Advancing the Safety, Health, and Well-Being of Commercial Driving Teams Who Sleep in Moving Semi-Trucks

The Tech4Rest Pilot Study

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Objective: To test the feasibility, acceptability, and potential effectiveness of engineering and behavioral interventions to improve the sleep, health, and well-being of team truck drivers (dyads) who sleep in moving semi-trucks. **Methods:** Drivers ($n = 16$) were exposed to Condition A: a new innerspring mattress, and Condition B: a novel therapeutic mattress. A subsample of drivers ($n = 8$) were also exposed to Condition C: use of their preferred mattress (all chose to keep B), switching to an active suspension driver's seat, and completing a behavioral sleep-health program. Primary outcomes were sleep duration, sleep quality, and fatigue. Behavioral program targets included physical activity and sleep hygiene. **Results:** Self-reported sleep and fatigue improved with mattress A, and improved further with mattress B which altered vibration exposures and was universally preferred and kept by all drivers. Condition C improved additional targets and produced larger effect sizes for most outcomes. **Conclusions:** Results support these interventions as promising for advancing team truck drivers' sleep, health, and well-being.

Keywords: behavioral intervention, commercial truck drivers, fatigue, hierarchy of controls, mattress, physical activity, seat, sleep, sleep hygiene, team truck drivers

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The results reported herein correspond to specific aims of the project ''Engineering & Behavioral Controls for Truck Drivers' Sleep, Safety, & Health'' (Ryan Olson and Peter Johnson, MPIs) within the Oregon Healthy Workforce Center, funded by the National Institute for Occupational Safety & Health (grant number U19OH010154, Leslie Hammer and Ryan Olson MPIs). This work was also supported by a Safety and Health Improvement Project grant from the State of Washington (grant number 2014YH00280, Pete Johnson and Ryan Olson MPIs), and the Oregon Institute of Occupational Health Sciences via funds from the Division of Consumer and Business Services of the State of Oregon (ORS 656.630).

The project was reviewed and approved by the Oregon Health & Science University Human Subjects Institutional Review Board (eirb protocol #15440). Additional review and oversight was provided by the University of Washington Institutional Review Board. Human subjects provided written informed consent to participate in the study.

The authors report no conflicts of interest.

Clinical Significance: The cab enhancements (seat and mattress) evaluated show promise for improving sleep and reducing fatigue among truck driving teams. A behavioral program produced added benefits, including increased physical activity in this sedentary occupation. Such effects may improve the well-being of driving teams and reduce the risk for fatigue-related crashes.

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Commercial truck driving is an economically and socially important occupation. In 2017, 70% of all US freight value (representing $12.42 trillion) was transported on commercial trucks.[1] Across all US industries in 2018, about 2 million people were employed as heavy-duty commercial truck drivers.[2] If self-employed drivers are included in estimates, the US has nearly 6.6 million commercial drivers' license holders with 4 million drivers operating interstate.[3] The US economy is heavily dependent on the trucking industry and the well-being of commercial truck drivers.

This important working population needs protection and support for their safety, health, and well-being. In 2017, ''Transportation and Material Moving'' occupations had a fatality rate that was 4.5 times higher than the US average per 100,000 workers, and experienced the highest total number of fatalities with 1443 lives lost.[4] Fatal and serious injuries to drivers can occur during tasks like manually handling freight or chaining tires, but predominantly involve large truck crashes. These large truck crashes are substantially less frequent per vehicle mile traveled than those involving passenger cars, but are 20% to 55% more likely to result in a fatality than crashes involving only passenger cars.[5] Each death of a commercial or passenger vehicle occupant results in tremendous loss and suffering among family members, friends, co-workers, and employers. In addition, the cost of each fatal large truck crash averages over $7 million,[6] with total annual US costs of crashes near $40 billion.[7]

Fatigue is a common contributing factor in single vehicle and fatal-to-the-driver large truck crashes.[8] In Washington State, 60% of truck driver fatalities are vehicle-related, and half of those fatalities were caused by single vehicle accidents where drivers lost control of their truck—a type of crash where fatigue is a likely factor.[9–11] In 1995 the National Transportation Safety Board evaluated 182 fatal-to-the-driver large truck crashes, and found that fatigue was the principle cause of the crash in 31% of cases.[12] Thus, studying working conditions that may reduce fatigue, and improve driver sleep and well-being, is an important scientific priority.

Work exposures that may produce fatigue among commercial truck drivers include long work hours, vibrations, shift work, and unfavorable sleeping conditions.[13] In the United States, driving is permitted for up to 11 hours per day and 60 hours per week.[14] An additional 3 hours may be spent on-duty each day, potentially resulting in very long 14-hour work shifts. Irregular shift timing and duration, including night driving,[15] can misalign a driver's sleep opportunities in relation to their body clock, resulting in difficulty falling or staying asleep, short overall sleep duration, and/or poor general sleep quality. The sleeping environment in commercial trucks, or sleeper berths, may also not be ideal. Conditions may include a poor quality mattress, noise or light pollution, vibration, and uncomfortable temperatures.[16–18] Available evidence suggests that these working conditions generate a degree of chronic sleep restriction for truck drivers when they are on the road. Long-haul truck drivers average 1 to 2 fewer hours of sleep per night in the truck sleeper berth (≈6 h) compared to when sleeping at home.[16,19]

Truck driving teams (dyads), where one person drives while their partner sleeps, typically transport high value or perishable freight. The work arrangement minimizes ''down time'' and speeds deliveries by keeping the truck moving during the majority of each 24-hour period. Compared to solo driving, team driving involves elevated night work, and also exposes drivers to vehicle movements and whole body vibrations (WBV) during most sleep opportunities. Dingus et al[20] investigated the impact of the sleeper berth environment on both solo and team drivers' sleep and performance. For objective sleep duration and quality analyses, researchers used a ''Nightcap'' measurement system (no longer available) that used data from eyelid movements and head position to estimate sleep duration, awakenings, and sleep efficiency. Sufficient Nightcap and survey data were available for 9 team and 12 solo drivers ($n = 21$) for analyses. Researchers reported that sleep quality was reduced in the sleeper berth for both solo drivers and teams relative to their sleep at home. Teams experienced the poorest sleep quality on the road (about 4 times as many awakenings than at home) due to disruptions caused by vibrations. Findings from Dingus et al[20] and the broader literature encourage interventions to improve job design and cab/sleeper features for commercial truck drivers, but especially for teams. Such interventions could improve drivers' sleep and well-being, reduce fatigue, and reduce the risk of safety incidents.

Additional evidence encourages an expanded and integrated view of truck drivers' work exposures and impacts on sleep, safety, health, and well-being. The exposures discussed above interact with other factors in the cab, and the broader work environment, to place commercial drivers at further risk for musculoskeletal pain, chronic diseases, and reduced well-being. Daily exposures to WBV in the truck seat are related to chronic musculoskeletal pain and disorders, including debilitating and costly low back injuries.[21–23] Fatigue and sleep deficiency are associated with obesity, chronic diseases,[24,25] and early death.[26,27] Sleep deficiency, alone and in combination with the circadian disruption typical of night shift work, may contribute to obesity and chronic diseases (eg, diabetes) in part through negative impacts on carbohydrate metabolism and appetite.[28–31] Moreover, sleep deficiency combined with long sedentary work hours, and unfavorable environments for healthy eating and physical activity, is a particularly obesogenic milieu of exposures. Truck drivers' obesity prevalence is two times greater than that of the general population (69% vs 31%).[32] Obesity increases the risk for sleep disorders like insomnia[33] and obstructive sleep apnea.[34,35] Among truck drivers, untreated sleep apnea increases the risk for serious crashes by five times.[36] The job requires sustained vigilance and exposes drivers to a range of stressors, but with limited daily breaks, daily off duty time, and time at home to recover. In total, truck driving can take a toll on workers' general psychological health, quality of life, and well-being.[13] Without protective interventions and strong workplace supports, drivers can easily become trapped in ever-worsening positive feedback loops that exacerbate sleep, safety, health, and well-being problems.

Need for Interventions Informed by the Hierarchy of Controls Applied to *Total Worker Health*®

In our view, the interacting exposures experienced by team truck drivers call for *Total Worker Health*® (TWH) approaches to selecting and testing interventions. TWH is defined by NIOSH as ''...policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being.''[37] As with traditional safety interventions, TWH interventions should be prioritized with guidance from a hierarchy of controls. In the traditional hierarchy, hazard control tactics for workers are prioritized in the following order: elimination, substitution, engineering controls, administrative controls, and personal protective equipment.[38] NIOSH has more recently published a hierarchy of controls applied to TWH, which labels hazard control tactics a little differently in the following order of priority: eliminate, substitute, redesign, educate, and encourage.[39] Considering this hierarchy applied to TWH, elimination, substitution, and redesign may be conceptualized as engineering controls, and education and encouragement may be conceptualized as behavioral or administrative controls. In the traditional hierarchy, administrative controls are conceptualized as changes to work policies and procedures, including behavioral interventions such as training and motivational tactics, to reduce workers' exposures to hazards (ie, education and encouragement in the TWH hierarchy). For the purposes of our project we will use the term ''behavioral controls'' as an umbrella term to capture education and encouragement in the hierarchy of controls as currently applied to TWH.

Engineering Controls

A range of engineering controls may improve the truck cab and sleeper berth to reduce fatiguing or sleep disturbing exposures for teams. These include improved insulation or auditory noise cancelling systems, minimally disturbing auxiliary power units to provide heating and cooling when the truck is parked, improved seat technology to reduce WBV exposures during driving, and improved mattress systems to increase comfort levels and reduce sleep disturbance in a vibrating moving vehicle. In the current project, we focused on substituting seat and mattress technologies.

Original equipment manufacturers have reported experimentation with truck cab features to benefit driver sleep and health, but publicly available data on impacts are limited. Daimler trucks in Germany evaluated cab enhancements, including seat and mattress upgrades, in collaboration with researchers from the University of Regensburg.[40,41] Daimler researchers evaluated the effects of an enhanced Actros truck cab (which they named the Mercedes-Benz "TopFit Truck") relative to a standard production vehicle with fleet drivers in a naturalistic driving study. Enhancements included improved sound insulation, a larger bed, a massage seat with adjustment settings for napping, a computer programmed sound system to play relaxing music for naps, and vehicle attachments and instruction videos for in-cab cable pull exercises. They reported drivers had less mental stress and improved fuel efficiency while working in the enhanced cab, but expanded and detailed empirical outcomes were not available publicly. Following these studies, Daimler reported incorporating some cab enhancements into their New Actros commercial truck that began production in 2011 for the European market. Peer reviewed scientific studies of cab enhancements like these are needed to advance the sleep, health, and well-being of both team and solo truck drivers.

