Work-Related Fatigue

Relationship Between Perceived and Performance Fatigability in Career Firefighters

Amber N. Schmitz, MA, Hayden K. Giuliani-Dewig, PhD, Megan R. Laffan, MA, Abigail J. Trivisonno, MA, Gena R. Gerstner, PhD, Jacob A. Mota, PhD, Nicholas A. Buoncristiani, MS, and Eric D. Ryan, PhD

Objective: The purpose of this study was to (1) examine the relationship between perceived work-related fatigue and performance fatigability, and (2) assess the impact of percent body fat (%BF) on perceived fatigue constructs in career firefighters. **Methods:** Thirty-nine career firefighters completed body composition testing, the Occupational Fatigue Exhaustion Recovery (OFER15) scale assessing three subscales of work-related fatigue (acute fatigue, chronic fatigue, and inter-shift recovery), and maximal leg extensor isometric strength testing prior to and following an isotonic fatiguing protocol. **Results:** Performance fatigability was not associated with any of the OFER15 perceived work-related fatigue variables ($P \geq 0.513$). Greater %BF was associated with greater %Δ peak torque ($r = -0.41$, $P = 0.010$) but none of the OFER15 perceived work-related fatigue variables ($P \geq 0.638$). **Conclusions:** Performance fatigability was not associated with OFER15 perceived work-related fatigue, and greater adiposity negatively impacted performance fatigability but not perceived fatigability.

Keywords: occupational health, neuromuscular function, shiftwork, obesity

LEARNING OUTCOMES

- Work-related fatigue can be measured by perceived self-report or physical performance; however, the two fatigue constructs are not related in career firefighters.
- Our findings indicate that greater body fat negatively affects performance fatigability in career firefighters, highlighting the impact of obesity on firefighter fatigability.

Work-related fatigue impacts 37% of US employees, resulting in reduced productivity, missed work, and an annual cost of $136.4 billion.[1–3] Further, numerous adverse health effects have been linked to work-related fatigue including musculoskeletal injuries,[4,5] mental health disorders,[6] cardiovascular disease,[7] decreased quality of life,[8] and all-cause mortality.[9] In 2019, the National Institute for Occupational Safety and Health (NIOSH) hosted a forum titled “Working Hours, Sleep and Fatigue” to address knowledge gaps and highlight the need for future research across various industries including the public safety sector.[10] Firefighters are critical to protecting public health and safety. Due to their shiftwork, the strenuous nature of their job tasks, and exposure to traumatic events and occupational stressors, firefighters are considered to be more susceptible to work-related fatigue.[11–13]

Work-related fatigue has been shown to negatively impact firefighter job performance and safety.[14–17] For example, firefighter work-related fatigue has been associated with decrements in physical (ie, balance,[18] strength[19]) and cognitive (i.e., reaction time,[20] vigilance[21]) variables, likely contributing to decreased performance on firefighter critical tasks.[12,14] For example, previous authors[14] reported an association between increased fatigability during an isotonic leg extensor fatiguing task and decreased stair climb performance in career firefighters. Further, work-related fatigue has been suggested to contribute to an increased risk of motor vehicle accidents, fatal injuries, and a four times greater risk of nonfatal injury and illness when compared to other state and local government workers.[15–17]

Previous studies have assessed work-related fatigue with subjective measures of perceived fatigue (the psychological attribute representing deviations from homeostasis),[13,22] while others have used objective measures of performance fatigability (the capacity of skeletal muscle and nervous system to sustain activity).[19,22–24] Both constructs of fatigue have previously been shown to negatively impact job performance[14,25] and injury risk[26,27] in first responders. Although independent constructs of fatigue, previous authors have found associations between perceived fatigue and performance fatigability in clinical populations.[28–32] However, there is little work done exploring this relationship in first responder populations. Evaluations of perceived fatigue may be an efficient and cost-effective tool to track and manage work-related fatigue in firefighters; however, it is unclear whether perceived fatigue is associated with physical constructs of fatigue (i.e., performance fatigability). It is also important to consider that demographic characteristics previously associated with higher levels of work-related fatigue (i.e., increased adiposity)[33–35] are more prevalent in the fire service when compared to the general population,[36] potentially confounding fatigue measurements and increasing their risk of experiencing work-related fatigue. Thus, the purpose of this study was to (1) examine the relationship between perceived work-related

