.046$, $\eta_p{}^2 = 0.062$) and mean AP velocity ($F(1,62) = 5.30$, $p = 0.025$, $\eta_p{}^2 = 0.078$), but post hoc paired comparisons showed no further significance in both cases. Additionally, there was a significant TASK × SLEEP interaction on mean AP velocity ($F(1,63) = 4.04$, $p = 0.049$, $\eta_p{}^2 = 0.060$). Post hoc paired comparisons revealed that quiet standing in good sleepers resulted in significantly slower mean AP velocity than serial 7's in good sleepers ($t = -4.438$, $p = 0.0012$, $d = -1.05$). There was no significant main effect of SLEEP or interaction effects of LOAD × SLEEP × TASK for Range AP, Range ML, Mean velocity, or mean velocity ML.

Notably, when a significant main effect was observed (95% ellipse area), the effect size was large, whereas the three significant interaction effects had medium or small magnitudes.

(**a**) Anterior–posterior range



(**b**) Medial–lateral range

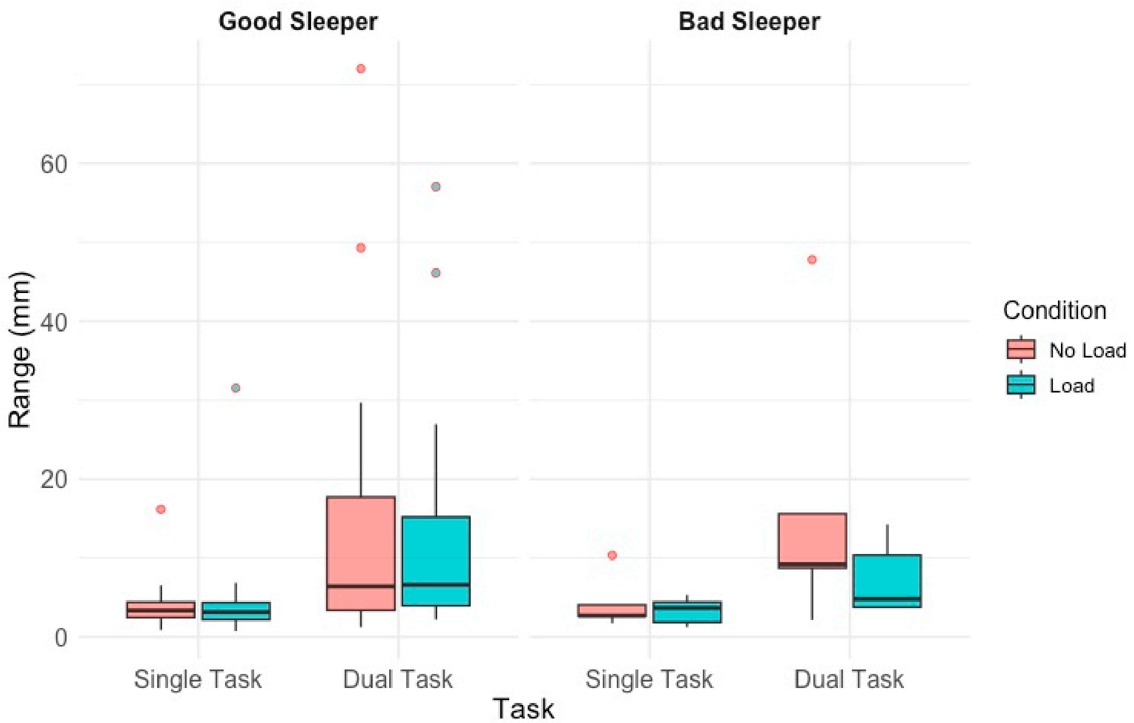
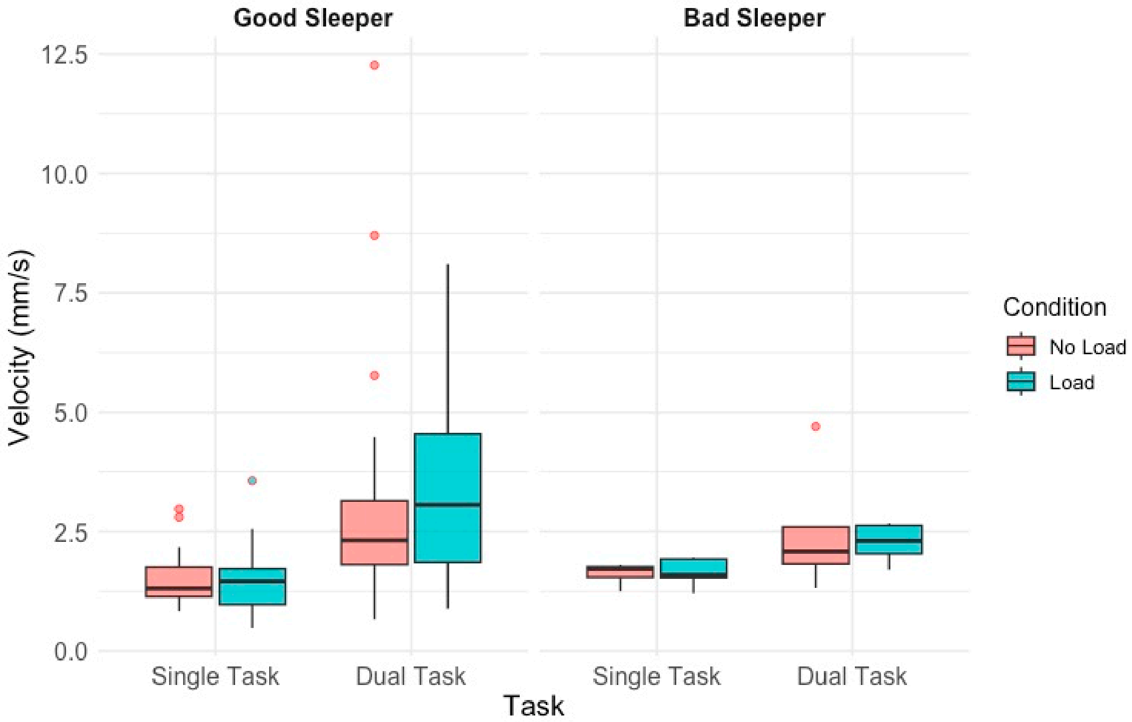


