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Quantification of On-Duty Workload in Active-Duty Firefighters

Rudi A. Marciniak
University of Wisconsin-Milwaukee

QUANTIFICATION OF ON-DUTY WORKLOAD
IN ACTIVE-DUTY FIREFIGHTERS

by

Rudi A. Marciniak

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ABSTRACT

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Firefighters are at an elevated risk of musculoskeletal and cardiovascular injury driven by over-exertion. To date, workload in the fire service is quantified as the call volume of a 24-hour shift. However, call volume does not account for the individual demands of different call types (i.e., medical vs. fire emergency), nor does it account for the influence of individual differences on responses to job demands. Sport-athlete populations have utilized traditional external (i.e., stimulus) and internal (i.e., response) training load measures to quantify task workload and inform injury-prevention strategies, however, minimal use of such measures have been utilized in an on-duty setting in the fire service. Therefore, the purpose of this dissertation research was to quantify on-duty workload in the fire service and specifically: (a) examine for differences in workload across emergency call types, (b) examine the influence of a fire suppression and/or auto-extrication call on the load of a 24-hour shift, and (c) identify predictors of workload, including measures of health and fitness and established workload (i.e., call volume) factors. Accordingly, 38 active-duty firefighters were recruited to participate in this two-phase study. Phase 1 included a laboratory session to quantify participant health and fitness characteristics, including peak aerobic capacity, body mass index, and waist circumference. Following, participants completed Phase 2 on-duty data collection to quantify workload of individual medical (MED) and fire calls with (FIRE1) and without (FIRE0) fire suppression and/or auto-extrication, as well as for 24-hour shifts. External workload was quantified as Impulse Load (IMPULSE) and internal workload was quantified physiologically as Edward's Training Impulse (eTRIMP), perceptually as Foster's Session Rating of Perceived Exertion (sRPE), and overall using the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). The results indicated that FIRE1 calls have significantly greater IMPULSE, eTRIMP, sRPE, and NASA-TLX workloads than MED and FIRE0. Additionally, the response to at least one FIRE1 call across a 24-hour shift significantly increases the IMPULSE, eTRIMP, sRPE, and NASA-TLX workloads of the shift compared to 24-hour shifts with similar call volumes. Upon examining for workload predictors, total call volume of a 24-hour shift is a significant predictor of the objective work (i.e., IMPULSE) completed across that shift but remains uninfluenced by aerobic capacity or obesity status. The physiological workload (i.e., eTRIMP) of a 24-hour shift is predicted by FIRE1 call volume, as well as aerobic capacity thus suggesting that individuals with lower oxygen consumption efficiencies will accumulate greater physiological workloads across a shift. The perceived workload (i.e., sRPE) is also significantly predicted specifically by the volume of FIRE1 calls. Finally, the NASA-TLX as an overall workload measure is unrelated to both measures of call volume, nor the examined measures of health and fitness. Collectively, these results suggest that preparation and recovery strategies may need to specifically target firefighters with exposure to fire suppression and/or auto-extrication calls, including unique call and shift strategies. Additionally, due the influence of aerobic capacity on the physiological workload of 24-hour shifts, targeted strategies to enhance aerobic capacity may decrease the workload response across a shift and support exertion-driven injury mitigation.

This dissertation is dedicated to all tactical athletes, especially those serving as first responders.
Thank you for your service.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter I: Introduction & Literature Review

Background & Practical Context

Firefighting is an extremely hazardous occupation with high risks for injury (Kurlick, 2012). The National Fire Protection Association (NFPA) estimates that approximately 64,875 firefighter injuries occurred in the line of duty in 2020, demonstrating a 7% increase from the prior year (Campbell & Evarts, 2021). Additionally, though only approximately 5% of on-duty job demands include fire suppression (Kales et al., 2007), firefighters are disproportionally at risk for cardiac events during or following strenuous exertion (Smith et al., 2016). In particular, the odds of sudden cardiac death (SCD), which consistently accounts for the largest share of on-duty deaths (R. F. Fahy et al., 2020), range from 10 to 130 times greater during emergency duties compared to non-emergency duties (Farioli et al., 2014; Haller & Smith, 2019; Kales et al., 2007; Kales et al., 2003). Compared to non-fireground operations, firefighters are more likely to incur injuries during fireground operations, which accounted for 22,450 injuries, or approximately 35% of all reported firefighter injuries, in 2020 (Campbell & Evarts, 2021). The largest causal factor of fireground injuries in 2020 was musculoskeletal overexertion or strain where approximately 2 out of 5 injuries were considered strains, sprains, or muscular pain injuries (Campbell & Evarts, 2021). Non-fireground injuries accounted for the other 65% of on-duty injuries in 2020 where strains, sprains, and muscular pain also accounted for majority of injuries incurred (Campbell & Evarts, 2021). The care of such injuries are extraordinarily costly and per firefighter injury may range in cost of approximately $1,500 to $5,400 (Butry et al., 2019). The cost of direct injury care, not including the additional costs required for lost work-time and/or over-time costs to firefighters covering open shifts, results in an estimated annual cost per department of approximately $197,860 or a national cost of up to $5.9 billion (Butry et al., 2019). Therefore, mitigating on-duty cardiovascular events and musculoskeletal injury could reduce economic costs, while more importantly, prevent unnecessary insult and lost worktime in the firefighter population.

Currently, there is a paucity of literature that provides insight on the quantifiable workload experienced by firefighters while on-duty. In athletic populations, the quantification of workload utilized for preparation of sporting-related tasks, often referred to as training load, has been linked to risk of injury. Specifically, athletes who over- or under-train for the load demands of their sport may demonstrate a reduction in readiness to perform and subsequently be at a greater risk for musculoskeletal injury (Blanch & Gabbett, 2016; Bourdon et al., 2017; Eckard et al., 2018). Conversely, athletes who satisfy an appropriate training load as it relates to the demands of their sport may experience a reduction in musculoskeletal injury risk (Blanch & Gabbett, 2016; Bourdon et al., 2017; Eckard et al., 2018). Due to known links between training load and musculoskeletal injury risk among sport athletes (Blanch & Gabbett, 2016; Bourdon et al., 2017; Eckard et al., 2018) and similar injury risk present in the firefighter population, utilization of training load concepts may be useful to identify firefighters that may be at risk for on-duty musculoskeletal injury as a result of overexertion or strain. There is also potential that the risk for cardiovascular injury, which is unique to the firefighting population in comparison to the sport-athlete population, may be more readily identified through workload metrics. However, a vital component to identifying firefighters that are potentially at a heightened risk for musculoskeletal and/or cardiovascular injury, and then implementing specific training programs to improve the ability to meet job workload with a reduction in injury risk, is first describing the load of their job demands and identifying fitness characteristics that may reduce the magnitude of that workload.

