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ARTICLE

The impact of repeated bouts of shiftwork on rapid strength and reaction time in career firefighters

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ABSTRACT
The purpose of this study was to examine the influence of repeated bouts of shiftwork on lower extremity maximal and rapid strength and reaction time in career firefighters. Thirty-five firefighters (3 females; 34.3 ± 9.1 years) performed a psychomotor vigilance test (PVT) and reactive maximal isometric strength assessment prior to and following a full shift rotation (three 24-hr on-off shifts). Reaction time (RT), maximal, absolute and normalised rapid strength (50, 100, 150, 200 ms), and PVT measures were assessed on-site. Separate linear regression models were used to evaluate the POST-PRE change in variables adjusted for BMI, age, sleep, and call duration. Early (50 ms) absolute rapid strength was the only variable significantly reduced (–25.9%; $p = 0.031$) following the full shift rotation. Our findings indicate that early rapid strength may be a sensitive measure in detecting work-related fatigue, despite minimal changes in sleep between work and non-work nights and a low call duration.

Practitioner summary: We examined the impact of repeated shiftwork on changes in reaction time and neuromuscular function. Early rapid strength was a sensitive, portable lab assessment that feasibly measured work-related fatigue in career firefighters. Interventions that mitigate work-related fatigue may be impactful at preventing falls and/or risk of musculoskeletal injury.

Abbreviation: *a*: absolute; BMI: body mass index; F: force; FAM: familiarisation; MVC: maximal voluntary contraction; *n*: normalised; NW: non-work; PF: peak force; PVT: psychomotor vigilance test; RT: reaction time; SD: standard deviation; W: work

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Introduction

Approximately 38% of the workforce in the United States have reported experiencing work-related fatigue, resulting in lost productive time and an excess cost of $101 billion annually to employers (Ricci, et al. 2007). Given that firefighters are exposed to a variety of occupational hazards as well as long and strenuous shifts, these conditions increase their susceptibility to work-related fatigue and likely contribute to the incidence of motor vehicle accidents, slips, trips, and falls, and overexertion musculoskeletal disorders (Evarts and Molis 2018; Fahy and Molis 2019). Specifically, firefighters exhibit one of the highest rates of occupational injuries (Houser, et al. 2004), with an estimated annual cost of $2.8–7.8 billion (National Institute of Standards and Technology 2005). Furthermore, work-related fatigue has been shown to persist with other health-related conditions (e.g. depressive disorders, diabetes, heart disease) (Ricci, et al. 2007), and is compounded with work characteristics of physically demanding occupations (Trinkoff, Storr, and Lipscomb 2001; Akerstedt, et al. 2002).

Physiologically, fatigue has been shown to impair neuromuscular function by delaying reaction times (McLean, Borotikar, and Lucey 2010) and decreasing maximal and rapid strength (Linnamo, Hakkinen, and Komi 1997; Buckthorpe, Pain, and Folland 2014), which may increase the risk of an on-duty accident resulting in an injury (e.g. slips, trips, and falls) (Swaen 2003). While the cause of injuries is multi-faceted,

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occupational injury rates have been shown to increase with working hours (Dembe et al. 2005), which is common for career firefighters in the United States who work 24-hour shifts in a designated rotation (i.e. shiftwork) (Billings and Focht 2016). Shiftwork has received much attention because it causes circadian dysrhythmia (Billings and Focht 2016) and has been cited as one of the most influential occupational risk factors for elevated blood pressure, metabolic syndrome, and cardiovascular disease (Jennings et al. 2007; Fialho et al. 2006; Wolk et al. 2005; Kitamura et al. 2002). Apart from apparent health, performance, and injury risks linked to work-related fatigue, several studies on fatigue in health care settings (Baldwin and Daugherty 2004; Baldwin, et al. 2003; Mittal, et al. 2004; Rogers et al. 2004) suggest patient safety and quality of care also suffer. This is especially detrimental for firefighters in the context of the dangerous nature of their jobs as errors in performance can impact the safety of other individuals and the public. For instance, a lapse in attention, slower reaction time, and/or impaired rapid strength could put oneself, other firefighters, or victims in greater danger.