Figure 1. *Cont.*

(**c**) Mean velocity



(**d**) Anterior–posterior mean velocity

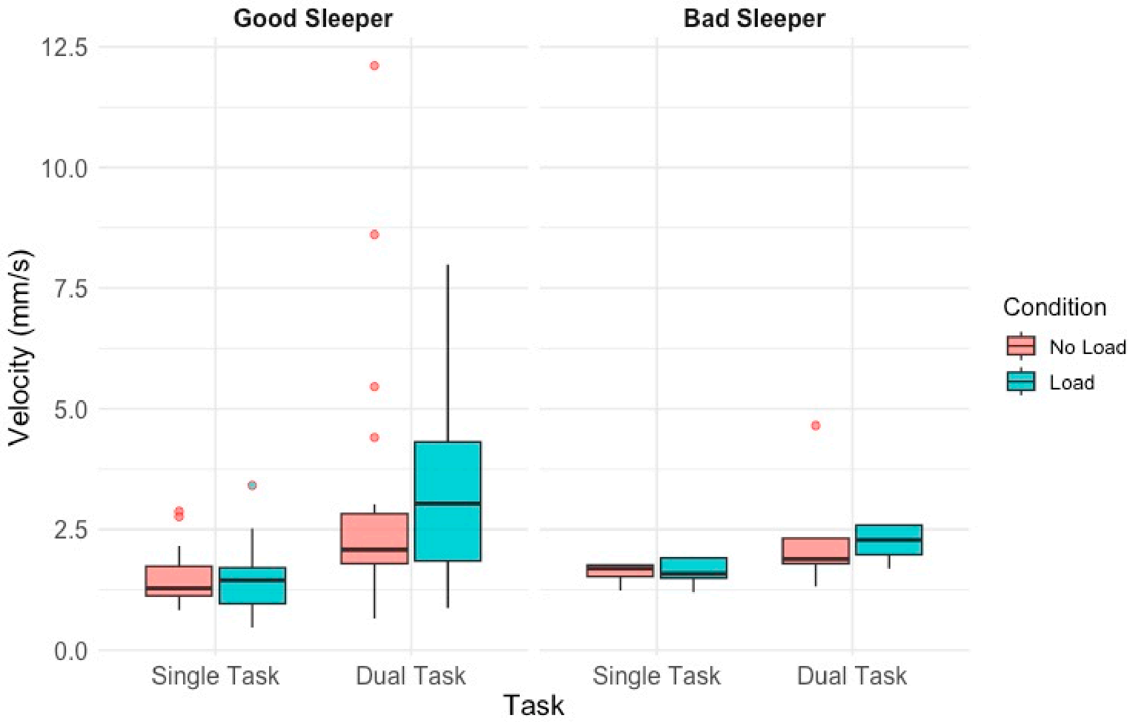
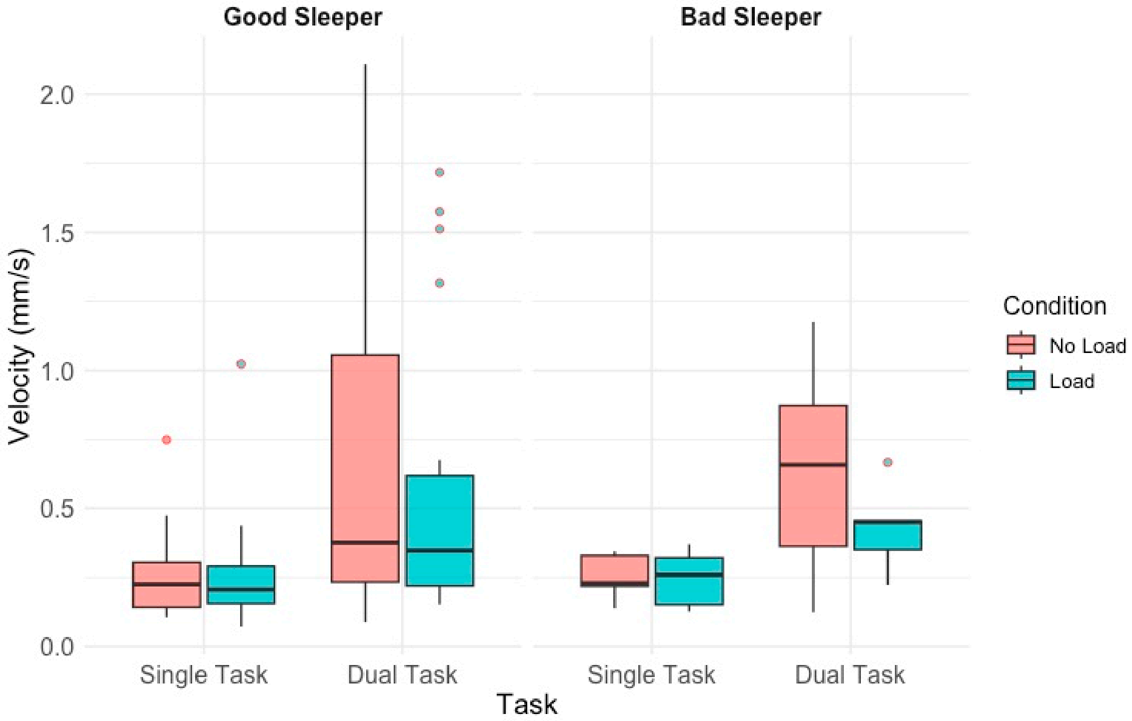