From the MOTION Science Institute, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina (A.N.S., G.R.G., N.A.B., E.D.R.); Carolina Center for Healthy Work Design and Worker Well-Being, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina (A.N.S., G.R.G., N.A.B., E.D.R.); Human Movement Science Curriculum, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina (A.N.S., N.A.B., E.D.R.); Neuro Performance Innovation Center, Rockefeller Neuroscience Institute, West Virginia University, Morgantown, West Virginia (H.K.G.-D.); Lineberger Comprehensive Cancer Center, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina (M.R.L.); United States Performance Center, Charlotte, North Carolina (A.J.T.); and Neuromuscular and Occupational Performance Laboratory, Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, Texas (J.A.M.).

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Ethical considerations and disclosure: Written informed consent was obtained from all subjects. The study was approved by the University of North Carolina institutional review board #18-1458.

Address correspondence to: Eric D. Ryan, PhD, MOTION Science Institute, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, 209 Fetzer Hall, CB #8700, Chapel Hill, NC 27599-8700 (edryan@email.unc.edu).

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fatigue and performance fatigability and (2) assess the impact of percent body fat (%BF) on each fatigue construct in career firefighters.

METHODS

Participants

Thirty-nine male, career firefighters (all demographic data are included in Table 1) participated in this study.[37] Participants reported no history of neuromuscular, cardiovascular, or metabolic diseases. Participants were excluded if they were a smoker or had any major surgery or recent injury (within the last 3 months) to the lower extremities or lower back. This study was approved by the University of North Carolina at Chapel Hill institutional review board (#18-1458) for the protection of human subjects.

Experimental Design

Participants visited the laboratory in the morning on one occasion. All participants were asked to fast for 8 hours, refrain from caffeine intake and smokeless tobacco use for 12 hours, and vigorous lower body exercise for 48 hours prior to testing. To minimize the effect of acute fatigue, firefighters were asked to (1) reschedule if they felt significantly fatigued prior to their scheduled visit, and (2) complete the 0–10 rating of fatigue scale (0, not fatigued at all; 10, total fatigue and exhaustion—nothing left) upon arrival.[38] Each participant completed an informed consent document, health history questionnaire, and the OFER15 scale, a 15-item questionnaire assessing three components of work-related fatigue—acute fatigue (AF), chronic fatigue (CF), and inter-shift recovery (IR). Participants then completed a body composition assessment and were familiarized with the leg extensor strength and fatigue protocols. Following a 10-minute rest period and consumption of a standardized meal (Carnation Breakfast Essentials High Protein 8 fl oz; fat 6 g, carbohydrate 28 g, protein 15 g), participants performed a maximal strength and fatigability assessment of the leg extensor muscles.

Body Composition

Stature and body mass were measured using a calibrated stadiometer and scale (Health o meter 2101 KL, Bridgeview, IL). Dual-energy x-ray absorptiometry (DXA, GE Lunar iDXA, General Electric Medical Systems Ultrasound & Primary Care Diagnostics, Madison, WI) scans were used to assess participant body fat percentage. Participants were in the supine position in the center of the DXA table wearing athletic clothing free of metal. Participants were instructed to remain still during the entire scan.

TABLE 1. Mean ± Standard Deviation (SD) and Range Values for Demographic and Fatigue Variables

	Mean ± SD	Range
Age (yr)	32.7 ± 8.2	20–50
Stature (cm)	179.0 ± 7.4	159.2–194.6
Body mass (kg)	92.7 ± 19.1	65.1–133.2
BMI (kg/m^2)	28.9 ± 5.3	20.9–41.1
%BF (%)	24.1 ± 8.0	9.9–39.4
Rating of Fatigue Scale (AU)	1.5 ± 1.1	0–5
%ΔPT (%)	−10.9 ± 10.7	−35.8–10.2
CF score (AU)	13.9 ± 14.1	0–50
AF score (AU)	33.9 ± 18.3	0–66.7
IR score (AU)	75.8 ± 18.4	26.7–100

BMI, body mass index; %BF, percent body fat; %ΔPT, % change in peak torque; CF score, chronic fatigue score; AF, acute fatigue score; IR score, inter-shift recovery score; and AU, arbitrary units.