Traditionally, work scheduling characteristics have been examined using self-reported measures of fatigue (Akerstedt, et al. 2002; Paley and Tepas 1994; Huibers et al. 2004). These measures, however, provide little insight into the physiological consequences of work-related fatigue and limit future prevention efforts. Recent studies have successfully employed a psychomotor vigilance test (Thompson 2019; Thompson et al. 2016; Mehta et al. 2020) and strength assessments (Thompson 2019; Thompson, Stock, and Banuelas 2017) over successive shifts to determine decrements in performance related to shiftwork fatigue. Moreover, previous authors (Morcelli et al. 2016) have utilised a reactive strength assessment to examine both reaction time and rapid strength. These neuromuscular assessments may help to identify the specific factors that contribute to work-related fatigue.

To our knowledge, rapid strength measures have yet to be utilised to examine fatigue in public safety populations. Investigating performance fatigability (e.g. declines in maximal and rapid strength) across a shift rotation may provide a sensitive method for detecting work-related fatigue. Thus, the purpose of the present study was to examine the influence of repeated bouts of shiftwork on two distinct measures of fatigue including reaction time from the psychomotor vigilance test (PVT) scores (i.e. neurocognitive) and a novel reactive lower extremity force assessment (i.e. neuromuscular) in career firefighters while controlling for individual demographics (i.e. age, BMI) and work characteristics (i.e. sleep, call duration) known to influence work-related fatigue. In addition, this study aimed to improve external validity by capturing assessments immediately around a full shift rotation, on-site at local fire stations.

Table 1. Descriptive statistics for demographics and work schedule characteristics in ($N = 35$) career firefighters.

Variable	Mean	SD	Range
Age (years)	34.29	± 9.09	(20–50)
Mass (kg)	97.03	± 21.34	(63.96–151.95)
Stature (cm)	177.93	± 7.80	(153.00–192.00)
BMI (kg·m^{-2})	30.50	± 5.65	(22.05–44.40)
Total call duration (hours)	2.83	± 1.83	(0.45–7.52)
W/NW sleep (%)	97.95	± 13.71	(57.93–118.68)

SD: standard deviation; BMI: body mass index; W/NW: work to non-work.

Materials and methods

Participants

Thirty-five career firefighters (32 males, 3 females) volunteered for this repeated measures investigation (demographics listed in Table 1). None of the participants reported any metabolic or neuromuscular diseases, or musculoskeletal injuries sustained within the past three months specific to the low back, hip, knee, or ankle. All participants completed and signed an approved consent form, and a health history and exercise status questionnaire. This study was approved by the University Institutional Review Board.

Experimental design

Testing occurred on three separate occasions at local fire stations at the same time of day ± 1 hour. The first visit was a familiarisation trial where the participants practiced the PVT and the reactive maximal isometric strength assessment. The second visit was the PRE testing session, four days following the familiarisation session, in coordination with the start of the participants' respective shift rotation, which included the PVT and the reactive maximal isometric strength assessment. At the conclusion of the participants' respective shift rotation, five days after PRE, POST testing of the PVT and the reactive maximal isometric strength assessment was performed. See Figure 1 for an example of the testing sessions in conjunction with the rotation schedule. All participants refrained from any vigorous physical activity 24 hours prior to all testing.