Figure 1. *Cont.*

(**e**) Medial–lateral mean velocity



(**f**) 95% ellipse area

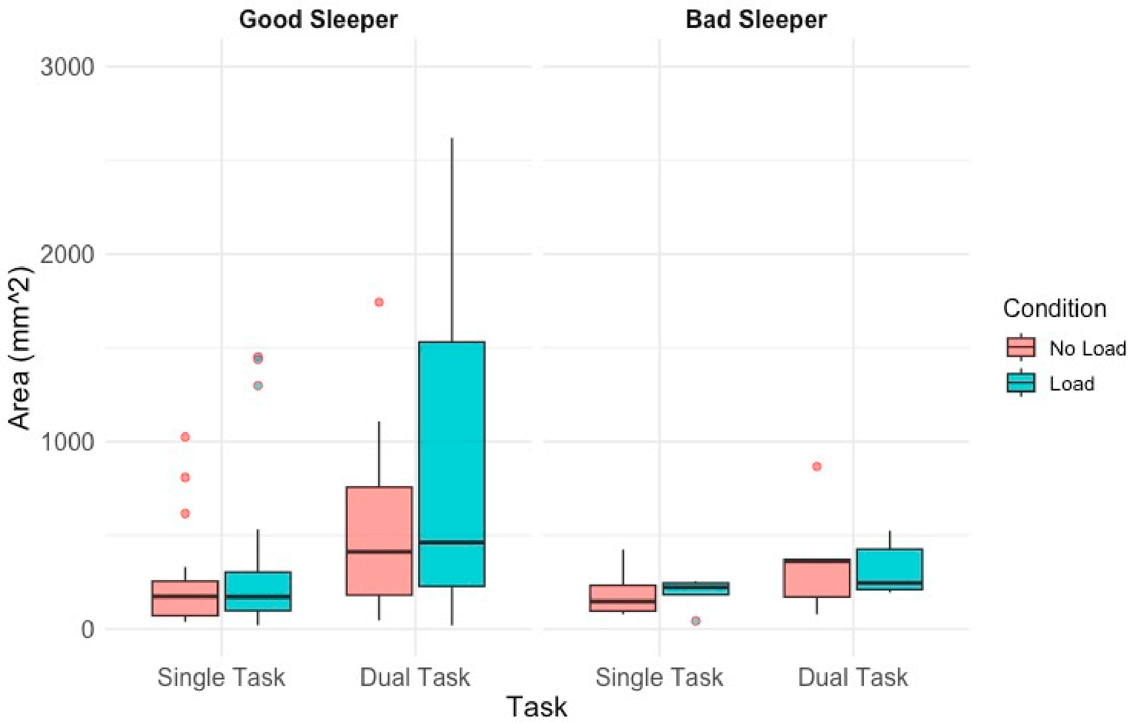


Figure 1. Box plots of median values of center of pressure variables by load, task, and sleep conditions. Note: Good sleepers were defined as having a PSQI global score ≤ 5.

Table 2. Results from an aligned ranks transformed repeated measures ANOVA.