Familiarization

Participants were familiarized with the lower body strength and fatiguing protocol using their dominant leg, determined as the preferred foot to kick a ball. Each participant was provided with a warm-up consisting of three isometric leg extension contractions between 50%–75% of their perceived maximum effort before performing one isometric maximal voluntary contraction (MVC). Participants then performed five isotonic leg extension contractions at 40% of their familiarization MVC peak torque (PT). Active extension of the leg through the entire range of motion was followed by the dynamometer passively returning the leg to the starting position (please see details below). Participants were provided with a 10-minute rest period before performing the isometric strength testing and fatigability assessments.

Isometric Strength Testing

Participants were seated in a calibrated dynamometer (HUMAC Norm; Computer Sports Medicine Inc, Stoughton, MA) to measure leg extension PT. The dominant leg was flexed at 60° below horizontal (0° = full extension). The center of the subject's knee joint was aligned with the axis of rotation of the dynamometer. The lower leg was secured to a lever arm using a padded Velcro strap, 5-cm proximal to the lateral malleolus of the ankle. Straps were placed around the chest, pelvis, and contralateral limb to stabilize the participant during testing. After a warm-up of three isometric submaximal leg extensions (between 50%–75% of perceived max), participants were instructed to hold their arms across their chest and kick out "as hard and as fast as possible" for 3–4 seconds with strong verbal encouragement. Participants completed three MVCs, each separated by a 2-minute rest period. The highest PT value measured was used to calculate the load for the isotonic fatiguing protocol.

Fatigability

An isotonic fatiguing protocol, involving a constant load at 40% PT and unconstrained velocity, was utilized because of its high relevance to activities of everyday life.[39] Participants performed 30 consecutive isotonic contractions through 80° range of motion from 90° of knee flexion to 10° of flexion (0° = full extension). Each participant was instructed to kick out as hard and as fast as they could until their leg reached 10° of flexion. The dynamometer then passively returned the leg to the starting position (90°) at a speed of 45°•s^{-1}. Participants performed one contraction every 3 seconds and were instructed to fully relax during the passive return of their leg. Immediately following the fatiguing task, participants performed an isometric leg extension MVC. The 30-repetition protocol was chosen because the duration (90 seconds in total) is similar to previous studies[40] who have examined critical and essential firefighter tasks (eg, stair climb). During pilot testing, a load of 40% PT was found to be the highest load that participants could achieve near full range of motion for 30 repetitions.

Signal Processing

A Biopac data acquisition system (MP150WSW; Biopac Systems Inc, Goleta, CA) was used to collect torque (Nm), position (radians), and velocity (radians • s^{-1}) at 2 kHz. All data were stored on a personal computer (ThinkPad T420; Lenovo, Morrisville, NC) and processed off-line with a custom-written program (LabVIEW 15; National Instruments, Austin, TX). Torque, position, and velocity signals were filtered using a fourth-order, zero phase shift low-pass Butterworth filter with a 150Hz cutoff frequency.[41] Isometric PT of baseline and post-fatigue MVCs were determined as the highest 500millisecond epoch. Performance fatigability was determined by the percent reduction in peak torque (%ΔPT) from pre-fatigue and post-fatigue MVCs.

Fatigue Questionnaire

Each participant completed the OFER15, a questionnaire comprised of 15 questions examining three occupational fatigue components: AF, CF, and IR.[42] Previous authors have demonstrated that the scale has high internal reliability (Cronbach α, 0.84 to 0.86) and face, construct, and discriminate validity.[42] Participants were asked to recount their experiences in the last few months when responding to the questions. The OFER15 scale is a seven-point Likert scale ranging from 0 (strongly disagree) to 6 (strongly agree) with a combination of positively and negatively keyed items. Negatively keyed items were reverse scored (ie, final score = 6 − original score). Specifically, in the AF subscale, two questions (i.e., questions 9, 10) were negatively keyed, and in the IR subscale, three questions (i.e., questions 11, 13, 15) were negatively keyed. A formula was used to calculate each subscale score: (sum [item scores]/30) × 100. Higher AF and CF scores indicated greater occupational fatigue, whereas greater IR scores indicated better recovery.