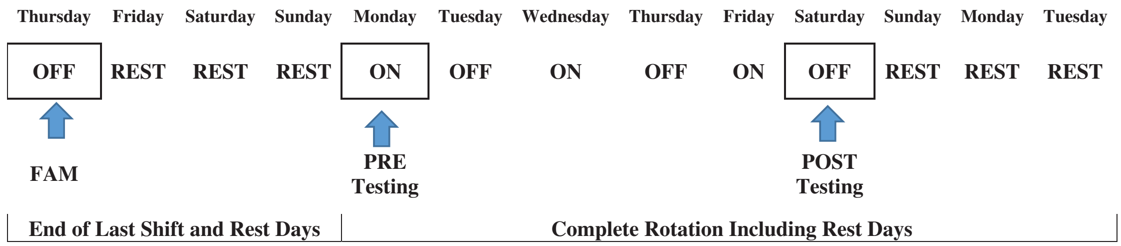

Figure 1. An example of the testing sessions in conjunction with the firefighter shift schedule including the familiarisation (FAM) session following the end of the last shift on a rotation, the PRE testing session at the start of the next rotation, and the POST testing session at the end of their last shift on a rotation. Note: a full rotation occurs over a nine-day period.

Psychomotor vigilance test

The PVT was developed to conduct a simple, reliable, and cost effective visual reaction time (RT) test (Khitrov et al. 2014). This validated, freely downloadable PC software program (Khitrov et al. 2014) was used in conjunction with a PC laptop (Think Pad R400, Lenovo, Morrisville, NC, USA) and optical mouse (USB Wired Optical Mouse, Lenovo, Morrisville, NC, USA). The PVT was conducted as per the procedures of Khitrov et al. (2014), which has been shown to be comparable to the gold standard. Versions of the PVT have been used in other shift working populations (i.e. nurses, emergency response pilots) (Thompson et al. 2016; Mehta et al. 2020) who must remain vigilant on duty. While the gold standard version is traditionally a 10-minute task, shorter versions (i.e. 3 or 5-minute PVT) have demonstrated acceptable reliability (Khitrov et al. 2014) and have been used in emergency responders for feasibility (Thompson et al. 2016; Mehta et al. 2020). Participants completed the PVT in a seated position, and were asked to exclusively focus on the PVT for the total 5-minute duration of the test in a separate room without distractions. The interstimulus intervals were between 2 and 10 seconds. The variables obtained from the PVT included mean reaction time (meanRT), and the fastest and slowest 10% of reaction time attempts over the 5-minute duration of the test.

Reactive force assessments

The isometric strength assessments were conducted on a custom-built calibrated isometric dynamometer to examine leg extensor force production (Figure 2) (Giuliani et al. 2020). Participants were seated with their lower right leg secured to the dynamometer lever arm using a lightly padded strap (60 mm width) placed five cm proximal to the lateral malleolus of the ankle. A shin guard was placed on the lower leg of the participant to ensure the leg could extend rapidly with no perceived pain. Restraining straps were placed over the chest, pelvis, and left thigh, and participants were required to keep their arms crossed in front of their chest during testing. The participants' right leg was secured at 60° below the horizontal plane.

Prior to maximal strength testing, participants performed a warm-up comprised of two submaximal isometric voluntary contractions at 50 and 75% of their perceived maximal effort for 3–4 s. Each participant then performed 3–4 reactive maximal voluntary contractions (MVCs) for 3–4 s with two minutes of recovery between trials. Reaction time (RT) was measured concurrently with the strength assessments, which has been frequently used to assess age-related changes in neuromuscular function (Morcelli et al. 2016; Laroche et al. 2007) and changes following resistance training interventions (Laroche 2009; LaRoche et al. 2008). By using a randomly delayed light stimulus (between 2 and 8 seconds), the participants were signalled to initiate the isometric MVC. Over the duration of each MVC, participants received strong verbal encouragement in which they were instructed to extend 'as hard and fast as possible' without any preceding countermovement or pretension as previously described (Thompson et al. 2014; Thompson et al. 2013). To ensure the quality of the MVCs, each MVC was visually inspected for pretension or countermovement. The slope of the baseline (100 ms) prior to contraction onset was calculated to determine if there was pretension or a countermovement prior to the MVC. During analyses, if the slope values exceeded $\pm$ 5 N·sec^{-1} during baseline (preceding 100 ms), the MVC was discarded. Consequently, three participants were excluded prior to subsequent analyses as all of their MVC attempts exceeded this threshold. The average baseline force slope values of the remaining participants were -0.01 ± 1.85 and 0.33 ± 1.30 N·sec^{-1} for PRE and POST, respectively.