	Main Effect	Interaction Effects			
COP Measure	**Sleep**	**L × T**	**L × S**	**T × S**	**L × T × S**
Range-AP (mm)	0.336	0.170	0.325	0.148	0.313
Range-ML (mm)	0.988	0.750	0.142	0.929	0.175
Mean Velocity (mm/s)	0.732	0.055	0.323	0.069	0.304
Mean Velocity-AP (mm/s)	0.669	**0.025 (Medium)**	0.428	**0.049 (Small)**	0.312
Mean Velocity-ML (mm/s)	0.744	0.743	0.400	0.931	0.357
95% Ellipse Area (mm^2)	**0.016 (Large)**	**0.046 (Medium)**	0.112	0.056	0.116

Notes: (1) Values are *p*-values and significant ($p < 0.05$) are in bold. (2) Good sleepers were defined as having a PSQI global score ≤ 5. (3) For statistically significant ($p < 0.05$) effects, the magnitude of the effects is included in parentheses. (4) Abbreviations: AP, anterior–posterior; ML, medial–lateral; L, load carriage, S, sleep quality; T, dual-task.

3.3. Sleep Cut-Off Sensitivity Analysis

When the PSQI cut-off was changed to <5, there were 14 good sleepers and 9 bad sleepers. Tables A1 and A2 along with Figure A1 present the descriptive and statistical results for the alternative PSQI cut-off (Appendix A). With this PSQI cut-off value there was no significant main effect of SLEEP or interaction effects between LOAD × SLEEP × TASK for any postural stability variable ($p > 0.05$). For both PSQI cut-off values, the Spearman correlations between the PSQI global and COP outcome measures were not found to be statistically significant ($p > 0.05$), in any case.

4. Discussion

This study examined the effects of chronic sleep quality, dual tasks, and load carriage on COP measures in healthy young adults. Our findings indicated that sleep quality had minimal effects on postural stability, as only the 95% ellipse area was greater in good sleepers than bad sleepers. Additionally, the sensitivity analysis found that when the cut-off for defining good and poor sleepers was changed, sleep no longer had an effect of on any COP measures. The correlation analysis supported the lack of influence of sleep quality on postural stability. A key strength of the present study is the sensitivity analysis on the selection of PSQI cut-off for defining good and bad sleepers, which provided a more complete understanding of the influence of sleep quality on postural stability.

As previously mentioned, research investigating the effects of chronic poor sleep quality on postural stability is conflicting [20,21,29]. All studies included young adults with no health issues that would have impaired postural stability [20,21,29]. A similarity between studies is that all use the PSQI to assess sleep quality. However, Tanwar et al. [29] and Furtado et al. [20] reported using greater than or equal to five as bad sleepers, where Saraiva et al. [21] used greater than five to define bad sleepers. Another difference between the studies was the instrumentation and the subsequent measures of postural stability [20,21,29]. Similar to the present study, Saraiva et al. used a force plate system and reported COP measures [21]. Furtado et al. collected postural data using a Biodex Balance System, and instead of COP measures being reported, reported variables such as the stability index and sway index were used to assess dynamic stability [20]. Tanwar et al. used the Y-balance test, which is a single leg dynamic assessment of postural stability [29]. Therefore, the combined findings of previous research and the current study suggest that sleep quality has minimal to no impact on static postural stability, even under dual-task conditions. However, more challenging tasks that require dynamic stability do appear to elicit an effect of sleep quality where good sleepers have greater postural stability [20,29].

The possibility that sleep quality influences dynamic, but not static, postural stability appears reasonable based on control mechanisms of posture [51]. The control of balance during quiet standing and movement (e.g., gait) depends on a complex interaction of physiological mechanisms and the high-level processing of sensory information to maintain stability [51]. For young adults, static balance is primarily managed through motor tasks that engage subcortical reflexive control systems; in contrast, more demanding balance tasks necessitate additional supraspinal control [12,51]. Given that sleep deprivation disrupts functional connectivity within the motor cortex and cerebellum [52], which have crucial roles in the control and coordination movement of movement [53], it is not surprising that more complex motor tasks are more likely to be impaired by poor sleep quality (i.e., a consequence of repeated bouts of sleep deprivation). This assertion is corroborated by studies demonstrating that dynamic stability differs significantly between individuals with good versus poor sleep quality [20,29], and by research indicating subtle influences of sleep quality on gait among healthy young adults [54]. For example, Martin and colleagues recently reported that in healthy, young adults, sleep quality had subtle effects on gait [54].

Additionally, when considering our previously reported findings from the larger study [39] and the interaction effects in the present study, more cognitively challenging conditions appear necessary to have an effect on COP measures of postural stability in young, healthy adults. The lack of influence of load on postural stability was initially unexpected. However, the lack of significant findings concerning the effect of load on postural stability in this study may be attributed to the magnitude of the load utilized and its symmetrical distribution. A systematic review and meta-analysis found that load carriage diminishes postural stability in healthy, young adults, with the positioning and mass of the load being key factors that can further impact stability [18]. Specifically, greater increases in load magnitude lead to more pronounced reductions in postural stability, while posterior load placement diminishes stability compared to a load balanced anteriorly and posteriorly or solely placed anteriorly [18]. The load used in the present study was 7.2 kg whereas many prior studies have used heavier loads [18].