Statistical Analysis

All descriptive data are presented as mean ± standard deviation. Pearson product-moment correlation coefficients (r) were used to determine the association between performance fatigue (%ΔPT) and each perceived fatigue variable (CF score, AF score, and IR score). A separate correlation analysis was also performed between each of the fatigue variables (e.g., performance and perceived fatigue) and the pre-testing rating of fatigue scores, %BF, and age. Due to the high prevalence of obesity,[36] large age range of career firefighters,[43] and previous research highlighting the impact of obesity and age on fatigue,[19,33–35] an additional partial correlation analysis controlling for %BF and age was performed when examining the association between performance and perceived fatigue variables. All statistical procedures were performed using SPSS version 28 (IBM; Chicago, IL). An alpha level of $P \leq 0.05$ was set to determine statistical significance.

RESULTS

All mean ± SD and the range values are presented in Table 1. None of the participants had to reschedule due to excessive fatigue and reported minimal fatigue (1.5 ± 1.1 AU) prior to testing. There were no significant associations between performance fatigability (%ΔPT) and each of the OFER15 scores (AF, CF, or IR; $r = -0.07$–0.11, $P \geq 0.513$). Further, these associations were unaffected when controlling for %BF and age ($r = -0.13$–0.07, $P \geq 0.387$). Pre-testing rating of fatigue scores were not significantly associated with any fatigue variables ($r = -0.01$–0.17, $P \geq 0.313$). Age was not significantly associated with any fatigue variables ($r = -0.31$–0.28, $P \geq 0.058$). Greater %BF was associated with greater performance fatigability ($r = -0.41$, $P = 0.010$) but none of the OFER15 fatigue variables including CF, AF, or IR ($r = -0.08$–0.05, $P \geq 0.638$) (see Fig. 1).

DISCUSSION

The primary findings of this study indicated that a laboratory-based assessment of performance fatigability (%ΔPT) was not associated with any of the OFER15 perceived work-related fatigue variables in career firefighters. However, greater %BF was negatively associated with %ΔPT (greater performance fatigability), but none of the OFER15 perceived work-related fatigue variables.

Although we are unaware of previous authors examining the relationship between perceived work-related fatigue and acute performance fatigability in firefighters, previous studies have investigated the relationship between perceived and performance fatigue in clinical populations and have reported mixed findings.[28–32,44,45] For instance, in patients with multiple sclerosis (MS), performance fatigability of the finger, elbow, and shoulder during a sustained isometric protocol was associated ($r = 0.41$–0.59) with perceived fatigue measures (i.e., fatigue severity scale [FSS], modified fatigue impact scale).[29,30,32] Similarly, in studies utilizing the leg extensor muscles, a significant but weak association was reported between measures of perceived fatigue (i.e., FSS, Functional Assessment of Chronic Illness Therapy Fatigue Scale) and performance fatigability during an isokinetic protocol in MS patients ($r = 0.20$) and a sustained isometric protocol ($r = 0.30$) in rheumatoid arthritis patients.[28,31] However, other previous studies with MS patients are in agreement with our findings and did not find a significant association between perceived fatigue (i.e., Neurological Fatigue Impact [NFI-MS]) and performance fatigability involving intermittent handgrip contractions.[44,45] However, caution is warranted when comparing fatigue outcomes of healthy and clinical populations due to the potential differences in the underlying mechanisms of fatigue.

The discrepancies in results between our study and previous work may be due to (1) the differences in the populations being tested, (2) variables that may uniquely impact perceived fatigue and performance fatigability, and (3) the timing of assessments. For example,