For many decades the industry standard commercial driver seats have been passive air suspension (aka, air-ride) seat systems.[42] In recent years, active suspension and semi-active suspension seats have come to market. Examples include the Clear Motion (formerly Bose Ride II) Active Suspension Seat (Clear Motion, Woburn MA), and semi-active suspensions seats including the Sears Atlas II AVS (Davenport, IA). Initial evidence suggests these technologies are a significant advancement for reducing drivers' exposures to WBV.[43] In a one-year randomized controlled trial with truck drivers, Johnson and colleagues[42] demonstrated that industry-standard air suspension seats had a minimal impact on vibration exposures or pain, but new active suspension seat technology reduced drivers' exposure to WBV by 45% and self-reported low back pain by 30%. Given these encouraging results, the Tech4Rest study included the Clear Motion Active Suspension Seat for evaluation as a cab enhancement for teams.

Similarly, conventional innerspring mattresses appear to have been the long-term industry standard supplied by original equipment manufacturers for commercial truck sleeper berths. In our interactions with drivers, some report seeking out early opportunities to replace their innerspring mattresses with a new one from their employer because they wear out relatively quickly. Other drivers report adding a foam pad on top of their innerspring mattress to increase comfort, or replacing the innerspring mattress with an alternative mattress. Such alternative mattresses can include memory foam, foams of different densities, and/or unique suspension systems to support a foam mattress.[43,44] An example is the ThevoRelief "therapeutic" mattress (Thomashilfen, Bremervörde, Germany), which includes interlocking foams of different densities to support different body regions, and a unique wing suspension system. An engineer, who was employed by an original equipment manufacturer, shared that his company had tested the ThevoRelief mattress with a small group of driving teams who rated it very favorably (Josef Loczi, personal communication, September 2013). However, we are unaware of any published subjective or objective research of driver comfort and preferences for standard or alternative sleeper berth mattresses. Given this research gap, and the novel design and favorable anecdotal report for the ThevoRelief mattress system, we selected this mattress as a further cab enhancement to evaluate with teams.

Behavioral Controls

Behavioral controls to advance team driver sleep and health should be evidence-based, tailored for commercial truck drivers, and amenable for administration on mobile devices such as smart phones or tablets. Sleep hygiene education, while typically insufficient as a stand-alone sleep intervention, is a common element of effective multicomponent sleep programs for treating insomnia.[45] Examples of traditionally accepted sleep hygiene practices for the general population include limiting activities in bed to sleep and sex, avoiding stimulants and alcohol for four to six hours before bed time, and establishing a regular soothing bedtime routine. Sleep hygiene education may help team truck drivers who are experiencing insomnia, but it is also a worthwhile topic of further study because the *direct effects* of traditional sleep hygiene practices remain substantially unproven in the general population.[46] Regular engagement in physical activity is also viewed as an effective sleep enhancing practice, although intense exercise close to bed time is typically discouraged. Sherrill et al[47] found that within a sample of men, walking only six blocks per day was associated with a 50% reduced risk of any sleep disorder. Combining sleep hygiene education with a physical activity program is a promising behavioral approach to promoting sufficient sleep. For example, Wang and colleagues[48] evaluated a 1-month physical activity counseling intervention combined with sleep restriction (shortening time in bed) for individuals with insomnia. The combined intervention was significantly better than sleep restriction alone for reducing daytime fatigue and sleepiness, and produced a 30-minute increase in daily total sleep time and a 90-minute decrease in wake time after sleep onset. These effects were achieved through a modest increase of 45 minutes of weekly moderate/vigorous physical activity (pre-median = 110 min/wk, post median = 155 min/wk).[48]

Another relevant sleep and fatigue intervention, tailored commercial truck drivers, is the North American Fatigue Management Program.[49] This program includes a combination of sleep disorder screening and treatment with a package of training content for executive leaders, shippers/receivers, dispatchers, drivers, and drivers' family/household members. For drivers, the educational content includes four training sessions lasting 90 minutes each on fatigue management education, sleep and sleep disorders, trip planning, and wellness and lifestyle. The program was evaluated with 121 drivers from two companies, with 77 drivers completing post-program measurements. Post program measurements were required to take place at least 2 weeks after the last educational topic was completed, and included self-reported and actigraphic sleep outcomes. Corporate partners reported offering fewer training sessions, shorter sessions, or combining topics in order to implement the program. Results showed that drivers increased the duration of their main sleep period on duty days by 20 minutes and increased subjective reports of sleep quality by 10.1%. Analyses for drivers with and without obstructive sleep apnea showed greater effects for those without a sleep disorder. Drivers diagnosed with obstructive sleep apnea who were compliant with treatment had better results than those who were less compliant with treatment.

Given the beneficial effects of a healthy body weight and exercise for sleep, effective health promotion programs tailored for commercial drivers are also relevant. The literature includes descriptions of corporate case studies of health promotion programs[50] and a handful of peer-reviewed interventions for commercial drivers.[51–59] Among the more effective interventions,[53–55] the SHIFT (Safety and Health Involvement For Truckers) intervention[53] uses a game-like mobile health (or m-health) approach for engaging truck drivers in making changes. The program involves an intergroup weight loss competition supported with goal setting and self-monitoring; individual and social comparison feedback; online training on healthy weight loss, eating, exercise, and sleep; and health coaching using a motivational interviewing approach. In a cluster randomized controlled trial with commercial truck drivers ($n = 452$) based at 22 terminals from 5 companies, SHIFT produced significant between group intervention effects for body mass index ($-1.00\,kg/m^2$), daily fruit and vegetable servings consumed (+0.70 servings), and days per week with 30 minutes of physical activity (+0.67 days per week). The intervention also showed a non-significant trend of +15 more minutes of reported sleep each night. Sleep-health interventions, delivered in an m-health format like SHIFT, offer an evidence-based format for advancing team truck drivers' sleep, health, and well-being.

Introduction Summary

Truck driving is a potentially dangerous occupation with an elevated fatality rate relative to the US average for all industries. Fatal large truck crashes, although rare per vehicle mile traveled relative to passenger car crashes, often involve truck driver fatigue as a contributing factor. The team driving work arrangement presents a combination of work exposures that may place workers at risk for interacting sleep, safety, health, and well-being problems. Research has devoted little attention to this population, and the nature of the problem encourages integrated intervention approaches that are informed by the hierarchy of controls applied to TWH. The present study addresses these research gaps by evaluating evidence-based and promising engineering and behavioral controls to advance team drivers' sleep, safety, health, and well-being.

METHODS

Prior to participant enrollment, all study procedures were reviewed and approved by the Oregon Health & Science University human subjects Institutional Review Board.

Participants and Setting

Two trucking companies in the Pacific Northwest region of the US participated. Company 1 specialized in refrigerated freight transport on the west coast, with teams having home time about once per week. Company 2 had both dry and refrigerated freight divisions, and their teams typically traveled across the lower 48 states, and had less predictable schedules and home time. Teams were recruited through direct satellite text messages sent by dispatchers, as well as by flyers, emails, and word-of-mouth through company personnel. Researchers called interested drivers to screen them for eligibility, and criteria included employment as a team driver and self-reported adherence to any prescribed treatment for obstructive sleep apnea (if applicable). Both members of a driving team needed to be eligible and willing to volunteer in order to enroll in the study. If a driver reported non-compliance with a prescribed treatment for obstructive sleep apnea, the study procedure was to verbally inform them of their ineligibility and the urgent importance of starting or resuming treatment, and to send a letter that included the same information.

A total of 18 team drivers, representing 10 total driving teams, expressed initial interest and were prescreened for eligibility. Of these drivers, two (not on the same team) did not progress beyond screening; one was ineligible because they were not actively working as a team driver; and the other declined to participate after the prescreening phone call. Ultimately, 16 drivers (8 teams) completed the informed consent process and enrolled in the study. Eight of these drivers (four teams) were employed at Company 1, and the other eight drivers (four teams) were employed at Company 2.

Experimental Conditions

Background on Sleeper Berths and Seats

In commercial truck sleeper berths, the primary (lower) mattress is typically used by both team members as they take turns sleeping. Each team member may choose to swap the bedding and use their own pillow during each rest period (although bedding changes are less likely if a team is a married or a domestically partnered couple). Sleeper berths include a safety restraint system for the lower sleeping area that is required to be engaged when a driver sleeps in a moving truck. Sleeper berths may also possess an upper ‘‘bunk’’ that may be folded away when not in use. The upper bunk is narrower than the lower mattress, and may only be used when the truck is parked. Our conditions, and data collection and analyses, focused on each participant's use of the primary lower mattress while their partner was driving. Only the driver's seat was manipulated in the study, with no changes being made to the passenger seat.

Baseline Mattresses and Seats

Baseline mattresses were those being used by teams at the time of enrollment, and were typically what employers provided as standard practice (see below). Some teams augmented their baseline mattress with a foam pad on top. At both Company 1 and 2, teams were all using standard innerspring mattresses before they volunteered for the study.

At Company 1, baseline seats were industry standard air suspension seats (Captain Seat; National Seating, New Albany, OH). At Company 2, baseline truck seats were also industry standard air suspension seats (Isringhausen Elite 2.0 Model 5030/880; Isringhausen Inc., Ladson, SC). Both companies operated late model Freightliner Cascadia trucks, but Company 1 trucks had a shorter wheelbase than Company 2 trucks (5.30 vs 6.09 m). Company 1 also used super single tires on the rear axle instead of standard dual tires used at Company 2.

Condition A: New Standard Mattress (Control)

Control mattresses were newly purchased models of employers' standard innerspring style mattresses. At Company 1 teams received the Freightliner Innerspring Mattress (Model 302F/ABP N60C 388739 [17.8 × 99.1 × 203.2 cm], Freightliner, Portland, OR). At Company 2 teams received the Freightliner Quilted Innerspring Mattress (Model 22-75833-001 [15.2 × 99.1 × 200.7 cm], Freightliner, Portland, OR). If applicable, participants were asked not to use mattress accessories (ie, foam topper pads) during the test condition unless their sleep quality was adversely affected by the lack of accessories.