As such, this review will first present the multi-faceted demands of firefighting. This content will include an overview of the physiological response firefighters experience while on-duty, including across various emergency call types (i.e., medical and fire). Following, a brief overview will be presented on the psychological demands of firefighting, and in turn, link the need to examine the demands of firefighting using a multi-system perspective.

The following literature review will define the current use of training load as it applies to athletic populations. This content will introduce different types of training loads, including external and internal loads. Additionally, the definitions and current use of established measures for each load type will be presented, including impulse load, Edwards' training impulse, Foster's session rating of perceived exertion, and the National Aeronautics and Space Administration Training Load Index. This review will then highlight previous research that suggests how these external and internal load measures can be used to quantify the load requirements of a task and potentially support the identification of individuals that may be at an increased risk for injury.

Following, the content will describe how the principles of training load will be applied to the firefighter population to establish the workload demands required of this occupation. Additionally, the current understanding of the workload demands of firefighting as it relates to shifts (i.e., 24-hour shifts), as well as various types of emergency calls (i.e., medical and fire), will be presented and summarized.

This review will then describe the intersection of workload and health and fitness measures. Specifically, links between firefighter ability to meet job demands and health and fitness measures supported by The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI), a collaboration between the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFF, 2018), will be established. The WFI health and fitness measures to be presented will include obesity and cardiovascular measures.

At the conclusion of the review, literature gaps on the use of workload to quantify the external and internal load of firefighter job demands as it relates to loads between varying types of emergencies and across a 24-hour shift will be identified. Additionally, the paucity of research on characteristics that may be predictive of firefighter workload will be established.

Firefighting Demands

Firefighting is an extremely difficult occupation that requires the safe completion of various essential job demands which elicit responses from multiple systems, including physiological and psychological. The strain experienced when conducting firefighting activities is typically driven by a combination of demanding physical tasks and extremely hot and dangerous environments (Smith et al., 1997). More specifically, the physiological demand of firefighting begins at the sound of the alarm to elicit a heart rate response (Marciniak, Tesch, et al., 2021), which calls the crew to an emergency that is designated as medical or fire in nature where firefighters are required to work unexpectedly at high intensities and then subsequently return to lower intensity work around the fire station. While the overall call total experienced throughout a shift, as well as distribution of call types (i.e., medical or fire), varies by the fire station location and density of the surrounding population (Karter, 2013), research suggests that the sounding of the alarm elicits an increased heart rate response for both call types, but to a greater magnitude of increase is observed in fire calls (Marciniak, Tesch, et al., 2021). Additionally, Kaikkonen and colleagues (2017) demonstrated that, aside from differences in tone responses, a 6-hour ambulance shift where only medical calls are responded to elicited lower average heart rate responses than a 6-hour fire rescue shift, thus suggesting that while both emergency types elicit physiological responses, fire emergencies elicit greater heart rate responses than medical emergencies. Firefighter heart rate responses during a fire suppression task are known to reach intensities of 95% maximal heart rate or greater (Horn et al., 2013). Moreover, live fire emergencies often require multiple bouts of suppression where, after a short break period, the same firefighters return to the fire for additional work bouts, which subsequently increase heart rate responses with each repeated exposure (Horn et al., 2013). Altogether, the physical demands of firefighting are extreme and unpredictable in nature, with a greater intensity elicited by fire over medical emergencies.

In addition to the physiological demands, research demonstrates that firefighting is also mentally strenuous. Along with the physiological responses being heightened for fire suppression tasks, Smith and colleagues (1997) suggest that the presence of a live fire during a simulated ceiling overhaul elicited a heightened psychological response as measured by task rating of perceived exertion. However, across a 24-hour shift with only medical emergency responses (i.e., no fire emergencies), urinary catecholamines are elevated, leading Lim and colleagues (1987) to suggest that a baseline level of stress is present even in the absence of physically demanding fire calls with the presence of a live fire. Further, non-fire suppression emergencies (e.g., motor vehicle accidents) are known to lead to anticipatory tension and post-call anxiety while on-duty (Barnes, 2000). Aside from the lack of sleep experienced on-duty as a result of emergencies occurring at any time of the day and circadian rhythm disruption (Billings & Focht, 2016), the trauma experienced on-duty is also known to contribute to lingering hypervigilance and sleep disturbances (Barnes, 2000).

Due to the intermittent high-intensity physiological and various psychological demands described above, it is evident that understanding the job demands placed on firefighters requires a multi-system paradigm. There is potential that some job tasks required of firefighters may present as less physiologically demanding, but potentially stimulate a greater psychological demand, or vice versa. Through use of a multi-faceted lens, researchers can readily quantify these unpredictable demands placed on firefighters in a specific manner and capture a wholistic understanding to firefighter workload.

Training Load

Among athlete populations, clinicians and practitioners utilize training, or the programmed "work" an athlete completes (Gabbett et al., 2017; Gabbett & Ullah, 2012), to attain specific performance outcomes. The summation of work (i.e., cumulative stress from training sessions, games, etc. over a period of time; Gabbett et al., 2014) athletes complete through training is most commonly referred to as training load. Training load has historically been utilized to monitor training adaptations in response to a training program, understand individual training responses, and identify fatigue and/or subsequent needs for recovery (Bourdon et al., 2017; Jones et al., 2017). Measures of training load are often manipulated to elicit a training response (i.e., shorter sprint time to first base in baseball, etc.). In general, loads are characterized and quantified independently as either external or internal and are encouraged to be monitored for determination of training program responses and adaptations (Bourdon et al., 2017; Gabbett et al., 2014).

External Load. External training load measures are objective measures of the work completed by the participant and are measured specific to the nature of training they are prescribed (Bourdon et al., 2017; Impellizzeri et al., 2019). External load can, in a more general sense, be considered the "stimulus" that the individual is performing to accomplish the parameters of the training program. Common measures of external load include speed, distance, power output, and accelerometer-derived parameters (Bourdon et al., 2017; Impellizzeri et al., 2019).

