Postural Balance Changes in On-Duty Firefighters: Effect of Gear and Long Work Shifts

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Objective: *The objective of this study was to investigate the impact of long work shifts and turnout gear, including the self-contained breathing apparatus (SCBA) on firefighters' postural stability.* ***Methods:*** *Sixteen firefighters were assessed using a portable forceplate system at the fire station. Postural sway parameters were recorded at the beginning of the work shift and repeated until the work shift ended.* ***Results:*** *Task had the greatest impact on postural stability for all sway parameters. Turnout gear, with and without SCBA, improved postural stability. Postural stability decreased as firefighters spent more time on duty.* ***Conclusions:*** *Prolonged work shifts may be an important contributor to the high prevalence of slips and falls among firefighters. In all, the results indicate that many aspects of the firefighters' job may adversely impact their postural stability and potentially increase the risk of falling.*
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Firefighting is an extremely dangerous profession. Firefighters frequently are the first emergency response personnel at the scene of a vehicle crash, fire, flood, earthquake, or act of terrorism. Approximately 2 million fires are reported each year in the United States, and fire departments respond to a fire every 18 seconds.[1] Firefighters are exposed to chemical agents (eg, carbon monoxide and other products of combustion), physical agents (eg, heat, noise), and stress (physical and psychologic).[2] This varied and complex on-duty exposure may explain the high injury rates among firefighters, with 38,045 fireground injuries (24.0 per 1000 fires) occurring in 2003.[3] Fall, slip, and jump were the second leading cause of injury accounting for 27.6% of the total fireground injuries.[3] In another study, slips or falls accounted for 19% of fireground injuries for the period of 1994 to 1998.[4]

In an effort to decrease injury rates, firefighters are required to wear significant amounts of personal protective equipment (PPE), including the self-contained breathing apparatus (SCBA), when responding to a fire incident. Despite their protective value, some studies have suggested that the use of PPE (usually referred to as turnout gear by firefighters) may by itself pose an additional load on the firefighters, increasing their risk of slips and falls. Heineman et al found a significant association between SCBA use and falls among firefighters.[5] A recent study by Kincl

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et al[6] found a significant difference in postural stability in workers wearing different levels of protective equipment when their postural muscles were fatigued. Firefighters also have potential fatigue issues because they work long shifts (12–48 hours) and often are required to work without breaks (eg, few rest breaks while fighting the fires). The combination of heavy PPE and long working periods may place firefighters at particular risk of fall-induced injuries. Furthermore, in a hazardous environment, maintaining an upright position becomes a challenge with the increased physical demands of the job and working under unfavorable conditions (eg, little or no visual cues and walking on surfaces damaged by fires). The purpose of this pilot study was to investigate the effect of PPE use (including the SCBA) and long work shifts on postural stability of firefighters.

Subjects and Methods

Subjects

Eighteen firefighters at the Sycamore Township Fire Department, Cincinnati, Ohio (Station 92), volunteered for this study. The purpose of the study and a quick description were introduced to the firefighters during one of the staff meetings by the fire chief and one of the researchers (TS). One to three subjects (maximum number of firefighters that could be tested on the same day without interfering with their work) were recruited from firefighters reporting to duty on days of data collection. The sample size (80% power; alpha = 0.05) was determined from a previous study.[6] Volunteers were screened using a health questionnaire and were excluded if they had history of any of the following conditions that may affect their balance: dizziness, tremors, alcoholism, vestibular disorders, neurologic disorders, diabetic symptoms, or chronic back pain. Each subject signed a consent form and was given study guidelines before the test session. The postural sway testing method and experimental procedures followed a protocol approved by the University of Cincinnati Institutional Review Board. All subjects who volunteered to participate in the study met the inclusion criteria with no exclusions being made. Two subjects (one male and one female) decided to withdraw for personal reasons. Sixteen firefighters participated in the study (one female and 15 males). All participating firefighters were white. The study group included 10 full-time and six part-time firefighters. Demographic information is shown in Table 1.