Condition B: Novel Therapeutic Mattress (Intervention)

The intervention mattress was a ThevoRelief Model 100 (for body weights up to 100 kg) or ThevoRelief Model 135 (for body weights 100–135 kg; 19.1 × 99.1 × 190.5 cm [foam mattress component is 10.9 cm thick], Thomashilfen, Bremervörde, Germany). The ThevoRelief mattress utilizes interlocking foam of varying densities to support different body regions, a unique wing suspension system, and a fabric envelope that zips closed to hold the components together.[44] As with Condition A, participants were asked not to use mattress accessories during the test condition unless their sleep quality was adversely affected by the lack of accessories.

Condition C: Preferred Mattress, Active Suspension Seat, & Behavioral Sleep-Health Program

The active suspension seat (Clear Motion, Woburn, MA) uses a built-in accelerometer to measure vehicle-induced vibrations, and then an on-board controller and linear electric motor actively counteracts and reduces the driver's vibration exposure. These seats have been shown to reduce WBV exposures by 45% relative to the industry standard air suspension seats.[42] The seat was installed by maintenance personnel at each respective company according to manufacturer instructions.

The behavioral sleep-health program, named Fit4Sleep for implementation, was adapted from the established SHIFT program for truck drivers.[51] Adaptations were guided by the effective prior intervention for individuals with insomnia reviewed in the introduction.[48] Some content was also adapted, with permission, from the North American Fatigue Management Program. The resulting Fit4Sleep program was a 13-week inter-team walking competition supported with goal setting, weekly self-monitoring (tracking) of walking minutes and sleep hygiene practices, computer based training, and health coaching every 2 weeks. In addition to the walking competition, drivers could also set an optional weight loss goal and complete optional training in healthy body weight management and diet. The program's m-health website (www.fit4sleep.net) hosted self-monitoring and training, and provided dynamic feedback, scores, and competition rankings. The team that met their weekly walking goal during the most weeks out of 13 won the competition and were awarded $100 each. Individuals could earn Fit4Sleep certification and $100 by logging 10/13 weeks, completing 4/6 health coaching calls, and completing 3/3 training topics. Competition and individual incentives were not mutually exclusive.

At the beginning of the program, each driver set an individual weekly walking goal of 50, 100, or 150 minutes. The team's weekly walking goal was a sum of team members' individual goals. Optional weight loss goals were 3, 5, and 10 lb (1.4, 2.3, and 4.5 kg). For each week of the program, drivers were asked to track their walking minutes and days per week they engaged in their self-selected behavioral sleep-health goals. Behavioral goal options included: 7 to 8 hours sleep, relaxing sleep routine, (all electronic) screens off 30 minutes before sleep, pleasant sleep environment (clean bedding, no light, noise control, 60–67 degrees Fahrenheit), avoid caffeine or energy drinks 4 hours before bed, avoid nicotine 2 hours before bed, avoid alcohol 4 hours before bed, and limit naps to 20–30 minutes. Drivers who set an optional weight loss goal could also track their weekly weight and success meeting selected behavioral weight management goals, including: reduce a high calorie habit, reduce portions, and eat more fruit and vegetable servings.

Three online training topics were implemented using cTRAIN (Northwest Education Training and Assessment, Lake Oswego, OR). These included the ‘‘Fit4Sleep Orientation,’’ which described how the program and competition would work, and was completed before goal setting; ‘‘Why Fit4Sleep?,’’ which addressed the sleep protective benefits of regular walking, and interactions between physical activity, sleep, and diet; and ‘‘Healthy Sleep,’’ which addressed sleep physiology, circadian rhythms, and sleep hygiene practices.

Health coaching protocols were adapted from those used in the SHIFT program and informed by motivational interviewing techniques.[60] The first call was approximately 45 minutes and sought to build rapport between the participant and coach. Subsequent calls were shorter (10–15 min) and focused on drivers self-directed goals for physical activity and sleep hygiene practices. Health coaching calls were delivered by an experienced female coach who is a member of the Motivational Interviewing Network of Trainers and the fifth listed author. The fifth listed author attended a motivational interviewing workshop and received one-on-one training and supervision from the more experienced coach.

Experimental Design

The ClearMotion Active Suspension Seat had been studied as a standalone intervention,[42,61] but the ThevoRelief mattress had not. Therefore, the current pilot study was designed to isolate mattress conditions first, and then evaluate all intervention components together. A planned randomized controlled trial (clinicaltrials.gov, NCT 03108599) will evaluate cab enhancements (seat and mattress) together, followed by a phase with the added behavioral intervention.

The current pilot study employed a within subjects repeated measures design to evaluate each condition. To protect against potential order effects on drivers' evaluations of mattresses, the order of Conditions A and B was counter-balanced across companies. To minimize drivers' potential reactivity to mattresses or bias in their evaluations, researchers referred to mattresses in the most neutral terms possible (ie, the first or second mattress), and avoided describing either as having any good, bad, or special characteristics. Mattresses were also both described as being newly purchased, and were each covered with a clean fitted sheet provided by researchers. The project was implemented in two waves. The first four teams (eight drivers) from Company 1 participated in mattress Conditions A and B in that order. The second four teams (eight drivers) from Company 2 completed mattress Conditions B and A in that order, and then Condition C (preferred mattress, active suspension seat, Fit4Sleep). Conditions A and B lasted for 2-to-3 weeks depending on driver schedules, and Condition C lasted for 3 months. Measures were collected at baseline and at each subsequent condition transition/end, with one extra accelerometer sample just before the end of Condition C (see "Measures" below). The data collection and implementation phases of the study began on September 11th, 2017, and concluded July 3rd, 2019.

Measures

Researchers met with teams at truck terminals at each time point to collect biometrics and a survey, and to initiate a subsequent 2-week accelerometer sampling period. During this period vibrations were measured with accelerometers installed in trucks, and drivers' sleep and physical activity were measured with wrist- and hip-worn accelerometers, respectively. To support sleep analyses drivers completed daily computer-based sleep diaries. Employers were also asked to provide electronic log book data to support and inform analyses of all accelerometer data (sleep, physical activity, and WBV). At each visit drivers were provided with feedback about their biometric assessments relative to normal and abnormal standards. In addition to data collected at each measurement time point (biometric, survey, and accelerometer), an extra accelerometer sample was collected during the last weeks of Condition C in order to generate objective sleep and physical activity measures at both the beginning and end of the behavioral program. In the results section, the first Condition C accelerometer sample is labeled C_1, and the second extra accelerometer sample is labeled C_2.

Intervention Process Measures

We asked drivers about whether they made modifications to mattresses (eg, use of a foam mattress top) and monitored delays or problems with the installation of a mattress or seat. Participation in the Fit4Sleep intervention was tracked by the intervention website, and included when and what drivers tracked, and data submitted with each tracking entry. Online training completion and test scores were recorded by the Northwest Education Training and Assessment website (Lake Oswego, OR). The occurrence and durations of coaching calls were recorded by coaches.

Whole Body Vibration Measures

We measured participants' WBV exposures on mattresses and seats to characterize exposures, and to assess whether intervention cab technologies were reducing or altering exposures. Four tri-axial accelerometers (AX3, Axivity Ltd., Newcastle, United Kingdom), which have been proven to have WBV measurement accuracy within 10% compared to gold standard systems, were affixed to the mattress top, bedframe, driver seat top, and truck floor. Devices collected raw vibration data continuously at 400 Hz for approximately 4 days. The mattress top accelerometer was attached with gaffer's tape underneath the team's reported location for placing their pillows. The bedframe accelerometer was taped to midpoint of the sidebar of the bedframe. The seat top device was taped into the bottom of a thin, circular, and moderately firm piece of foam, which then was placed and secured to the top of the seat with gaffer's tape centered under the anticipated region of the drivers' sacrum. The seat top accelerometer set up was then covered with a protective cloth seat cover. The floor accelerometer was magnetically mounted to the metal frame that secured the driver's seat to the floor of the truck cab. Concurrently, global positioning system (GPS) data were collected at 1 Hz utilizing a portable GPS unit (Model CR-Q1100P; Qstarz Co., Taipei, Taiwan).

Drivers' electronic log records were used to identify and select periods in the WBV data files where one of the team truck drivers was in the sleeper berth, and the other was driving the truck. For analysis, LabVIEW programs (Version 2016; National Instruments, Austin, TX) were used to align acceleration data with GPS data and combine them into one file for each team. Once the files were created, a LabVIEW program was used to apply weighting as described in ISO 2631-1[62] to the raw, unweighted acceleration data, and additional LabVIEW programs were used to calculate the predominant, Z-axis average weighted vibration exposures that were normalized to 8 hours, termed "A(8)." Additionally, power spectral density (PSD) analyses were conducted to further examine the truck mattress and truck floor vibrations in the frequency domain.[63] Mattress and floor PSDs were simultaneously obtained and calculated from a 60 second segment during each known sleep period for each team driver when the truck was moving. Determining truck movement was based on the magnitude and variation in the floor vibration signal. When trucks were not moving, variation in the floor vibration was absent. These samples were then used to compare the WBV exposures at different frequency contents across all conditions.

Data were analyzed further to compare and contrast mattress types using JMP Statistical Discovery Software (Version 13; SAS Institute; Cary, NC). Means and standard deviations were calculated for A(8) exposure parameters at each measurement location. The mean for A(8) exposure were compared to the ISO 2631-1 daily vibration action limits to determine if there was a difference between the exposures experienced in our study and the recommended standard exposure limits.

Primary Outcome Measures

Primary outcome measures were within-person changes in sleep duration and quality, and fatigue. Self-reported measures included sleep duration and quality using items four and six from the Pittsburg Sleep Quality Index[64]; sleep-related impairment[65,66]; and fatigue.[67] In a preface to the self-report survey, drivers were asked to reflect on the past month or most recent test period when responding. Accelerometer-based measures of sleep duration and sleep efficiency were collected with a wrist-worn Actigraph wGT3X-BT (ActiGraph, Pensacola, FL). This device was selected based on preliminary studies indicating that Actigraph's native band pass filter, which down-weights frequencies outside of the typical human spectrum, produced data that were less affected by truck vibrations than other device options. Participants were asked to wear devices for 2 weeks except for when they were going to get wet (ie, swimming, or bathing). During the same actigraphic sampling period, drivers completed a daily sleep diary using either a tablet with a docked keyboard (ASUS Transformer 10.1" Notebook, Beitou District, Taipei, Taiwan), or a PC laptop (Model 3490, Dell, Round Rock, TX; or ThinkPad Edge E420 or E430, Lenovo, Beijing, China). The sleep diary survey was a LabVIEW application adapted for the study from the second author's prior projects.