One unexpected finding was that participants with better sleep quality, per the traditional PSQI cutoff, had greater values of postural sway, measured by the 95% ellipse area. Typically, higher values of COP measures, particularly 95% ellipse area [11], are assumed to indicate decrease stability. This discrepancy may be attributed to unbalanced sample sizes [55], limitations of self-reported sleep quality [56], and the dichotomization of sleep quality into good versus bad sleepers [48–50]. The lack of statistical significance in the sensitivity analyses supports that these factors warrant consideration when interpreting the findings.

This study has several limitations that should be considered when interpreting the findings. First, the sample size was small and included non-emergency responders. A larger cohort of emergency responders would potentially reveal subtle effects that were not detectable in this study and enhance the generalizability. As the present study was a replication study utilizing a secondary analysis of data collected for another aim the sample size was based on an a priori power analysis for the aim of the primary study [39]. While this approach didn't require the collection of new data for a replication of the study of Saraiva et al. [21], which are needed in exercise science [57], a drawback was that the sample was small.

Second, the assessment of sleep quality relied on subjective measures, which can introduce bias in the data [56]. Subjective reports of sleep may not accurately reflect the true sleep patterns or the quality of rest obtained by participants [56]. Although the PSQI has been found to be valid and reliable [41], the incorporation of objective measures such as polysomnography or actigraphy would provide a more accurate assessment of sleep quality. Currently, objectively monitoring chronic sleep quality is challenging in healthy populations and, although many wearables are able to monitor sleep, the reliability of these devices remains limited [58]. Future studies could benefit from incorporating objective measures, such as polysomnography or actigraphy, to obtain more precise and reliable data on sleep quality.

Another limitation of this study is that the magnitude of load carriage was lower than that used in previous studies, which often employed military-style loads (e.g., rucksack) [18]. However, the load used in this study matched the standard load carried by law enforcement officers in our county, supporting the ecological validity of the primary study. Due to the study design being a replication study and a secondary analysis of an existing dataset, incorporating a heavier load condition was not feasible. Future studies should include heavier load conditions to better understand the interaction between the effects of sleep and load carriage on postural stability.

Other limitations of the present study existed and should be acknowledged to guide future research. One was the balance tasks utilized may not have been sufficiently challenging to elicit significant differences between groups with varying sleep quality. Future research could benefit from integrating more complex and dynamic balance tasks, which would provide a deeper understanding of how sleep quality impacts postural control under the demanding conditions that emergency responders often face. While all participants were full-time college students who regularly carried backpacks, we did not assess for specific postural deviations such as hyperlordosis, hyperkyphosis, or scoliosis, and nor did we record additional factors such as work-related load carriage habits, shift schedules, or other occupational activities that could influence postural control. These factors could have provided valuable context for interpreting the results and understanding individual variability in postural sway responses. Future studies should incorporate these measures to offer a more comprehensive characterization of the sample and further clarify the relationship between habitual load carriage, postural adaptations, and motor control.

5. Conclusions

In summary, our findings indicate that sleep quality generally does not diminish postural stability, and nor does it significantly interact with dual-task and law enforcement officer style body-worn load conditions during static balance tests in heathy, young adults. Practitioners who may be screening individuals for risk of injury via postural stability assessments would be advised to incorporate balance tasks of sufficient challenge to induce clinically meaningful changes in postural stability. Future studies would be advised to include both static and dynamic tasks to assess postural stability, implement actigraphy to provide objective measures of sleep quality, and use heavier load carriage conditions. Given that slips, trips, and falls are prevalent injury mechanisms among emergency responders, who often report poor sleep quality and are required to perform dual tasks while carrying loads, future studies should focus on more demanding dynamic balance tasks to enhance our understanding in this area.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article or the Appendix A.

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Appendix A

Table A1. Participant characteristics and comparison of good to bad sleepers.

Variable	All Participants (*n* = 23)	Good Sleepers (*n* = 14)	Bad Sleepers (*n* = 9)	*p*-Value
Age (years)	23.0 (20, 26.5)	25.5 (20.2, 31.8)	21.0 (20.0, 23.0)	0.059
Height (cm)	168.5 (161.5, 175.3)	172.0 (166.1, 177.5)	162.0 (159.5, 168.5)	0.095
Mass (kg)	73.3 (68.1, 83.8)	76.3 (71.1, 84.0)	68.0 (59.8, 71.5)	0.056
BMI (kg/m2)	25.8 (24.1, 27.4)	26.1 (24.2, 27.4)	25.2 (23.5, 25.8)	0.213
PSQI	4.0 (3.0, 5.0)	3.0 (3.0, 4.0)	6.0 (5.0, 6.0)	<0.001

Notes: (1) Values are presented as median (interquartile range). (2) Differences between good and bad sleepers were assessed with a Mann-Whitney-U tests. (3) Good sleepers were defined as PSQI global score ≤ 6. (4) Abbreviations: BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index.

Table A2. Results from aligned ranks transformed repeated measures ANOVA.