Questionnaire

Before testing, each subject completed a screening health and work questionnaire and a session questionnaire. The health and work questionnaire collected information on age, sex, job category (full vs part-time), duration on the job, smoking, daily consumption of caffeine, monthly consumption of alcohol, use of medications, and previous injuries or falls. The session questionnaire was developed to record the subject's duration on duty, number and duration of emergency runs, use of SCBA, number of hours slept on the test day, and subject's perceived exertion level using Borg's Scale.[7]

Postural Sway Measurement

To maintain upright balance, a person must keep his center of gravity (CG) inside the base of support (BOS) created by his feet placement. Sensory information (visual, somatosensory, and vestibular) causes the person to continuously adjust his CG position to accommodate the effect of gravity. These continuous adjustments cause the natural human sway. Measurement of postural sway is a noninvasive method to indirectly measure the effect of both physiological and biomechanical stress on the subject.[8]

To quantify changes in postural stability, a microprocessor-based Hall-effect type force platform system, Accusway Plus (Advanced Mechanical Technologies Inc., Watertown, MA), with a laptop computer using SwayWin95 software to collect data was used. Each of the postural balance tests lasted 30 seconds and force plate data was collected at 50 Hz. The output from this system is used to calculate the x and y coordinates of the movement of the center of pressure (CP) corresponding to body sway.[9] The location of the CP approximately coincides with that of the CG during a static task.[10,11] The movement of CP has been used for quantifying postural stability in previous research studies.[6,12–18]

Independent Variables

The independent variables were task—three levels, PPE—three levels, and time on work shift—three levels. The tasks were standing with eyes open on the plate (EO), standing with eyes closed on foam (FC), and reach task (RE). The PPE were standard uniform, turnout gear, and SCBA. Time on work shift included

TABLE 1
Demographics of the Study Group (n = 16)

Variable (units)	Mean	Standard Deviation	Minimum	Maximum
Age (yr)	31.38	7.10	19.00	56.00
Height (m)	1.83	0.09	1.68	2.03
Weight (kg)	97.89	21.73	62.14	143.34
Body mass index (kg/m^2)	29.35	6.11	20.05	40.25
Smoke (cigarettes/d)	5.31	8.84	0.00	20.00
Alcohol (drinks/mo)	12.08	20.40	0.50	84.00
Caffeine (drinks/d)	2.56	1.84	0.50	7
Duration on job (yr)	9.97	5.99	1.50	22.00

baseline (at the start of the shift) and measurements every 12 hours until the shift was completed.

Task

For postural sway testing, the following protocol was used:

Eyes Open on the Plate (EO). The subject stood on the plate with his or her eyes open and remained quiet with the arms to the side. All sensory inputs were available during this test. The measurements recorded during this task were used as a reference task for comparisons with other tasks.

Eyes Closed on Foam (FC). The subject stood on a 4-inch thick foam pad placed on top of the plate with his or her eyes closed and remained quiet with the arms to the side. During this test, the vestibular system inputs were primarily available. This task simulates a situation in which there is limited visibility (eg, heavy smoke) and the floor is partially destroyed by the fire. In previous studies, this test has been shown to be sensitive to subtle postural balance effects when the central nervous system is placed in a challenging environment.[11,17,19]

Reach (RE). The subject stood on the platform for 8 seconds. On command, he/she lifted a 5-lb. weight from a shelf placed at knee height in front of him or her to chest level. The lifting was repeated four times; then the subject replaced the weight on the shelf and stood quietly for the remaining part of the 30-second test period. This test evaluated the maintenance of balance during task performance.

Personal Protective Equipment

Subjects performed each of the previously mentioned tasks (EO, FC, and RE) while wearing three different outfits.

Standard Uniform. This consisted of the fire department-provided t-shirt, pants, and boots. This uniform is worn by firefighters during their shift at all times. The reference outfit measurements for PPE were completed with participants wearing the standard uniform.

Turnout Gear. This consisted of standard U.S. firefighter protective apparel (garment, pants, helmet, and boots). This uniform is worn on top of the standard uniform when firefighters are responding to a fire run before they leave the fire station. The average weight of the turnout gear is 20 lbs.; however, depending on the gear size and the presence of rescue tools carried by some firefighters in their pockets, it may weigh up to 20 lbs. more.

Self-Contained Breathing Apparatus. Subjects carried a standard U.S. firefighter metal air bottle on their back and wore the facepiece around their necks on top of the turnout gear. The decision to wear the SCBA and to have the facepiece on depends on the type of run firefighters are responding to and follows standard protocols. The SCBA weighs 20 lbs. In this study, firefighters did not actually breathe though the SCBA as a result of practical issues because the study was conducted in the fire station while the firefighters were on duty.