A study-specific scoring protocol was created to prepare sleep actigraphy data for analysis. Scoring involved a multi-step process that utilized time-aligned data from driver log books, sleep diaries, actigraph on/off wrist sensors, and Actilife (version 6.13.3) autoscored sleep or wake classifications for each 60 second epoch. Prior to data visualization and scoring, Actilife's "Wear Time Validation" tab was used to consolidate brief <5-minute wear/non-wear intervals with adjacent longer duration intervals using a protocol created for the study. This was done because loosely worn Actigraph wGT3X-BT devices can generate many intermittent brief periods of "false" non-wear time. R-studio (version 1.2.5033) was used to produce multi-stream data visualizations, which scorers viewed at a 1 to 2 hours scale to inspect and apply scoring rules to set the start and stop of each "driver day," and each "rest interval." A driver day was defined as a work day (on duty period plus the subsequent sleeper berth opportunity) or an off duty day (≥6 h period of wakefulness plus the subsequent home sleep opportunity). The start and end of rest intervals during work periods were set within sleeper berth opportunities, and were also informed by sleep diary data when also available. Rest interval onset was defined as the beginning of an occurrence of ≥10 consecutive Actilife-scored sleep epochs, with the requirement that there were ≥6 epochs of Actilife-scored sleep epochs in the subsequent 10 minutes. Similarly, rest interval offset was defined as the beginning of ≥10 continuous wake epochs, followed by ≥6 wake epochs in the subsequent 10 minutes. Rest intervals were labeled valid for analysis if actigraph wear time was ≥80% of the rest interval. We selected this criterion for valid rest intervals because even after consolidating on/off wrist periods in records, it appeared that loosely worn devices generated meaningful amounts of intermittent "false" off wrist time (the person's data appeared active, yet the device recorded intermittent off wrist periods). For participants with wear time data of particularly poor quality, potentially due to very loosely worn devices or a malfunctioning sensor, rest intervals were labeled valid for analysis if activity patterns in the data indicated that the device was being worn and the identified rest and wake intervals were aligned with other data sources (notable transitions between driving and sleeper berth periods, and sleep/wake epochs; a <14 h sleeper berth period; and alignment [±2 h] with a sleep diary indicated rest interval). Each valid rest interval was then coded as a "nap" or "main sleep" period. Naps were defined as a rest interval with a minimum duration of 16 minutes, and a maximum duration of 90 minutes (duration of a typical ultradian cycle of sleep stages). However, an additional type of nap was allowed to be up to 3 hours long, if it was surrounded by on duty work time. All other valid rest intervals were coded as main sleep periods. If ≥90 continuous epochs of wake occurred after the onset of a main sleep period (a very long period of wakefulness during a sleep opportunity), multiple rest intervals were created for that sleep opportunity and coded as main sleep 1, 2, or 3.

All actigraphic sleep data samples were evaluated by two primary raters (fifth and ninth listed authors). Approximately 10% of valid driver sleep actigraphy days were scored by both raters to assess inter-rater agreement for the scoring decisions described above (eg, rest interval start and end times, rest interval type). For some variables an absolute match was required to be assessed as an agreement (eg, type of rest interval [nap or main sleep]). For other variables an agreement was defined as scored times being in close proximity (eg, ±16 min for start or end of main rest intervals, and ±5 min for start or end of nap rest intervals). Interrater agreement (agreements/agreements + disagreements) across all decisions was 81%.

Secondary Outcomes

Secondary measures included biometrics, sleep hygiene, musculoskeletal symptoms, well-being, diet, and exercise. Biometrics included height (Part #: 2131821009, Portable Stadiometer Measuring Rod, Seca North America, Chino, CA); weight, body mass index, and percent body fat (TBF-310GS total body composition analyzer, Tanita, Arlington Heights, IL); and resting blood pressure (average of three measurements, Intellisense Digital Blood Pressure Monitor HEM-907XL, Omron Healthcare Inc., Bannockburn, Illinois). Sleep hygiene was assessed with the Sleep Hygiene Index.[68] Musculoskeletal pain was assessed by asking participants to rate their pain in "the past month" (1 = no pain, 10 = worst pain you can imagine) for the low back, shoulder(s), wrist(s)/forearm(s), knee(s), neck, ankle(s)/feet, and leg pain/sciatica. Well-being was assessed using the mental and physical health subscales of the Patient-Reported Outcomes Measurement Information System (PROMIS).[69] To evaluate the benefits of the Fit4Sleep program in Condition C, healthy lifestyle behaviors were included in secondary outcomes. Dietary habits were measured with daily consumption of fruit and vegetable servings[70]; and frequency of consumption of sugary drinks, snacks, and fast food.[71] Self-reported physical activity was measured with the Healthy Physical Activity scale.[72]

Objective physical activity was measured with a hip-worn Actigraph wGT3X-BT or GT3X+ (Actigraph LLC, Pensacola, FL) during the 2-week accelerometer sampling periods. Physical activity analyses focused on Freedson bouts,[73] which are moderate-to-vigorous intensity physical activity bouts of 10 minutes or greater. For these hip-worn devices where the on/off wrist sensor is not applicable, prior to analysis, we used Actilife's Wear Time Validation tab to include all non-wear intervals of <120 continuous minutes in analyses, and to exclude all continuous non-wear intervals of ≥120 minutes. Days with excessive non-wear time (>240 min) were to be labeled invalid and excluded from analyses. Bout analyses are a conservative measure of physical activity but were selected due to vibrations of trucks potentially generating false physical activity. In preliminary research with solo truck drivers, we found that truck vibrations never created false 10-minute Freedson bouts during driving times as recorded in log books.

RESULTS

In our general approach to analyses, we included data from the full sample ($n = 16$) for contrasts focused on mattress conditions at baseline (Pre), A, and B. Analyses where Conditions A, B, and C were contrasted included only data from drivers at Company 2 because they were the participants exposed to all three conditions. Analyses of sample characteristics, intervention processes, and WBV were summarized with descriptive statistics and figures. Analyses of intervention effects were summarized with mean changes across conditions and standardized effect sizes (Cohen's *d*). Effect sizes close to 0.20 ($d \geq 0.17$) and larger were emphasized in our descriptive analyses of intervention effects. Effect sizes 0.16 and smaller were thus used as a cut off to refer to relatively stable or null effects. These thresholds were selected based on Cohen's categorization of 0.20 as a "small" effect size.[74]

Sample Characteristics

Table 1 provides a detailed summary of participant demographics and work backgrounds. The sample was predominantly male ($n = 13$), Caucasian ($n = 14$), and averaged 48.00 years of age (SD = 10.26). The proportions of the sample with high school, or high school plus some college education, were 31.25% and 56.25%, respectively. Most participants were married/partnered ($n = 15$). Participants' trucking industry experience averaged 3.57 years (SD = 4.14) and team driving experience averaged 2.61 years (SD = 2.13). Individual weekly driving and work time averaged 54.56 hours (SD = 8.56) and 61.38 hours (SD = 17.36), respectively. A meaningful proportion of drivers scored as ''high risk'' for obstructive sleep apnea (31.25%) based on the Berlin Questionnaire,[75] and an equal proportion reported having high blood pressure (31.25%). Company 1 and 2 driver demographics were highly similar except in two areas. Some Company 1 drivers reported having dependent kids at home ($n = 3$), while Company 2 drivers reported no dependent kids at home. Also, most Company 1 drivers ($n = 6$) reported having a company-assigned driving partner, while all Company 2 drivers ($n = 8$) reported self-selecting their driving partner.

TABLE 1. Tech4Rest Pilot Study: Truck Driver Demographics ($n = 16$)

Variable	Company 1 ($n = 8$) Mean (SD) or N (%)	Company 2 ($n = 8$) Mean (SD) or N (%)	Total Sample ($n = 16$) Mean (SD) or N (%)
Age (yr)	50.75 (10.83)	42.25 (9.53)	48.00 (10.26)
Sex (% Female)	1 (12.50%)	2 (25.00%)	3 (18.8%)
Race			
American Indian/Alaskan Native	0 (0.00%)	0 (0.00%)	0 (0.00%)
Asian	0 (0.00%)	0 (0.00%)	0 (0.00%)
Native Hawaiian/Pacific Islander	0 (0.00%)	0 (0.00%)	0 (0.00%)
Black/African American	0 (0.00%)	0 (0.00%)	0 (0.00%)
White	6 (75.00%)	8 (100.00%)	14 (87.50%)
>1 race	0 (0.00%)	0 (0.00%)	0 (0.00%)
Other	2 (25.00%)	0 (0.00%)	2 (12.50%)
Ethnicity (% Hispanic)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Household			
Married or Living with Partner	7 (87.50%)	7 (87.50%)	14 (87.50%)
Dependent Children ≥1	3 (37.50%)	0 (0.00%)	3 (18.75%)
Relationship with Driving Partner			
Company Assigned	5 (62.50%)	0 (0.00%)	5 (31.25%)
Spouse	2 (25.00%)	4 (50.00%)	6 (37.50%)
Boyfriend, Girlfriend	0 (0.00%)	4 (50.00%)	4 (25.00%)
Other	1 (12.50%)	0 (0.00%)	1 (6.25%)
Education			
Some High School	0 (0.00%)	1 (12.50%)	1 (6.25%)
High-school diploma or GED	2 (25.00%)	3 (37.50%)	5 (31.25%)
Some College or Technical School (no degree)	5 (62.50%)	4 (50.00%)	9 (56.25%)
Bachelor's degree	0 (0.00%)	0 (0.00%)	0 (0.00%)
Graduate degree	1 (12.50%)	0 (0.00%)	1 (6.25%)
Work Hours/Miles			
Total Weekly Driving Hours	49.38 (8.63)	59.75 (4.79)	54.56 (8.56)
Total Weekly On-duty Hours	53.12 (19.81)	69.62 (9.90)	61.38 (17.36)
Total Weekly Driving Miles	3362.50 (1452.03)	2662.50 (338.85)	3012.50 (1080.82)
Tenure (years)			
Tenure industry	5.78 (4.96)	1.35 (0.95)	3.57 (4.14)
Tenure current company	3.85 (2.15)	1.23 (0.85)	2.54 (2.08)
Tenure as team truck driver	4.01 (2.15)	1.21 (0.78)	2.61 (2.13)
Tenure with driving partner	1.47 (0.66)	1.21 (0.78)	1.34 (0.71)
Health Conditions			
Current Smoker	0 (0.00%)	3 (37.50%)	3 (18.75%)
Average use per day (users only)	–	15.00 (8.66)	15.00 (8.66)
Alcohol Use[a]	0.63 (1.06)	0.88 (0.99)	0.75 (1.00)
High blood pressure	4 (50.00%)	1 (12.50%)	5 (31.25%)
High Blood Pressure Medication[b]	3 (75.00%)	0 (0.00%)	3 (60.00%)
Heart Disease	0 (0.00%)	0 (0.00%)	0 (0.00%)
Heart Disease Medication[b]	–	–	–
High Cholesterol	3 (37.50%)	0 (0.00%)	3 (18.75%)
High Cholesterol Medication[b]	2 (66.67%)	–	2 (66.67%)
Diabetes	1 (12.50%)	0 (0.00%)	1 (6.25%)
Diabetes Medication[b]	1 (100.00%)	–	1 (100.00%)
Obstructive Sleep Apnea Risk[c]	3 (37.50%)	2 (25.00%)	5 (31.25%)

[a]Values are average number of drinks in the past month on a scale from 0 (None) to 8 (6 or more per day).

