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Effects of Occupational Tasks and Personal Protective Equipment On Static and Functional Balance Among Career Firefighters

Petra Kis

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EFFECTS OF OCCUPATIONAL TASKS AND PERSONAL PROTECTIVE EQUIPMENT
ON STATIC AND FUNCTIONAL BALANCE AMONG CAREER FIREFIGHTERS

by

PETRA KIS

(Under the Direction of Bridget Melton)

ABSTRACT

BACKGROUND: Musculoskeletal injuries are commonly incurred on the fireground among firefighters. Most injuries are attributable to overexertion, fall, jump, slip, and trip mechanisms. These injuries may be caused by many factors, including the independent and collective effects of wearing personal protective equipment (PPE) and the fatigue induced by performing occupational tasks. Therefore, the purpose of this study was to investigate the effect of PPE and fire suppression tasks on static and functional balance among firefighters. **METHODS:** 32 healthy male career structural firefighters (Age: 31.8 ± 9.5 yr) volunteered for this study. Static and Functional Balance Tests (FBT) were performed in 3 conditions and completed in sequential order. Condition #1 was completed in station uniform attire prior to work activity, condition #2 was completed in PPE prior to a fire suppression drill, and condition #3 was completed in PPE immediately after the fire suppression drill. Static balance outcomes were assessed using a force plate, whereas the modified FBT was performed by ambulating on a plank over and under a set of obstacles which yielded a time and error-based Performance Index (PI). The independent effects of PPE and occupational tasks on balance outcomes were assessed with paired sample t-tests and Wilcoxon Matched Pair Signed Rank test for non-normally distributed data. The level of significance was set at $p < 0.01$. **RESULTS:** The post-work PPE condition yielded greater values for mean sway velocity (Non-dominant leg eyes open; $z(28)=-3.10$, $p=0.002$, ES: 0.11), anterior-posterior excursion (Dominant leg eyes open: $z(28)=-3.83$, $p<0.001$, ES: -0.83; Non-dominant leg eyes open: $z(28)=-3.50$, $p<0.001$, ES: -0.72; Dominant leg eyes closed: $t(28)=-3.26$, $p=0.003$, ES: -0.60), and medial-lateral excursion (Dominant leg eyes open: $z(28)=-3.08$, $p=0.002$, ES: -0.44; Non-dominant leg eyes open: $z(28)=-2.63$, $p=0.009$, ES: -0.30). FBT time ($z(30)=-4.80$, $p<0.001$, ES: -1.14) and PI ($z(30)=-4.86$, $p<0.001$, ES: -1.66) were greater in the

pre-work PPE condition than uniform attire condition. **CONCLUSION:** PPE negatively affected firefighters' functional balance, whereas occupational tasks negatively affected static balance outcomes. These findings highlight the importance for the utilization of countermeasures to combat load carriage and occupational fatigue-induced decrements in neuromuscular function to reduce injury risk among structural firefighters.

INDEX WORDS: Tactical, Static balance, Functional balance, Firefighters

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ON STATIC AND FUNCTIONAL BALANCE AMONG CAREER FIREFIGHTERS

by

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CHAPTER 1

INTRODUCTION

Purpose of the Study

With this study, we would like to demonstrate the effects of PPE on static and functional balance measures, provide more evidence on the fire suppression task effect on balance measures, and highlight the potential risk for slip trip, and fall injuries due to balance impairments. Therefore, the purpose of this study was to investigate the effects of personal protective equipment (PPE) and fire suppression tasks on the static and functional balance among firefighters.

How This Study is Original

While research has investigated the effect of PPE on static and functional balance, there are only a few studies that have looked at the effect of specific occupational tasks on static and functional balance. Furthermore, to the best of our knowledge, this study is the first that has investigated both PPE and occupational tasks' effect on static and functional balance among firefighters in the same study.

CHAPTER 2

BACKGROUND

Firefighting is a dangerous profession. More than 60,000 injuries are incurred annually by firefighters (Campbell & Evarts, 2021). Musculoskeletal injuries (MSKI), such as sprains, strains, and muscular pain, are the leading nature of injury during fireground tasks (Campbell & Evarts, 2021). Most injuries are attributed to overexertion or strain (25%) and slip, trip, and fall (24%) mechanisms (Campbell & Hall, 2022). The average cost of overexertion and strain injuries has been reported to be \$11,428 in hospitalization and \$7,422 per emergency visit (Butry et al., 2019). Additionally, each fall-induced injury costs \$158,790 in hospitalization and \$6,618 per emergency visit (Butry et al., 2019). MSKI ranges in severity and typically requires days to months to heal, which induces fiscal consequences for the fire department. For instance, lost time injuries require backfilling the position with other personnel, which often results in increased overtime compensation costs and a greater workload on backfill personnel.

Personal protective equipment (PPE) is worn to reduce injury risk from cuts, burns, and inhalation of poisonous gasses and chemicals. PPE includes a specialized coat, pants, boots, hood, helmet, face mask, gloves, and self-contained breathing apparatus (SCBA). Despite the protective characteristics of PPE, it has been shown to negatively impact firefighters' neuromuscular function. Specifically, research indicates that PPE negatively impacts firefighters' functional balance (Kong et al., 2012; Hur et al., 2013) and gait quality, including increased step width, reduced stride length, and decreased gait speed (Rosengren et al., 2014). Furthermore, PPE has been found to negatively affect dynamic balance during dynamic single-leg balance tests, but not static balance assessments (Brown et al., 2019). Similarly, Kollock et

al. (2021) reported that dynamic postural stability index (DPSI) outcomes were attenuated in PPE and that greater relative external load significantly affected the firefighters' ability to maintain stability (Kollock et al., 2021). These deleterious effects may be due to the increased challenge of maintaining balance due to the external load (≈ 22 kg).

In addition to the compromising effects of PPE on firefighters' balance, performing occupational tasks in PPE has been shown to induce fatigue (Taylor et al., 2012) and physiological measures of strain (Williams-Bell et al., 2010; Smith et al., 2008). Indeed, Lesniak and coworkers (2020) demonstrated that PPE significantly reduced occupational work rate by 45% among firefighter recruits. Given that PPE exasperates the physical demand of performing strenuous occupational tasks (e.g., rescuing victims, climbing stairs, advancing charged hose lines, breaching structures), it serves to reason that this work-induced fatigue may negatively impact firefighters' neuromuscular function. To that end, physical exertion has also been found to negatively affect balance (Brown et al., 2019; Csiernik et al., 2017; Kollock et al., 2021). Research indicates that short bouts of exercise sessions in PPE negatively impact static and dynamic balance outcomes in firefighters (Games et al., 2020). Additionally, Hur et al. (2013) noted that the timed completion of a functional balance test increases following the completion of occupational tasks. Indeed, impaired balance and fatigue are intrinsic factors that may increase the risk of accidental slip, trip, and fall injuries among firefighters (Kong et al., 2013).

Although previous research has evaluated the independent effects of PPE and physical exertion on static and functional balance, additional research is warranted to explore the independent and collective effects of PPE and fire suppression tasks on static and functional balance outcomes. This information will bring awareness to potential risks for slip, trip, and fall injuries originating from balance impairments due to PPE and fire suppression tasks and provide

recommendations for the development of countermeasures. Therefore, the purpose of the study was to investigate the effect of PPE and fire suppression tasks on static and functional balance among incumbent firefighters. It was hypothesized that PPE and fire suppression drills would negatively affect static and functional balance measures.

CHAPTER 3

METHODS

Experimental Approach to the Problem

This study utilized a within-subjects design to evaluate the impact of PPE and occupational tasks in PPE on static and functional balance outcomes among firefighters. The independent variables included PPE status (station uniform vs. full PPE) and occupational tasks (pre-work with PPE vs. post-work with PPE). The dependent variables include the Functional Balance Test and static balance outcomes.

Participants

A convenience sample of 32 male career firefighters (Age: 31.8 ± 9.5 yr; Height: 182.39 ± 5.79 cm; Body mass: 94.70 ± 17.44 kg; Body mass index (BMI): 28.58 ± 5.16 kg/m²) from the southeastern United States volunteered to participate in the study. Inclusion criteria included being 18 years of age, employed as a career firefighter, and medically cleared for active duty. Exclusion criteria included current neurological disorders, postural disorders, an injury that may limit participation, or light duty status. Before data collection, participants were informed about the study procedures, requirements, and risks. Participants signed an informed consent form before testing. Institution Review Board approval was obtained prior to data collection (Protocol #: H19098).

Procedures

Firefighters completed the informed consent and demographic survey at the fire department's Training Center. In addition, firefighters completed a physical activity readiness questionnaire (PARQ) and daily readiness questionnaire (PAR-Q+, 2016) to confirm health status and ability to complete the study procedures with minimal risk. The research team measured standing height and body mass (Health o meter[®], Alsip, IL), explained and demonstrated the static and functional balance assessments, and firefighters were allowed to become familiarized with each test. Additionally, a certified athletic trainer was on-site during the fire suppression drill.

Fireground Drill

The fire department completes this fire suppression drill at the Training Center 2-3 times per year as part of in-service training, thus all firefighters were familiar with the task procedures. The fire suppression drill consisted of seven stations of fireground tasks that were performed while wearing ≈ 29.5 kg of PPE, but not breathing through the respirator. Immediately after the drill, firefighters were instructed to return to the testing center directly next to the drill ground to repeat the static and functional balance assessments.