COP Measure	Main Effect Sleep	Interaction Effects L × T	L × S	T × S	L × T × S
Range—AP (mm)	0.491	0.455	0.971	0.606	0.964
Range—ML (mm)	0.560	0.929	0.715	0.480	0.640
Mean Velocity (mm/s)	0.679	0.171	0.705	0.230	0.846
Mean Velocity—AP (mm/s)	0.653	0.108	0.736	0.191	0.956
Mean Velocity—ML (mm/s)	0.540	0.492	0.938	0.958	0.922
95% Ellipse Area (mm^2)	0.427	0.531	0.906	0.432	0.819

Notes: (1) Values are p-values and significant ($p < 0.05$) are bolded. (2) Good sleepers were defined as PSQI global score ≤ 6. (3) Abbreviations: AP, anterior-posterior; ML, medial-lateral; L, load carriage, S, sleep quality; T, dual-task.

(**a**) Anterior–posterior range

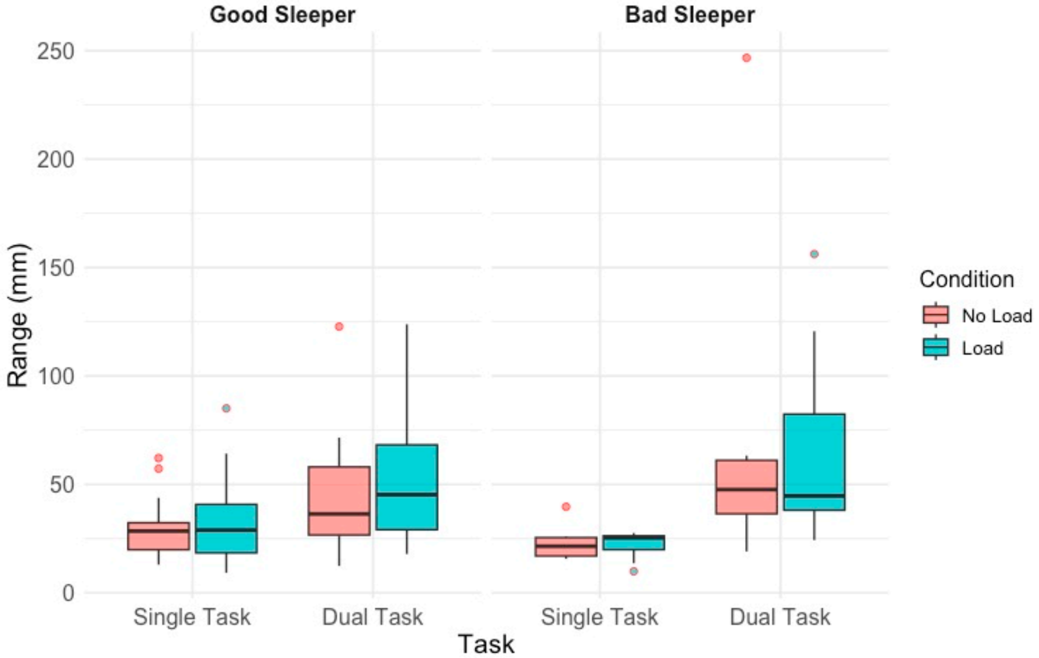
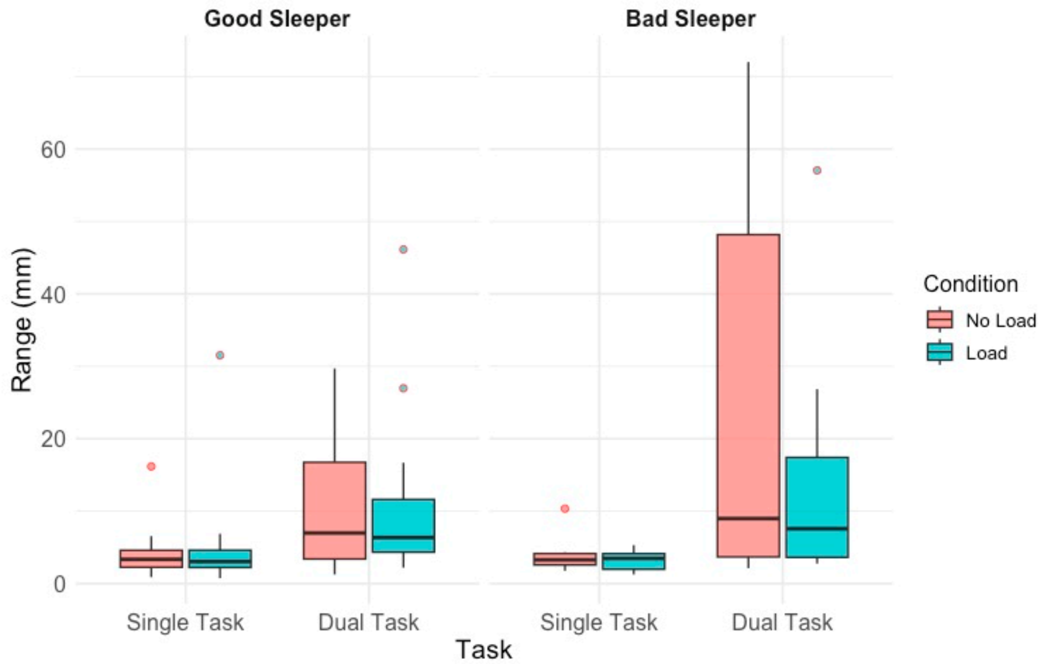


Figure A1. *Cont*.

