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Firefighter injuries are not just a fireground problem

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Abstract.
BACKGROUND: Linking firefighter injury reporting to general motion patterns may provide insight into potential injury mechanisms and the development of prevention strategies.
OBJECTIVE: To characterize the injuries sustained by members of a large Canadian metropolitan fire department over a 5-year span.
METHODS: Data were taken from injury reports filed by career firefighters between 2007 and 2011. Injuries were described by job duty, type, body part affected, and the general motion pattern employed at the time of injury (e.g. lifting).
RESULTS: Of the 1311 injuries reported, 64% were categorized as sprains and strains (musculoskeletal disorders – MSDs), the most frequent of which affected the back (32%). Categorized by job duty, 65% of MSDs were sustained while working at the fire station or during physical training-related activities. Only 15% were attributed to fireground operations. Furthermore, the associated job duty could not differentiate the types of injuries sustained; back injuries occurred primarily while lifting, knee injuries while stepping, and shoulder injuries during pushing/pulling-related activities.
CONCLUSIONS: Firefighter injuries are not just a fireground problem. Injury causation may be better understood by linking the injury location and type with motion patterns rather than job duties. This information could assist in developing general prevention strategies for the fire service.

Keywords: Ergonomics, knee injury, lower-back injury, musculoskeletal disorders, prevention

1. Introduction

Firefighters are commonly exposed to extreme environments wherein the physical demands of the job challenge their ability to perform safely. It is therefore not surprising that the rate of non-fatal injuries in the fire service ranks as one of the highest amongst all occupations in the United States, [1] and is approximately three times that reported for the private sector [2, 3]. Over the past several years, tremendous efforts have been made by organizations such as the International Associations of Fire Fighters and Fire Chiefs to highlight the importance of fire safety, and today fewer fires and fireground injuries are being reported [4]. However, firefighters are first responders to many emergencies, and therefore the prevention of firefighter injuries cannot be viewed as just a fireground problem. In fact, there is evidence to suggest that the majority of firefighter injuries are being sustained while attending to non-fire emergencies, performing station-related activities (e.g. equipment maintenance), and engaging in exercise and physical training [5–8].

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The National Fire Protection Association (NFPA) publishes annual estimates of firefighter injuries, [4] including general descriptions of the associated job duties and types of injuries being sustained (e.g. muscle strain). Specific to fireground operations, [9] further information is also provided regarding the body part injured (e.g. leg), specific activity being performed at the time of injury (e.g. handling hose line), and reported cause (e.g. overexertion). This work has been instrumental in establishing the prevalence of firefighter injuries in the United States and offers an excellent framework to build on in future research. However, there are two shortcomings of the NFPA's data that make it challenging to develop targeted injury prevention strategies. First, the data presented are extrapolations of self-reported summary statistics from more than two thousand American fire departments (career and volunteer). As such, identifying the specific needs for any one department, including those outside of the United States, would be difficult given possible differences in the distribution of on-duty responsibilities, [6, 7, 10] community demographics, [4] and climate. Second, limited insight can be gleaned with respect to potential injury mechanisms. For instance, it would be difficult to devise an appropriate strategy to prevent "leg" injuries that occur while "training", or "trunk" injuries caused by "overexertion". If additional information were made available regarding the specific location of injury (e.g. knee rather than leg) *together with* the general body motion pattern being used at the time injury (e.g. stepping), the imposed biomechanical demands could be categorized so that possible tissue-damaging mechanisms and targeted prevention strategies could be identified. Uncontrolled frontal plane knee motion while stepping or running, for example, could elevate the potential for cartilage and anterior cruciate ligament (ACL) damage [11]. Linking injury reporting to motion patterns may also provide greater insight into the onset and progression of cumulative injuries by identifying postures and motions that are common to a range of occupational activities.

The purpose of this study was to categorize the injuries sustained by firefighters from a large Canadian metropolitan department over a five-year span by job duty, motion pattern, and injury type and location. It was hypothesized that categorizing injuries in this way would provide an opportunity to identify targeted injury prevention strategies for the participating fire department, and offer insight towards the development of generalized interventions for the fire service.