The completion of a standardized set of fire suppression tasks were timed with a stopwatch (Apple Inc., Cupertino, CA). Firefighters were instructed to complete the tasks at a pace they would typically utilize on a live fireground. Specifically, firefighters ascended three flights of stairs while carrying a high-rise pack (30.5 m hose; ~ 67.3 kg) on their shoulder(s) and placed the pack on the landing before descending the stairs. Firefighters then proceeded to the Ceiling Breach station. Firefighters completed twenty repetitions of pushing and pulling

movements against 18.2 kg resistance using a 1.83 m pike pole on a ceiling breach and pull simulator. Then, firefighters walked to a Forcible Entry station where a 4.1 kg dead-blow sledgehammer was used to strike a 68.6 kg I-beam on a Keiser Force Machine to simulate a forcible entry task. The I-beam was struck until it moved at the end of the platform. Firefighters then proceeded to a hoseline advance task and placed a 1.75-inch charged hose line over their shoulder and advanced it 30.5 m. Next, firefighters performed a search task by crawling 30.5 m on hands and knees using the hose line as a guide. Firefighters were advised to maintain contact with the hose line with one hand. Next, firefighters proceeded to a Victim Rescue station, where they dragged a mannequin (75 kg) to a cone 7.62 m away and returned to the starting position (total distance: 15.2 m). Then, firefighters completed an equipment carry task by carrying (2) kettlebells (24 kg) approximately 6.1 m through a room simulator with a 90-degree turn and ascended a flight of stairs with a 90-degree turn halfway up, then turned around and returned out of the room, setting the weights down on the outside of the building.

Measurements

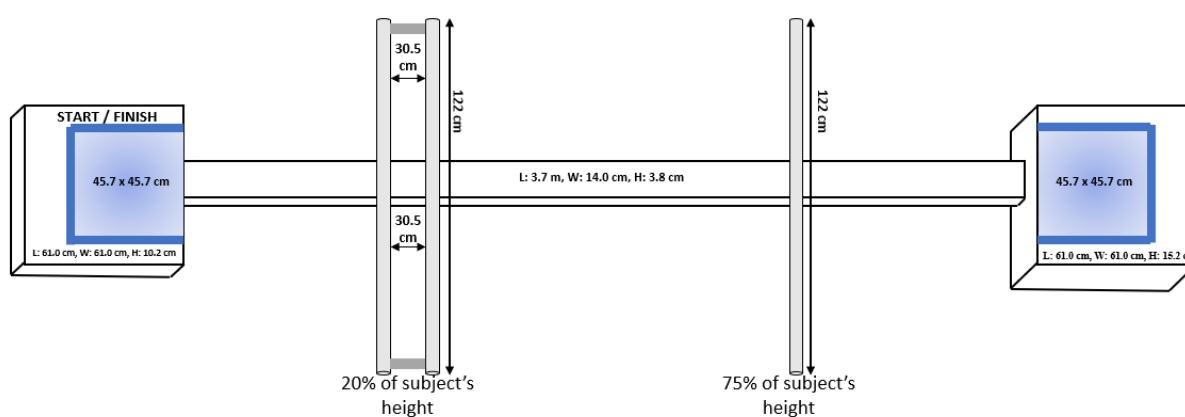
Static Balance Test. Static balance testing consisted of firefighters completing three 10-second trials for each of the four assessments while standing on the force platform [BTrackS™ Assess Balance System (San Diego, CA, USA), Sampling rate; 100 Hz)]. The four assessments included single-leg standing for dominant and non-dominant leg under eyes open and eyes closed conditions (Goldie et al., 1992; Nagai et al., 2017; Sell et al., 2010), which were performed in the same order during each condition. Outcome measures included mean body sway (measured by root mean square (RMS)), which was calculated using the center of pressure (COP) displacement in the anterior-posterior (AP) and medial-lateral (ML) directions. Mean sway velocity was calculated using the COP displacement over time. Kinetic force data was

captured by using BTrackS™ Assess Balance System ((San Diego, CA, USA), Sampling rate; 100 Hz). Firefighters were instructed to stand as still as possible while lifting one foot off of the force platform and flexing the knee to 90 degrees in a single-leg stance. For all stances, hands were placed on hips, and firefighters were instructed to look straight ahead with eyes open and closed. For the eyes open, trial participants were instructed to stand as still as possible once the tester said "go" and they could revert to a bilateral stance once the tester said, "relax." For the eyes closed conditions, firefighters were instructed to stand as still as possible and to close their eyes when the tester said "go" and open them when the tester said, "relax." Firefighters were given 5-10 s to put their legs down and regain balance before moving on to the next trial.

Functional Balance Test. Firefighters completed an occupationally relevant functional balance test (FBT) to safely assess dynamic balance. The FBT was created to be more applicable and reliable in testing functional balance in this population (Hur et al., 2013; Games et al., 2020). Based on firefighters' feedback during pilot data collection, the FBT was further modified to enhance relevancy to ambulating and navigating obstacles on the fireground by incorporating an additional obstacle to step over. Thus, the FBT included a step-down task, walking on a narrow plank and stepping over one obstacle, bending under a second obstacle, stepping up onto a platform, turning around in a confined space, and returning through the obstacles in reverse order. A schematic of the FBT is provided in Figure 1. The FBT time was initiated when the tester said "go" and terminated upon stepping onto the initial platform. Specifically, the firefighter began by standing on a platform (L: 61.0 cm, W: 61.0 cm, H: 10.2 cm), stepped down onto a plank (L: 3.7 m, W: 14.0 cm, H: 3.8 cm), walked 1.2 m and stepped over a barrier composed of 2 PVC pipes (H: 20% of firefighter's height, L: 30.5 cm). The firefighter then walked 1.2 m and bent under a single PVC pipe (H: 75% of firefighter's height) and walked 1.2

m to a second raised platform (L: 61.0 cm, W: 61.0 cm, H: 15.2 cm) where they turned around within a confined space (L: 45.7 cm, W: 45.7 cm) and returned through the obstacles to the initial platform. Participants were instructed to complete the test as fast and accurately as possible. They were told that the technique they use to complete the test does not matter if it is the most efficient for completing the tasks. The FBT was scored using a Performance Index (PI) [Performance Index = (2 × Major Error) + (1 × Minor Error) + (1 × Performance Time (s))] (Hur et al., 2013; Games et al., 2020). Errors were recorded throughout the trials. A major error was counted when the participant displaced a horizontal bar, both feet contacted the ground, or tripped or fell during the trial. A minor error was counted when the foot or hand contacted the ground, the hand contacted the platform, the turn was not performed in the designated confined space, the firefighter could not stop in the defined space, and lastly, when the participant touched a bar but did not displace it (Hur et al., 2013). Two trials of the FBT were performed in each condition, one without and one with the obstacles.

Figure 1. Functional Balance Test layout.



Work Rate – Cardiovascular Index. An index was developed to describe the cardiovascular demand relative to occupational work rate. Specifically, the fireground drill completion time

was divided by maximal heart rate (Work rate – Cardiovascular index = Fireground drill time / Relative peak heart rate). Relative peak heart rate was calculated during the fireground drill using the Tanaka maximum heart rate (HR) formula and the firefighter's peak HR during the drill (Relative HR = [Maximum HR / Tanaka Max HR estimation (208 - (0.7 x Age)) * 100] (Tanaka et al., 2001).

Data Analysis

Independent variables for this study included the gear condition station uniforms and PPE and three different time points. The dependent variables included sway velocity (Vel), sway root-mean-square (RMS), FBT time and FBT PI.

Basic statistics (mean \pm standard deviation) were used to describe demographic and dependent variable outcomes. The normality of sample distributions was assessed via Fischers' Coefficient of Skewness (Skewness / Standard error of Skewness). Sample distributions were considered skewed when the coefficient was greater than the absolute value of 1.0. For static balance measures the mean of the 3 trials was used in the analyses. The independent effects of PPE and occupational tasks on balance outcomes were assessed with paired sample t-tests for normally distributed variables and the Wilcoxon Matched Pair Signed Rank test for non-normally distributed variables. Most of the statistical analyses were calculated with Wilcoxon Matched Pair Signed Rank test however the following PPE related outcomes (Mean Sway velocity D_EO, AP RMS D_EO, AP RMS D_EC), and task related outcomes (Mean Sway Velocity D_EC, AP RMS D_EC, and AP RMS ND_EC) were assessed with paired sample t-test. Effect sizes were calculated using Cohen's d and interpreted as follows: small effect: 0.2; moderate effect: 0.5, large effect: 0.8 or higher (Lakens, 2013). Due to the potential for inflation

of Type 1 statistical error, the level of significance was set at $p < 0.01$. Test-retest reliability was assessed on the static balance outcomes using an intraclass correlation coefficient (ICC). In general, adequate levels of test-retest reliability were observed for most of the assessments.

Table 1 displays the test-retest reliability coefficients of postural sway outcomes. In cases where firefighters were unable to stay upright during the trial and fell, the reliability coefficient was not applicable. All data sets were analyzed by IBM® SPSS® Statistics 27 (IBM Corp., Chicago, IL) software.

Table 1. Reliability scores of the static balance tests.