Accelerometer-based measures. Monitoring external load with wearable technology, such as accelerometer use, has been increasingly utilized in sporting populations (Colby et al., 2014; Gabbett & Ullah, 2012; Gescheit et al., 2015; Scott et al., 2013; Wilkerson et al., 2016), where majority of studies have examined ball sports, male athletes, elite levels of competition, and young adults (Benson et al., 2020). Additionally, accelerometer-based measures have the potential to provide better load estimates than global positioning based systems (Vanwanseele et al., 2020). Several studies have demonstrated an association between load measured via acceleration and risk of overexertion injuries (Colby et al., 2014; Gabbett & Ullah, 2012; Wilkerson et al., 2016) within athletic populations. More specifically, links have been established between accelerometer-based measures of specific sport-stimuli and injury risk. For example, the cumulative sprint distance throughout a 3-week preseason exceeding approximately 1400 meters in elite football players (Colby et al., 2014), or a single training session exceeding 9 meters in elite rugby players (Gabbett & Ullah, 2012), have respectively elicited 3.7 and 2.7 times greater risk of overexertion injury. Further, Wilkerson et al. (2016) demonstrated that collegiate football players were at an increased risk of injury when they exhibited low variation in accelerometer-measured movement patterns or were exposed to a greater amount of plays throughout a 15-week period. Taken together, accelerometer-based measures have advanced the ability of sport scientists to identify individuals that may be at risk for preventable injury prior to an insult occurrence. It is important to note that, due to various ways of calculating external load based on changes in acceleration and the known differences in accelerometer-based measures when compared absolutely (Gómez-Carmona et al., 2019), researchers need to clearly establish how the external accelerometer load measure is calculated so that it is clearly understood and easily replicated (Bredt et al., 2020).

Impulse Load. An established measure of external load utilizing accelerometry is termed impulse load. Impulse load (Figure 1) is a triaxial accelerometry-based measure of external mechanical load that sums the forces from the medio-lateral, anterior-posterior, and vertical planes of motion for a task and scales the total forces by gravity to provide a final measure that is expressed in Newton-seconds (N·s; Gentles, Coniglio, Besemer, et al., 2018; Gómez-Carmona et al., 2019). The quantification of external load via impulse load has been utilized in various sporting populations, including women's college soccer (Gentles, Coniglio, Besemer, et al., 2018), men's college tennis (Gentles, Coniglio, Mahnken, et al., 2018), and women's college volleyball (Coniglio et al., 2018), as well as in tactical populations, including cadets in the Reserve Officers' Training Corps (ROTC; Zadeh et al., 2020). Specifically in collegiate women's soccer (Gentles, Coniglio, Besemer, et al., 2018) and singles tennis play (Gentles, Coniglio, Mahnken, et al., 2018), the quantified impulse loads have been used to inform the structure of practices and prescribe training loads to these athletes to better prepare for the stimulus of competition. Additionally, impulse load is sensitive to differentiating the external load differences between player positions within the same team (Coniglio et al., 2018). Finally, across a period of physical training within the ROTC, individuals with a high impulse load were at a greater risk for an overexertion-based injury, which was substantially increased if they also had a greater body mass index (Zadeh et al., 2020). Taken together, the current state of the literature demonstrates that external load can be measured via impulse load to quantify the demands of specific tasks, differentiate differences in stimuli across similar tasks, and identify individuals within tactical populations that are at an increased risk for an overexertion-based injury, however, this particular measure has yet to be strategically utilized within a firefighter population.

Impulse load is commonly measured by the Zephyr™ Bioharness (Coniglio et al., 2018; Gentles, Coniglio, Besemer, et al., 2018; Gentles, Coniglio, Mahnken, et al., 2018; Zadeh et al., 2020), which is a valid and reliable triaxial accelerometry measure during both continuous (Johnstone, Ford, Hughes, Watson, & Garrett, 2012a, 2012b) and discontinuous field-based (Johnstone, Ford, Hughes, Watson, Mitchell, et al., 2012) exercise. Additionally, a known strength to accelerometer-derived external load measures is the ability to function indoors without the use of satellites and subsequent potential for loss of signal, which is a limitation of global positioning systems (GPS; Gentles, Coniglio, Besemer, et al., 2018). Together with the established, very large correlations ($r = 0.950$) between impulse load and total distance measured via GPS (Gentles, Coniglio, Besemer, et al., 2018), the ability of impulse load to be utilized in place of other external load measures may be vital to accurately quantifying the external load demands of structural firefighting where most job tasks are completed indoors and/or in environments that do not effectively transmit the signaling of remote technology (i.e., GPS, Bluetooth, etc.).

Internal Load. Internal training loads are the relative biological stressors imposed on the individual during training (Bourdon et al., 2017) and reflect the intrinsic responses initiated by the external load stimuli (Impellizzeri et al., 2019). As noted above, the intrinsic responses to the external load demands, such as that of firefighting, are elicited in several forms (i.e., physiological, perceptual), and are therefore best measured using a multi-system approach. The majority of internal load measures are considered to be objective physiological measures (i.e., heart rate, etc.) or subjective perceptual measures (i.e., task rating of perceived exertion, etc.). In recent years, research has shifted from stand-alone use of internal load measures, with the most common being heart rate monitoring, to use of concurrent internal and external load measures (Figure 2), such as heart rate monitoring with an accelerometer-derived measure (Benson et al., 2020). Through combined use of external and internal load measures, scientists are better able to understand specific task characteristics like task speed, as system inputs (i.e., external load) and determine the intrinsic system response (i.e., internal load) that is elicited (Impellizzeri et al., 2019). For example, sports scientists may measure the impulse load (i.e., external load) across several soccer matches to determine if games of different external loads elicit similar heart rate responses in players, which could inform preparation strategies for specific future matches. As such, it is imperative to identify the internal load measures that have been established in the literature, such as training impulse, session rating of perceived exertion, and task load index, and determine which are best suited for on-duty load quantification within the firefighter population.