Signal processing

The force (N) signal was sampled at 2 kHz with a Biopac data acquisition system (MP150WSW; Biopac Systems, Inc., Santa Barbara, CA, USA) and stored on a

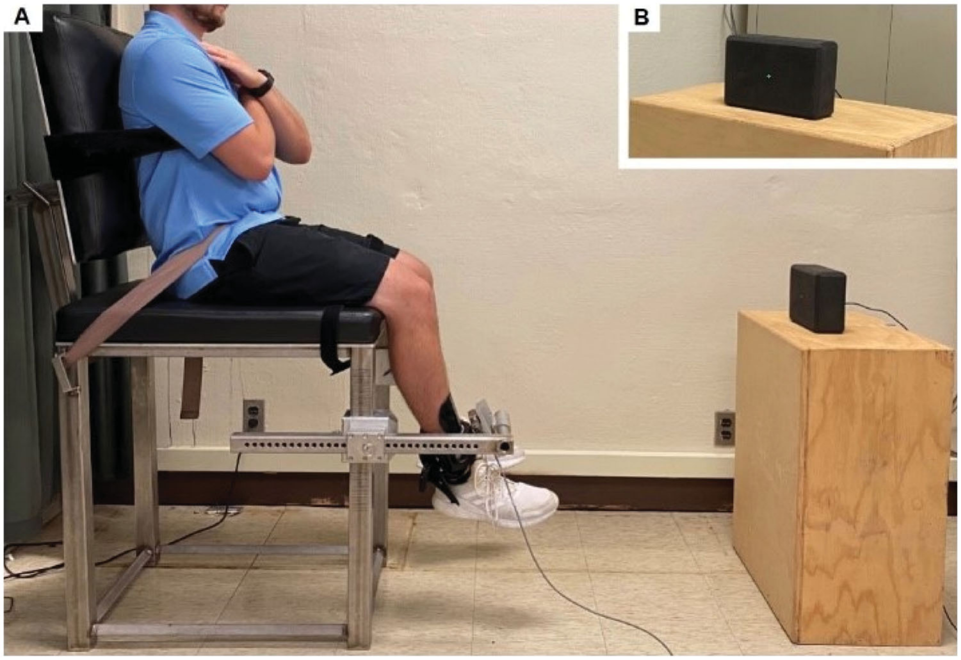

Figure 2. An example of the custom-built calibrated isometric dynamometer in a (a) lateral view including the light stimulus and (b) the front view of the light stimulus.

personal computer (Think Pad T420, Lenovo, Morrisville, NC, USA). A custom written software (Labview 8.5, National Instruments, Austin, TX, USA) was used to process all of the signals off-line. All of the force signals were corrected for baseline passive tension and filtered using a fourth order, zero phase shift low pass Butterworth filter with a 50 Hz cut-off frequency. Identification of the force onset was manually determined by the same experienced investigator using a high resolution x- and y-axis scale as recommended by Maffiuletti et al. (2016), similar to Gerstner et al. (2017). A horizontal line was plotted at 3 SDs above baseline and was used as a guide for manually determining where the signal deflected from baseline. The investigator zoomed in near the signal onset including the horizontal line and placed a vertical cursor at the point at which the respective signal deflected (i.e. last trough before signal deflection) from baseline (Maffiuletti et al. 2016).

The time period between the light stimulus presentation and the onset of force production was determined as RT (Figure 3). Isometric peak force (PF) was determined as the highest 100 ms epoch during the 3–4 s MVC plateau. The absolute and normalised rapid force variables were calculated from the absolute and normalised force-time curves, respectively, at 50 ms, 100 ms, 150 ms and 200 ms from onset (F_{50}, F_{100}, F_{150}, F_{200}). These specific time points were chosen to represent early (<100 ms) and late (100–200 ms) force–time characteristics, which may represent different physiological parameters according to previous authors (Gerstner et al. 2017; Andersen and Aagaard 2006).