Baseline - In station uniform												
Conditions	Mean Sway Velocity D_EO	Mean Sway Velocity ND_EO	Mean Sway Velocity D_EC	Mean Sway Velocity ND_EC	AP RMS D_EO	AP RMS ND_EO	AP RMS D_EC	AP RMS ND_EC	ML RMS D_EO	ML RMS ND_EO	ML RMS D_EC	ML RMS ND_EC
ICC	0.703	0.780	0.836	0.824	0.452	0.572	0.652	0.490	0.325	0.305	0.527	0.611
Pre activity - In PPE												
Conditions	Mean Sway Velocity D_EO	Mean Sway Velocity ND_EO	Mean Sway Velocity D_EC	Mean Sway Velocity ND_EC	AP RMS D_EO	AP RMS ND_EO	AP RMS D_EC	AP RMS ND_EC	ML RMS D_EO	ML RMS ND_EO	ML RMS D_EC	ML RMS ND_EC
ICC	0.648	0.727	0.775	0.691	N/A	0.342	0.337	0.432	0.025	N/A	0.197	0.274
Post activity - In PPE												
Conditions	Mean Sway Velocity D_EO	Mean Sway Velocity ND_EO	Mean Sway Velocity D_EC	Mean Sway Velocity ND_EC	AP RMS D_EO	AP RMS ND_EO	AP RMS D_EC	AP RMS ND_EC	ML RMS D_EO	ML RMS ND_EO	ML RMS D_EC	ML RMS ND_EC
ICC	0.895	0.779	0.832	0.817	0.736	0.765	0.754	0.404	0.299	0.032	0.636	0.715

AP RMS: Anterior Posterior root mean square, ML RMS: Mediolateral root mean square, D_EO: dominant leg eyes open condition, ND-EO: non-dominant leg eyes open condition, D-EC: dominant leg eyes closed condition, ND-EC: non-dominant leg eyes closed condition. ICC: Intraclass Correlation Coefficient. N/A: reliability coefficient was not applicable due to firefighters not being able to stay in an upright position/falling during the trials.

CHAPTER 4

RESULTS

Table 2 and Figure 2 display a comparison of static balance outcomes between conditions. Regarding the effect of PPE and occupational tasks on static balance, PPE post-work mean sway velocity was greater than pre-work PPE in the non-dominant leg eyes open condition ($z(28)=-3.10$, $p=0.002$, ES: 0.11). PPE post-work anterior-posterior RMS was greater than pre-work PPE in the dominant ($z(28)=-3.83$, $p<0.001$, ES: -0.83) and non-dominant leg eyes open ($z(28)=-3.50$, $p<0.001$, ES: -0.72), and the dominant leg eyes closed conditions ($t(28)=-3.26$, $p=0.003$, ES: -0.60). PPE post-work medial-lateral RMS was greater than pre-work PPE in the dominant ($z(28)=-3.08$, $p=0.002$, ES: -0.44) and non-dominant leg eyes open conditions ($z(28)=-2.63$, $p=0.009$, ES: -0.30). There was no effect of PPE in a non-fatigued state on static balance outcomes. In addition, there was no relationship between the relative change in static balance measures and work rate - cardiovascular index ($r \leq 0.43$, $p \geq 0.044$), and between fire suppression drill completion time and static and functional balance relative changes ($r \leq 0.46$, $p \geq 0.012$).

Figure 3 displays a comparison of FBT outcomes between conditions. There was no effect of occupational tasks on FBT time or PI. However, PPE negatively affected FBT measures. Specifically, FBT time ($z(30)=-4.80$, $p<0.001$, ES: -1.14) and PI ($z(30)=-4.86$, $p<0.001$, ES: -1.66) were greater in the pre-work PPE than uniform attire condition.

Table 2. Summary of static and functional balance outcomes by condition.

Station uniform - PPE														
	Mean Sway Velocity D_EO	Mean Sway Velocity ND_EO	Mean Sway Velocity D_EC	Mean Sway Velocity ND_EC	AP RMS D_EO	AP RMS ND_EO	AP RMS D_EC	AP RMS ND_EC	ML RMS D_EO	ML RMS ND_EO	ML RMS D_EC	ML RMS ND_EC	FBT Trial 2 Time	FBT Trial 2 PI
T score	0.107	—	—	—	0.843	—	0.099	—	—	—	—	—	—	—
Z Score	—	-0.412	-1.117	-0.901	—	-1.574	—	-0.402	-1.588	-0.235	-0.843	-1.489	-4.801	-4.86
p-value	0.916	0.681	0.264	0.367	0.406	0.116	0.922	0.688	0.112	0.814	0.399	0.136	<0.001	<0.001
Effect Size	0.019	0.115	0.311	0.145	0.151	0.217	0.018	-0.095	-0.118	-0.134	-0.057	-0.288	-1.141	-1.676
Pre occupational task PPE - Post occupational task PPE														
	Mean Sway Velocity D_EO	Mean Sway Velocity ND_EO	Mean Sway Velocity D_EC	Mean Sway Velocity ND_EC	AP RMS D_EO	AP RMS ND_EO	AP RMS D_EC	AP RMS ND_EC	ML RMS D_EO	ML RMS ND_EO	ML RMS D_EC	ML RMS ND_EC	FBT Trial 2 Time	FBT Trial 2 PI
T score	—	—	-0.492	—	—	—	-3.255	-1.533	—	—	—	—	—	—
Z Score	-1.168	-3.103	—	-0.616	-3.828	-3.503	—	—	-3.081	-2.627	-2.004	-0.897	-1.308	-0.465
p-value	0.243	0.002	0.627	0.538	<0.001	<0.001	0.003	0.137	0.002	0.009	0.045	0.370	0.191	0.642
Effect Size	-0.253	-0.509	-0.091	0.108	-0.830	-0.720	-0.604	-0.285	-0.444	-0.304	-0.401	-0.053	-0.245	-0.123

P-values in **bold** indicating statistical significant difference ($p < 0.01$) between Station uniform - PPE and Pre occupational task PPE - Post occupational task PPE. AP RMS: Anterior Posterior root mean square, ML RMS: Mediolateral root mean square, D_EO: dominant leg eyes open condition, ND-EO: non-dominant leg eyes open condition, D-EC: dominant leg eyes closed condition, ND-EC: non-dominant leg eyes closed condition.

Table 3. Bivariate correlations between work rate - cardiovascular index and static and functional balance outcomes.

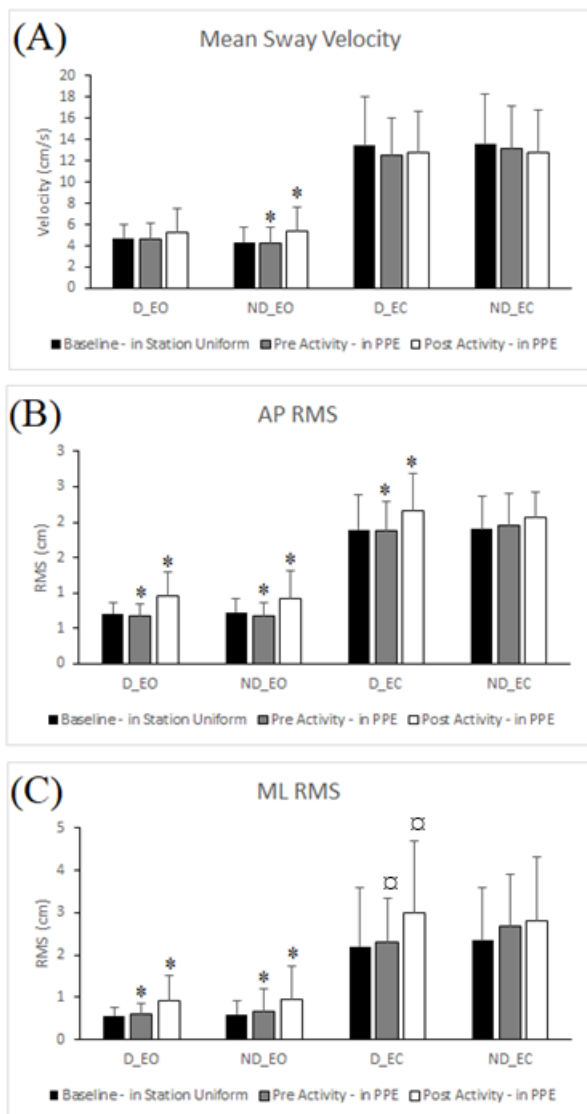
	Cardiovascular Index (Relative HR / Time)	
Cardiovascular Index (Relative HR / Time)	Pearson Correlation	1
	Sig (2-tailed)	
Relative Difference Score in Pre-Post Mean Sway Velocity D_EO	Pearson Correlation	-0.105
	Sig (2-tailed)	0.642
Relative Difference Score in Pre-Post Mean Sway Velocity ND_EO	Pearson Correlation	-0.170
	Sig (2-tailed)	0.449
Relative Difference Score in Pre-Post Mean Sway Velocity D_EC	Pearson Correlation	0.398
	Sig (2-tailed)	0.066
Relative Difference Score in Pre-Post Mean Sway Velocity ND_EC	Pearson Correlation	0.188
	Sig (2-tailed)	0.402
Relative Difference Score in Pre-Post AP RMS D_EO	Pearson Correlation	-0.241
	Sig (2-tailed)	0.280
Relative Difference Score in Pre-Post AP RMS ND_EO	Pearson Correlation	-0.419
	Sig (2-tailed)	0.052
Relative Difference Score in Pre-Post AP RMS D_EC	Pearson Correlation	0.039
	Sig (2-tailed)	0.864
Relative Difference Score in Pre-Post AP RMS ND_EC	Pearson Correlation	0.136
	Sig (2-tailed)	0.547
Relative Difference Score in Pre-Post ML RMS D_EO	Pearson Correlation	-0.091
	Sig (2-tailed)	0.686
Relative Difference Score in Pre-Post ML RMS ND_EO	Pearson Correlation	0.087
	Sig (2-tailed)	0.700
Relative Difference Score in Pre-Post ML RMS D_EC	Pearson Correlation	0.237
	Sig (2-tailed)	0.289
Relative Difference Score in Pre-Post ML RMS ND_EC	Pearson Correlation	0.073
	Sig (2-tailed)	0.748
Relative difference in Pre-Post FBT Trial 2 Time	Pearson Correlation	0.254
	Sig (2-tailed)	0.253
Relative difference in Pre-Post FBT Trial 2 PI	Pearson Correlation	0.434
	Sig (2-tailed)	0.044

AP RMS: Anterior Posterior root mean square, ML RMS: Mediolateral root mean square,

D_EO: dominant leg eyes open condition, ND-EO: non-dominant leg eyes open condition,

D-EC: dominant leg eyes closed condition, ND-EC: non-dominant leg eyes closed condition.