Edward's training impulse. Training impulse (TRIMP) was first proposed in the mid-1970's by Eric Banister as an attempt to quantify task load from the intensity and duration of the task (Borresen & Lambert, 2009; Foster et al., 2017). Banister's TRIMP was originally designed to quantify the load of steady-state tasks using the heart rate reserve response across the duration of the task, which limits the accuracy of this measure for tasks that utilize multiple modes of activity (Foster et al., 2017) and/or are interval in nature (Borresen & Lambert, 2009). In an attempt to quantify a training load that accounts for varying intensities of non-steady state tasks, Sally Edwards created a zone-based method of quantifying TRIMP in 1993, which utilizes the accumulated time in five arbitrary heart rate zones and sums the product of time spent in each zone throughout the task by weighted factors (Figure 3; Edwards, 1993). To date, Edwards' TRIMP (eTRIMP) has mainly been utilized in quantifying the load of sport demands, such as soccer (Casamichana et al., 2013; Impellizzeri et al., 2004; Younesi et al., 2021), rugby (Taylor et al., 2018), and tennis (Gentles, Coniglio, Mahnken, et al., 2018). Recently, eTRIMP was utilized to examine high-intensity functional training and demonstrated that during exercise that is discontinuous and interval in nature eTRIMP may more accurately represent the internal task load when compared to Banister's TRIMP (Crawford et al., 2018). As such, eTRIMP may be better suited to accurately reflect the physiological internal load of tasks with varying intensities and mixed modalities, such as firefighting, rather than Banister's original TRIMP measure.

Foster's session rating of perceived exertion. Along with the objective physiological internal load measure of TRIMP that is derived from heart rate intensity, research has established use of a subjective rating of perceived exertion in exercise and sports science to quantify a perceived internal load metric. The rating of perceived exertion scale that was developed by Gunnar A.V. Borg "involves the collective integration of afferent feedback from cardiorespiratory, metabolic, and thermal stimuli and feed-forward mechanisms to enable an individual to evaluate how hard or easy an exercise task *feels* at any point in time" (Eston, 2012, p. 175). Borg originally constructed the measure to increase linearly with exercise intensity using a scale ranging from 6 to 20 to denote heart rates that range from 60 to 200 beats per minute (Borg, 1970). Following, Borg adapted the 6 to 20 scale to form a category scale with ratio properties that ranged from 0 to 10 (Figure 4) to ease use by the lay population (Borg, 1982). Borg's 0 to 10 scale has demonstrated to be strongly related to exercise intensity and physiological factors, such as heart rate reserve and blood lactate (Borg, 1982). As such, Carl Foster sought to utilize Borg's 0 to 10 scale to develop a subjective internal load measure for use during times where heart rate may not be readily measured and created Foster's session rating of perceived exertion (sRPE; Foster et al., 1995). The sRPE of a task is quantified as the product of the post-task rating of perceived exertion using Borg's 0 to 10 scale and the task duration (Foster et al., 1995). Internal load measured via sRPE is the most commonly utilized metric of internal load in sporting populations (Andrade et al., 2020; Eckard et al., 2018). Additionally, though subjective in nature, sRPE is demonstrated to highly correlate to physiological (i.e., heart rate based) measures of load, such as eTRIMP (Foster et al., 2001). In fact, recent examination of sRPE of a high-intensity functional training task exhibited a strong positive correlation to eTRIMP (Tibana et al., 2018), thus demonstrating that this subjective internal load measure has potential to accurately support the representation of the physiological internal load of interval-based tasks. Subjective measures of sRPE have also demonstrated positive correlations to external load measures via triaxial accelerometry (McLaren et al., 2018; Scanlan et al., 2014). Gentles et al. (2018) demonstrated a very large positive correlation ($r = 0.84$) between sRPE and impulse load throughout a collegiate women's soccer match, thus suggesting that sRPE is a sensitive means of examining internal load responses to external load stimuli as measured by impulse load. The validity of sRPE to measure the internal load of non-steady state tasks, in combination with known links between sRPE and risk for musculoskeletal injury (Eckard et al., 2018) and overtraining syndrome (Foster, 1998), indicates that sRPE is a pertinent metric to explore in the multi-faceted and injuriously prevalent occupation of firefighting.

National Aeronautics and Space Administration-task load index. An established measure of internal load that encompasses multiple facets of load (e.g., physical, perceptual) is the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). The NASA-TLX was first developed by Sandra Hart and Lowell Staveland in 1988 to examine the "cost incurred by a human operator to achieve a particular level of performance" (Hart & Staveland, 1988, p. 140). Hart and Staveland's resulting NASA-TLX utilized measures on six subscales (Figure 5), including the mental demands, physical demands, temporal demands, frustration, effort, and performance perceptions by operators of aviation tasks (Hart & Staveland, 1988). Following task completion, participants rate the task(s) on each subscale (Figure 6) within a 100-points range with 5-point steps and respond to 15 pairwise comparisons of each subscale to determine their order of relevance to the overall load (Hart & Staveland, 1988). The number of times each subscale is selected as the most relevant to the load is then utilized to weight the score of that subscale, ranging from 0 (no relevance) to 5 (more important than all other factors), for an overall load score (Figure 7; Hart & Staveland, 1988). Additionally, due to the brevity of time necessary to complete this measure (i.e., less than one minute), it has been suggested to be useful in operational environments (Hart & Staveland, 1988) and is preferred by participants compared to other subjective workload assessments (e.g., Subjective Workload Assessment Technique (SWAT), Cooper-Harper Scale; Battiste & Bortolussi, 1988; Hill et al., 1992).

Since its inception, the NASA-TLX has been utilized prominently in aviation-based studies (Alaimo et al., 2020; Mansikka et al., 2019; Zheng et al., 2019), however it has been increasingly utilized in other non-aviation task examinations in more recent years, including use among military personnel (Hart, 2006) and sport athletes (Kesisoglou et al., 2021; Mullen et al., 2021). The NASA-TLX has been examined in tandem with other measures of external and internal load. Specifically, Alaimo et al. (2020) demonstrated that heart rate variability as a physiological internal load measure is negatively correlated (r = -0.44 to -0.66) to the subjective NASA-TLX and suggested the workload of pilots can be inferred from heart rate based measurements. Additionally, Mullen et al. (2021) demonstrated a positive association between the NASA-TLX and internal load measured via sRPE ($\eta^2 = 0.27$) as well as associations between the NASA-TLX physical demand subscale and external load measures of acceleration and time spent in sprint speeds among male rugby players. These findings demonstrate that the NASA-TLX may provide a more in-depth understanding of the underlying subscale factors (i.e., physical vs. mental demand, etc.) driving external and internal loads to support a greater understanding of the subjective underpinnings that mediate other load outcomes. Additionally, in male cyclists, it was demonstrated that while internal load measured via Banister's TRIMP and sRPE were significantly different between a 5-minute and a 20-minute maximal cycling bout, the NASA-TLX demonstrated no differences between the tasks (Kesisoglou et al., 2021), thus suggesting that the NASA-TLX may be vital when comparing the subjective load of tasks with different durations as a result of task duration not being included in the TLX scoring system. Despite the paucity of research that has concurrently examined task internal load via NASA-TLX and sRPE, the NASA-TLX has not been examined concurrently with other internal load measures (e.g., eTRIMP) or external load measures (e.g., impulse load). Therefore, the NASA-TLX may provide additional perspective on the subjective nature of the load of a task that can be supplemental to other load measures like impulse load and eTRIMP as well as supplement the known literature linking the NASA-TLX to sRPE.