2. Methods

2.1. Population

This study examined the injuries sustained by the Calgary Fire Department (CFD), a large metropolitan department in Western Canada. In 2011, the CFD consisted of 1363 uniformed personnel operating out of 37 stations. The mean (SD) age, height and body mass of CFD personnel was 38 (9) years, 1.80 (0.06) m, and 89 (11) kg, respectively, of which 2% were women. Members responded 100,695 times to 50,520 incidents, the most common of which were medical emergencies (46%), followed by false alarms (17%), hazardous conditions (16%), investigations (9%), and public service assistance (7%). Only 4% of all dispatches involved fire suppression activities.

2.2. Data source

Data were taken from injury reports filed by CFD personnel between 2007 and 2011. Included in these reports were details regarding the type of injury (e.g. sprain and strain), body part affected (e.g. knee), job duty, and a written description of the circumstances surrounding the event. For the purpose of this study, a reportable injury was defined in accordance with the Occupational Health and Safety regulations for Alberta, namely medical treatment, restricted work duties or lost time. Injuries sustained to any specific body part were also included in the analyses, as were those that manifested over a period of time (e.g. cumulative load injury), but could not be attributed to any single event.

2.3. Classification of injuries

Injuries reported in this study were described by type (i.e. sprain/strain, cut, bruise, fracture, burn, and other), body part affected, and job duty. Using documented accounts of the actual events (e.g. "strained low back lifting 250 kg patient at medical call"), sprain and strain injuries, defined herein as musculoskeletal disorders (MSDs), were also categorized by the general motion pattern employed at the time of injury. More specifically, inferences were made regarding the kinetics (e.g. external flexion moment about low back) and kinematics (e.g. single leg) of the associated activity based on details provided in the injury reports. In this way, tasks performed in any work environment comprising similar movement demands could be categorized using the same general pattern [12]. For example, bending, lifting and squatting were characterized by a similar general

pattern because each type of activity comprises a forward trunk lean and external flexion moment about the low back. Similarly, climbing stairs and stepping off the fire truck were assigned to the same general category because both are tasks involving a single-leg lunge-type motion pattern. Running could also be considered a lunge pattern; however, it was described separately as it is typically associated with higher movement speeds (and loads) than would be expected while stepping. The general motion patterns included in this study were: 1) bending, lifting and squatting, LFT (e.g. lifting patient); 2) jumping and landing, JMP (e.g. jumping off truck); 3) lunging and stepping, STP (e.g. stepping off truck); 4) running, RUN (e.g. jogging on track); 5) pushing and pulling, PSH (e.g. forcing a door); and 6) sitting, SIT (e.g. riding in pump). When insufficient detail was provided in the event description (e.g. "injured back while working out"), or when an injury could not be categorized using one of the abovementioned patterns (e.g. "hurt left wrist turning screwdriver"), injuries were grouped into "training" (TRN), "fireground" (FIR), or "other" (OTH) job categories. Injuries associated with a slip, trip or fall (SLP) were also uniquely identified and not characterized by a general motion pattern. Data are presented as the number and percentage of injuries sustained over the 5-year span.

3. Results

3.1. Total injuries

Between 2007 and 2011, 1311 injuries were reported, of which 64% were categorized as MSDs (Table 1). The most commonly reported MSDs affected the back (32%), knees (17%), ankles (15%) and shoulders (13%). Cuts and lacerations were the most common non-MSDs (33%), followed by bruises (27%), fractures (13%) and burns (7%).

3.2. Injuries by job duty

Categorized by job duty, 33–45% of all back, knee, ankle and shoulder MSDs occurred at the fire station (Table 2). Physical training activities were cited as the cause of 27% of all MSDs, including 32% of all shoulder incidents. Only 15% of MSDs were sustained while attending to fire emergencies. A further 12% occurred during non-fire emergencies, the majority of which affected the back. Traveling to and from an emergency and non-emergency work performed off-site each accounted for approximately 4% of all MSDs.