Work schedule characteristics

Sleep

Participants were given a Fitbit® Charge HR (Fitbit Inc., San Francisco, CA, USA) on the familiarisation visit. They were instructed to wear it every night through the morning of POST testing. The night prior to starting a 24-hr shift was considered a work (W) night of sleep, and the night following a 24-hr shift was considered a non-work (NW) night of sleep. There was a total of three W nights and six NW nights, which were averaged in minutes, respectively. These averages were used to calculate %W/NW to control for sleep in further analyses. When a participant missed one evening of sleep data ($N = 3$), the W or NW sleep was averaged out of two or five nights, respectively. We were unable to obtain sleep data for one individual due to technical issues.

Call duration

All of the local fire stations reported fire incident and firefighter activity through FIREHOUSE® software (ESO Solutions Inc., Urbandale, IA, USA). Reports for each participant were provided for the specific rotation when data was collected. On-call activity was assessed

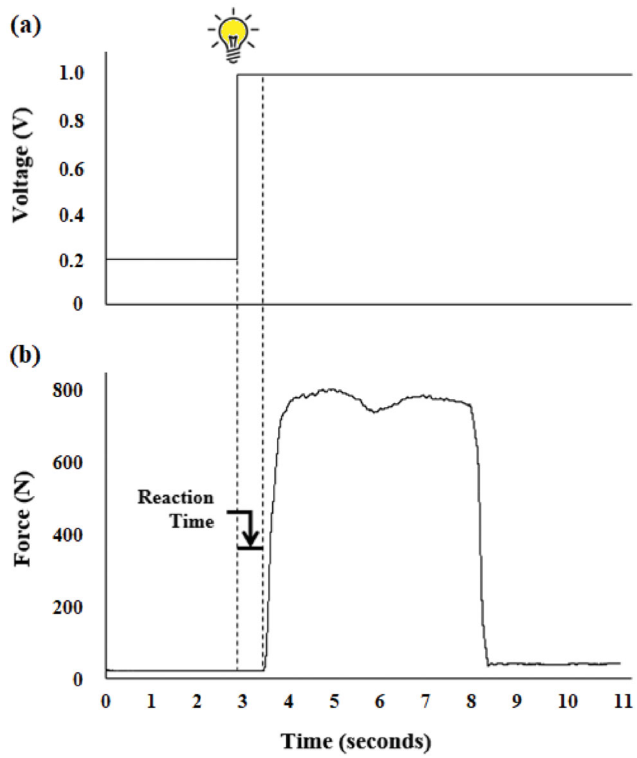

Figure 3. An example of the (a) light stimulus and the (b) force response during a reactive isometric maximal voluntary contraction. Reaction time is labelled as the time between the onset of the light stimulus and the onset of force production.

by the number of hours the participant was involved in EMS or fire calls per shift. The sum of the three 24-hr shifts over the rotation was used to determine call duration for further analyses.

Statistical analyses

The mean ± standard deviation (SD) and ranges were determined for all the demographic and work schedule characteristics. Separate linear regression models (see Equation 1) were used to evaluate the POST-PRE mean change in RT, PF, absolute and normalised rapid force, and PVT variables adjusted for BMI, age, sleep, and call duration. Each covariate was centred to have a mean of zero by subtracting the sample mean. Due to missing sleep data, all PVT regression analyses contained 34 individuals. Furthermore, in conjunction with the unusable rapid force data ($N = 3$), all regression analyses on force data only contained 31 individuals. Furthermore, observations were screened for outliers (standardized residuals $\geq$ 2.5). To minimise the influence of extreme values, one observation (standardized residual of 5.6) was removed from the slowest 10% of reaction time ($N = 33$).

$$\text{POST} - \text{PRE} = ß_0 + ß_1(\text{BMI}) + ß_2(\text{age}) + ß_3(\text{sleep}) + ß_4(\text{call duration}) \quad (1)$$

For each regression model, we estimated the adjusted mean change in the outcome, along with a 95% confidence interval. An alpha level was set *a priori* at 0.05 to determine statistical significance. Measures were analysed using SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

All demographic and work schedule characteristics are summarised in Table 1. The raw mean ± standard deviation values for PRE and POST as well as the adjusted mean change scores for the outcome variables are presented in Table 2.