Figure 2. The effect of PPE and fire suppression tasks on static balance outcomes in structural firefighters.



*Significant difference ($p < 0.01$) between conditions.

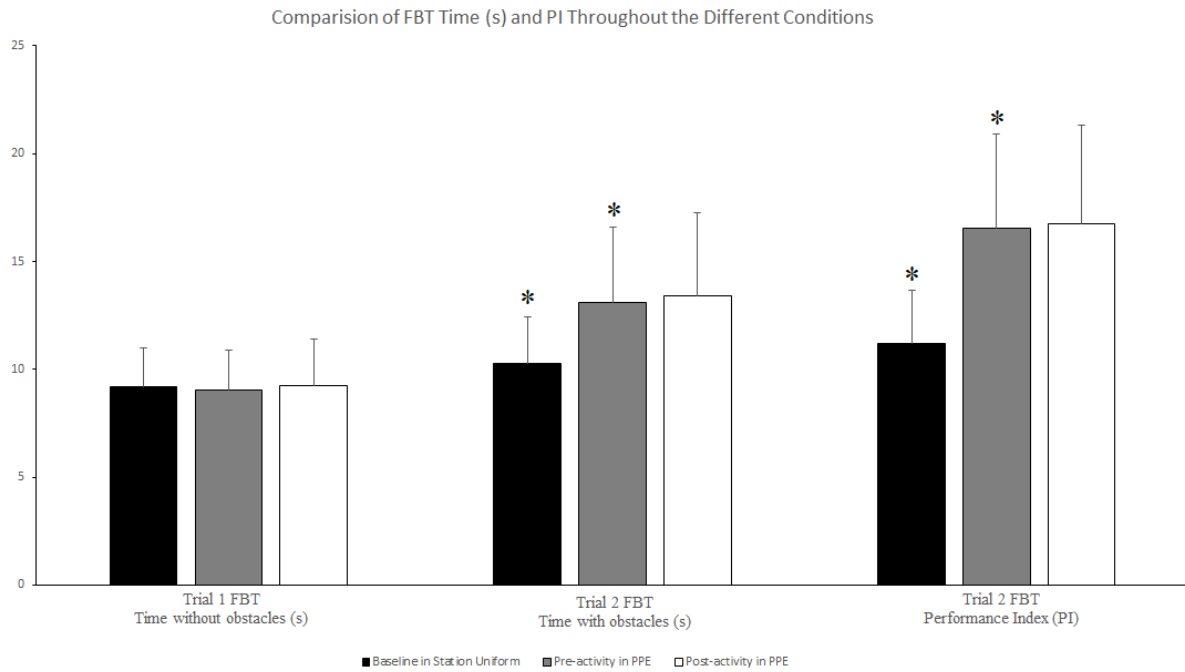
⊠Trending towards significant difference ($p < 0.05$) between conditions.

A: Mean sway velocity results from the static balance tests.

B: Anterior Posterior root mean square results from the static balance tests.

C: Medial Lateral root mean square results from the static balance tests.

Figure 3. The effect of PPE and fire suppression tasks on functional balance measures in structural firefighters.



*Significant difference ($p < 0.01$) between conditions.

CHAPTER 5

DISCUSSION

The purpose of this study was to examine the effect of PPE and occupational tasks on static and functional balance among structural firefighters. Interestingly, in a non-fatigued state, PPE did not affect static balance, which did not support our hypothesis. However, this finding is partially supported by Sobeih and coworkers (2006), who reported that the addition of PPE actually improved static balance outcomes among firefighters. The authors indicated that the additional external load could have lowered the center of gravity, which makes the person more "fixed" to the ground, which may enhance firefighters' stability in a static posture (Sobeih et al., 2006). In contrast, PPE impaired functional balance in a non-fatigued state, demonstrated by increased completion time, frequency of major and minor errors, and performance index, supporting our initial hypothesis. In this study, two trials of the FBT were performed in each condition, one trial without and one trial with obstacles. Interestingly, the time to complete the FBT without obstacles (i.e., not accounting for potential errors) was similar between PPE and non-PPE conditions (Figure 3.). However, using PPE with obstacles increased FBT completion time by 21% and the Performance Index by 32% (Figure 3.). Thus, when navigating fireground obstacles in PPE, firefighters moved more slowly and made more errors that may be associated with the risk of slip, trip, and fall injuries. These findings support previous research indicating that PPE impairs functional balance (Punakallio et al., 2003, Kong et al., 2012), albeit utilizing derivatives of this FBT. The physical properties of PPE may explain the impaired functional balance of firefighters in the present study. PPE is designed to protect firefighters from heat and toxic exposures. As such, the mass of the gear, especially the SCBA ($\approx 15\text{kg}$), may reduce

firefighters' ability to move quickly and accurately. Indeed, research has indicated that the addition of PPE (i.e., load carriage) reduces firefighters' work rate when performing a set of simulated fireground tasks (Lesniak et al., 2020). Further, mobility may be restricted by the bulky nature of the turnout gear, stiffness and weight of the boots, and potential contact between the helmet and air cylinder when bending under overhead obstacles. The bulky nature of PPE causes a gradually decreased range of motion in various movements, such as shoulder adduction, abduction, flexion, and lumbar rotation (Son et al., 2022). Collectively, these PPE factors appear to negatively affect firefighters' functional balance.

In addition to the effects of PPE, this study also investigated the effects of occupational tasks on static and functional balance outcomes. Our hypothesis was supported by the current findings, they demonstrated significant impairment in multiple static balance measures, including sway velocity and excursion. Similarly, Games and colleagues (2020) reported that static balance measures deteriorated among firefighters following exercise performed in thermal protective gear, as well as White & Hostler (2017), who also found that an exertion protocol performed in PPE negatively impacted multiple static balance outcomes. In general, physical activity has been shown to impair static balance measures in many studies and different settings (Zemkova et al., 2022). There are numerous physiological mechanisms that may be responsible for reductions in static balance outcomes. Specifically, fatigue is associated with postural sway and delayed onset of force generation, which may reduce joint stabilization (Lundin et al., 1993; Tropp et al., 1984; Yaggie & McGregor, 2002) and increase the risk of slip, trip, and fall injuries. Furthermore, residual fatigue is associated with a host of audio-visual and proprioceptive impairments (Derave et al., 2002; Hashiba et al., 1998; Lepers et al., 1997; Mello et al., 2009), which are reflected in attenuated static balance measures.

Interestingly, this study indicated that the occupational tasks appeared to preferentially affect the eyes-open static balance outcomes compared to eyes closed conditions (Figure 2). In eyes-open conditions, healthy individuals rely ~70% on their somatosensory, ~10% on visual, and ~20% on the vestibular system (Horak, 2006). In eyes closed condition the contribution of visual input is removed, resulting in greater reliance on the somatosensory and vestibular systems. In fatigued conditions, the somatosensory system is altered due to fatigue from occupational work. General muscular exercise/occupational work generates physiological interference and alteration of both the sensory receptors, and motor output for postural maintenance (Paillard, 2012) resulting in additional interference in the somatosensory system, which would impact those static balance measures even more.

Despite the negative effect of occupational tasks on static balance outcomes, the tasks, which were performed in ambient outdoor temperatures, did not impact functional balance, which falsified our hypothesis regarding the effect of occupational task on functional balance. These findings are supported by previous research. Specifically, Games and colleagues (2020) demonstrated that functional balance was not impaired by previous exercise performed in cool (14.24 °C) ambient temperatures among firefighters. However, this investigation indicated that performing the same exercise in a hot and humid environment negatively impacted functional balance (Games et al., 2020). Furthermore, exposing firefighters to heat alone did not impact functional balance, indicating that combining heat and physical activity may have a synergistic effect on functional balance. Therefore, it is possible that if the present study was replicated in a hot environment, decrements in functional balance may have been observed. Similarly, Angelini et al. (2018) found that vertical and horizontal boot clearance of ground obstacles decreased after performing simulated occupational tasks in hot ambient conditions (using an environmental

chamber and live burn building) but not after treadmill walking in normal temperature conditions. These findings further highlight the apparent importance of hot ambient temperature on functional balance and thus risk of slip, trip, and fall injuries among structural firefighters.

The work rate – Cardiovascular index was created and used as a surrogate measure of aerobic fitness and attempted to account for the internal load (i.e., peak HR) experienced relative to external workload (i.e., work rate or fireground completion time). One may hypothesize that a firefighter with greater cardiovascular fitness would produce a lesser peak HR relative to work rate. However, there was no relationship between the Work rate – Cardiovascular Index and relative change in pre/post fireground task static balance measures. This is interesting given that researchers have reported a significant positive correlation between a 12-min walk test distance and static balance among older men (Islam and colleagues, 2004). Thus, the lack of relationship in the present study may have occurred because the index relied on peak HR, not average HR, which is more reflective of cumulative internal load. Further research is warranted to investigate the relationship between cardiovascular fitness and static balance outcomes.

In this study, the average fire suppression drill completion time was 6.1 minutes. There is no set occupational task list/fire suppression drill that has been used in various studies therefore it is hard to compare our completion times to previous studies where their activities ranged from 14-20 minutes (Sobeih et al., 2006; White & Hostler, 2016; Hur et al., 2013; Angelini et al., 2018). This study highlights that even after a short amount of time static balance is noticeably impaired. When firefighters use a 30- or 60-minute cylinder it may last 15-30 minutes depending on the bottle and the firefighter. With those bottles, firefighters could have performed the tasks 2-5 times, which would yield 2-5 times longer activity, and more fatigue accumulating in the body. Hypothetically the changes we observed could be amplified by 2-5

times after the long work assuming they keep the same pace as they did in our 6.1-minute session. On average across the significant changes, we observed a 25% decrement in static balance measures. It is possible that these decrements would have got worse by several orders of magnitude if activity continued for a longer period, potentially observing not only 25% but an even higher percentage of static balance impairments.