Fifty-six percent of all non-MSDs were sustained at the fire station (Table 3), including 75% of cuts and lacerations, 48% of bruises, 47% of fractures, and 41% of burns. Physical training, fireground operations and non-fire emergency activities were associated with 17%, 13%, and 6% of all non-MSDs, respectively.

3.3. Injuries by motion pattern

Using the injury reports, 23% of MSDs were categorized as LFT-related (Table 4). LFT activities accounted for 43% and 34% of all back and shoulder MSDs, but only 1% and 5% of those affecting the ankle and knees. Conversely, activities categorized as STP were associated with 40% and 32% of ankle and knee injuries,

Table 1
The number (percentage) of injuries sustained between 2007 and 2011. Injuries are categorized as either a sprain and strain, or non-sprain and strain (e.g. cuts, fractures, etc.)

Injury Type	Injury Description	2007 ($n=274$)	2008 ($n=247$)	2009 ($n=321$)	2010 ($n=285$)	2011 ($n=204$)	5-YEAR ($n=1311$)
Sprains/Strains	Ankle	24 (8.8)	25 (10.1)	34 (10.6)	19 (6.7)	24 (11.8)	126 (9.5)
	Back	63 (23.0)	40 (16.2)	58 (18.1)	68 (23.9)	38 (18.6)	267 (20.1)
	Knee	37 (13.5)	28 (11.3)	40 (12.5)	21 (7.4)	15 (7.4)	141 (10.6)
	Shoulder	28 (10.2)	20 (8.1)	29 (9.0)	18 (6.3)	12 (5.9)	107 (8.0)
	Other[A]	38 (13.9)	35 (14.2)	51 (15.9)	50 (17.5)	30 (14.7)	204 (15.3)
	ALL	190 (69.3)	148 (59.9)	212 (66.0)	176 (61.8)	119 (58.3)	845 (63.5)
Non Sprains/Strains	Cut	23 (8.4)	32 (13.0)	37 (11.5)	35 (12.3)	33 (16.2)	160 (12.0)
	Bruise	24 (8.8)	25 (10.1)	33 (10.3)	33 (11.6)	16 (7.8)	131 (9.8)
	Fracture	12 (4.4)	13 (5.3)	11 (3.4)	10 (3.5)	16 (7.8)	62 (4.7)
	Burn	8 (2.9)	7 (2.8)	7 (2.2)	7 (2.5)	5 (2.5)	34 (2.6)
	Other[B]	17 (6.2)	22 (8.9)	21 (6.5)	24 (8.4)	15 (7.4)	99 (7.4)
	ALL	84 (30.7)	99 (40.1)	109 (34.0)	109 (38.2)	85 (41.7)	486 (36.5)

[A]Includes neck, hip, elbow, wrist, hand, foot, abdomen, chest, arm, leg, and groin. [B]Includes debris in eyes, bites/stings, electrical shock, loss of consciousness, and dehydration.

Table 2
The number (percentage) of sprain and strain injuries sustained between 2007 and 2011, categorized by the type of duties being performed at the time of the incident