Summary. In summary, established measures of external and internal loads, such as impulse load and eTRIMP, sRPE, and the NASA-TLX, respectively, have been utilized among sport athletes, and occasionally in occupational settings (i.e., military, aviation), to monitor the load of task demands and support the identification of individuals at a heightened risk for injury. Due to the high-risk for over-exertional musculoskeletal and cardiovascular injuries in response to the multi-faceted demands of firefighting, metrics historically utilized to quantify training load in sport athletes may be similarly helpful as a means to quantify the *workload* experienced by firefighters. In doing so, identification of firefighters that may be at an increased risk for a preventable injury due to overexertion may be actualized and the design and implementation of training and potentially recovery programs can be established to improve injury mitigation. Additionally, identifying firefighters that are experiencing greater workloads on-duty may prove through future research to negatively impact general health and as such, training and recovery programs that are produced may also positively impact firefighter health.

Firefighter Workload

Through examination of surrounding population density, community risk assessments, and geographical locations, departments strategically staff the companies at each station to uphold the NFPA alarm response criterion (i.e., alarm response time, etc.; NFPA, 2020). The fire service currently quantifies the load demands of firefighting through tracking emergency call volume across 24-hour shifts at individual station locations within and across departments. While it would be optimal to spread the call volume load equally across the stations within a department, the reality of the fire service is that call volume varies between stations. Though minimal research examining call volume has been conducted, and there is not an established threshold that constitutes low, medium, and/or high call volumes, higher call volumes have been linked to greater compassion fatigue (Watkins et al., 2021) and a greater likelihood for a work-related injury (Blackwell et al., 2011). Despite these links to fatigue and injury, limitations to utilizing call volume as the single metric for load include a lack of quantification differences across single emergency calls and/or across shifts of equal call volumes, deeming it essential to investigate more sensitive methods of load quantification.

As a result of the established high-risks for exertional cardiovascular and musculoskeletal injury among firefighters, combined with the efficacious use of external and internal load measures among sport athletes and gradual use within occupational populations, researchers have recently begun utilizing such measures within the firefighting population to quantify firefighter *workload*. Workload, or the quantified stimulus (i.e., external load) and response (i.e., internal load) to job demands, such as across single emergency calls and/or cumulatively across a shift, may provide a unique perspective on firefighter injury risk similar to training load in athletic populations. However, to date workload has only been examined utilizing traditional training load measures in three known studies (Bouzigon et al., 2015; Marcel-Millet et al., 2020; Webb et al., 2010).

Marcel-Millet, Ravier, and Groslambert (2020) were the first to examine the influence of different personal protective ensemble (PPE) and self-contained breathing apparatus (SCBA) conditions on the workload of a simulated firefighting task as well as the first to concurrently utilize external and internal load measures within this population. The firefighter participants completed a simulated task in three PPE and SCBA conditions, including PPE only, PPE and SCBA without breathing from a respirator, and PPE and SCBA with respirator use (Marcel-Millet et al., 2020). The simulated task required participants to complete a series of activities typically conducted during a firefighting operation (e.g., carrying hoses, stair climbing, completing a search in a dark, obstacle-ridden room, rescuing a mannequin; Marcel-Millet et al., 2020). Using Banister's TRIMP, eTRIMP, sRPE, and an accelerometer-based measure similar to impulse load (i.e., external load) but without scaling by gravity, Marcel-Millet et al. (2020) identified that within a firefighter population, physiological (i.e., Banister's TRIMP and eTRIMP) and perceived (i.e., sRPE) internal loads are significantly greater when a SCBA is donned with PPE. Conversely, the SCBA conditions exhibited reductions in the mean external load in comparison to the PPE only condition (Marcel-Millet et al., 2020). These results demonstrate that though the external load stimulus decreases with the donning of the SCBA with or without respirator use the internal load response is heightened both physiologically and perceptually (Marcel-Millet et al., 2020). Additionally, Marcel-Millet et al. (2020) demonstrated that sRPE was the only measure that differentiated a greater internal load response for the SCBA condition with respirator use in comparison to the SCBA without respirator use condition. As such, the author's concluded that the rating of perceived exertion significantly increased with respirator use (Marcel-Millet et al., 2020), thus demonstrating an increased perceived internal load and supporting the notion that future research could benefit from a multi-system load investigation due to measures quantifying different aspects (e.g., physiological, perceived) of workload in a simulated setting.

Finally, Marcel-Millet et al. (2020) examined relationships between the workload measures and demonstrated that within a firefighter population, physiological internal load measures (i.e., Banister's TRIMP and eTRIMP) are moderately correlated with perceived internal load (i.e., sRPE; r = 0.579 and r = 0.668, respectively), however the internal load measures were all non-significantly related to external load (i.e., the acceleration-based measure). Despite concluding from these results that acceleration-based measures may not be relevant for measuring the external load of job-tasks in firefighters (Marcel-Millet et al., 2020), there are several methodological-based factors that may support the lack of correlation between the internal and external load measures. First, the tri-axial accelerometer utilized by Marcel-Millet et al. (2020) was worn on the hip and due to firefighter job demands often including upper body movement without locomotion (e.g., chopping, pike pulling actions), an accelerometer may be more reliable if located closer to the upper limb (e.g., around the chest). Additionally, it is possible that accelerometry is not a sensitive measure to identify differences in PPE and SCBA conditions throughout a simulated task, but is adequate for examining external load in a non-simulated, or on-duty, setting that involves more gross tasks than those completed in this study.