Limitations

There were a few limitations to this study. While our sample size has adequate statistical power for most of the data, we are missing some other crucial data such as heart rate measures. While 32 firefighters participated, only 24 maximal heart rate was recorded due to faulty equipment during the first day of data collection. The missing heart rate could have played a role in not finding any correlation between our Work rate – Cardiovascular Index and the static balance measures. The equipment used in the study could also be included in the list of limitations. For static balance measure, BtrackS™ Assess Balance System (San Diego, CA, USA) was used, even though it has been validated by various studies, specifically O'Connor and colleagues (2016) indicated that BtrackS™ Assess Balance System had a <1% magnitude of error compared to force platform, and it can serve as a low-cost solution for balance testing; however, force platforms are considered to be the gold standard when it comes to measuring the ground reaction forces and moments involved in human movements. Another limitation is the fact that there was only a single trial of the FBT, limiting our ability to report reliability on this specific test. Furthermore, FBT time was measured by stopwatch potentially adding additional human error as inconsistent reaction time when starting and stopping the stopwatch. The weather may have affected the results as testing was conducted over three days, where each shift completed the tests on a different day; however, the weather was pretty consistent (Temperature:

61±6.2 °F, Humidity: 82±20.8%). Previous studies have indicated that additional heat next to fire suppression drill heavily impacts balance outcome measure therefore, another limitation of ours was not using heat in this study. Moreover, the data were collected on the days when firefighters were on a work shift as it was part of the fire department's training. Testing on a shift day could have caused additional stress to the firefighters or influenced their effort and focus levels which could have interfered with the balance measures. To avoid the limitations, future studies should collect data on the same day or test in a controlled environment, test the firefighters when they are not working, and use force platforms to collect static balance measures.

Practical Applications

The present study indicated that PPE had no impact on static balance however, it had decremental effects on functional balance. When considering other research, the addition of PPE makes firefighters more stable however, the bulkiness of the gear negatively affects functional balance drastically, causing an increased risk for slip trip and fall injuries. A recommendation for PPE development would be to create gear that is less bulky and made from a more flexible material to enhance movement proficiency in PPE, especially among smaller stature and female firefighters. In addition, the findings indicated that occupational tasks negatively impacted static balance indicating that the neuromuscular fatigue might increase the risk for slip trip and fall injuries. Balance training has been found to improve balance performance among different populations (Emery et al., 2005; Steadman et al., 2003) therefore, to offset these postural stability decrements, balance training should be incorporated into firefighters' training as well. Furthermore, balance training alone has been proven to decrease risk of ankle injuries as well (Attar et al., 2022).

Conclusion

Balance is an essential component of the firefighter profession. Balance perturbations can lead not only to the firefighter getting injured but potentially threaten civilian lives. Balance can be affected by many variables. PPE negatively impacted firefighters' functional balance. In contrast, occupational tasks had a negative effect on static balance outcomes. These findings highlight the importance of the utilization of countermeasures to combat load carriage and occupational fatigue-induced decrements in neuromuscular function to reduce injury risk among structural firefighters.

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APPENDIX A

IRB APPROVAL



Institutional Review Board (IRB)
 PO Box 8005 • STATESBORO, GA 30460
 Phone: 912-478-5465
 Fax: 912-478-0719
 IRB@GeorgiaSouthern.edu

To: Melton, Bridget
 Klibert, Jeff; Grosicki, Greg; Cleveland, Richard; Kis, Petra

From: Georgia Southern Institutional Review Board

Amendment Approval Date: March 8, 2023

Current Expiration Date: February 28, 2023

Original Approval Date: March 12, 2019

Subject: Status of **Modification Request** for Approval to Utilize Human Subjects in Research
 Amendment #: 7
 Originally Approved By: **Medical Board**

After a review of your Extension Request for the following research project, it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable

Protocol #: H19098
Title: Physiological Profile of First Responders in Southeast United States
Maximum Number of Subjects: 500

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your extension and modification.

Modification Description: Addition of Petra Kis as Co-PI;
 Removal of Thomas Nagel as research assistant;
 Removal of Sarah Lanham as research assistant;
 Addition of balance protocol as an option for the fitness protocol;
 Updated consent form to reflect balance protocol language.

Special Conditions: None

Please provide the IRB with any information concerning any significant adverse event, whether or not it is believed to be related to the study, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator prior to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a Research Study Termination form to notify the IRB Coordinator, so your file may be closed.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

Health Risks Among Fire Fighters

Jahnke, S. A., Poston, W. S. C., Jitnarin, N., & Haddock, C. K. (2012). Health concerns of the U.S. fire service: perspectives from the firehouse. *American Journal of Health Promotion, 27*(2), 111–118. <https://doi.org/10.4278/ajhp.110311-qual-109>

Health is extremely important in the fire department since they are the first responders, they have to be in good health to do their job well. The article Health Concerns of the US fire service: Perspective from the Firehouse lists the various health concerns and risks that apply to firefighters, such as cancer, cardiovascular diseases, physical activity and fitness, sleep, nutrition, mental health, and injuries. Importantly, this article has some great highlights and quotes straight from the firehouse allowing us to have a better understanding of the health concerns of the firefighters straight from the source.

Ras, J., & Leach, L. (2022). Relationship between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service. *Inquiry, 59*, 004695802210844. <https://doi.org/10.1177/00469580221084485>.

This article took place in South Africa, Cape Town. 124 full-time firefighters participated in this study. The purpose of this study was to determine the relationship between physical activity and coronary artery disease risk factors, between CAD risk factors and musculoskeletal injuries, and between physical activity and musculoskeletal injuries. The article's hypothesis was proven by the study, according to the results leisure time physical activity and physical inactivity were significantly related to aging, obesity, and cigarette

smoking. Furthermore, the prevalence of musculoskeletal injuries was 27.4%, and the most common musculoskeletal injury was found to be shoulder injuries. Age, BMI, and cigarette smoking were significant predictors of physical inactivity in this study. This article shows the prevalence of physical inactivity and aging, cigarette smoking, and BMI in firefighters. Unlike other articles, shoulder injury was the most common musculoskeletal injury among firefighters.

Elliot, D. L., & Kuehl, K. S. (2007). Effects of sleep deprivation on firefighters and EMS responders (Final Report to International Association of Fire Chiefs [IAFC]). Portland, OR: Oregon Health & Science University.

This report from 2007 is an incredibly detailed report on the effects of sleep deprivation on firefighters and EMS responders. This source discusses the physiological effects of sleep deprivation, the transportation industry and sleep deprivation, postgraduate medical training and sleep deprivation, firefighters, EMS responders, and sleep deprivation, and the measures to effectively manage work hours. Importantly the main part I will use in this article is the firefighters, EMS responders, and sleep deprivation section. Since it is such a huge issue among firefighters. They are shift workers, meaning they could be working 24to72 hours long shifts which can cause sleep deprivation among them.

Smith, D. L., Horn, G. P., Goldstein, E., & Petruzzello, S. J. (2008). Firefighter fatalities and injuries: the role of heat stress and PPE. *Illinois Fire Service Institute*

The leading cause of on duty-death is heart attacks and one of the largest portions of fire ground injuries come from slip, trip, and fall. For that reason, this project studied how heat stress may be a common causal factor in both firefighter heart attacks and slips, trips, and falls. 122 make fighters participated in the study across the state of Illinois.

Some of the major findings were that a large portion of the firefighters were overweight, and a large number were pre-hypertensive or hypertensive. Furthermore, firefighting activity causes significant physiological disruption, such as increased heart rate and increased core temperature. Wearing PPE had significant determinants of gait and balance measures regardless of the type of PPE. This article created some recommendations after their finding, such as extreme obesity should be considered a disqualifying condition, fire departments should include defined cardiovascular standards in the hiring/recruiting process. To reduce slip, trip, and fall injuries training should include exercises to improve balance. Importantly this article provides some great recommendations to reduce death and injuries among firefighters. This article also provides blood work and affects blood work by activity.

Firefighter Injury Background

Szubert, Z., & Sobala, W. (2002). Work-related injuries among firefighters: sites and circumstances of their occurrence. *International Journal of Occupational Medicine and Environmental Health*, 15(1), 49-55.

The purpose of this study was to determine the injury ratio, causes, and duration of temporary work disability from on-duty injuries. 29 fire stations took part in the study in Poland. Data was conducted from the human resources department and the safety services. Results suggested that most injuries occurred during the compulsory physical training activities which caused 41% of the post-injury absence at work. Furthermore, according to the result, employees who worked there for less than 1 year had a higher risk of injury than the ones who worked there longer. Injuries during emergency operations accounted for 25% of all injuries and resulted in 24% of post-injury absences. Data

suggests that frequency of injury and age are not dependent however the increasing age increased the duration of work disability. Importantly this article is a major source of sites and circumstances of injuries among firefighters. Furthermore, it is a major source for various injuries and post-injury disability duration among Polish firefighters.

Hong, O., Phelps, S., Feld, J., & Vogel, S. (2012). Occupational injuries, duty status, and factors associated with injuries among firefighters. *Workplace Health & Safety*, 60(12), 517-523.

This study is assessing the type of occupational injuries, duty status, and factors that are associated with injuries among firefighters. The study was conducted across 3 U.S States with a total of 437 participants. The study was conducted through only surveys from the firefighters, the survey questions were focusing on firefighters' whole career and not just one specific year, and most of the questions included "Have you ever experienced...".