(**b**) Medial–lateral range



(**c**) Mean velocity

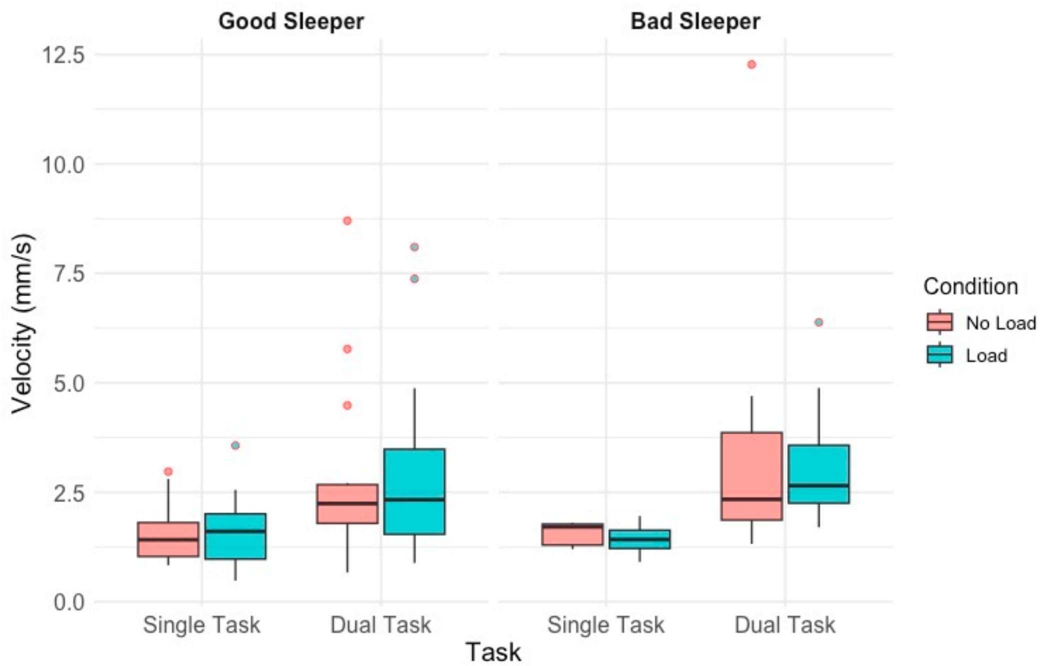
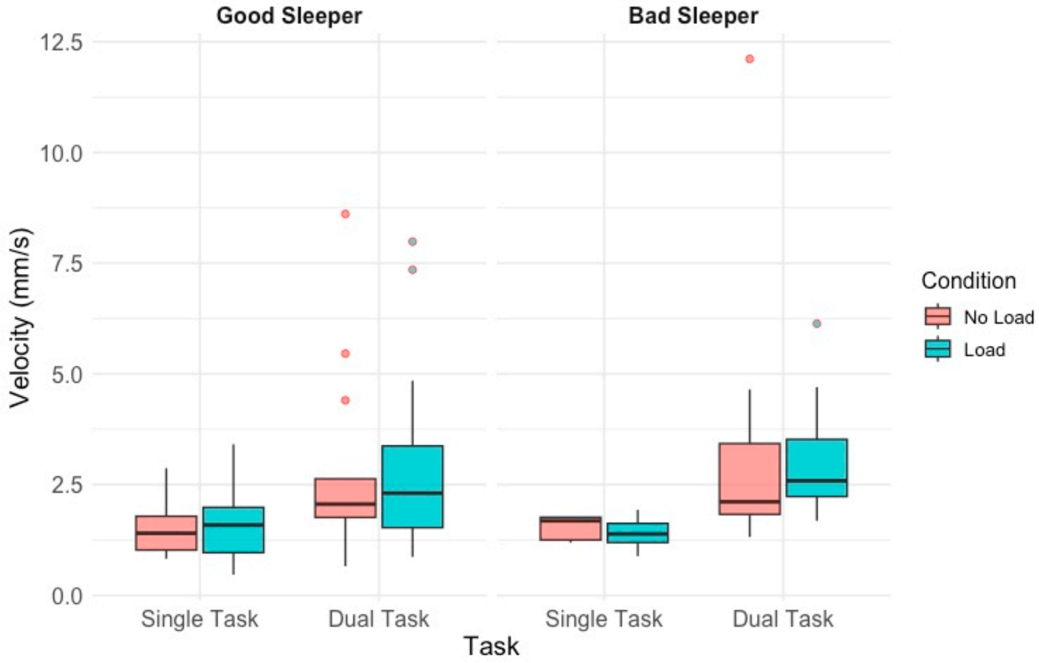


Figure A1. *Cont*.