Type of Duty/Job Site	Ankle ($n=126$)	Back ($n=267$)	Knee ($n=141$)	Shoulder ($n=107$)	Other[A] ($n=204$)	ALL ($n=845$)
Fire Station	56 (44.5)	88 (32.9)	61 (43.2)	45 (42.1)	70 (34.3)	320 (37.9)
Physical Training	38 (30.2)	48 (18.0)	31 (22.0)	34 (31.8)	74 (36.3)	225 (26.6)
Gymnasium	20 (15.9)	24 (9.0)	16 (11.3)	23 (21.5)	38 (18.6)	121 (14.3)
Training Center	17 (13.5)	22 (8.2)	13 (9.2)	11 (10.3)	35 (17.2)	98 (11.6)
Wellness Center	1 (0.8)	2 (0.7)	2 (1.4)	0 (0.0)	1 (0.5)	6 (0.7)
Emergency (Fire)	17 (13.5)	36 (13.5)	26 (18.4)	15 (14.0)	30 (14.7)	124 (14.7)
Structural Fire	13 (10.3)	32 (12.0)	19 (13.5)	14 (13.1)	28 (13.7)	106 (12.5)
Non-Structural Fire	4 (3.2)	4 (1.5)	7 (5.0)	1 (0.9)	2 (1.0)	18 (2.1)
Emergency (Non-Fire)	10 (7.9)	56 (21.0)	18 (12.8)	7 (6.5)	11 (5.4)	102 (12.1)
Medical Emergency	4 (3.2)	40 (15.0)	8 (5.7)	3 (2.8)	4 (2.0)	59 (7.0)
Motor Vehicle Accident	5 (4.0)	10 (3.7)	5 (3.5)	4 (3.7)	5 (2.5)	29 (3.4)
Hazmat Emergency	0 (0.0)	2 (0.7)	1 (0.7)	0 (0.0)	1 (0.5)	4 (0.5)
Other Emergency	1 (0.8)	4 (1.5)	4 (2.8)	0 (0.0)	1 (0.5)	10 (1.2)
Enroute to/from Call	0 (0.0)	31 (11.6)	0 (0.0)	1 (0.9)	8 (3.9)	40 (4.7)
Off-Site Non-Emergency	5 (4.0)	8 (3.0)	5 (3.5)	5 (4.7)	11 (5.4)	34 (4.0)

[A]Includes neck, hip, elbow, wrist, hand, foot, abdomen, chest, arm, leg, and groin.

Table 3
The number (percentage) of non-sprain and -strain injuries sustained between 2007 and 2011, categorized by the type of duties being performed at the time of the incident

Type of Duty/Job Site	Cut ($n=160$)	Bruise ($n=131$)	Fracture ($n=62$)	Burn ($n=34$)	Other[A] ($n=99$)	ALL ($n=486$)
Fire Station	119 (74.4)	63 (48.1)	29 (46.8)	14 (41.2)	47 (47.5)	272 (56.0)
Physical Training	16 (10.0)	33 (25.2)	11 (17.7)	4 (11.8)	10 (10.1)	84 (17.3)
Gymnasium	6 (3.8)	10 (7.6)	10 (16.1)	0 (0.0)	1 (1.0)	27 (5.6)
Training Center	10 (6.3)	23 (17.6)	11 (17.7)	4 (11.8)	9 (9.1)	57 (11.7)
Wellness Center	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Emergency (Fire)	11 (6.9)	14 (10.7)	6 (9.7)	11 (32.4)	19 (19.2)	61 (12.6)
Structural Fire	10 (6.3)	11 (8.4)	5 (8.1)	9 (26.5)	16 (16.2)	51 (10.5)
Non-Structural Fire	1 (0.6)	3 (2.3)	1 (1.6)	2 (5.9)	3 (3.0)	10 (2.1)
Emergency (Non-Fire)	6 (3.8)	9 (6.9)	4 (6.5)	3 (8.8)	9 (9.1)	31 (6.4)
Medical Emergency	1 (0.6)	4 (3.1)	1 (1.6)	0 (0.0)	0 (0.0)	6 (1.2)
Motor Vehicle Accident	4 (2.5)	0 (0.0)	1 (1.6)	2 (5.9)	3 (3.0)	10 (2.1)
Hazmat Emergency	0 (0.0)	1 (0.8)	1 (1.6)	1 (2.9)	2 (2.0)	5 (1.0)
Other Emergency	1 (0.6)	4 (3.1)	1 (1.6)	0 (0.0)	4 (4.0)	10 (2.1)
Enroute to/from Call	1 (0.6)	6 (4.6)	0 (0.0)	0 (0.0)	3 (3.0)	10 (2.1)
Off-Site Non-Emergency	7 (4.4)	6 (4.6)	2 (3.2)	2 (5.9)	11 (11.1)	28 (5.8)

[A]Includes debris in eyes, bites/stings, electrical shock, loss of consciousness, and dehydration.

respectively. RUN-related activities also affected the ankles and knees more than the back (17 and 15 MSDs, compared to 2), as were incidents described by JMP. Thirty-two of the 46 PSH injuries affected the shoulders, while just 5 back-related. Of the 31 SIT injuries, 25 were to the back.