[b]Percentages were calculated as the ratio of individuals currently taking medication to total number of participants that reported being diagnosed with the health conditions, respectively.

[c]Percentages reflect proportion of individuals scored as ''high risk'' for obstructive sleep apnea based on the Berlin Questionnaire,[75] which includes summary scores on two separate categories of the scale, as well as if they reported high blood pressure or a BMI over 30kg/m^2.

Intervention Process Results

All ($n = 16$) participants completed both mattress evaluation Conditions A and B without asking for any mattresses to be removed, although one team reported modifying Condition A with a foam mattress pad on top. Exposure to mattress conditions went as planned with the exception of one team at Company 1, who inadvertently received the ThevoRelief model 135 even though their body weights were 80.51 and 97.07 kg. Driver ratings of mattress characteristics and comfort were nearly twice as high for mattress B relative to mattress A in all categories (see Fig. 1). All ($n = 16$) participants chose to keep mattress B. Thus, mattress B was used by the relevant subsample of participants ($n = 8$) during Condition C.

During Condition C the installation of active suspension seats included one exception. One team's seat installation was delayed by about 2 weeks because the mechanic initially had issues with the alignment of the seat top and seat base. A second installation attempt was successful. One team ($n = 2$) in Company 2 terminated their employment 1 month before completion of Condition C. This team completed the final self-report and health assessment measurements at C_2, but did not provide C_2 actigraphy or WBV accelerometer data. Their available self-report and health data were included in analyses.

During the Fit4Sleep program in Condition C, all participants ($n = 8$) completed their first coaching call, and on average, drivers completed 2.25 (SD = 1.28) of the 6 planned calls. Six of the eight drivers regularly used the Fit4Sleep website to set behavioral health goals, track their behaviors, view their progress, as well as the progress of the other teams, and complete their training; two of the drivers did not use the website and instead tracked their behavior using paper workbooks. Drivers completed weekly behavior tracking an average of 8.13 (SD = 3.76) times out of 13 opportunities. Based on website and paper-based tracking data, drivers' tracking was almost exclusively focused on monitoring and reporting weekly walking minutes. No drivers set or tracked sleep hygiene behavioral goals. However, coaches reported that sleep hygiene was a consistent topic in health coaching calls. On the website drivers self-reported an average of 156.01 (SD = 84.63) walking minutes per week, exceeding the recommended standard of 150 minutes per week for health benefits.[76] On average, those who tracked their weekly walking goal on the website reported meeting their goal 91.67% (SD = 12.91) of the time. On average, individuals completed 1.25 (SD = 0.71) out of 3 required training topics. However, this average likely underestimated training exposure because a technical issue with a video in the third training topic prevented drivers from completely finishing it. For the two training topics with available pre- and post-test data, average percent correct scores were 61.92% (SD = 24.22) on the pre-tests and 93.75% (SD = 14.72) on the post-tests. Three of the eight drivers chose to set an optional weight loss goal, and one of those drivers set additional optional dietary goals (eg, reduce portions, reduce a high calorie habit, and eat more fruits and vegetables). Two of the three drivers with a weight loss goal tracked their weight and averaged 9.50 (SD = 2.12) submissions. At the end of Condition C one of these drivers had lost 3.63 kg (8.00 lb), and the other lost 4.30 kg (9.48 lb). Due to the technical issue with the training, the individual certification criteria for training was reduced to two out of three topics completed. The health coaching requirement was also adjusted for one team who reported being unclear on the expectation to complete four out of six possible calls. With these adjusted requirements, four of the eight teams in the behavioral program were awarded individual certification.

Whole Body Vibration Results

Z-axis A(8) data from the mattress tops were compared between the two mattress types, which included the measures from both companies. The average A(8) for the innerspring mattress was 0.35 m/s^2 (SD = 0.12), and a slightly higher exposure level (0.40 m/s^2, SD = 0.14) was measured from the novel therapeutic mattress ($d = 0.36$). The WBV exposures from both types of mattresses and the air suspension seats in the trucks were below the daily vibration action limit of 0.5 m/s^2. Relative to z-axis A(8) exposures measured from the air suspension seats at Company 2 during Conditions A and B (0.28 m/s^2, SD = 0.03), the active suspension seat lowered (0.20 m/s^2, SD = 0.04) the WBV exposures ($d = -2.43$).

In addition, to further investigate the WBV exposures as a function of frequency, the median PSDs from the truck floor and

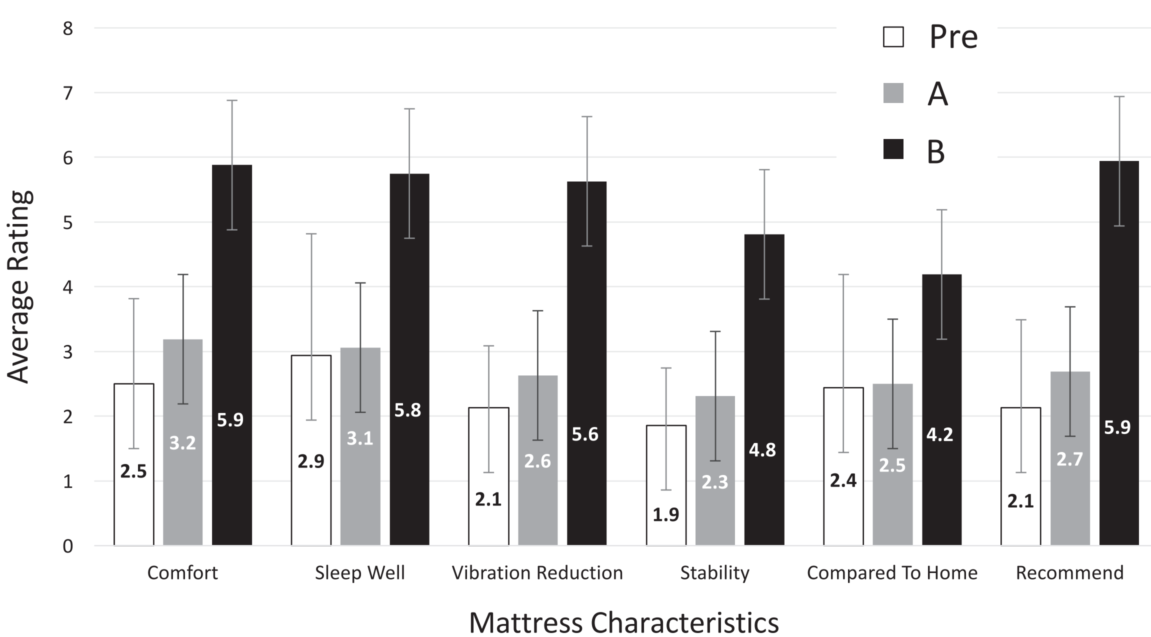

FIGURE 1. Team drivers' ratings of mattress characteristics and comfort.

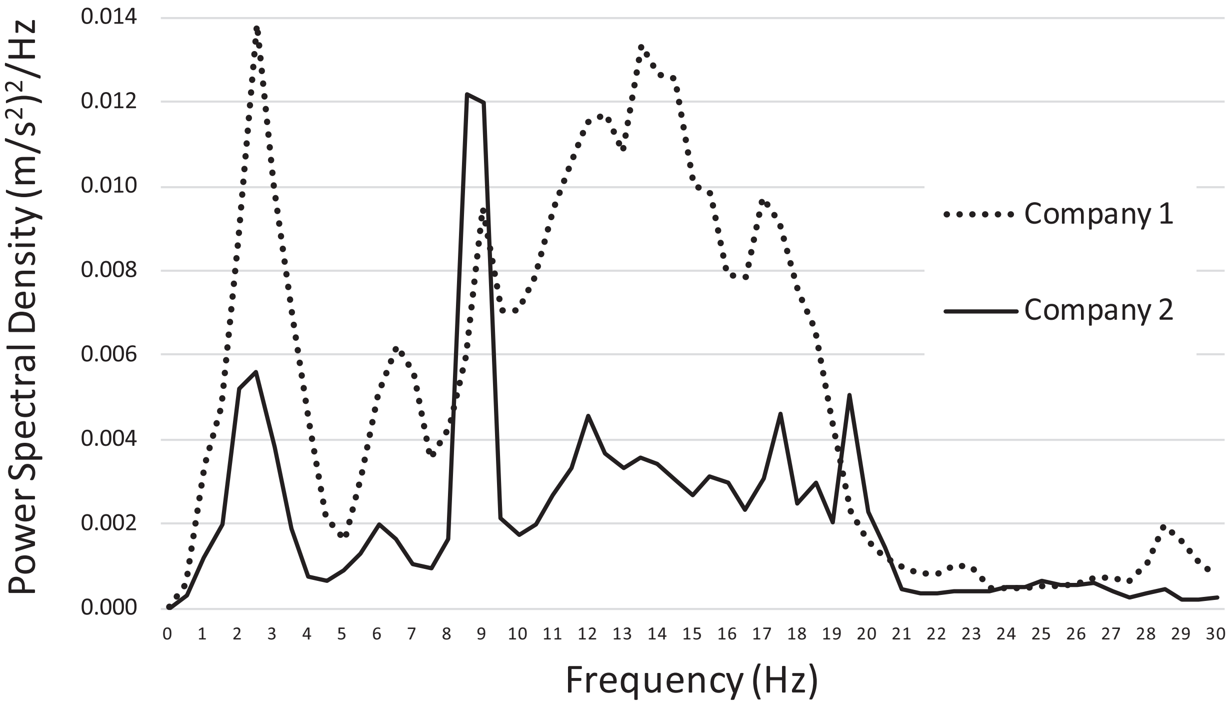

FIGURE 2. Floor median Z axis whole body vibration power spectral density: Companies 1 and 2.

mattress top were compared between companies and mattress conditions. Figure 2 shows that the low frequency peaks in the floor PSDs were centered around 2 Hz and similar between the two companies. However, there were differences between companies in the higher frequency floor PSD peaks, which were centered around 14 Hz for Company 1, and 9 Hz for Company 2. As shown in Fig. 3, the PSDs for the mattresses were company dependent with Company 1 having higher PSDs compared to Company 2. With Company 1, the mattress in Condition A had more higher frequency vibration energy (8–20 Hz) compared to the mattress in Condition B; whereas, with Company 2, the mattress in Condition A had more lower frequency vibration energy (1–4 Hz) than the mattress in Condition B.