Time on Work Shift

Firefighters work in shifts that vary in length (12–48 hours) depending on the needs of work. To study the effect of long work shifts on postural stability, subjects were first tested at the beginning of their work shift. Testing was repeated every 12 hours until the subject's work shift ended. The measurements recorded at the beginning of the work shift were used as a baseline for comparisons with later measurements.

Dependent Variables

The area and length of the CP sway pattern, obtained from the x–y plots, in addition to the mediolateral (ML) and anteroposterior (AP) excursions, were used to characterize the postural sway. Sway area (SA) is the area of the projection of the body's CP on the horizontal x–y plane as a result of sway; SL is the distance traveled by the CP. The ML and AP excursions are the net deviation of the CP in the ML and AP directions, respectively. An increase in any of those parameters indicates an increase in postural sway and implies a decrease in postural stability.

Materials and Methods

Instrument Calibration

Before data collection, a daily calibration of the forceplate with a known weight (calibration bar) was performed by placing the calibration bar over five predetermined points and collecting data for 30 seconds. The process was repeated three times for each point. Forceplate measurements of the calibration bar were within 2% of actual values, and no adjustments to the forceplate before the testing started were required. At the end of each session, calibration was repeated three times at only one predetermined point to ensure quality of the data collected. The reproducibility of the postural sway or static balance test was also evaluated at the end of the study. Results showed no significant changes in the sway parameters between the two trials, implying excellent reproducibility of the method. Other researchers have reported similar results.[20] Comparable findings were also obtained from our laboratory's other studies.[11,21,22] The correlations between test/retest ranged between 0.65 to 0.9, and there was no statistically significant difference between the values from one test to the other.

Data Collection

At the beginning of the work shift (6:00 AM), each subject completed a session questionnaire and then performed each of the three test tasks (EO, FC, and RE) wearing the standard uniform, turnout gear, and the SCBA in order. Each of these tests lasted 30 seconds. During each session, tests were done consecutively, with time in between, just enough for the firefighter to put

on his or her turnout gear and then the SCBA (30–45 seconds). One full test session for one firefighter performing all tasks and wearing all different outfits lasted approximately 15 minutes. To ensure accuracy and subjects' compliance, testing was conducted in a quiet room at the basement of the fire station. In case of an emergency dispatch, testing was stopped and repeated as soon as the firefighter returned. In addition, all tests were repeated twice and averaged for the first session. No repetitions were done during the follow-up sessions. This protocol was used in previous studies to indirectly assess the effect of different stressors on the central nervous system (CNS).[6] The whole experimental procedure was repeated every 12 hours until the end of the work shift (12–48 hours depending on work requirements). During testing, subjects stood in the middle of the forceplate with their feet 30° apart. Their footprints were traced on the first session and saved for the following tests to standardize their position. Physical measurement of height and weight were collected for each subject at the beginning of the testing session.

Statistical Methods

The data files were imported into the Statistical Analysis System (SAS) for data analysis. Continuous outcomes were analyzed in mixed repeated-measure analysis of covariance models by SAS Proc Mixed. The continuous outcome variables (SA, SL, ML excursion, and AP excursion) were transformed to their natural logarithm to achieve approximate normality. The main effects of task (eyes open, eyes closed on foam, and reach), outfit worn (uniform, turnout gear, and turnout gear plus the SCBA), and work shift duration (sessions one, two, and three) were included as classification variables. Two-factor interactions among each of these main effects were also included in the initial models. The following covariates were included in the initial model; job category (full- vs part-time), duration on the job (years), monthly consumption of alcohol, and the number of cigarettes smoked in the preceding 12 hours, 8-oz. caffeine drinks, emergency runs, and number of hours slept. Backward elimination of insignificant interactions and covariates was performed until final models were determined that included only the main effects and significant two-factor interactions and covariates. An alpha level of 0.05 was used to judge significance in all models.

Results

Firefighters' self-reported physical effort and rating of perceived exertion data were collected using the session questionnaire. The results are presented in Table 2.

As expected, task had a significant effect on all postural sway parameters (Table 3). For sway area (SA) eyes closed on foam (FC) increased SA by 241%, whereas performing the reach task (RE) increased SA by 1158% from the reference task (EO) (Fig. 1). Eyes closed on foam (FC) increased SL by 117%, whereas performing the reach task (RE) increased it by 314% from the reference task (EO). The ML and AP excursions showed the same trend.