SLP MSDs accounted for 21% of all injuries (Table 4) and affected each area of the body (36, 55, 46 and 16 ankle, back, knee and shoulder, respectively). Injuries receiving the broad classification of TRN and FIR were attributed to 8% and 2% of all MSDs, respectively.

3.4. Injuries by job duty and motion pattern

Of the injuries sustained at the station, the majority were categorized as LFT (22%), STP (27%) and SLP (29%) (Table 5). Those most commonly attributed to training were described as TRN (30%), RUN (22%), LFT (14%) and PSH (13%). Only 14% of fireground MSDs could not be categorized by a general motion pattern; 32%, 23% and 11% were described as a SLP, LFT and STP, respectively. Non-fire emergency MSDs were described by the same general patterns, although LFT activities alone accounted for 56% of all incidents.

Table 4
The number (percentage) of sprain and strain injuries sustained between 2007 and 2011, categorized by the type of activity being performed at the time of the incident

Incident Description	Ankle ($n = 126$)	Back ($n = 267$)	Knee ($n = 141$)	Shoulder ($n = 107$)	Other[A] ($n = 204$)	ALL ($n = 845$)
Bending/Lifting/Squatting	1 (0.8)	114 (42.7)	7 (5.0)	36 (33.6)	38 (18.6)	196 (23.2)
Jumping/Landing	7 (5.6)	3 (1.1)	7 (5.0)	0 (0.0)	3 (1.5)	20 (2.4)
Lunging/Stepping	50 (39.7)	15 (5.6)	45 (31.9)	1 (0.9)	23 (11.3)	134 (15.9)
Running	17 (13.5)	2 (0.7)	15 (10.6)	0 (0.0)	16 (7.8)	50 (5.9)
Pushing/Pulling	0 (0.0)	5 (1.9)	0 (0.0)	32 (29.9)	9 (4.4)	46 (5.4)
Sitting	0 (0.0)	25 (9.4)	0 (0.0)	0 (0.0)	6 (2.9)	31 (3.7)
Slipping/Tripping/Falling	36 (28.6)	55 (20.6)	46 (32.6)	16 (15.0)	27 (13.2)	180 (21.3)
Exercise/Training Activity[B]	6 (4.8)	24 (9.0)	4 (2.8)	5 (4.7)	28 (13.7)	67 (7.9)
Fireground Activity[B]	0 (0.0)	2 (0.7)	7 (5.0)	2 (1.9)	6 (2.9)	17 (2.0)
Other Activity[C]	1 (0.8)	14 (5.2)	6 (4.3)	9 (8.4)	34 (16.7)	64 (7.6)
Unspecified	8 (6.3)	8 (3.0)	4 (2.8)	6 (5.6)	14 (6.9)	40 (4.7)

[A]Includes neck, hip, elbow, wrist, hand, foot, abdomen, chest, arm, leg, and groin. [B]Includes activities relevant to the specified job duty not categorized using the above general descriptors. [C]Includes activities not categorized using the above descriptors (e.g. motor vehicle accidents).

Table 5
The number (percentage) of sprain and strain injuries sustained between 2007 and 2011, categorized by the type of duties and activity being performed at the time of the incident