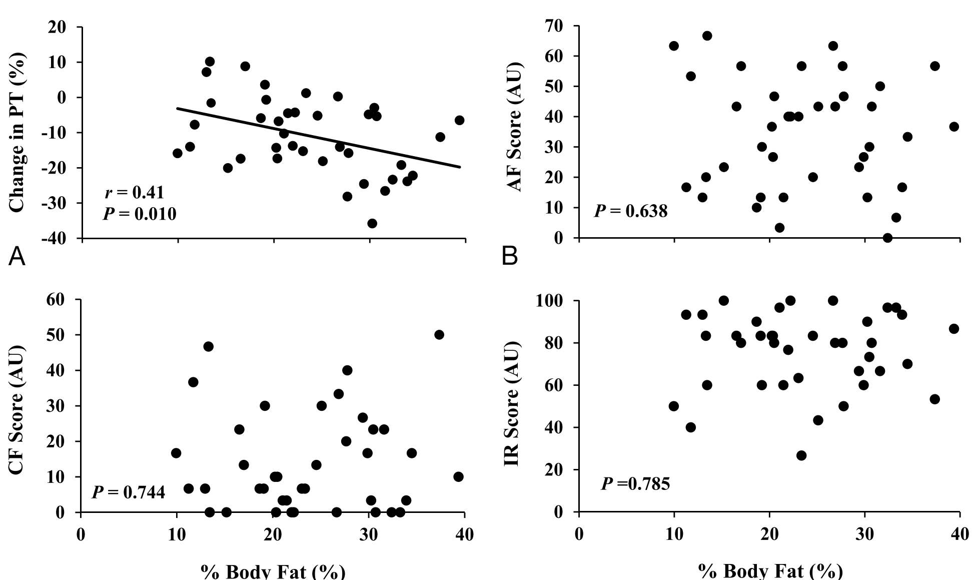

FIGURE 1. The relationship between percent body fat and (A) change in peak torque (PT), (B) acute fatigue (AF), (C) chronic fatigue (CF), and (D) intershift recovery (IR).

previous authors have reported a significant association between perceived fatigue and performance fatigability in MS patients, but not in healthy controls.[29] It is possible that the greater variance in the perceived fatigue values observed in clinical populations (SD = 0.9–1.59) compared to healthy controls (SD = 0.6–0.79) may impact the presence of a positive association.[29,30] It is also important to consider that perceived fatigue and performance fatigability are different constructs of fatigue, originating from distinct physiological mechanisms and likely impacted by different factors. For instance, previous authors[44] demonstrated a significant association between perceived fatigue and cognitive performance fatigability (Continuous Performance Test), but not with any of the physical performance assessments (6-minute walk test and repetitive maximal hand grip test) in MS patients. Unlike physical assessments of performance fatigability, cognitive performance fatigability has been linked to disrupted brain activation control.[46,47] Because perceived work-related fatigue has been shown to negatively affect similar mechanisms (i.e., disruptions to prefrontal cortex control over the sympathetic nervous system),[48] it is possible that measures of cognitive performance fatigability may be more sensitive to work-related fatigue than physical performance fatigability measures. However, future studies are necessary to test this hypothesis. In addition, assessment timing may impact the relationship between performance fatigability and perceived work-related fatigue. For instance, Giuliani et al[19] reported a significant association ($r = 0.352$) between scores on the IR subscale and changes in isometric leg extensor strength across a "Kelly" shift rotation (three 24-hour shifts in a 9-day cycle) in career firefighters. It is likely that because the IR subscale captures the perceived recovery between the end of one shift and the onset of the next,[42] it is more strongly associated with the changes in isometric strength across a shift cycle, rather than an acute measure of performance fatigability at one time point. Similarly, it is possible that the CF subscale is more strongly associated with performance fatigability assessments that are captured over longer periods that may better capture CF. However, it is important to note that the AF subscale was not associated with the acute performance fatigability assessment.

The results of this study indicated that %BF was associated with performance fatigability, but none of the OFER15-perceived work-related fatigue variables. Our findings are supported by authors who demonstrated that obese individuals experience greater performance fatigability.[49–52] Although speculative, previous authors[49–52] have suggested that obesity-related reductions in performance fatigability are due to a combination of physiological mechanisms. For example, obese individuals have reduced muscle capillarity, potentially limiting muscle blood perfusion, oxygen delivery, and metabolite clearance during exercise.[53,54] Additionally, authors[50,55] suggest that the greater proportion of highly fatigable type II muscle fibers in obese individuals may contribute to greater performance fatigability. It is possible that participants with lower levels of %BF engaged in more physical activity, which may improve their fatigue resistance.[56] However, this is speculative, as we did not examine their current exercise habits in this study.