Personal protective equipment produced a significant reduction of postural sway (Table 3). Wearing the SCBA significantly decreased SL and ML excursion by 9.5% and 2.4%, respectively, from the standard uniform (reference outfit), whereas the turnout gear alone produced 10% and 4.1% decrease, respectively (Fig. 2). The changes in SA and AP excursion were not significant.

Postural sway increased as firefighters spent longer time on their

TABLE 2
Physical Effort, Sleep Period, and Number of Emergency Runs Reported by the Study Group ($n = 16$)

Variable (units)	Mean	Standard Deviation	Minimum	Maximum
Sleep in the past 12 hr (hr)	4.38	21.13	0.00	6.50
Number of emergency runs per shift	3.44	2.53	0.00	9.00
Rating of perceived exertion (Borg Scale)	9.06	3.00	6.00	16.00

TABLE 3
Main Effects and Significant Covariates and Interactions for Postural Sway

Dependant Variable	Independent Variable	*P* Value
Sway area	Task	0.0001
	PPE	0.23
	Work shift time	0.43
	Task*PPE	0.005
Sway length	Task	0.0001
	PPE	0.0001
	Work shift time	0.09
	Task*PPE	0.001
Mediolateral excursion	Task	0.0001
	PPE	0.02
	Work shift time	0.055
	Task*PPE	0.0016
Anteroposterior excursion	Task	0.0001
	PPE	0.95
	Work shift time	0.73

PPE indicates personal protective equipment.

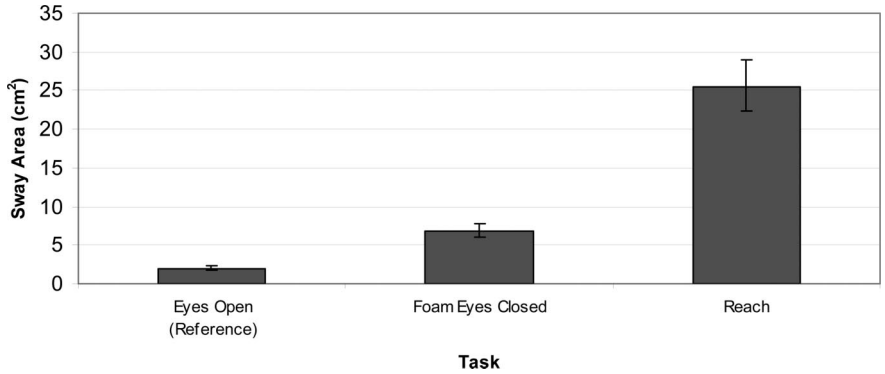

Fig. 1. Effect of task performed on sway area (adj. $P < 0.0001$ for all multiple comparisons).

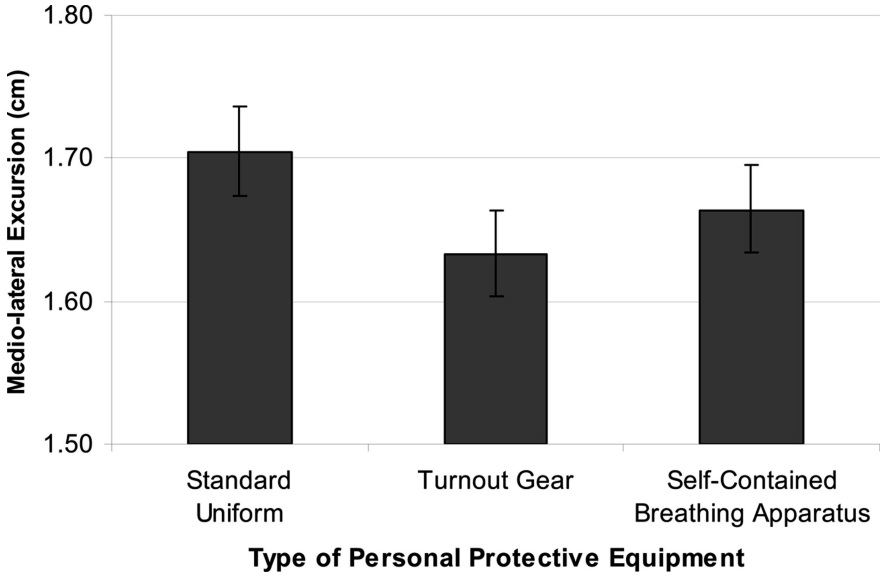

Fig. 2. Effect of personal protective equipment on mediolateral excursion (adj. $P < 0.0001$ for all multiple comparisons).