In addition to utilizing external and internal load measures to examine the influence of firefighter specific gear on the load of a simulated task, researchers have partially examined on-duty internal load demands among firefighters. Specifically, across a 10-hour portion of the firefighters' shift, the internal load of four daily tasks (e.g., inventory, physical training, maneuver, service work) and four types of rescue interventions (e.g., person rescue, firefighting, road accidents, diverse operations) were measured using Banister's TRIMP and sRPE (Bouzigon et al., 2015). Though no additive information was provided by the authors to explain the characteristics of the observed daily tasks or rescue interventions, the physiological internal load (i.e., Banister's TRIMP) during physical activity, maneuver, and service work were all greater than the inventory task, with maneuver and service work also greater than physical activity (Bouzigon et al., 2015). Additionally, the perceived internal load (i.e., sRPE) was greater in the physical activity and service work daily tasks than maneuver and inventory. Together, these results demonstrate that physiological and perceptual measures of internal workload are sensitive to differentiating the demands of various on-duty tasks. As it relates to the rescue interventions, the four interventions elicited similar measures of Banister's TRIMP, as well as sRPE (Bouzigon et al., 2015). It is important to note that the authors did not provide information as to the heart rate response, rating of perceived exertion, or duration components that comprised the quantified internal load quantities in this study, so it is impossible to further deduce if the internal loads were in fact similar, or appear similar despite different contributions to the loads from the various factor contributions. Additionally, Bouzigon et al. (2015) investigated differences in the quantified internal loads between Banister's TRIMP and sRPE for the daily tasks and rescue interventions, however, due to the differences in calculation methods for each internal load measure, it may be inappropriate to directly compare units of TRIMP to sRPE as completed in this study.

The final research study to date that utilized workload measures within firefighters specifically examined the subjective overall load (i.e., internal load) of a simulated, computer-based drill through use of the NASA-TLX. In this study, the firefighter participants completed the Fire Strategies and Tactics Drill, which is a forced-choice decision making challenge that utilizes two emergency scenarios with corresponding questions common to fire suppression while cycling at 60% of their maximal aerobic capacity or cycling alone without the computer-based drill (Webb et al., 2010). Following both conditions, the participants completed the NASA-TLX for the task(s) within 5-minutes of exercise cessation (Webb et al., 2010). The results demonstrated that the combination of the Fire Strategies and Tactics Drill while cycling elicited a significantly greater internal load as measured by the NASA-TLX, which was in parallel with an elevated cardiovascular response (i.e., heart rate) for the condition as well (Webb et al., 2010). From these outcomes, Webb et al. (2010) suggested that additional stress was perceived by participants due to the demands of the Fire Strategies and Tactics Drill. Essentially, these results support the notion that the NASA-TLX is sensitive to measuring increased overall internal load imposed by fire strategy decision-making.

Summary of Current Literature. Although the use of training load measures to quantify firefighter workload may provide a unique perspective on firefighter injury risk similar to that in athletic populations, only three research studies to date have utilized such measures (Bouzigon et al., 2015; Marcel-Millet et al., 2020; Webb et al., 2010). Though one study (Marcel-Millet et al., 2020) demonstrated that physiological and perceived internal loads are sensitive to differentiate PPE conditions with and without a SCBA, these workload measures have yet to be examined in an on-duty setting where some emergencies do not require SCBA use (i.e., medical emergencies) while others do (i.e., fire emergencies). Additionally, while the same study (Marcel-Millet et al., 2020) demonstrated that physiological and perceived internal load measures appear to be related to each other, yet both are unrelated to accelerometer-based external load measures, it remains unknown if the paired use of external and internal load measures will demonstrate similar outcomes when examined in live emergency settings and/or with the acceleration measures collected with device placement closer to the upper extremity. Though a single study (Bouzigon et al., 2015) did examine physiological (i.e., Banister's TRIMP) and perceived (i.e., sRPE) internal loads in an on-duty setting, the lack of information provided on the daily task and rescue intervention characteristics across the 10-hour collection period from this study, as well as the contributing load quantification factors (i.e., heart rate, perceived exertion, duration) for each task, make it nearly impossible for reader's to deduce how these findings contribute to the existing literature. As such, it remains unknown how physiological and perceived internal load may vary across different emergency call types (i.e., medical vs. fire), what the internal loads are across an entire 24-hour shift, and what magnitude of external load is stimulating such internal load responses. Finally, one study has demonstrated that the NASA-TLX is sensitive to measuring workload in a computer-based, fire-scenario setting among firefighters (Webb et al., 2010), however, the NASA-TLX has yet to be utilized in quantifying the overall internal load of on-duty firefighter demands, including across different emergency call types (i.e., medical vs. fire) and across a 24-hour shift.

Hypothesized Firefighter Workload Model. The state of the existing literature has begun to utilize traditional training load measures within a firefighter population, however the use of these training load measures towards quantifying firefighter workload may be falling short by not applying them in a manner specific to the occupational demands of firefighting. In an on-duty setting, as presented above, the job demands of firefighting are cyclical in nature where firefighters are consistently rotating through periods of performance (e.g., responding to an emergency call) and preparation (e.g., recovering from each call to prepare for the next unpredictable emergency; Figure 8). Following the sound of the tone calling a crew to an emergency call, the tasks required to meet the emergency demands elicit actions (i.e., external load) which result in physical and psychological responses (i.e., internal load) for each firefighter throughout the entire call. Following the completion of a single call, the firefighters begin preparation for the next subsequent call while on-duty, which results in the continuation of this work cycle. Furthermore, upon completion of the final emergency call for their 24-hour period firefighters begin recovering from their shift, which informs their level of preparation towards their next scheduled shift. Through the quantification of the workload cycle required of firefighters, including the quantification of the external load (e.g., stimulus), and internal load (e.g., response) to the demands of firefighting, the preparation strategies both on- and off-duty could be enhanced to maximize firefighter job readiness and minimize preventable injury.

In addition to quantifying the workload cycle required of firefighters, it is important to recognize that the job demands, or performance aspect, of firefighting are relatively uncontrollable (e.g., emergency call type, total call volume, length of emergency response duration). However, there is potential to control factors of preparation within the cycle that influence a firefighter’s ability to meet the performance demands of their job at the next initiation of this cycle. Moreover, due to firefighters entering this job cycle as individuals with unique health and fitness characteristics, there is potential that firefighters with specific characteristics may be more prepared, or trained, to meet the performance demands of their job as well as able to recover to a greater extent and enter the cycle more prepared than other firefighters. Therefore, it is important to quantify the workload demands of firefighting and identify potential health and fitness characteristics that can be targeted in future research as controllable factors towards maximizing job preparation.