Incident Description	Station ($n = 320$)	Training ($n = 225$)	Fire ($n = 124$)	Non-Fire[A] ($n = 104$)	Enroute ($n = 37$)	Other[B] ($n = 35$)
Bending/Lifting/Squatting	71 (22.2)	31 (13.8)	29 (23.4)	58 (55.8)	0 (0.0)	7 (20.0)
Jumping/Landing	14 (4.4)	2 (0.9)	3 (2.4)	1 (1.0)	0 (0.0)	0 (0.0)
Lunging/Stepping	85 (26.6)	18 (8.0)	14 (11.3)	11 (10.6)	0 (0.0)	6 (17.1)
Running	0 (0.0)	49 (21.8)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.9)
Pushing/Pulling	11 (3.4)	29 (12.9)	3 (2.4)	2 (1.9)	0 (0.0)	1 (2.9)
Sitting	3 (0.9)	0 (0.0)	0 (0.0)	0 (0.0)	27 (73.0)	1 (2.9)
Slipping/Tripping/Falling	93 (29.1)	22 (9.8)	39 (31.5)	19 (18.3)	0 (0.0)	7 (20.0)
Exercise/Training Activity[C]	0 (0)	67 (29.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Fireground Activity[C]	0 (0)	0 (0.0)	17 (13.7)	0 (0.0)	0 (0.0)	0 (0.0)
Other Activity[D]	29 (9.1)	5 (2.2)	1 (0.8)	10 (9.6)	10 (27.0)	9 (25.7)
Unspecified	14 (4.4)	2 (0.9)	18 (14.5)	3 (2.9)	0 (0.0)	3 (8.6)

[A]Includes medical, motor vehicle, Hazmat and other emergency calls. [B]Includes off-site non-emergency work. [C]Includes activities relevant to the specified job duty not categorized using the above general descriptors. [D]Includes activities not categorized using the above descriptors (e.g. motor vehicle accidents).

SIT activities were attributed to 73% of the enroute MSDs; all others were the result of motor vehicle collisions.

4. Discussion

Consistent with previous findings from the United States, [2–4, 6, 7, 13] MSDs comprised the majority of injuries reported by CFD, the most common of which were those affecting the back, knees, ankles and shoulders. The percentage of back injuries (32%) was identical to that reported by Poplin et al. [6] but lower than has been cited by others (37–48%) [13, 14]. These differences are likely due to variation in factors that can influence injury potential, such as the distribution of on-duty responsibilities, community demographics, and climate. For instance, CFD personnel must deal with cold and icy conditions over longer winter seasons, which could elevate their risk of slips and falls relative to firefighters working in a warmer locale. The distribution of CFD's injuries by job duty was also different than has been previously reported. In 2011, the NFPA estimated that 44% of all injuries sustained by American firefighters (career and volunteer) occurred during fireground operations, compared to just 11% during physical training. Conversely, Poplin et al. [6] found that in one mid-sized department from southwestern United States, only 10% of the injuries sustained over a 5-year span occurred while attending to fire emergencies, but 33% were related to physical exercise. The injury distribution for CFD

better aligns with the data presented by Poplin and colleagues (24% and 14.1% of all injuries were sustained during training and fireground operations, respectively), though fewer injuries were sustained while performing both job duties combined than while attending to fire station-related responsibilities. This inter-department variation highlights why additional information regarding the nature of the imposed demands may be needed to develop targeted injury prevention strategies for a participating department.

The most novel contribution from this study may be that irrespective of job duty, the general motion pattern used by CFD personnel at the time of injury was strongly associated with the type of injury sustained. Of the MSDs categorized by a general pattern, back injuries occurred primarily during LFT (114 of 164), knee injuries were associated with STP and RUN (60 of 74), and shoulder injuries were attributed to LFT and PSH (68 of 69). These data suggest that information regarding the associated motion pattern might offer insight not otherwise available regarding the nature of the biomechanical demands imposed on the body. During lifting and bending, for example, firefighters must use their trunk musculature to oppose the external moment produced about the low back. If for any reason, the lumbar spine is deviated, the spine's passive tissues (e.g. ligaments, discs) will be tasked with opposing these external demands [15]. When the demands on passive tissues are of a sufficient magnitude, frequency or duration, a lower back injury will occur [16]. Similarly, many knee injuries are associated with "dynamic valgus", [11] which describes a frontal plane collapse of the stance limb during STP- and RUN-related activities. Like a deviated spine, this motion pattern also transfers load-bearing responsibilities from proximal muscles to passive structures. All firefighter injuries will never be avoided, but including the associated motion patterns in the surveillance of injuries will assist scientists, ergonomists, and health and safety personnel to identify potential mechanisms so that efforts can be made to reduce the risk of sustaining similar injuries in the future.