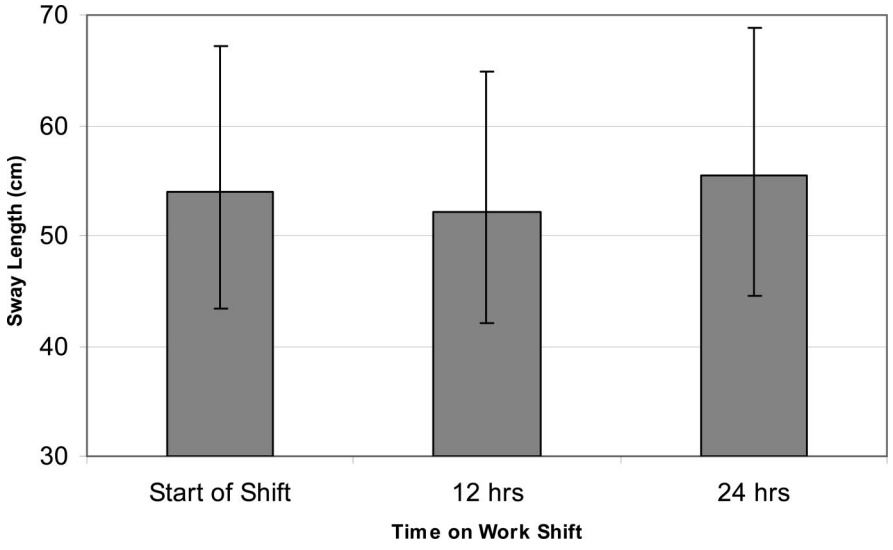

Fig. 3. Effect of time on the work shift on sway length ($P = 0.09$, multiple comparisons were not significant).

work shift. All postural sway parameters increased by the end of the 24-hour work shift (Fig. 3), with a borderline significant effect on ML excursion ($P = 0.055$). Both SL and SA decreased after 12 hours but only to increase above the baseline (start of shift) at the end of the 24-hour work shift, but the results were not significant (Table 3).

The interaction between task and PPE was significant for SA, SL, and ML excursion (Table 3). The interaction effect occurred under the eyes closed on foam task where there existed significant differences between PPE types with no differences between PPE type for the other tasks. The presence of turnout gear as well as SCBA produced less sway than the regular uniform (Fig. 4).

Discussion

Maintaining postural balance is essential for firefighters to carry out their duties. This study investigated the effect of personal, occupational, and environmental factors on postural balance of firefighters during their work shift.

Turnout gear, including the SCBA, improved all postural sway measurements when compared with the standard uniform (with the exception of AP excursion). The improvement was statistically significant for both SL ($P < 0.0001$) and ML excursion ($P < 0.015$) and independent of the duration of the work shift. This improvement was opposite to our initial hypothesis for the study, in which the added weight and restriction of mobility imposed by the gear and SCBA were thought to decrease postural balance. Biomechanically speaking, two possible changes could have happened. First, the additional weight (turnout gear and the SCBA) could have actually lowered the overall center of gravity of the fireperson, making the subjects more "fixed" to the forceplate with less movement of their center of pressure. Second, firefighters' experience (through better muscular contractions of the postural muscles) in

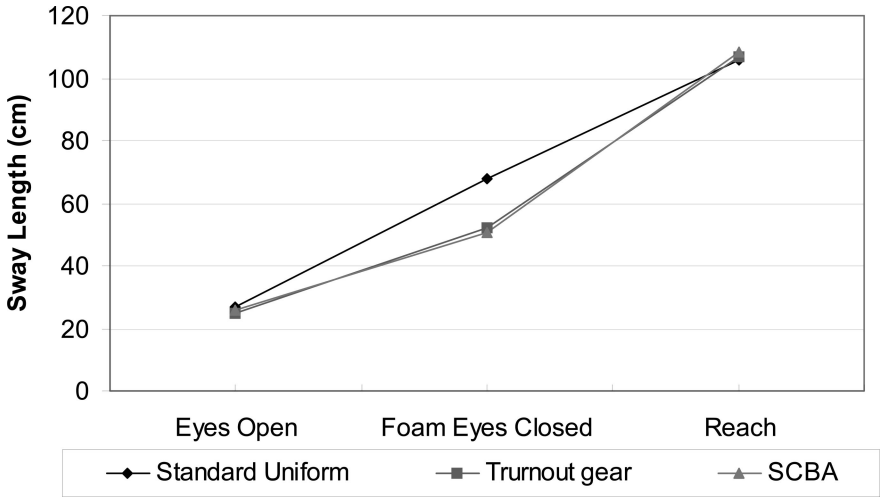

Fig. 4. Sway length as a function of task and personal protective equipment, including the self-contained breathing apparatus (SCBA).