Intersection of Workload and Health and Fitness

In an effort to improve the readiness for duty and wellness of fire department uniformed personnel, The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) was established through the collaboration of the IAFF and the International Association of Fire Chiefs (IAFF, 2018). The WFI outlines an overall wellness and fitness system with the purpose of maintaining firefighter physical and mental capabilities towards completing their job demands (IAFF, 2018). Researchers have demonstrated links between specific measures of health and fitness utilized by the WFI, including obesity and cardiovascular measures, and readiness to meet job demands as well as the risk of over-exertional musculoskeletal injuries and cardiovascular risk factors.

Obesity. Lower levels of obesity (Kales & Smith, 2017; Smith et al., 2016), as measured by body mass index (Fahs et al., 2009; Smith et al., 2016) and percent body fat (Poston et al., 2011; Smith, 2011), have been linked to enhanced job readiness as well as reduced risk of SCD and musculoskeletal injury in firefighters. Research suggests that obese firefighters are approximately three times more likely to experience an on-duty SCD fatality (Smith et al., 2016). This statistic is alarming because approximately 75% of firefighters are considered overweight or obese when measured by either body mass index or percent body fat (Poston, Haddock, et al., 2011). In addition to risk of SCD, firefighters meeting the definition of class II or III obesity, which equates to a body mass index of greater than 35 kg/m^2, demonstrate nearly 5 times the number of missed work days due to injury compared to firefighters meeting the normal weight body mass index definition (Poston, Jitnarin, et al., 2011). Therefore, firefighters with lower levels of obesity are at a lower risk for injury and are likely able to perform the intense physical job demands better than individuals with a greater obesity level. As such, there is potential that mass distribution across the body measured via body mass index may be related to the workload experienced by firefighters on-duty, thus making it essential to examine such contributions to external and internal load in this population.

Cardiovascular Health and Fitness. Similar to measures of obesity, cardiovascular function, often measured as aerobic capacity, has also been linked to enhanced readiness to meet job demands and reduced risk for SCD in firefighters. To adequately perform job-tasks that are highly strenuous on the cardiovascular system like fire suppression, the NFPA has established a guideline for firefighters to achieve and maintain an aerobic capacity of at least 42 mL/kg/min, or 12 metabolic equivalents (NFPA, 2013). Aerobic capacity has been linked to simulated fireground test completion time (Elsner & Kolkhorst, 2008), such that greater aerobic capacity is related to quicker completion time on fireground tests (Sheaff et al., 2010). Additionally, a greater aerobic capacity has been suggested to be protective of cardiovascular health through reducing risk for SCD (Hernesniemi et al., 2020). Interestingly, aerobic capacity reduces risk of cardiovascular disease independent of other cardiovascular risk factors (i.e., body mass index, etc.; Baur et al., 2011), which is impactful as the presence of cardiovascular disease or cardiovascular risk factors increases the risk of SCD in firefighters (R. F. Fahy et al., 2020; Kales et al., 2003). Further, firefighters with an aerobic capacity less than 43 mL/kg/min are 2.2 times more likely to sustain an injury compared to firefighters with an aerobic capacity that exceeds 48 mL/kg/min (Poplin et al., 2014). In combination with measures of obesity, firefighters with a body mass index greater than 25 kg/m^2 are 3.3 times more likely to not meeting the NFPA aerobic capacity guideline (Nogueira et al., 2016). Moreover, abdominal obesity measured via waist circumference is a significant predictor ($R^2 = 0.30$) of firefighter aerobic capacity (Barry et al., 2019). Therefore, firefighters with higher aerobic capacities independent of, or in combination with, lower levels of obesity are at a lower risk for injury and are likely more able to perform intense physical job demands. As such, there is reason to examine the relationships between firefighter aerobic capacity, in addition to various obesity measures, and the external and internal load of on-duty job demands.

Potential Role of Health and Fitness in Workload. To address the clear links between obesity and aerobic fitness, the WFI has implemented tests for each of these factors through measures of body mass index and percent body fat, as well as incremental treadmill testing to quantify aerobic capacity, to identify firefighters that may be underprepared for their job demands and support them to improve these factors in a non-punitive manner (IAFF, 2018). Due to the demonstrated links between these health and fitness factors and the ability to meet the job demands of firefighting, it is likely that these factors will demonstrate relationships to external and/or internal workload. Though the job demands of firefighting are highly uncontrollable (e.g., total call volume throughout a 24-hour shift, the type of emergencies requiring a response, the length of an emergency call response) health and fitness factors specific to firefighters as individuals are controllable. Moreover, through the identification of factors that are related to the magnitude of external and internal workload, it is possible that training interventions for firefighters can target the specific external and internal workload quantities of their job to maximize preparation for duty and minimize risk for cardiovascular and/or musculoskeletal injury throughout completion of the firefighter workload cycle.

Literature Review Conclusions

Firefighting is an extremely hazardous occupation where firefighters are at risk for cardiac events that result in SCD (Smith et al., 2016) and musculoskeletal injury from overexertion or strain (Campbell & Evarts, 2020). The care of such injuries result in large, annual expenses at both a departmental and national level (Butry et al., 2019), in addition to the negative, personal experiences imposed on this first responder population.

Firefighter populations are at risk for over-exertion based injuries similar to sport athlete populations where links have been established between injury risk and measures of training load, including both external and internal load measures (Blanch & Gabbett, 2016; Bourdon et al., 2017b; Eckard et al., 2018). Though several research studies have begun to utilize traditional training load measures within the firefighter population, minimal research has been conducted with these measures in an on-duty setting. Marcel-Millet et al. (2020) demonstrated that internal load measures (i.e., eTRIMP, sRPE) are sensitive to differentiating PPE conditions with and without a SCBA and appear to be related to each other, yet unrelated to accelerometer-based external load measures when measured at the hip during a simulated firefighting task. Additionally, Bouzigon et al. (2015) have examined physiological (i.e., Banister's TRIMP) and perceived (i.e., sRPE) internal loads in an on-duty setting for a 10-hour period, however the lack of information on the specific tasks measured make it nearly impossible to utilize these findings in an impactful manner. Finally, Webb et al. (2010) demonstrated that the NASA-TLX is sensitive to measuring workload in a computer-based, fire-scenario setting among firefighters, however this measure has yet to be utilized in an on-duty setting including across different emergency call types (i.e., medical vs. fire) and across a 24-hour shift. As such, there are clear gaps in the literature as it pertains to the workload of on-duty firefighting job demands, including across different emergency call types (i.e., medical vs. fire) and entire 24-hour shifts, as well as what controllable measures of health and fitness are related to the external and internal loads experienced while on-duty.