Categorizing firefighter injuries by the body part affected *together with* associated motion patterns may offer valuable insight into a department's injury problem, and the development of suitable prevention strategies. Over the 5-years investigated, back, knee, and shoulder injuries were sustained while performing LFT-, STP-, and PSH-related activities, respectively, on the fireground, at the station, and while training. In other words, the associated job duty could not differentiate the types of injuries that were sustained. As such, there may be merit in developing prevention strategies that focus on the (re-)training of general movements that are common to a variety of job tasks. Frost et al. [17] recently showed that 12-weeks of exercise could change *how* firefighters' performed a range of job task simulations. Interestingly however, the positive adaptations were observed primarily amongst a group of participants who received movement-oriented instruction and feedback during the intervention. Firefighters who did not receive any movement cues exhibited potentially injurious motion patterns post-training (i.e. more spine and frontal plane knee motion during job simulations). Although these kinematic adaptations were not found to affect low-back loading, [18] a movement-oriented exercise approach may help to prevent many of the exercise-related injuries being sustained by firefighters. That is, if emphasis is placed on stabilizing key postural and motion characteristics hypothesized or demonstrated to increase the "margin of safety" when exercising.

Similar to previous findings, [6–8] a large proportion of CFD injuries did occur during physical exercise- and training-related activities. However, it is difficult to interpret this result without information regarding the number of hours spent performing each job duty. To find that more injuries were sustained during training than occurred on the fireground could simply reflect the fact that the firefighters' spent more time training. Furthermore, because firefighters *must* be physically fit for their health and safety [7, 19–22], it would be unwarranted and perhaps irresponsible to deny them the opportunity to enhance or maintain their physical readiness while on-duty. Instead, it may be more appropriate to re-evaluate their current exercise and physical training practices to determine how best to regulate work-related mechanical exposures using principles of ergonomics and exercise science. In military populations who also report high rates of exercise- and physical training-related injuries [23], some success has been achieved by employing long-standing training principles such as progressive overload, specificity, and individualization, [24] in addition to emphasizing *how* the exercise is performed [25]. Fortunately, exercise and physical training activities are probably the most feasible aspects of a firefighter's job to modify.

While the results of this study lend novel insights into the characterization of firefighter injuries, it is important to note that qualitative descriptions of body motions alone cannot explain injury causation. A firefighter's motion patterns certainly influence the magnitude and

distribution of biomechanical loading, but the frequency, rate, and duration of loading must also be considered to accurately identify an injury mechanism [26]. Overexertion, for example, has been cited as the primary cause of MSDs sustained by firefighters; [4, 6, 13] however, this broad definition likely masks the fact that many sprains and strains result from an accumulation of damage over time [26]. The documented injury would simply be the culminating event. In this study, many of the MSDs reported were sustained while stepping off the truck – a seemingly mundane task often performed numerous times over a single shift. While it is possible that one exposure could impose a demand sufficient to cause injury, more plausible is that the injured tissue was weakened over a period of days, weeks, or months, such that eventually stepping from the truck imposed a load that exceeded the degraded tissue's tolerance. It is also conceivable that the motion pattern used was similar to that employed during other STP-related activities performed on the fireground or while training. In other words, firefighters' movement patterns may transcend several activities, regardless of job duty, implying that tissue damage cannot be easily attributed to the performance of any single task. It is also for this reason that firefighter injuries cannot be treated as just a fireground problem.

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Conflict of interest

Ian Crosby is a member of the Calgary Fire Department. The other authors have no conflicts to declare.

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References

[1] Bureau of Labor Statistics. Workplace injuries and illnesses - 2011: United States Department of Labor 2012.

[2] Seabury SA, McLaren CF. The frequency, severity and economic consequences of musculoskeletal injuries to firefighters in California: RAND Center for Health and Safety in the Work place. 2010.