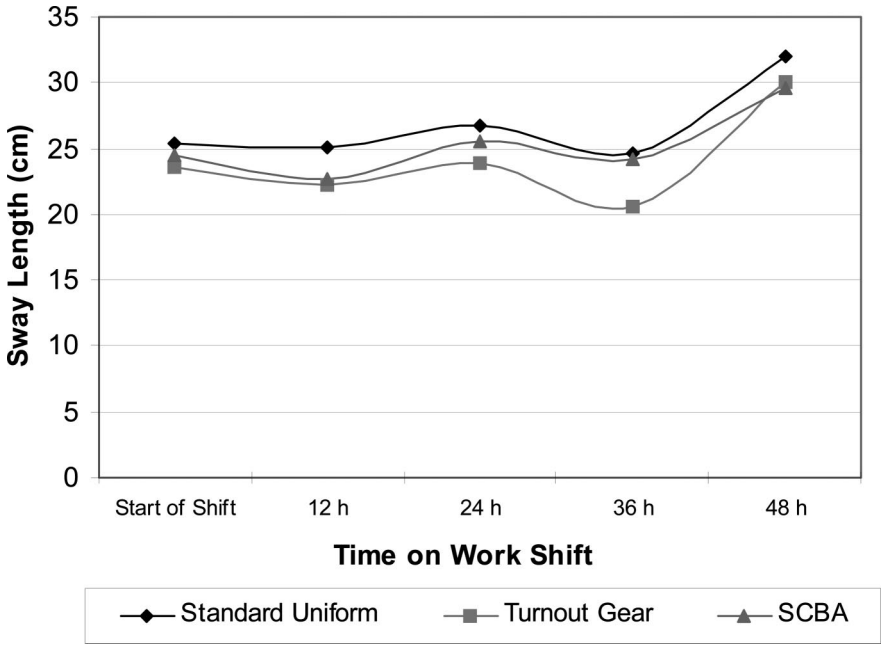

Fig. 5. Changes in sway length of one firefighter during a 48-hour shift performing the eyes open task while wearing the three different outfits, including the self-contained breathing apparatus (SCBA).

maintaining proper upright balance with SCBA might have a major contribution in the observed improvement in postural balance. Another explanation may be the triggering of a conditional reflex, in which firefighters become more alert, resulting in the recruitment of more muscles to maintain their balance when they have their gear on. However, this conjuncture requires further investigation.

A limited number of studies has investigated the effect of PPE on postural sway. In a study by Kincl et al,[6] the use of PPE increased postural sway parameters. However, the study involved a group of volunteers who had little experience wearing the equipment. In another study by Punakallio et al,[23] the use of SCBA increased postural sway parameters among firefighters tested during their off-duty time. The different testing conditions (off-duty, performing both static and dynamic tests, in a laboratory setting) may have affected the outcomes of the firefighters and contributed to the difference between their findings and the findings of our study. The use of different types of PPE in previous studies may be another factor that contributed to the different results from the current study.

The change in biomechanics during the experimental tasks, as well as when wearing the additional equipment, may have only scratched the surface with respect to environmental demands and postural balance. Real-life situations may tax the firefighter's neuromuscular system even more than what was tested in this study. Some evidence is shown by the epidemiologic study by Heineman et al[5] who reported a significant association between the use of the SCBA and fireground injuries resulting from falls (odds ratio, 4.0; 95% confidence interval, 1.2–12.9).