Psychomotor vigilance test

For the PVT RT measures, the mean, and fastest and slowest 10% adjusted mean change scores were not significantly different from zero ($p = 0.107$–0.945).

Force

The adjusted mean change score was not significantly different from zero for MVC RT ($p = 0.188$) or PF ($p = 0.653$). For the absolute rapid force variables, aF_{100}, aF_{150}, and aF_{200} adjusted mean change scores were not significantly different from zero ($p = 0.134$–0.486). However, the adjusted mean change score for aF_{50} was significantly lower during POST testing ($p = 0.031$). For the normalised rapid force variables, nF_{50}, nF_{100}, nF_{150}, and nF_{200} adjusted mean change scores were not significantly different from zero ($p = 0.061$–0.539).

Discussion

Work-related fatigue has been suggested to be one of the primary causes of occupational injury (Dembe et al. 2005), however little is known regarding the influence of shiftwork on neuromuscular function in career firefighters. The primary findings of the present study showed that when controlling for BMI, age, sleep, and call duration, early (50 ms) rapid force production was reduced following a common shift rotation (Kelly shift: three 24-hr on-off shifts). None of the remaining variables including later (100–200 ms) absolute or normalised rapid force, PF, RT, or vigilance-

Table 2. Raw mean ± standard deviation (SD) values for the PRE and POST outcome variables and estimated adjusted mean change, along with 95% confidence intervals.

Outcome	Sample	Pre	Post	Mean Change (95% CI)$^{\Delta}$
PVT meanRT (ms)	$N=34$	277.74 ± 52.60	278.40 ± 45.23	0.65 (−18.59, 19.90)
PVT slowest 10% (ms)	$N=33$	410.74 ± 71.59	420.57 ± 89.89	9.83 (−17.99, 37.66)
PVT fastest 10% (ms)	$N=34$	205.78 ± 18.89	212.41 ± 25.09	6.63 (−1.51, 14.77)
RT (ms)	$N=31$	258.32 ± 54.12	248.42 ± 37.66	−11.67 (−29.42, 6.07)
PF (N)	$N=31$	693.64 ± 124.67	699.68 ± 138.90	6.63 (−23.33, 36.59)
aF_{50} (N)	$N=31$	37.67 ± 42.35	27.90 ± 25.24	−10.28 (−19.57, −0.99)*
aF_{100} (N)	$N=31$	207.46 ± 129.86	187.10 ± 106.98	−21.69 (−50.53, 7.15)
aF_{150} (N)	$N=31$	334.85 ± 119.81	320.58 ± 102.93	−12.93 (−41.56, 15.70)
aF_{200} (N)	$N=31$	402.10 ± 125.88	392.77 ± 106.46	−8.40 (−32.86, 16.06)
nF_{50} (%MVC)	$N=31$	5.08 ± 4.75	3.97 ± 3.29	−1.16 (−2.39, 0.06)
nF_{100} (%MVC)	$N=31$	28.97 ± 15.01	26.58 ± 13.39	−2.51 (−7.23, 2.21)
nF_{150} (%MVC)	$N=31$	47.64 ± 12.62	45.79 ± 11.65	−1.62 (−5.84, 2.59)
nF_{200} (%MVC)	$N=31$	57.40 ± 12.08	56.16 ± 10.92	−1.10 (−4.73, 2.53)

RT: reaction time; PF: peak force; F: force; a: absolute; n: normalised; PVT: psychomotor vigilance test.
*$p \leq 0.05$, significant difference between PRE and POST.
$^{\Delta}$Model estimated means adjusted for BMI, age, call duration, and sleep.

related (PVT) RT measures were significantly reduced following the shift rotation.