Contrary to our findings, previous authors have reported that obesity, measured by BMI and waist circumference, is associated with greater perceived fatigue in the general population[33,35] and factory shift workers.[34] However, it is important to note that previous authors[33–35] utilized various questionnaires to assess work-related fatigue. For instance, Lin et al[34] utilized the Multidimensional Fatigue Symptom Inventory, a questionnaire measuring perceived fatigue over the past one-week period by taking the sum of five subscales (i.e., general fatigue, physical fatigue, emotional fatigue, mental fatigue, and vigor). It is possible that differences in the survey (i.e., subscale types, scoring the survey as a sum vs scoring each subscale separately, amount of time participants were asked to recount) could impact perceived fatigue scores and contribute to the contrasting results. In support of this, previous authors[19] utilizing the OFER15 scale have reported a significant association between BMI and perceived work-related fatigue among career firefighters. Although it is unclear why %BF is associated with performance fatigability but not perceived work-related fatigue in firefighters, a possible explanation is that obesity-related reductions in performance fatigability have been directly linked to physiological mechanisms (i.e., limited blood perfusion, muscle fiber type composition). Meanwhile, perceived work-related fatigue may be more complex and heavily influenced by additional variables such as sleep deprivation and emotional exhaustion, commonly reported consequences of firefighter shift work.[57,58] Further work is needed identify key factors that contribute to perceived work-related fatigue.

In summary, the findings of the current investigation indicated that performance fatigability was not associated with any of the OFER15 perceived work-related fatigue subscales in career firefighters. Although greater %BF was associated with greater performance fatigability, it was not associated with any of the OFER15 perceived work-related fatigue subscales. These findings are significant given firefighters are considered to be more susceptible to work-related fatigue[11,12] and are more likely to be overweight and obese when compared to the general public.[36] Given the complexity of firefighter work-related fatigue, this study may provide novel insight into the proper assessment and management of work-related fatigue in an at-risk population.

REFERENCES

1. Janssen I, Bacon E, Pickett W. Obesity and its relationship with occupational injury in the Canadian workforce. *J Obes* 2011;2011:e531403.
2. Ricci JA, Chee E, Lorandeau AL, Berger J. Fatigue in the U.S. workforce: prevalence and implications for lost productive work time. *J Occup Environ Med* 2007;49:1–10.
3. Binnewies C, Sonnentag S, Mojza E. Daily performance at work: feeling recovered in the morning as a predictor of day-level job performance. *J Organ Behav* 2008;30:67–93.
4. Swaen G, van Amelsvoort LGPM, Bultmann U, Kant I. Fatigue as a risk factor for being injured in an occupational accident: results from the Maastricht cohort study. *Occup Environ Med* 2003;60:88–92.
5. Williamson A, Lombardi DA, Folkard S, Stutts J, Courtney TK, Connor JL. The link between fatigue and safety. *Accid Anal Prev* 2011;2:498–515.
6. Shields M. Long working hours and health. *Health Rep* 1999;11:33–48.
7. Honkonen T, Ahola K, Pertovaara M, et al. The association between burnout and physical illness in the general population—results from the Finnish Health 2000 Study. *J Psychosom Res* 2006;61:59–66.
8. Woo D, Lee Y, Park S. Associations among working hours, sleep duration, self-rated health, and health-related quality of life in Korean men. *Health Qual Life Outcomes* 2020;18:287.
9. Nylén L, Voss M, Floderus B. Mortality among women and men relative to unemployment, part time work, overtime work, and extra work: a study based on data from the Swedish twin registry. *Environ Med* 2001;58:52–57.
10. Wong I, Swanson N. Approaches to managing work-related fatigue to meet the needs of American workers and employers. *Am J Ind Med* 2022;65:827–831.
11. Widiyanto H, Nasri SM. Factors affecting work fatigue in firefighters. *Int J Soc Health* 2024;3:389–397.
12. Marvin G, Schram B, Orr R, Canetti EFD. Occupation-induced fatigue and impacts on emergency first responders: a systematic review. *Int J Environ Res Public Health* 2023;20:7055.
13. Jeklin AT, Davies HW, Bredin SSD, et al. Fatigue and sleep patterns among Canadian wildland firefighters during a 17-day fire line deployment. *J Occup Environ Hyg* 2020;17:364–371.
14. Ryan ED, Laffan MR, Trivisonno AJ, et al. Neuromuscular determinants of simulated occupational performance in career firefighters. *Appl Ergon* 2022; 98:103555.
15. U.S. Department of Labor. Work injuries and illnesses of local government firefighters in 2009. [Bureau of Labor Statistics web site]. December 7, 2012. Available at: https://www.bls.gov/opub/ted/2012/ted_20121207.htm. Accessed July 24, 2024.
16. Maloney SM. Nonfatal Injuries and Illnesses Among State and Local Government Workers. [Bureau of Labor Statistics web site]. March 2014. Available at: https://www.bls.gov/spotlight/2014/soii-gov-workers/home.htm. Accessed July 24, 2024.
17. Maguire BJ. Ambulance safety. In: Cone DC, ed. *NAEMSP. Emergency Medical Services: Clinical Practice & Systems Oversight*. Hoboken, NJ: Wiley Publishing; 2014.
18. Pau M, Kim S, Nussbaum MA. Fatigue-induced balance alterations in a group of Italian career and retained firefighters. *Int J Ind Ergon* 2014;44:615–620.