The length of time the firefighters work influenced the postural balance with an initial improvement followed by a decline. The mean response of all sway parameters (except AP) decreased (implying improved balance) during the second test session (12 hours work shift) from all subjects when compared with the baseline (ie, first session). However, this was followed by an increase even above the baseline values during the third test session (24-hour work shift). The changes in mean ML excursion and SL were borderline significant ($P = 0.055$ and 0.09, respectively). Longer shifts may have even more of an impact with the sleep–work cycle potentially playing an important role in the response, especially because fatigue may be contributing. Figure 5 gives an example of SL response from one firefighter evaluated during a 48-hour shift. This increase in SL response could be the result of fatigue of the muscles used for maintaining balance or as a result of the fact that normal sway follows a circadian rhythm with the maximum

sway occurring near the early morning or a combination of both. Nakano et al[24] reported similar findings suggesting the possibility of a circadian rhythm. Based on the one firefighter, extended shift work has the potential for significant ramifications on postural stability. However, further research is needed that more comprehensively investigates the issue of extended work shifts.

Task had the greatest impact on all firefighters' postural sway parameters, the reach task produced the highest values followed by the eyes closed on foam test when compared with the eyes open standing still task (reference task). This is in accordance with previous studies on postural balance while performing stationary tasks.[6,19,25] These types of tasks can occur during emergency calls that a firefighter encounters during a work shift. Fighting fires offers many potential conditions and tasks that are similar to those evaluated in the current study. For example, reach tasks occur when removing material or lifting objects while the eyes closed standing on foam task would simulate the conditions similar to walking on unstable floors where the vestibular system is challenged to a maximum to maintain postural balance. Differences between the tasks may also have larger ramifications for firefighters because they are oftentimes changing environments and have to respond under very adverse conditions (eg, slippery conditions, hot or cold environments, and high stress). These conditions may also potentially minimize the beneficial effect of wearing PPE. However, it is important to note that the relationship between static postural sway measures and balance demands in real fire and rescue work are not well understood. In our study, dynamic balance testing was not feasible when firefighters were on duty.

The interaction between task and gear was significant for SA, SL, and ML excursion. Wearing the turnout gear (with or without the SCBA) significantly improved postural balance for the eyes closed on foam task (FC). For the standing still (EO) and reach (RE) tasks, wearing the turnout gear did not produce a significant change. Again, this may be the result of the effect of the added weight that helps to "fix" the firefighters to the plate or as a result of the initiation of a reflex that makes the firefighters more "alert" to their balance when they have their gear on.

Several factors that were shown to affect postural sway parameters in previous studies were not significant in our study and were removed from the final models. These included body mass index, rating of perceived exertion, smoking, and caffeine and alcohol consumption. This could be the result of a healthy worker effect, in which only healthy, fit subjects were able to maintain their highly demanding job as firefighters and were available for us to study. Another reason could be our small sample size that showed little variation in these factors. In addition, our subjects were predominantly males and were all selected from the same fire station, this may limit the generalization of our results. It is important to note that the emergency runs our subjects responded to, during the random days of testing, were all emergency medical service runs (EMS runs) and no actual fires were encountered. Fire runs are usually more physically demanding than EMS runs and may involve exposure to combustion products, some of which may have significant effects on the central nervous system. It was not possible for us to evaluate such effects.

Tasks were performed in the same order throughout the test sessions raising a question regarding systematic error as a result of motivation and learning. Although motivation and learning are important factors to consider in such study design, we believe that our subjects were highly motivated because they all volunteered to participate in the study and were interested in the results because they could relate directly to their safety while on duty. As a result of practical difficulties, randomization was not performed in this study; however, we believe it did not have a major effect on the final results. Learning would have lead to improvement in final postural sway parameters; however, the results show that as time increased, the sway parameters got worse. On the other hand, within each test session, we did not observe any trends indicating that the sway parameters improved as subjects performed more tests. Nevertheless, randomization of trials is an important factor to be considered in future studies.

Some recent studies indicate that physical fitness can affect balance abilities.[26–28] All firefighters have to pass an annual medical examination and another annual fitness test to be allowed on duty. In our study, no data were collected regarding individual physical fitness because all our subjects were "healthy firefighters." In addition, our main outcome measures (postural sway parameters) were investigated as "within-subject" variables, whereas different levels of physical fitness are observed "between-subjects" and may have only minimal effect on the final results.

Conclusions

The results of this study indicate that turnout gear, with and without SCBA, improved postural stability during stationary tasks, although it is an additional load. The decrease in postural stability caused by long work shifts (although not significant) may be a potential contributor to the high prevalence of slips and falls among firefighters. Further investigation of different firefighting tasks on postural balance should be undertaken, particularly with respect to long-term shift work. The effect of heat stress and exposure to combustion products are important variables to consider in future studies conducted perhaps in a firehouse that has more fire calls.

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