Intervention Effects

Mattress Conditions A and B Results

Changes in self-reported primary outcomes for sleep duration, quality, and fatigue all changed in expected directions with mattress A resulting in better driver outcomes than drivers' original (Pre) mattress, and mattress B resulting in better outcomes than both other mattresses (Pre and A). Effect sizes (Cohen's *d*) for mattress Condition B relative to the Pre condition ranged from 0.19 to 0.82 in absolute magnitude (see Table 2 for a summary of self-reported Primary and Secondary Outcomes for mattress conditions). Actigraphically measured total sleep time on work days for mattresses A and B was 7.89 hours (SD = 0.98) and 8.25 hours (SD = 1.27) per driver day, respectively. Actigraphically measured sleep efficiency was stable. See Table 3 for actigraphic sleep results for mattress conditions.

For participants who had a sleep actigraphy sample from every condition ($n = 15$), 24.64 hours (SD = 1.23) was the average duration of a driver day. At Company 1 ($n = 7$) the average number of measured days was 16.00 (SD = 3.32), and at Company 2 ($n = 8$) the average number of measured days was 35.88 (SD = 9.39). All ($n = 15$) drivers had at least one nap. At Company 1 ($n = 7$) an average of 7.00 (SD = 2.71) driver days had naps (on average, individual participants had naps on 42.56% [SD = 10.55] of their measured days), whereas at Company 2 ($n = 8$) an average of 8.50 (SD = 4.75) driver days had naps (on average, individual participants had naps on 25.58% [SD = 13.54] of their measured days). Across all drivers, the average duration of a nap was 0.94 hours (SD = 0.19). Fourteen of the fifteen drivers had at least 1 day with more than one main sleep period that were split by 90 minutes or more wake time. At Company 1 ($n = 7$) drivers exhibited split sleep on an average of 2.57 (SD = 2.70) driver days (on average, individual drivers had split sleep on 16.98% [SD = 17.77] of their measured days), while at Company 2 ($n = 8$) drivers exhibited split sleep on an average of 6.50 (SD = 4.07) driver days (on average, individual drivers had split sleep on 19.51% [SD = 13.03] of their measured days). The average duration of time between main sleep periods was 3.18 hours (SD = 0.94) across all ($n = 15$) participants (Company 1 = 3.51 [SD = 0.99]; Company 2 = 2.93 [SD = 0.88]).

Among secondary outcomes, ratings of global health, measured body weight, systolic blood pressure, and most musculoskeletal symptoms were relatively stable across Conditions A and B relative to the Pre condition. However small to moderate effect sizes in desirable directions were observed with mattress B relative to the Pre condition for systolic blood pressure ($d = -0.19$), low back pain ($d = -0.28$), shoulder pain ($d = -0.43$), and pain in the ankles/feet ($d = -0.25$). Small unexpected increases in musculoskeletal pain were observed for the forearm/wrist region ($d = 0.19$) and leg pain or sciatica ($d = 0.18$) during Condition B relative to Pre. During mattress Condition A drivers showed an unexpected increase in systolic blood pressure relative to the Pre condition ($d = 0.31$). Condition A also produced a moderate reduction in shoulder pain relative to the Pre condition ($d = -0.47$).

Condition C Results (Therapeutic Mattress + Active Suspension Seat + Fit4Sleep Program)

Results for Company 2 drivers across Conditions A, B, and C are summarized in Tables 4 and 5. Conditions A and B results in this sub-sample were very similar to what was observed in the full

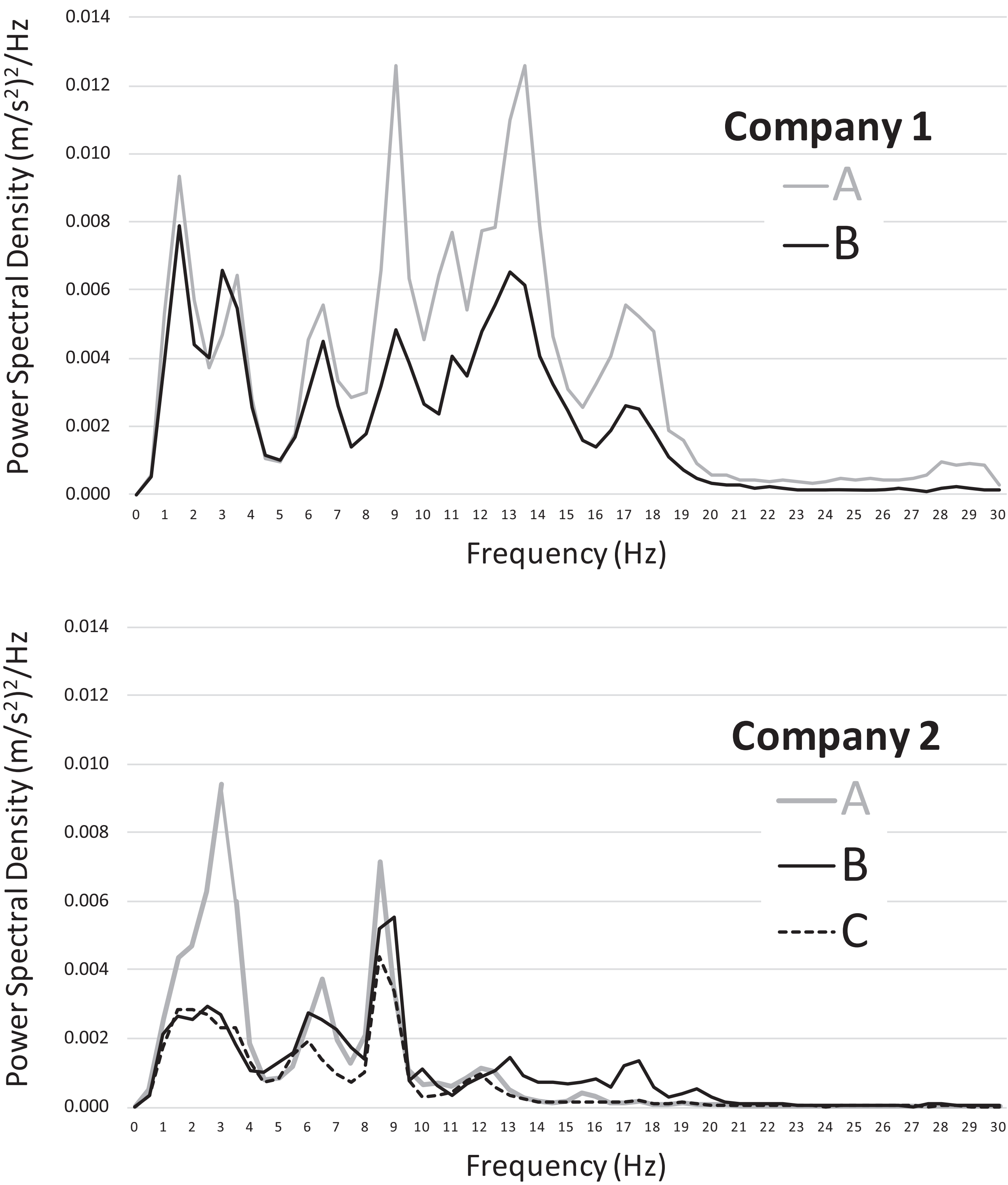

FIGURE 3. Mattress top median Z axis whole body vibration power spectral density: Companies 1 and 2. A = Condition A, B = Condition B, and C = Condition C. Conditions B and C both involved the therapeutic mattress.

sample. On the whole, Condition C created further improvements in self-reported sleep and fatigue outcomes, with moderate-to-large effect sizes in expected directions ranging from 0.37 to 1.49 in magnitude. While actigraphic sleep results showed the same improvement trend in total sleep time across Conditions A and B, both condition C_1 and C_2 actigraphic measurements showed reduced total sleep time relative to Condition A. On the whole, average sleep efficiency was highest in Conditions A and C_2, and varied between 0.84 and 0.87 (ie, average proportion of time in each rest interval scored as sleep).

Condition C included an expanded range of secondary outcomes due to the targets of the Fit4Sleep program, which included

TABLE 2. Tech4Rest Pilot Study: Self-Report and Biometric Outcomes for Mattress Conditions ($n = 16$)

	Condition Means (SD)			Mean Differences and Effect Sizes			
	Pre	A	B	A-Pre		B-Pre	
Outcomes	**M (SD)**	**M (SD)**	**M (SD)**	**MD**	***d***	**MD**	***d***
Primary Outcomes							
Sleep and Fatigue							
Sleep duration (hours)[a]	6.30 (1.15)	6.37 (1.49)	6.60 (1.71)	0.07	0.05	0.30	0.19
Sleep quality (0-3)[b]	1.62 (0.62)	1.25 (0.58)	1.19 (0.40)	−0.37	−0.63	−0.43	−0.82
Sleep related impairment (8–40)	17.82 (7.26)	16.81 (5.97)	14.69 (5.74)	−1.01	−0.15	−3.13	−0.45
Fatigue (0–48)	8.31 (7.44)	6.94 (5.53)	6.12 (6.68)	−1.37	−0.21	−2.19	−0.31
Secondary Outcomes							
Global health (9–50)	38.75 (5.56)	38.69 (4.09)	38.62 (5.15)	−0.06	−0.01	−0.13	−0.02
Sleep Hygiene Index (0–48)[b,c]	18.25 (5.26)	18.88 (4.96)	16.38 (4.60)	−0.37	−0.07	−1.87	−0.38
Biometrics							
Body weight (lb)	198.47 (42.47)	199.69 (42.76)	197.72 (41.79)	1.22	0.03	−0.75	−0.02
Body Mass Index (kg/m^2)	30.32 (5.72)	30.34 (5.89)	30.29 (5.69)	0.02	0.00	−0.03	−0.01
Diastolic BP (mmHg)	74.81 (11.96)	76.44 (11.84)	74.69 (10.98)	1.63	0.14	−0.12	−0.01
Systolic BP (mmHg)	119.25 (13.35)	123.12 (11.73)	116.44 (15.42)	3.87	0.31	−2.81	−0.19
Musculoskeletal Pain (0–10)							
Neck	2.94 (2.89)	2.62 (2.68)	2.88 (2.25)	−0.32	−0.11	−0.06	−0.02
Shoulder(s)[a]	3.60 (2.20)	2.53 (2.33)	2.60 (2.44)	−1.07	−0.47	−1.00	−0.43
Wrist(s)/Forearm(s)	0.94 (1.81)	1.06 (1.77)	1.31 (2.12)	0.12	0.07	0.37	0.19
Low Back	3.25 (2.65)	2.88 (2.94)	2.50 (2.71)	−0.37	−0.13	−0.75	−0.28
Leg pain or Sciatica	1.94 (2.74)	2.25 (2.98)	2.44 (2.76)	0.31	0.11	0.50	0.18
Knee(s)	1.69 (2.24)	1.75 (2.52)	1.62 (2.45)	0.06	0.03	−0.07	−0.03
Ankle(s)/Feet	0.56 (1.26)	0.50 (0.82)	0.31 (0.60)	−0.06	−0.06	−0.25	−0.25