19. Giuliani HK, Gerstner GR, Mota JA, Ryan ED. Influence of demographic characteristics and muscle strength on the occupational fatigue exhaustion recovery scale in career firefighters. *J Occup Environ Med* 2020;62:223.
20. Stout JW, Beidel DC, Brush D, Bowers C. Sleep disturbance and cognitive functioning among firefighters. *J Health Psychol* 2021;26:2248–2259.
21. Ferguson SA, Smith BP, Browne M, Rockloff MJ. Fatigue in emergency services operations: assessment of the optimal objective and subjective measures using a simulated wildfire deployment. *Int J Environ Res Public Health* 2016;13:171.
22. Behrens M, Gube M, Chaabene H, et al. Fatigue and human performance: an updated framework. *Sports Med* 2023;53:7–31.
23. Enoka RM, Duchateau J. Translating fatigue to human performance. *Med Sci Sports Exerc* 2016;48:2228–2238.
24. Gerstner GR, Mota JA, Giuliani HK, et al. The impact of repeated bouts of shiftwork on rapid strength and reaction time in career firefighters. *Ergonomics* 2022;65:1086–1094.
25. Sheaff AK, Bennett A, Hanson ED, et al. Physiological determinants of the candidate physical ability test in firefighters. *J Strength Cond Res* 2010;24: 3112–3122.
26. Lin MH, Huang YC, Chen WK, Wang JY. Sleepiness and injury risk in emergency medical service workers in Taiwan. *PloS One* 2020;15:e0229202.
27. Ghasemi F, Zarei H, Babamiri M, Kalatpour O. Fatigue profile among petrochemical firefighters and its relationship with safety behavior: the moderating and mediating roles of perceived safety climate. *Int J Occup Saf Ergon* 2022;28:1822–1828.
28. do Espírito Santo RC, Pompermayer MG, Bini RR, et al. Neuromuscular fatigue is weakly associated with perception of fatigue and function in patients with rheumatoid arthritis. *Rheumatol Int* 2018;38:415–423.
29. Severijns D, Van Geel F, Feys P. Motor fatigability in persons with multiple sclerosis: relation between different upper limb muscles, and with fatigue and the perceived use of the arm in daily life. *Mult Scler Relat Disord* 2018;19:90–95.
30. Steens A, de Vries A, Hemmen J, et al. Fatigue perceived by multiple sclerosis patients is associated with muscle fatigue. *Neurorehabil Neural Repair* 2012;26: 48–57.
31. Taul-Madsen L, Dalgas U, Kjolhede T, et al. A head-to-head comparison of an isometric and a concentric fatigability protocol and the association with fatigue and walking in persons with multiple sclerosis. *Neurorehabil Neural Repair* 2020;34:523–532.
32. Wolkorte R, Heersema DJ, Zijdewind I. Muscle fatigability during a sustained index finger abduction and depression scores are associated with perceived fatigue in patients with relapsing-remitting multiple sclerosis. *Neurorehabil Neural Repair* 2015;29:796–802.
33. Lim W, Hong S, Nelesen R, Dimsdale JE. The association of obesity, cytokine levels, and depressive symptoms with diverse measures of fatigue in healthy subjects. *Arch Intern Med* 2005;165:910–915.
34. Lin YC, Chen JD, Chen CJ. Abnormal liver function and central obesity associate with work-related fatigue among the Taiwanese workers. *World J Gastroenterol WJG* 2008;14:6541–6545.
35. Başkurt Z, Başkurt F, Ercan S, Çetin C. Association among measures of physical function, functional disability and self-perceived fatigue in individuals with obesity. *BMC Med Res Methodol* 2017;20:9032–9038.
36. Poston WSC, Haddock CK, Jahnke SA, et al. The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort. *J Occup Environ Med* 2011;53:266–273.