Previous authors have found work-related fatigue declines in absolute maximal and rapid strength in a shiftwork population (i.e. nurses) (Thompson 2019; Thompson, Stock, and Banuelas 2017). Thompson, Stock, and Banuelas (2017) specifically investigated absolute maximal and rapid strength in nurses with accumulating work shifts (three 12-hour shifts in 4 days) and demonstrated a decline from pre to post-testing at early (50 ms; −19.2%) and late (200 ms; −14.5%) time intervals, in addition to maximal strength (−7%). In contrast, our findings demonstrated significant reductions (−25.9%) in rapid strength at only the early time intervals (50 ms), which was also similar when normalised to PF (−21.9%; $p=0.061$). Potential differences between our findings and those reported by Thompson, Stock, and Banuelas (2017) may be due to the nurses experiencing greater fatigue over the accumulating work shifts. Our firefighters experienced minimal changes in sleep between work and non-work nights and low call duration (Table 1), two factors which may be significant contributors to work-induced fatigue over the shift rotation (Billings and Focht 2016). Furthermore, in Thompson, Stock, and Banuelas (2017) and the present study, early rapid strength showed the greatest decline, suggesting that rapid strength at 50 ms may be the most sensitive time point to measure changes in strength due to work-related fatigue. This is in line with previous findings from Buckthorpe, Pain, and Folland (2014) indicating that quadriceps fatigue induced a more pronounced effect on rapid force than on maximal strength, particularly during the initial 50 ms time interval. Early and later phases of rapid strength have been suggested to be influenced by unique neuromuscular contributions (e.g. neural *vs.* muscular) (Palmer et al. 2015; Doran, Van Dongen, and Dinges 2001). For instance, changes in early force production have been attributed to alterations in neural drive (i.e. motor unit recruitment and firing frequency) (Aagaard et al. 2002). While both neural and contractile fatigue have been cited to contribute to absolute rapid force, Buckthorpe, Pain, and Folland (2014) found that changes in the early phase of normalised rapid force are likely due to impairment in muscle activation and neural efficacy. Although not specifically measured in this study, these findings may influence common firefighter injuries (e.g. slips, trips, and falls). For example, leg extensor fatigue has been reported as a predictor in falls risk (Parijat and Lockhart 2008), and the ability to react quickly and produce force rapidly may be critical to restabilizing after the loss of balance and/or preventing fall-related injuries (Palmer et al. 2015). Specifically, it has been suggested that early rapid strength (0–50ms) may be an important discriminator of falls risk in the elderly (Palmer et al. 2015). It is possible that a greater fatigue stimulus (i.e. decreased sleep on shift nights and/or higher call duration) would invoke differences in later rapid and maximal strength. Based on these findings in conjunction with Thompson and colleagues (LaRoche et al. 2008; Thompson et al. 2013), rapid strength at early time intervals seems to be sensitive marker of lower body work-induced fatigue.

The vigilance-related measures showed no significant impairments for mean RT (−0.2%), slowest 10% (−2.4%), or fastest 10% (−3.2%) over the rotation. While vigilance tests have been used frequently in occupational or sleep-related studies, few studies have examined PVT variables for accumulating work shifts (Thompson 2019; Thompson et al. 2016). Previous investigations have involved accumulating shifts in nurses for three consecutive 12-hour shifts (Thompson