This study found approximately 66% of the participants suffered from occupational accidents or injuries. The most reported injuries were muscle sprains or strains (74%), upper or lower extremity injuries (60%) back injuries (54%) burns (28%), hazardous chemical exposures (15%), broken bones (12%), and needle stick injuries (12%). This article summarizes the type of occupational injuries and related duty status, furthermore it also identified demographic and work-related characteristics that were associated with reported occupational injuries. Importantly this article helps to see the various injuries among firefighters and their effect on-duty status. More than 50% of the participants reported no-duty status, 46.3% reported modified duty status and 31.9% reported both no-duty and modified duty status due to occupational injuries.

Campbell, R., & Evarts, B. (2021). United States firefighter injuries in 2020. National Fire Protection Association. <https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Emergency-responders/osffinjuries.pdf>

The report from 2020 about firefighter injuries in the United States the statistics about firefighters in 2020. It lists how many injuries occurred, the number of exposures to infectious diseases, the nature of the injuries, and where and how the incident occurred. This report is a reliable source to use for firefighter injuries. According to the article most of the injuries are accounted for by the fire ground. Furthermore, the leading injury is said to be muscle pain, strain, and strain. The leading cause of injury on the fire ground was overexertion followed by falls, jumps, and slips. Importantly this source shows one of the most recent statistics about firefighters' injuries, including the type of injuries, the injuries by the type of duty, the nature and causes of injuries, and injuries by year on both fire ground and non-fire emergencies.

Heineman, E., Shy, C. M., & Checkoway, H. (1989). Injuries on the fireground: Risk factors for traumatic injuries among professional fire fighters. *American Journal of Industrial Medicine*, 15(3), 267–282. <https://doi.org/10.1002/ajim.4700150304>.

This article was published in 1989. The subjects of this study were active firefighters who lost work time due to injuries such as smoke inhalation, burns, or falls. The article lists participants, the injuries they recorded, and the fires throughout the study. It also compares the characteristics and the injuries correlated with those characteristics.

According to the article over three-quarters of the burns involved the head, face, neck, hands, and or wrist, of these burns 32% were first degrees, 65% were 2nd degrees, and 1 third-degree burn. two -thirds of the falls resulted in sprains, primarily on the back and

the knee. Of the injured firefighters, 90% were off duty for more than 3 days due to their injuries suffered on-site. According to the study, SCBA is associated with falls but not with burns. Importantly, this article lists the various risk factors among firefighters. According to the study, SCBA use was associated with fall risk with an 11.8 odd ratio, furthermore truck members had a higher risk of falls with a 17.7 odd ratio.

Karter, M. J. (2009). *Patterns of firefighter fireground injuries*. Massachusetts: National Fire Protection Association.

The *Patterns of FFI 2009* summarizes the patterns within firefighters and all their injuries. It lists the injuries' occurrence, what the specific injuries are, the percentage breakdown of the injuries, the leading causes of injuries, the activities that lead to injuries, and so on. The data for this article comes from 2003-2006. Importantly this document is a major source to get facts about firefighters' injuries, it is a very detailed document about firefighters and their injury patterns.

Frost, D. M., Beach, T. A., Crosby, I., & McGill, S. M. (2015b). Firefighter injuries are not just a fireground problem. *Work-a Journal of Prevention Assessment & Rehabilitation*, 52(4), 835–842. <https://doi.org/10.3233/wor-152111>

The study by D.M Frost was conducted over five years, between 2007 and 2011 from a large Canadian Metropolitan fire department. This study aimed to categorize the injuries sustained by firefighters by job duty, motion pattern, and injury type and location.

According to the result over the 5 years, 1311 injuries were reported, of which over 60% were categorized as musculoskeletal disorder (MSD). The most common MSDs affected the back, knees, ankles, and shoulders. Cuts and lacerations were the most common non-

MSDs. Importantly this article brings attention to the injuries suffered by firefighters, it breaks down the injuries by job duty, motion pattern, and type and location.

Orr, R. M., Simas, V., Canetti, E., & Schram, B. (2019). A Profile of injuries sustained by firefighters: A critical review. *International Journal of Environmental Research and Public Health*, 16(20), 3931. <https://doi.org/10.3390/ijerph16203931>

This review aimed to identify, critically appraise, and synthesize key findings from recent literature investigating firefighting musculoskeletal injuries to develop a profile of the injuries experienced by this unique population. Of 8231 studies 17 made it through the screening and were used for this review. The main findings of this critical review formed 4 main categories. The categories were 1 musculoskeletal injury incidence in firefighters, 2 commonly injured body sites, 3 common natures of injury, and the last common mechanisms of injury. According to the review, the w most common sites were the back and lower extremities of the body. The most common nature of the injury was sprains and strains. The other most common nature was wounds, cuts, lacerations, and contusions. The most common mechanisms of injury were wound to be slips, trips, and falls, the second most common was bending, lifting, and squatting. Importantly, this review provides an overall report of all the injuries, sites of injuries, and mechanisms of injuries. This review is a great summary of various articles about injuries in firefighters. Furthermore, this review compares the firefighting population to other tactical populations.

Butry, D. T., Butry, D. T., Webb, D., Gilbert, S., & Taylor, J. (2019). *The economics of firefighter injuries in the United States* (p. 44). Gaithersburg, MD, USA: US Department of Commerce, National Institute of Standards and Technology.

<https://doi.org/10.6028/NIST.TN.2078>

This report summarizes, identifies, and evaluates data and literature from firefighters' economic costs among their injuries. This source lists all the firefighters' injuries, illnesses, health exposures, and occupational diseases. It also talks about the economic burden that comes with any of those injuries, illnesses, health exposures, and occupational diseases. Furthermore, it talks about the data gaps that exist in the literature about firefighters such as cancer, mental health, and numerous others. This report provides a great cost report for firefighter incidents as well. Importantly this report helps provide a background on the data on firefighter injuries and their costs, it includes multiple tables about firefighters' injuries and the cost they come with, and it lists the economic burden that follows an incident in the fire department. Furthermore, it also identifies the research gaps.

Slip Trip and Fall Injuries among Fire Fighters

Rosengren, K. S., Hsiao-Wecksler, E. T., & Horn, G. P. (2014). Fighting Fires Without Falling: Effects of Equipment Design and Fatigue on Firefighter's Balance and Gait. *Ecological Psychology*, 26(1–2), 167–175. <https://doi.org/10.1080/10407413.2014.875357>

The article *Fighting Fires without Falling: Effects of equipment design and Fatigue on Firefighter's Balance and Gait* examines the potential cause of slips, trips, and falls. One of the leading causes of injuries among firefighters comes from slips, trips, and falls. This article examines how various factors associated with the firefighter, specific tasks involved in firefighting, and the environment relate to the occurrence of slips, trips, and falls. According to this article, inexperience is one of the causes of falls, furthermore personal protective equipment decreases balance abilities and worsens gait as well.

Moreover, the environment of the workplace is also one of the potential causes of slips, trips, and falls. Importantly, this article is a great source for potential causes of slips, trips, and falls among firefighters. It lists potential risks and why they are considered a risk as well.

Kong, P. W., Suyama, J., & Hostler, D. (2013). A review of risk factors of accidental slips, trips, and falls among firefighters. *Safety Science*, *60*, 203–209.

<https://doi.org/10.1016/j.ssci.2013.07.016>

The article *A review of risk factors of accidental slips, trips, and falls among firefighters* was conducted on the financial cost of slips, trips, and falls among firefighters, but mainly works with the factors that could influence slips, trips, and fall occurrence. It lists out all the factors and explains why they are risk factors. Both intrinsic (balance, age, experience, muscular strength and fitness, body mass, fatigue) and extrinsic factors (personal protective equipment, impaired vision, surface condition, heat) are widely discussed in the article. Importantly, this article provides a great breakdown of both intrinsic and extrinsic factors that could increase the risk of accidental slips, trips and falls. The intrinsic and extrinsic factors are further broken down into multiple factors such as fatigue, balance, PPE, reduced vision, and many more.

Poplin, G. S., Harris, R. K., Pollack, K. M., Peate, W. F., & Burgess, J. L. (2012). Beyond the fireground: injuries in the fire service. *Injury Prevention*, *18*(4), 228–233.

<https://doi.org/10.1136/injuryprev-2011-040149>

This study was conducted between 2004 and 2009. The purpose of the study was to look more into the injuries beyond the fireground incidents. Data was collected from 21 fire stations. Data collection included the nature of the injuries, agent, mechanism, body

location, environment, abbreviated injury scale, functional capacity index, and lost time status. Results showed that the mean age of those injured was 17.9, and 64% of injuries were among those in their 30s and 40s. Most of the injuries occurred between 7 am and 1 pm, the time when most of the training drills and exercises were performed. 95% of the injuries were classified as minor, and 3.2% were moderate injuries. Results showed that one-third of the injuries were caused by physical exercise activity, 16.9% were patient transport, 11.1% were training, and 10.2% came from a fire ground operation. According to the article strains and sprains were the most common injuries. This article shows that only a small portion of the injuries occur on the fire ground. This study also supports that the most common injury types are musculoskeletal injuries such as sprains and strains among firefighters.

Fatigue / Overexertion and Falls among Fire Fighters

McNulty, L. A., Dyal, M., DeJoy, D. M., & Smith, T. M. (2020). Firefighter overexertion: A continuing problem found in an analysis of non-fatal injury among career firefighters. *International Journal of Environmental Research and Public Health*, 17(21), 7906. <https://doi.org/10.3390/ijerph17217906>

The article *Firefighter overexertion: a continuing problem found in an analysis of non-fatal injury among career firefighters* aimed to provide an update on injury occurrences specific to career firefighters. The study lasted for 2 years; data was collected from 2 large metropolitan fire departments in the US. This study confirms that the largest source of injury among firefighters is over exhaustion, over exhaustion could cause further decremental effects on the body which increases the risk of exposures resulting in injury. Importantly, this article provides a great breakdown of the distribution of causal

factors/exposures of reported injuries among the 2-fire department participating in the study.