Pre=baseline ; A=new coil spring mattress; B=novel therapeutic mattress. MD=mean difference. *d*=Cohen's *d*. BP=blood pressure. Self-reported sleep outcomes were asked relative to participant experiences in the truck sleeper berth. Sleep duration and sleep quality were items four and six, respectively, from the Pittsburgh Sleep Quality Index.[64] Sleep related impairment was calculated from the PROMIS Sleep Related Impairment scale.[65,66] Fatigue was calculated from the Swedish Occupational Fatigue Inventory.[67] Global health was calculated from the PROMIS Physical and Mental Health scale.[69]

[a]Only 15 participants had legible survey data for this measure at baseline, so one participant's data were excluded from all mean calculations, and mean difference tests.

[b]Lower scores and negative MD and *d* values reflect better outcomes and improvement for these sleep-related outcomes. For remaining outcomes directional changes are more intuitive, where changes represent more or less of a construct or measured outcome.

[c]Due to a potential confound from the experimental mattress condition with an item from the Sleep Hygiene Index[68] ("I slept on an uncomfortable mattress"), results were computed after omitting this item.

physical activity and diet variables. The addition of the active suspension seat and behavioral program to the therapeutic mattress resulted in improvements in self-reported global health ($d = 0.27$) and physical activity ($d = 1.49$). Actigraphic measures of 10+ minute physical activity bouts during the first 3 weeks of the Fit4Sleep program (C_1) showed large increases relative to Condition A for the number of bouts per week ($d = 1.07$), mean bout duration ($d = 0.68$), and total weekly time in bouts ($d = 1.16$). Total weekly time in actigraphically measured physical activity bouts was at its highest in C_1, averaging about 20 minutes per week. Physical activity bout effect sizes reduced, but were still present, during the last 3 weeks of the program (C_2). Self-reported weekly moderate intensity exercise during Condition C averaged about 72 minutes (reported mean of 2.4 days per week with 30 minutes of moderate physical activity), and represented a large increase over the Pre condition levels ($d = 1.83$). Also relative to the Pre condition, large reductions in consumption of sugary drinks, snacks, and fast food meals were observed for Condition C (*d* range, −0.75 to −1.30), but during the same condition, an unexpected decrease in reported daily fruit and vegetable consumption ($d = -0.60$) was also observed. In Condition C compared to the Pre condition, musculoskeletal pain was reduced in the low back ($d = -0.20$), shoulders ($d = -0.53$),

TABLE 3. Tech4Rest Pilot Study: Objective Sleep Actigraphy Outcomes for Mattress Conditions ($n = 15$)

	Condition Means (SD)		Mean Differences and Effect Sizes	
	A	B	B-A	
Primary Outcomes	**M (SD)**	**M (SD)**	**MD**	***d***
Sleep (Actigraphy)				
Total sleep time per driver day (hours)	7.89 (0.98)	8.25 (1.27)	0.36	0.31
Sleep efficiency (proportion)	0.84 (0.05)	0.83 (0.05)	0.00	0.04

Only 15 participants had usable actigraphy data for relevant conditions. Actigraphy had no "Pre" condition. A=new coil spring mattress; B=novel therapeutic mattress. MD=mean difference. *d*=Cohen's *d*. Total sleep time per driver day included naps and all main sleep periods. Sleep efficiency was calculated for main sleep periods excluding naps as the average proportion of a total rest interval for which actigraphic data indicated that the participant was actually sleeping.

TABLE 4. Tech4Rest Pilot Study: Self-Reported and Biometric Outcomes Across All Study Conditions at Company 2 ($n = 8$)

	Condition Means (SD)				Mean Differences and Effect Sizes					
	Pre	A	B	C	A-Pre		B-Pre		C-Pre	
Outcomes	M (SD)	M (SD)	M (SD)	M (SD)	MD	*d*	MD	*d*	MD	*d*
Primary Outcomes										
Sleep and Fatigue										
Sleep duration (hours)	6.12 (0.99)	6.44 (1.95)	6.12 (2.01)	6.69 (1.81)	0.32	0.18	0.00	0.00	0.57	0.37
Sleep quality (0–3)[a]	2.00 (0.53)	1.50 (0.53)	1.38 (0.52)	1.12 (0.64)	−0.50	−0.94	−0.62	−1.19	−0.87	−1.49
Sleep-related impair (8–40)	20.89 (8.89)	18.62 (6.82)	17.62 (6.30)	13.88 (5.87)	−2.27	−0.25	−3.27	−0.39	−7.01	−0.93
Fatigue (0–48)	11.25 (8.53)	6.75 (6.02)	5.38 (5.50)	6.75 (7.09)	−4.50	−0.60	−5.87	−0.73	−4.50	−0.56
Secondary Outcomes										
Global Health (9–50)	38.75 (5.50)	39.38 (3.38)	39.25 (3.88)	40.12 (3.94)	0.63	0.13	0.50	0.09	1.37	0.27
Sleep Hygiene Index (0–48)[a,b]	19.63 (3.89)	20.63 (3.50)	18.00 (4.57)	17.50 (4.24)	1.00	0.27	−1.63	−0.38	−2.13	−0.52
Physical Activity and Diet										
Physical activity (0–7 days)	0.31 (0.46)	0.78 (0.91)	0.53 (0.77)	2.42 (1.69)	0.47	0.55	0.22	0.27	2.11	1.83
Fruit/veg (servings per day)	5.25 (4.77)	3.00 (3.30)	2.50 (3.46)	3.12 (1.55)	−2.25	−0.53	−2.75	−0.66	−2.13	−0.60
Sugary drinks (0–10)	6.00 (2.39)	5.38 (1.77)	4.50 (1.85)	4.12 (2.30)	−0.62	−0.30	−1.50	−0.70	−1.88	−0.80
Sugary snacks (0–10)	4.88 (2.23)	5.12 (2.10)	3.88 (1.73)	3.25 (2.12)	0.24	0.12	−1.00	−0.49	−1.63	−0.75
Fast food (0–10)	3.62 (0.52)	2.25 (1.91)	2.12 (1.55)	1.88 (1.55)	−1.37	−0.91	−1.50	−1.02	−1.76	−1.30
Meals from home (0–10)	5.63 (2.20)	5.25 (3.37)	5.75 (2.82)	4.88 (3.52)	−0.38	−0.13	0.12	0.05	−0.75	−0.26
Biometrics										
Body weight (lb)	182.62 (31.32)	184.88 (32.74)	181.75 (32.38)	179.32 (32.96)	2.26	0.06	−0.87	−0.03	−3.30	−0.10
Body Mass Index (kg/m^2)	28.19 (4.96)	28.54 (5.23)	28.16 (5.21)	28.56 (5.19)	0.35	0.06	−0.03	0.00	0.37	0.07
Diastolic BP (mmHg)	75.25 (12.16)	76.25 (9.22)	72.38 (10.46)	75.50 (10.64)	1.00	0.09	−2.87	−0.25	0.25	0.02
Systolic BP (mmHg)	118.25 (10.86)	118.25 (8.51)	110.50 (16.49)	117.00 (11.84)	0.00	0.00	−7.75	−0.56	−1.25	−0.11
Musculoskeletal Pain (0–10)										
Neck	3.88 (3.00)	3.25 (2.87)	3.38 (2.20)	2.38 (2.45)	−0.63	−0.21	−0.50	−0.18	−1.50	−0.54
Shoulder(s)	5.00 (1.69)	3.00 (2.51)	3.62 (2.50)	3.62 (2.88)	−2.00	−0.92	−1.38	−0.62	−1.38	−0.53
Wrist(s)/Forearm(s)	1.50 (2.27)	1.50 (2.33)	2.00 (2.33)	1.62 (2.56)	0.00	0.00	0.50	0.22	0.12	0.05
Low back	4.25 (2.82)	4.25 (2.82)	3.75 (2.55)	3.75 (2.19)	0.00	0.00	−0.50	−0.19	−0.50	−0.20
Leg pain or Sciatica	3.12 (3.40)	4.12 (3.27)	3.50 (2.88)	3.38 (3.46)	1.00	0.30	0.38	0.12	0.26	0.07
Knee(s)	1.50 (2.14)	1.38 (2.50)	1.75 (2.76)	2.75 (2.43)	−0.12	−0.05	0.25	0.09	1.25	0.54
Ankle(s)/Feet	0.50 (1.41)	0.38 (0.74)	0.38 (0.74)	0.75 (1.16)	−0.12	−0.11	−0.12	−0.11	0.25	0.19

Pre=baseline; A=new coil spring mattress; B=novel therapeutic mattress. C=therapeutic mattress + active suspension seat + Fit4Sleep program. MD=mean difference. *d*=Cohen's *d*. BP=blood pressure. Self-reported sleep outcomes were asked relative to participant experiences in the truck sleeper berth. Sleep duration and sleep quality were items 4 and 5, respectively, from the Pittsburgh Sleep Quality Index.[64] Sleep related impairment was calculated from the PROMIS Sleep Related Impairment scale.[65,66] Fatigue was calculated from the Swedish Occupational Fatigue Inventory.[67] Global health was calculated from the PROMIS Mental and Physical Health scale.[69] Physical activity was calculated as the average of items 2-6 on the Healthy Physical Activity Scale.[72] Sugary drinks, sugary snacks, fast food, and meals from home reported for the past month on a scale with 0 to 10 options (0 = never; 5 = 3-4 times per week; 10 = 5 or more times per day).[71]

[a]Lower scores and negative MD and *d* values reflect better outcomes and improvement for these sleep-related outcomes. For remaining outcomes directional changes are more intuitive, where changes represent more or less of a construct or measured outcome.