2019) as well as for three 12-hour shifts within a four day period (Thompson et al. 2016). Both of these studies (Thompson 2019; Thompson et al. 2016) demonstrated significant impairments in mean RT (–6.0%; –16.8%) and slowest 10% (–10.9%; –25.7%) with the greater impairments occurring in three consecutive shifts. However, Thompson et al. (2016) found no significant impairment in fastest 10% (–3.0%), which is similar to the present study. The lack of significant changes in our PVT values and later phase force variables may suggest that our firefighters may have not experienced the same level of work-related fatigue as the nurse samples in the aforementioned studies (Thompson 2019; Thompson et al. 2016). This also may suggest that the PVT variables are not as sensitive at detecting work-related fatigue in comparison to early rapid force in certain circumstances. It is possible that this is due to the lack of interrupted sleep patterns during the shift rotation. For example, the PVT has been suggested to measure neurocognitive performance and is sensitive to sleep deprivation (Doran, Van Dongen, and Dinges 2001); however, this was not indicated in our sample which demonstrated similar sleep patterns between work and non-work nights. Additionally, it is unclear how the hours between consecutive shifts may impact recovery (i.e. 12-hrs for nurses and 24-hrs for firefighters) or how other work-related characteristics (e.g. psychological, physical demands) could have contributed. Despite the lack of neurocognitive fatigue presented in this sample, previous studies have indicated an interaction between cognitive fatigue and neuromuscular fatigue (Mehta and Agnew 2012; Mehta, Nussbaum, and Agnew 2012; Shortz et al. 2015).

It is important to note that both high call duration (i.e. greater work load) (Trinkoff, Storr, and Lipscomb 2001; Akerstedt, et al. 2002) and lack of sleep (Billings and Focht 2016) may contribute to accumulating fatigue, neither of which were observed in our sample. It is probable that call duration is influenced by the location of the fire department (i.e. population density) (Evarts and Stein 2020). In a previous study by Billings and Focht (Billings and Focht 2016), 73% of firefighters reported poor sleep quality as defined by the Pittsburgh Sleep Quality Index. Furthermore, the authors reported a strong association between the number of sleep interruptions and sleep quality, which suggests that call duration during the night may negatively influence sleep patterns (Billings and Focht 2016). Interestingly, out of the three shift schedules examined, the Kelly shift exhibited the poorest sleep quality (Billings and Focht 2016) suggesting these firefighters may experience the greatest circadian dysrhythmia. However, we did not examine sleep quality (only duration), which would be an important consideration within this population for future studies. Regarding demographics, our sample is reflective of the broader firefighter population in terms of sex (Evarts and Stein 2020), age (Evarts and Stein 2020), and BMI (Jitnarin et al. 2014). Combined with our testing occurring on-site at fire stations, these factors may have improved our external validity. In addition, the portable assessments of strength and reaction time made it more feasible for firefighters to participate at the initiation and conclusion of a respective shift rotation.

The present study demonstrated that fatigue-based impairments in early (50 ms) absolute rapid force was observed after a shift rotation (three 24-hr on-off shifts) regardless of minimal changes in sleep between work and non-work nights and low call duration. Our findings may indicate that early rapid force is a sensitive measure in detecting work-related fatigue. A unique feature of this study was our portable lab assessments, which made on-site testing at fire stations feasible. Moreover, our assessments measured the physiological consequences of work-related fatigue using a novel reactive rapid strength assessment used previously in older adults (Morcelli et al. 2016; Laroche et al. 2007; Laroche 2009; LaRoche et al. 2008), whereas previous work scheduling characteristics have been examined using self-reported measures of fatigue (Akerstedt, et al. 2002; Paley and Tepas 1994; Huibers et al. 2004). Interventions that mitigate work-related fatigue may be impactful at preventing falls and/or risk of musculoskeletal injury. For example, short duration (∼10 minutes of training three times a week) worksite resistance training (Sundstrup, et al. 2016) has been shown to effectively enhance fatigue resistance. Lastly, it is important to note our limitations. For feasibility of on-site testing, we used the 5-minute version of the PVT, which is shorter than the standard 10-minute test. However, it is possible that the 10-minute PVT would have been more sensitive in detecting work-related fatigue. Further, our current sample included career firefighters in North Carolina, and thus it is unclear how other shift schedules, inclusion of volunteer firefighters, or career firefighters from other regions may influence these initial findings requiring future study. In addition, although our sample included a similar percentage of women (8%) as seen from national estimates (Evarts and Stein 2020), future studies are needed to further examine potential sex-specific differences following repeated bouts of shiftwork among firefighters.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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