Walton, S. M., Conrad, K. M., Furner, S. E., & Samo, D. G. (2003). Cause, type, and workers' compensation costs of injury to fire fighters. *American Journal of Industrial Medicine*, 43(4), 454–458. <https://doi.org/10.1002/ajim.10200>

The article by Surrey M. focuses on the measures of cause, nature, and cost of injury among firefighters. This study is a cross-sectional study, data were collected between the years 1992 and 1999. For the cause of injury categories were created, these categories included overexertion, lifting, pushing or pulling, reaching or throwing, and various others. Results suggested that the most common cause of injury was overexertion followed by burns, slip trips, or falls. Data shows the most common nature of the injury was straining/sprains, followed by others combined and cuts/lacerations/fractures. According to the data overexertion-related injuries were associated with high workers' compensation costs, higher than other causes. This study suggests that overexertion is one of the costliest sources of injury, furthermore, overexertion also caused the most injuries among the firefighter within the studies time period. Just like other articles, this one suggests that sprains and strains are the most common nature of injuries.

PPE Background

Taylor, N. A., Lewis, M. C., Notley, S. R., & Peoples, G. E. (2012). A fractionation of the physiological burden of the personal protective equipment worn by firefighters. *European Journal of Applied Physiology*, 112(8), 2913–2921. <https://doi.org/10.1007/s00421-011-2267-7>

In this study, 3 different trials were used to determine the effect of PPE on firefighters'

performance. They had 2 low-intensity trials including walking and stepping and one high-intensity trial, which was an obstacle course. The study aimed to provide information on the physiological burden associated with each piece of protective equipment. Results showed a decrease in obstacle course performance in all subjects, a 27% decrease was seen in performance in the high-intensity obstacle course trials. Furthermore, the complete PPE reduced exercise tolerance by 56% across all subjects. Results suggest that from the whole PPE, the boots create the greatest metabolic demand. Importantly, this article not only proved the complete PPE effect on performance but also provides the different equipment effects individually as a fraction as well. While most articles suggest that the self-contained breathing apparatus has the biggest effect since it is the heaviest, this is the first article that indicates that the boots have the biggest impact on performance.

Balance / Influence of Balance on Firefighters

Games, K. E., Winkelmann, Z. K., & Eberman, L. E. (2020). Physical Exertion Diminishes Static and Dynamic Balance in Firefighters. *International Journal of Athletic Therapy and Training*. <https://doi.org/10.1123/ijatt.2019-0063>

The article *Physical exertion diminishes static and dynamic balance in Firefighters* was designed to study the effects of physical exertion on static and dynamic balance within firefighters. For static balance, they used an AMTI force plate to measure rectangular displacement with 3 sets of eyes open double leg trials and 3 sets of eyes open single leg (dominant leg) trials. To assess the dynamic balance, they used the Y balance test, 3 times in every direction. Both balance tests were performed in their PPE gear.

Importantly this study has shown decreased balance ability in both dynamic and static

balance among firefighters after post-activity. This article suggests that physical exertion has detrimental effects on balance measures.

Sobeih, T. M., Davis, K. G., Succop, P. A., Jetter, W. A., & Bhattacharya, A. (2006). Postural balance changes in on-duty firefighters: effect of gear and long work shifts. *Journal of Occupational and Environmental Medicine*, 68-75.

The aim of the *Postural balance changes in on-duty firefighters: effect of Gear and long work shifts* study was to investigate the impact of long work shifts and turnout gear on postural stability in firefighters. To analyze balance 3 tests were performed on the force plate, eyes open double leg standing still for 30 seconds, eyes closed on a foam pad double leg standing still for 30 seconds and the last one was a reaching task, the subject stood on the platform for 8 seconds than instructed to lift a 5 lbs. weight 4 times and stand still for the remaining part of the 30 seconds. Results suggest as the task becomes more difficult the postural stability decreases with it. Furthermore, it suggests that the turnout gear with and without SCBA improved postural stability. However, postural stability decreases as firefighters spend more time on duty. Importantly, this article shows how the firefighters' gear could impact balance as well as the time spent on duty. It also suggests that the decreased postural stability caused by long shifts could be a potential contributor to accidental slips, trips, and falls.

Kong, P. W., Suyama, J., Cham, R., & Hostler, D. (2012). The relationship between physical activity and thermal protective clothing on functional balance in firefighters. *Research Quarterly for Exercise and Sport*, 83(4), 546-552.

The article *The Relationship Between Physical Activity and Thermal Protective Clothing on Functional Balance in Firefighters* examines the relationship between baseline

physical training and the use of firefighter thermal protective clothing (TPC) with breathing apparatus on functional balance tests. Participants were split up into groups by their physical activity. There were 4 conditions for the balance testing, the first was wearing regular clothing and shoes, the second was wearing TPC without SCBA, the third and fourth condition was wearing TPC and SCBA, in the 3rd one participants carried the mask around their neck, and in the last one, they were wearing the mask. Balance testing was done on a special beam, they started from the end walks to the other end which was 2.45m long then turned 180 on the beam and walked back to the start. Participants were instructed to walk as fast as possible but also as accurately as possible. Balance trials were scored. The study found that firefighters slow down their movement when wearing TPC, furthermore, it suggested that SCBA impairs balance among those who do not participate in regular resistance training. Importantly, this article shows a new view toward balance and physical activity. The balance test they use is very specific to the population. However, unlike other articles, this one did not suggest impairment in balance with the fire-specific equipment.

White, S. R., & Hostler, D. (2017). The effect of firefighter protective garments, self-contained breathing apparatus and exertion in the heat on postural sway. *Ergonomics*, *60*(8), 1137–1145. <https://doi.org/10.1080/00140139.2016.1257162>

The purpose of this study was to examine the effects of thermal protective clothing (TPC) and self-contained breathing apparatus (SCBA) on postural control during quiet standing before and after a heavy physical exertion protocol. Furthermore, an additional purpose was to investigate 2 different cylinder masses on the same postural control trials. 12 college-age students were recruited as participants. The first thing they had was a

baseline balance measure in long pants, a shirt, and athletic shoes, then the exertion protocol conditions were conducted on 3 separate days. The exertion protocol was performed in a heated environmental chamber. Balance measures were quantified by center of pressure (COP) position, and root mean square COP variability. According to the results, COP excursion and variability increase with exertion in the TPC and the SCBA conditions. The different cylinder masses had no significant effect on balance measures. Importantly this article agrees with other articles that TPC and SCBA affect balance measures negatively which increases the risk of slips, trips, and falls. This article also shows various balance measures and not just the center of pressure movement, which helps understand the balance decrements even more.

Kollock, R. O., Thomas, J. K., Hale, D., Sanders, G. J., Long, A. B., Dawes, J., & Peveler, W. W. (2021). The Effects of firefighter equipment and gear on the static and dynamic postural stability of fire cadets. *Gait & Posture*, 88, 292–296.

<https://doi.org/10.1016/j.gaitpost.2021.05.034>

The article by R. Kollock investigates the effect of firefighter equipment and gear on static and dynamic postural control among fire cadets. 26 male fire cadets were participating in the study. The study's main outcome measures were limits of stability (LoS) and dynamic postural stability index (DPSI). The DPSI cadets were asked to perform 3 single leg landings on a force plate and data was collected followed by the landing for 3 seconds. Participants completed 2 static balances as well. The dynamic and static balance tasks were performed with and without firefighter equipment and gear. According to the study, only the dynamic balance tasks showed significant differences among the gear and no gear trials. Studies suggest that firefighter equipment and gear

may have a significant impact on balance measures. Importantly, this article not only compared the static balance measures among the fire cadets but the dynamic balance as well. For the dynamic balance, they used a specific landing task that could mimic a fire ground environment.

Brown, M., Char, R. M. M. L., Henry, S. O., Tanigawa, J., & Yasui, S. (2019). The effect of firefighter personal protective equipment on static and dynamic balance. *Ergonomics*, 62(9), 1193–1201. <https://doi.org/10.1080/00140139.2019.1623422>

The article by M. Brown was investigating the effect of firefighter personal protective equipment (PPE) on static and dynamic balance among firefighters. The purpose of the study was to quantify the effects of PPE on balance measures. 3 different balance measures were performed with each condition, static single leg, dynamic single leg balance test, and limits of stability test. The four different conditions were athletic clothing which served as control, turnouts, turnouts + SCBA, and turnouts + SCBA + mask. According to the article, the turnouts + SCBA and the turnouts + SCBA + mask conditions negatively affect dynamic balance. These results suggest that the mask has the most effect on balance. Importantly, this article studied 3 different balance tests to see the different effects on balance measures with the 4 different conditions. This is one of the few studies that studied firefighting gear so broken down and suggested that the face mask might be the most significant piece of equipment when it comes to balancing impairments.

Hur, P., Rosengren, K. S., Horn, G. P., Smith, D. L., & Hsiao-Wecksler, E. T. (2014). Effect of protective clothing and fatigue on functional balance of firefighters. *Journal of Ergonomics*, S2(02). <https://doi.org/10.4172/2165-7556.s2-004>

This study was investigating the effect of protective clothing and fatigue on functional balance of firefighters. The purpose of the study was to examine the effects of wearing personal protective equipment (PPE) and the design of PPE, and strenuous firefighting activity on functional balance. Two different PPE were tested, one of them was the standard and the other one was the enhanced PPE which was a lighter version of PPE. A functional balance test was used to assess the functional balance of firefighters. The balance test included stepping up, stepping down, turning, walking along a beam, and passing under an obstacle. A functional balance test was performed 3 times, a baseline in the station uniform, a pre-activity test in PPE, and post-activity with PPE after a live-fire stimulated fire ground activity. According to the results, PPE significantly impaired functional balance by slowing down movement speed and increasing errors. The strenuous activity resulted in slower performance speed and fewer errors. The 2 different PPE did not have a significant difference in performance. This article shows the effect of PPE on functional balance. This is the first article that suggested decreased balance errors after activity. However, they suggested that firefighters trade off speed for accuracy in need of greater caution.