[b]Due to a potential confound from the experimental mattress condition with an item from the Sleep Hygiene Index[68] ("I slept on an uncomfortable mattress"), results were computed after omitting this item.

and neck ($d = -0.54$). However, unexpected increases in pain in the ankles/feet ($d = 0.19$) and knees ($d = 0.54$) also occurred.

DISCUSSION

Truck driving teams face particularly challenging work conditions for maintaining sufficient sleep, minimizing fatigue, and maximizing their safety, health, and well-being. The Tech4Rest pilot study, and a subsequent planned randomized controlled trial, were designed to evaluate interventions informed by the hierarchy of controls applied to TWH. Engineering controls included a novel therapeutic mattress and active suspension seat. Behavioral controls included a tailored physical activity and sleep intervention, adapted from an established effective m-health intervention platform and model.

Due to the lack of prior data on the therapeutic mattress, we compared that condition alone to an industry standard innerspring mattress alone. On the whole, our findings suggest that there are benefits to providing drivers with a new industry standard innerspring mattress, but that the therapeutic mattress was strongly preferred and produced larger improvements in self-reported sleep and fatigue outcomes. Assessments of WBV exposures suggest that the therapeutic mattress does not reduce total exposure to WBV, but may alter the distribution of vibration frequencies to which drivers are exposed. Previous studies have estimated the resonant frequency of the lumbar vertebrae and spine to be between 4 and 12 Hz.[77] In addition, lower frequency vibrations at or below 3.2 Hz, have been associated with uncomfortable driving and riding experiences.[78] While there was variance in the patterns of PSDs across the two companies, the therapeutic mattress reduced the vibration levels for Company 2 drivers in these frequency ranges that could potentially harm drivers' sleep quality.

Altered vibration patterns on mattress tops were different across the two companies, as were observed floor vibration characteristics. These cross-company differences may be due to road conditions and/or truck characteristics. While both companies operated late model Freightliner Cascadia vehicles, Company 1 operated trucks with a shorter wheelbase (5.30 vs 6.09 m) and used super single tires on the rear axle instead of standard dual tires used at Company 2. Compared to dual tires, super single tires have 10 PSI more tire pressure and weigh 50 lb less (the safety director at Company 1 reported improved fuel efficiency with this truck configuration). These differences in vehicle characteristics could

TABLE 5. Tech4Rest Pilot Study: Objective Sleep and Physical Activity Actigraphy Outcomes Across All Study Conditions at Company 2 ($n=8$)

	Condition Means (SD)				Mean Differences and Effect Sizes					
	A	B	C_1	C_2[a]	B-A		C_1-A		C_2-A	
Outcomes	M (SD)	M (SD)	M (SD)	M (SD)	MD	*d*	MD	*d*	MD	*d*
Primary Outcomes										
Sleep (Actigraphy)										
Total sleep time per driver day (hours)	8.20 (0.71)	8.47 (1.43)	8.15 (1.01)	7.54 (1.67)	0.27	0.22	−0.05	−0.06	−0.41	−0.31
Sleep efficiency (proportion)	0.87 (0.03)	0.85 (0.04)	0.84 (0.04)	0.87 (0.03)	−0.02	−0.52	−0.02	−0.66	0.00	0.07
Secondary Outcomes										
Physical Activity (Actigraphy)										
Freedson bouts per week	0.28 (0.44)	0.46 (0.50)	1.18 (1.10)	0.56 (0.75)	0.18	0.38	0.90	1.07	0.19	0.30
Mean bout duration[b] (minutes)	5.56 (7.86)	5.50 (5.89)	11.59 (9.77)	8.43 (9.40)	−0.06	−0.01	6.03	0.68	1.02	0.11
Total time in bouts per week (minutes)	4.40 (7.63)	5.02 (5.57)	21.25 (18.98)	8.82 (11.47)	0.62	0.09	16.85	1.16	2.95	0.29

Actigraphy had no ''Pre'' condition sample. A=new coil spring mattress; B=novel therapeutic mattress; C=therapeutic mattress + active suspension seat + Fit4Sleep program. C_1 is weeks 1–3 of Condition C (start of intervention), and C_2 is weeks 10–13 of Condition C (end of intervention). MD=mean difference. *d*=Cohen's *d*. Total sleep time per driver day included naps and all main sleep periods. Sleep efficiency was calculated for main sleep periods excluding naps as the average proportion of a total rest interval for which actigraphic data indicated that the participant was actually sleeping. Freedson bouts were required to be 10 or more continuous minutes of moderate intensity physical activity.[73]

[a]Two participants (one team) did not have actigraphy data for physical activity analyses at C_2. As such, their data are excluded from mean calculations and mean difference tests at C_2.

[b]Individuals that had no bouts were given zero minutes in average and total bout time in order to compare average bout time across condition (only two participants had Freedson bouts in every condition).

have potentially caused the higher vibration levels at the floor in the Company 1 trucks.

In Condition C, the addition of an active suspension seat and behavioral sleep health program to the therapeutic mattress created further improvements to self-reported sleep and fatigue outcomes. These were most pronounced during the first few weeks of the behavioral program (Condition C_1). However, actigraphically measured total sleep time means were reduced during Conditions C_1 and C_2 relative to Condition A. This was an unexpected observation, but may be explained in part by the tendency of actigraphy to misclassify sedentary behavior as sleep. In Condition C, physical activity increased and drivers may have been less sedentary before bedtime or after they woke up (eg, taking a short walk). During the sleep-health program drivers reported improvements to their general well-being, physical activity, and diet. Physical activity improvements were further verified through actigraphy using a very conservative analysis approach unlikely to be affected by truck vibrations. While these beneficial effects of Condition C interventions cannot be fully attributed to any one component, a future planned randomized controlled trial will evaluate the effects of the cab enhancements alone (mattress and seat), followed by an evaluation of any added benefits of a tailored behavioral program.

Strengths, Limitations, and Future Directions

Strengths of the project include the evaluation of interventions informed by the hierarchy of controls applied to TWH, and an overall integrated approach that considered occupational sleep, safety, health, and well-being factors together. The project also included assessments of WBV exposures for both mattresses and seats, and objective measures of sleep and physical activity to supplement self-report measures. Potential sequence effects were minimized for mattress conditions by counterbalancing the order of implementation across companies. Intervention process measures also provided an assessment of exposure to intervention components. On the whole, effect sizes observed in the current pilot project were encouraging that the interventions selected may be effective as a package for improving sleep and well-being, and reducing fatigue, among team truck drivers.

Limitations suggest areas for future investigation. While we made special efforts to communicate about the mattresses in neutral terms to minimize bias, drivers could not be fully ''blinded'' to study conditions and may have inferred that the less-usual therapeutic mattress was the experimental or special mattress being evaluated. This could have partially influenced drivers' ratings and universal preferences for the therapeutic mattress. The seat was also a detectable change in technology relative to a standard passive suspension seat, and could have created expectations among drivers that they would experience benefits. Given that blinding drivers to cab enhancements is not possible, future research could benefit from including additional objective measures of driving performance or fatigue that would be less influenced by expectations of bias. For example, commercially available on-board monitoring systems for commercial truck fleets can capture factors such as lane departures, late responses to traffic events, and hard braking. Moreover, in a within-subjects design each participant serves as their own control, which has many advantages including minimizing variance across conditions. However, when evaluating behavioral interventions, between groups designs offer opportunities to control for additional factors, such as attention. Thus, future researchers may want to weigh the pros and cons of within- versus between-subjects designs when evaluating behavioral interventions.

As noted above in the discussion, the active suspension seat and behavioral program were evaluated together with the therapeutic mattress, which prevents drawing conclusions about which component led to the larger effect sizes observed in Condition C. The planned randomized controlled trial will address this limitation, in part. A fully powered randomized controlled trial will also permit stronger conclusions about the effectiveness of interventions in general. The cab enhancements we evaluated are important because drivers spend so much time in the driver's seat and sleeper berth. However, future research could investigate the benefits of additional cab enhancements, such as improved sound insulation or sound cancelling technology in the sleeper berth. For driving teams, it would be ideal if engineering research could investigate the feasibility of developing active suspension mattress platforms that might perform similarly to active suspension seats. In addition, future research will also need to evaluate cost-to-benefit ratios for cab enhancements. Economic considerations include barriers and facilitators to corporate adoption of cab enhancements. To illustrate, for companies that purchase new vehicles, cab enhancements are unlikely to be adopted unless the original equipment manufacturer offers them as selectable features or upgrades at the point of purchase.

Actigraphy has limitations as a data collection method, especially when measuring sleep in a vibrating environment. While our preliminary studies identified a device that was less affected by truck vibrations than other products, a degree of measurement error in the current project is presumed. Future research with teams would benefit from the re-creation of the Nightcap technology used in a previous study,[20] or from adding additional measures to actigraphy to assist with identifying sleep, such as devices that measure respirations, body temperature, and/or heart rate.

The study lasted for several months for each team, but longer-term benefits of interventions will require longer-term follow-up measurements in future studies. We did follow-up informally with teams at Company 1, and all four teams were still using the therapeutic mattress over a year after data collection ended, and reported being satisfied with it. The effects of the behavioral program, while strong, were diminished at the end of the 3-month period. Future research should experiment with ways to sustain engagement and behavior changes through the completion of such programs, and provide long-term support for the maintenance of newly established physical activity and sleep hygiene behaviors. Considering the hierarchy of controls, the most important support provided by employers for teams' physical activity would be an organization of day-to-day work that provided predictable and sufficient opportunities to take walking or exercise breaks. Future research is needed to examine team drivers' schedules that facilitate healthy physical activity, and those that may suppress it. The public and private infrastructure for truck drivers is also important. Drivers' opportunities to wash after exercising are often limited to using a sink at a public or private rest stop. Also, many truck stops are not designed to provide safe or pleasant areas to walk or exercise, and indoor exercise areas at truck stops are extremely limited when weather is too extreme for outdoor activity.

CONCLUSION

A TWH approach to selecting and testing interventions for truck driving teams proved to be feasible, well accepted by drivers, and produced small-to-large effect sizes on a range of sleep, health, and well-being outcomes. Future research is encouraged to replicate, extend, and build upon these findings in order to protect and advance the TWH of team drivers.

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