(**d**) Anterior–posterior mean velocity



(**e**) Medial–lateral mean velocity

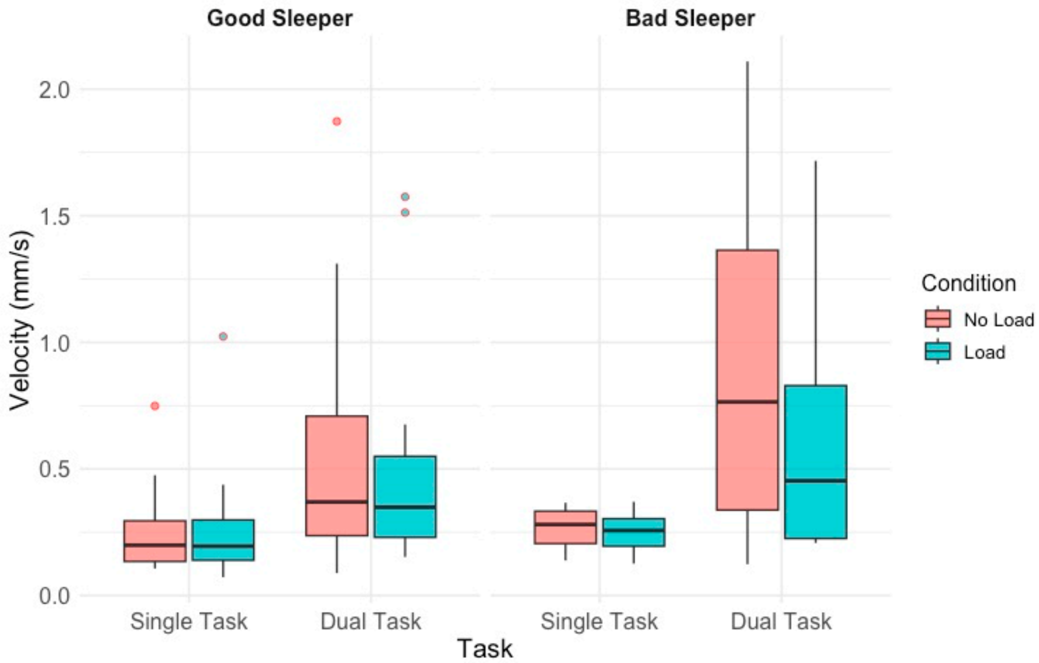


Figure A1. *Cont.*

(**f**) 95% ellipse area

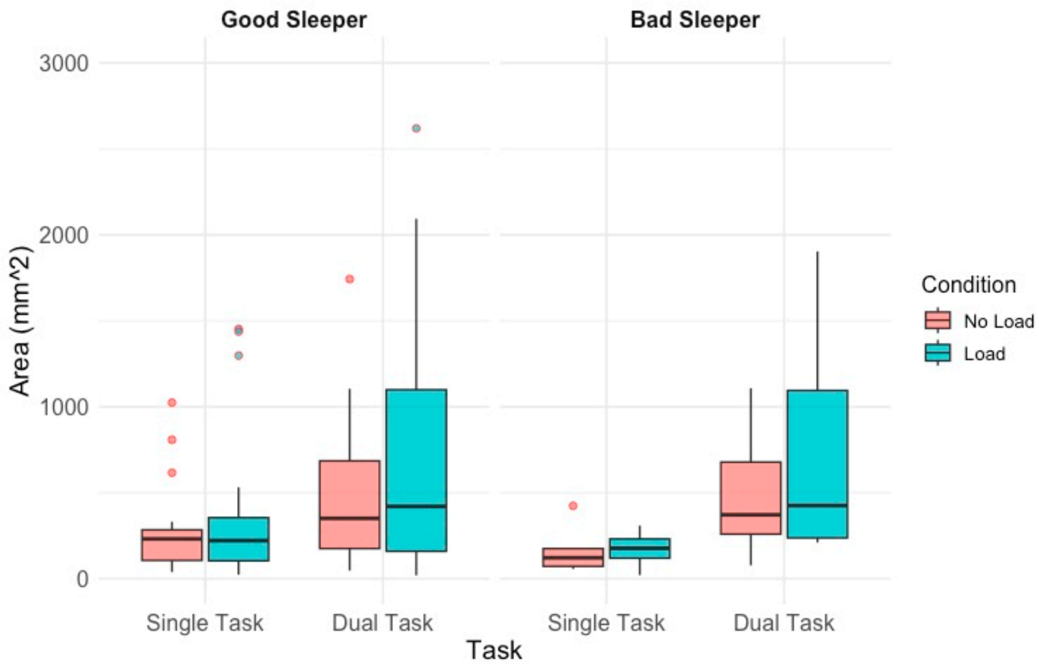


Figure A1. Box plots of median values of center of pressure variables by load, task and sleep conditions. Note: Good sleepers were defined as having a PSQI global score ≤ 6.

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