37. Laffan M. The neuromuscular contribution to stair climb performance in career firefighters. 2019. doi:https://doi.org/10.17615/rwet-5s92.
38. Micklewright D, St Clair Gibson A, Gladwell V, Al Salman A. Development and validity of the rating-of-fatigue scale. *Sports Med* 2017;47:2375–2393.
39. Cheng AJ, Rice CL. Fatigue and recovery of power and isometric torque following isotonic knee extensions. *J Appl Physiol* 2005;99:1446–1452.
40. Kleinberg CR, Ryan ED, Tweedell AJ, Barnette TJ, Wagoner CW. Influence of lower extremity muscle size and quality on stair-climb performance in career firefighters. *J Strength Cond Res* 2016;30:1613–1618.
41. Thompson BJ. Influence of signal filtering and sample rate on isometric torque —time parameters using a traditional isokinetic dynamometer. *J Biomech* 2019; 83:235–242.
42. Winwood PC, Lushington K, Winefield AH. Further development and validation of the Occupational Fatigue Exhaustion Recovery (OFER) Scale. *J Occup Environ Med* 2006;48:381–389.
43. Haynes H, Stein G. U.S. Fire Department Profile - 2015. 2017.
44. Aldughmi M, Bruce J, Siengsukon CF. Relationship between fatigability and perceived fatigue measured using the neurological fatigue index in people with multiple sclerosis. *Int J MS Care* 2017;19:232–239.
45. Iriarte J, de Castro P. Correlation between symptom fatigue and muscular fatigue in multiple sclerosis. *Eur J Neurol* 1998;5:579–585.
46. Bellgrove MA, Hester R, Garavan H. The functional neuroanatomical correlates of response variability: evidence from a response inhibition task. *Neuropsychologia* 2007;42:1910–1916.
47. Walhovd KB, Fjell AM. White matter volume predicts reaction time instability. *Neuropsychologia* 2007;45:2277–2284.
48. Querstret D, Cropley M. Exploring the relationship between work-related rumination, sleep quality, and work-related fatigue. *J Occup Health Psychol* 2012;17:341–353.
49. Cavuoto LA, Nussbaum MA. The influences of obesity and age on functional performance during intermittent upper extremity tasks. *J Occup Environ Hyg* 2014;11:583–590.
50. Garcia-Vicencio S, Martin V, Kluka V, et al. Obesity-related differences in neuromuscular fatigue in adolescent girls. *Eur J Appl Physiol* 2015;115: 2421–2432.
51. Maffiuletti NA, Jubeau M, Munzinger U, et al. Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *Eur J Appl Physiol* 2007; 101:51–59.
52. Mehta RK, Cavuoto LA. Relationship between BMI and fatigability is task dependent. *Hum Factors* 2017;59:722–733.
53. Gavin TP, Stallings HW, Zwetsloot KA, et al. Lower capillary density but no difference in VEGF expression in obese vs. lean young skeletal muscle in humans. *J Appl Physiol* 2005;98:315–321.
54. Kern PA, Simsolo RB, Fournier M. Effect of weight loss on muscle fiber type, fiber size, capillarity, and succinate dehydrogenase activity in humans. *J Clin Endocrinol Metab* 1999;84:4185–4190.
55. Kriketos AD, Baur LA, O'Connor J, et al. Muscle fibre type composition in infant and adult populations and relationships with obesity. *Int J Obes* 1997; 21:796–801.
56. Bogdanis GC. Effects of physical activity and inactivity on muscle fatigue. *Front Physiol* 2012;3:142.
57. Frost C, Toczko M, Merrigan JJ, Martin JR. The effects of sleep on firefighter occupational performance and health: a systematic review and call for action. *Sleep Epidemiol* 2021;1:100014.
58. Ro ca AC, Mateizer A, Dan CI, Demerouti E. Job demands and exhaustion in firefighters: the moderating role of work meaning. A cross-sectional study. *Int J Environ Res Public Health* 2021;18:9819.