Games, K. E., Winkelmann, Z. K., McGinnis, K., McAdam, J., Pascoe, D. D., & Sefton, J. M. (2020). Functional performance of firefighters after exposure to environmental conditions and exercise. *Journal of Athletic Training*, 55(1), 71–79. <https://doi.org/10.4085/1062-6050-75-18>

This article aimed to examine the effect of environmental conditions, including hot and ambient temperatures, and exercise on functional and physiological outcome measures, including balance, rectal temperature, and perceived exertion. 13 subjects participated in

the study. The study included 3 conditions, exercise in the heat, standing in the heat, and exercise in ambient temperature, all conditions were performed in gear. Furthermore, all 3 functional balance testing (pre-intervention, post-intervention, post-recovery) were performed in their gear as well. Balance testing was conducted through a balance test that was specifically developed for firefighters, using a performance index (PI) to score balance performance in the study. According to the results PI was negatively affected by exercise. The rectal temperature increased in all testing conditions. According to the results neither exercise nor heat alone influenced balance but rather the conditions combined. Importantly this article suggests that balance is affected by exercise and temperature together but not by themselves. Furthermore, it is a great source for functional balance testing. Their balance testing was specifically created for firefighters.

Load Carriage Effect on Fire Fighters

Park, K. U., Hur, P., Rosengren, K. S., Horn, G. P., & Hsiao-Wecksler, E. T. (2010). Effect of load carriage on gait due to firefighting air bottle configuration. *Ergonomics*, 53(7), 882–891. <https://doi.org/10.1080/00140139.2010.489962>

The purpose of the *Effect of load carriage on Gait due to firefighting air bottle configuration* article was to investigate the effects of different bottle configurations on gait performance, they used kinematic and kinetic measures with slow and fast walking over 3 walking conditions and 4 bottle variations. The participants were volunteers and career firefighters. Data suggests that the mass of the bottle had a significant effect on gait performance while the size of the bottle did not make a difference. Importantly this article shows how load carriage can affect gait performance. Gait performance can affect the risk of slips, trips, and falls among firefighters.

Angelini, M. J., Kesler, R. M., Petrucci, M. N., Rosengren, K. S., Horn, G. P., & Hsiao-

Weckslar, E. T. (2018). Effects of simulated firefighting and asymmetric load carriage on firefighter obstacle crossing performance. *Applied Ergonomics*, 70, 59–67.

<https://doi.org/10.1016/j.apergo.2018.02.006>

The purpose of this article was to investigate the potential effects of acute fatigue and asymmetric load carriage on firefighter obstacle crossing. This study not only looked at the load carriage on the obstacle crossing performance, but they were also investigating the effect of exercise protocols on obstacle crossing in comparison to live fire conditions. The results suggest that post-activity fatigue resulted in significant differences in clearances of the lead, however, it did not affect the choice of the lead foot. Importantly this article shows that load carriage has a significant effect on obstacle-crossing performance. This article can be used to further deepen the load carriage effects on firefighters' movements. Due to distracted movement slip, trip, and fall risk could be increased.

Change in Balance with Load or Occupational Task

DiDomenico, A., Gielo-Perczak, K., McGorry, R. W., & Chang, C. (2010). Effects of simulated occupational task parameters on balance. *Applied Ergonomics*.

<https://doi.org/10.1016/j.apergo.2009.10.004>

The purpose of this study was to examine several factors that represented actual task and environmental parameters that workers may encounter when working on a narrow structure and determine if changes in these parameters can affect balance. For this study there were 3 weight conditions, using a 6.8kg weight in the right and left hand separately, using an 11.4 kg weight in the right and left hand separately, and a no weight condition.

And three more surface conditions were used, a long beam, a short beam, and a ground surface. The center of pressure measures was recorded with a force platform to examine the effect of the different conditions on balance. According to the results, holding a weight did not have a significant effect on balance measures. However, the effect of surface conditions was significant on all balance measures. Importantly this article shows how different surface conditions can affect balance, which could be used in firefighters as well even though this study was not specifically working with firefighters. Diminished balance can increase the risk of slips, trips, and falls among all workers.

Balance Background

Kuczyński, M., & Wieloch, M. (2008). Effects of accelerated breathing on postural stability.

Human Movement, 9(2). <https://doi.org/10.2478/v10038-008-0012-9>

The purpose of this study was to investigate the effect of respiration on body balance in quiet standing. 37 participants took part in the study. There were two trials with eyes open, standing still for 20 seconds, between every trial they had a 30-second break. For the first trial, participants were instructed to do natural breathing while doing the trials, for the second trial subjects were instructed to follow a metronome with their breathing pattern. During the trials, the center of pressure (COP) was recorded. Results showed that forced breathing increased the COP dispersion range, furthermore, it increased the mean velocity in the anteroposterior plane. This study suggests that faster breathing could negatively impact balance measures. This is relevant to my study because as firefighters work, they get more tired, and they increase the number of breaths taken which could impair balance which could lead to a higher risk of falling.

Nardone, A., Tarantola, J., Giordano, A., & Schieppati, M. (1997). Fatigue effects on body balance. *Electroencephalography and Clinical Neurophysiology*, *105*(4), 309–320.
[https://doi.org/10.1016/s0924-980x\(97\)00040-4](https://doi.org/10.1016/s0924-980x(97)00040-4)

This article was investigating the effects of different exercises and different intensities of exercise on balance measures such as sway area (SA), sway path (SP), and center of foot pressure (CFP). Treadmill running and cycle ergometer pedaling were used to assess the effect of exercise, for exercise intensity they performed the exercises below and above the threshold of fatigue. For balance testing, eyes open and eyes closed conditions were tested, balance testing took about 10 minutes per participant. Results showed that the Romberg quotient significantly increased after the exercise. The mean position of CFP was unchanged with exercise. Fatigue induced an increase in various balance measures, while the non-fatigue condition had no effect. After the fatigued cycle ergometer condition, a negligible increase or decrease in body sway was seen. Non-fatigue cycle ergometer condition had no significant effect on the balance measure. This article shows the effect of fatigue on balance measures. Even though this article is not specific to firefighters it clearly shows that fatigue will impair balance measures.

Cetin, N., Bayramoglu, M., Aytar, A., Surenkok, O., & Yemisci, O. U. (2008). Effects of lower-extremity and trunk muscle fatigue on balance. *The Open Sports Medicine Journal*, *2*(1).
The purpose of this study was to examine the impact of fatigue of the lower-extremity and trunk muscles on the results of static and dynamic balance tests. 30 healthy volunteers participated in the study. To develop the fatigue condition, a stair master device was used. Testing was done over 3 days, on day 1 they recorded the pre-fatigue balance measurements, on days 2 and 3 they used the stair masters to create fatigue then

they performed the static and dynamic balance trials. According to the results, there were significant differences between the pre-fatigue and the post-fatigue balance measurements. There were significant differences in the post-fatigue trunk and lower extremity muscles and balance scores, however the dynamic left, right, and front balance scores did not show a significant difference between pre- and post-fatigue measures. Importantly this article suggests balance decrements after fatigue protocol. According to the results both dynamic and static balance are impacted by fatigue. This is important since firefighters tend to develop fatigue during their duty. Fatigue on duty could impair balance and it could potentially increase the risk of injuries.

Balance Measure Return to Baseline after Activity

Fox, Z. G., Mihalik, J. P., Blackburn, J. K., Battaglini, C. L., & Guskiewicz, K. M. (2008).

Return of Postural Control to Baseline After Anaerobic and Aerobic Exercise Protocols.

Journal of Athletic Training, 43(5), 456–463. <https://doi.org/10.4085/1062-6050-43.5.456>

This article aimed to evaluate the effects of fatigue on postural control in healthy college-aged athletes performing anaerobic and aerobic exercise protocols and to establish an immediate recovery time course from each exercise protocol for postural control measures to return to baseline status. Division I collegiate athletes participated in the study. Participants performed the baseline balance testing at the orientation session then they came back to the intervention session. The intervention session consisted of the 2 different exercise protocols on 2 different days and the post-balance test which were taken at 3, 8, 13, and 18 minutes after exercise. According to the results, postural control ability declined after each exercise session. Furthermore, balance measures returned to baseline within 13 minutes for both exercise sessions. Importantly, this article helps us

give a timeline for when the balance is still affected by exercise and when that decline diminishes. According to this article, by 13 minutes after the exercise postural control ability returns to baseline which suggests that we should conduct our balance testing before that time mark.

Susco, T. M., Tc, V. M., Gansneder, B. M., & Shultz, S. J. (2016). Balance Recovers Within 20 Minutes After Exertion as Measured by the Balance Error Scoring System. *Journal of Athletic Training*, 39(3), 241–246.

The goal of this study was to determine the balance recovery timeline after functional exertion protocol using the Balance Error Scoring System (BESS). 100 participants took part in the study, which consisted of 5 groups: a control group, a test at 0, 5, 10, and 15 minutes after exercise, and another posttest at 20 minutes for all groups. According to the results, the exertion protocol negatively affected the balance measures, the biggest effect was seen in the single-leg and the tandem stance trials. Results suggest that 20 minutes after the exertion protocol balance measures returned to baseline. This article gives us a better timeline for when the balance decreases due to exertion protocol diminishes. According to this article, balance returns to baseline by the 20 minutes mark which suggests that we should conduct the balance testing before that time to see the effects of the specific task list and gear on balance measures.