[3] Reichard AA, Jackson LL. Occupational injuries among emergency responders. Am J Ind Med 2010;53(1):1-11.

[4] Karter Jr MJ, Molis JL. U.S. Firefighter injuries - 2011: National Fire Protection Association 2012.

[5] Szubert Z, Sobala W. Work-related injuries among firefighters: Sites and circumstances of their occurence. Int J Occup Environ Health 2002;15(1):49-55.

[6] Poplin GS, Harris RB, Pollack KM, Peate WF, Burgess JL. Beyond the fireground: Injuries in the fire service. Inj Prev 2012;18(4):228-33.

[7] Jahnke SA, Poston WS, Haddock CK, Jitnarin N. Injury among a population based sample of career firefighters in the central USA. Inj Prev 2013;19(6):393-8.

[8] Bylund PO, Björnstig U. Medical impairing injuries among Swedish firefighters. Work 1998;12(2):117-22.

[9] Karter Jr MJ. Patterns of firefighter fireground injuries: National Fire Protection Association 2012.

[10] Cloutier E, Champoux D. Injury risk profle and aging among Quebec firefighters. International Journal of Industrial Ergonomics 2000;25(5):513-23.

[11] Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. Am J Sports Med 2005;33(4):492-501.

[12] Frost DM, Beach AC, McGill SM, Callaghan JP. The predictive value of general movement tasks in assessing occupational task performance. Work, (in press).

[13] Walton SM, Conrad KM, Furner SE, Samo DG. Cause, type and workers' compensation costs of injury to fire fighters. Am J Ind Med 2003;43(4):454-8.

[14] Albert D. An investigation into the prevalence and risk factors of occupational musculoskeletal injuries in firefighters in the Durban Metropolitan Fire Department. [Dissertation]. Dalbridge, South Africa: Durban University of Technology; 2009.

[15] McGill SM. Distribution of tissue loads in the low back during a variety of daily and rehabilitation tasks. J Rehabil Res Dev 1997;34(4):448-58.

[16] McGill S. The biomechanics of low back injury: Implications on current practice in industry and the clinic. J Biomech 1997;30(5):465-75.

[17] Frost DM, Beach TAC, Callaghan JP, McGill, SM. Exercise-based performance enhancement and injury prevention for firefighters: Contrasting the fitness- and movement-related adaptations to two training methodologies. Journal of Strength and Conditioning Research, (in press).

[18] Beach TAC, Frost DM, McGill SM, Callaghan JP. Physical fitness improvements and occupational low-back loading - An exercise intervention study with firefighters. Ergonomics 2014;57(5):744-63.

[19] Cady LD, Bischoff DP, O'Connell ER, Thomas PC, Allan JH. Strength and fitness and subsequent back injuries in firefighters. J Occup Med 1979;21(2):269-72.

[20] Michaelides MA, Parpa KM, Henry LJ, Thompson GB, Brown BS. Assessment of physical fitness aspects and their relationship to firefighters' job abilities. J Strength Cond Res 2011;25(4):956-65.

[21] Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. J Strength Cond Res 2004;18(2):348-52.

[22] Roberts MA, O'Dea J, Boyce A, Mannix ET. Fitness levels of firefighter recruits before and after a supervised exercise training program. J Strength Cond Res 2002;16(2):271-7.
[23] Jones BH, Knapik JJ. Physical training and exercise-related injuries: Surveillance, research and injury prevention in Military populations. Sports Med 1999;27(2):111-25.
[24] Knapik JJ, Rieger W, Palkoska F, Van Camp S, Darakjy S. United States Army physical readiness training: Rationale and evaluation of the physical training doctrine. J Strength Cond Res 2009;23(4):1353-62.
[25] Goss DL, Christopher GE, Faulk RT, Moore J. Functional training program bridges rehabilitation and return to duty. J Spec Oper Med 2009;9(2):29-48.
[26] Kumar S. Theories of musculoskeletal injury causation. Ergonomics 2001;44(1):17-47.