Literature Gap #1. There is a paucity of research that quantifies the external and internal load demands of various emergency call types required of firefighters, including medical and fire emergencies. Only a single study has collected on-duty firefighter workloads across different emergency types using only physiological (i.e., Banister's TRIMP) and perceptual (i.e., sRPE) internal workloads with no inclusion of an external load measure (Bouzigon et al., 2015), however no information was provided on the nature of or specific tasks completed during the emergency responses examined. Therefore, it remains unclear what the external load of different emergency types are that stimulate the internal load responses and/or if calls of different natures (i.e., medical or fire) elicit similar internal load responses. Additionally, although one study has examined the influence of various combinations of personal protective equipment on firefighter external and internal workload (Marcel-Millet et al., 2020), the research was collected during simulated rescue interventions in temperate conditions and is therefore unlikely to represent the external or internal load of realistic fire emergency response demands. *Finally, a multi-system examination of different emergency response types remains entirely unexamined and may demonstrate significant load demands specific to each call type that could be essential to preparing firefighters from different department and station locations that experience different types of, and total call volume of, medical and fire emergencies.*

Literature Gap #2. Only a single study has collected on-duty firefighter internal load measures (Bouzigon et al., 2015), however only physiological (Banister's TRIMP) and perceived internal loads (sRPE) were examined without inclusion of an external load measure. Additionally, Bouzigon et al. (2015) measured the internal load of tasks within a 10-hour period (rather than across an entire 24-hour shift) utilizing a physiological internal load measure (i.e., Banister's TRIMP) that has been demonstrated to inadequately characterize the load of non-steady state activities such as that required of firefighting. Finally, an examination of the influence of call volume, the currently utilized measure of load in the fire service, on the workload of a 24-hour shift has yet to be conducted. *As such, it remains unknown what external and internal load demands are elicited across a 24-hour shift that is typically required of firefighters and/or how call volume may influence shift workload.*

Literature Gap #3. Finally, the firefighter workload literature is void of potential health and fitness characteristics supported by the WFI that may contribute to firefighter workload across 24-hour shifts. While the literature has established ties between firefighter aerobic capacity and risk of sustaining injury (Poplin et al., 2014), as well as firefighter obesity and risk for on-duty SCD fatality (Smith et al., 2016), the literature has not established how such characteristics may moderate the external and internal load demands of on-duty firefighters. *As such, firefighters may be unknowingly at a greater risk for injury or SCD due to increased workload demands, thus warranting an investigation of the relationships between WFI supported health and fitness characteristics and firefighter workload.*

Rationale for Dissertation Research

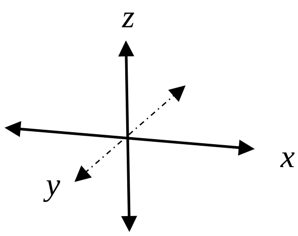
Study 1. This study examined differences in external and internal loads across different emergency call types in active-duty firefighters. External load was quantified utilizing Impulse

Load, while internal load was quantified utilizing Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index. This study is the first of its kind to specifically quantify and examine for differences in load across different types of emergency calls utilizing both external and internal load metrics.

Study 2. The second study sought to quantify the external and internal loads across 24-hour shifts in active-duty firefighters and examine the influence of a structural fire emergency on shift workload. Similar to the first study, external load was quantified utilizing an accelerometry-based measure termed Impulse Load. Internal load was quantified utilizing Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index. This study was the first of its kind to quantify external and internal loads in tandem across a 24-hour shift within the active-duty firefighter population, as well as the first to account for potential job factors, like call volume, that may increase the load.

Study 3. Finally, the third study sought to identify health and fitness factors and established measures of load in the fire service (i.e., call volume) that significantly predict the workload of 24-hour shifts. The health and fitness factors that were measured include obesity and cardiovascular fitness measures. The established measures of load included overall call volume (i.e., total medical and fire calls combined) and fire call volume of 24-hour shifts. These factors were analyzed for potential contributions to external load, quantified utilizing Impulse Load, and internal load, quantified utilizing Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index, of 24-hour shifts. This study is the first of its kind to identify controllable health and fitness factors, in combination with established load measures in the fire service, that predict the external and internal load demands of firefighting and inform future research on workload reduction and/or preparation among active-duty firefighters.

Figures & Tables



x = forces in the medio-lateral plane
y = forces in the anterior-posterior plane
z = forces in the vertical plane

$$\text{Impulse Load} = \sum_{s=1}^{n} \frac{\sqrt{(x_s^2 + y_s^2 + z_s^2)}}{9.8067}$$

Figure 1. Quantification of impulse load. Adapted from "The demands of a women's college soccer season" by J.A. Gentles, C.L. Coniglio, M.M. Besemer, J.M. Morgan, and M.T. Mahnken, 2018, *Sports, 6*(16), p. 5. Copyright 2018 by the Multidisciplinary Digital Publishing Institute.

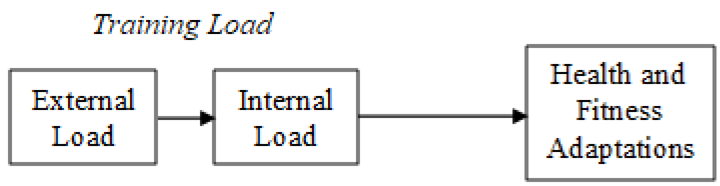


Figure 2. Current Use of Training Load.

Maximal Heart Rate Zone	Weighting Factor
50-60%	1
60-70%	2
70-80%	3
80-90%	4
90-100%	5

$$\text{eTRIMP} = \sum_{i=1}^{5} (Duration \cdot Weight\ Factor)$$

Figure 3. eTRIMP heart rate zone weighting factors.

0	Nothing at all
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong
•	Maximal

Figure 4. Borg's CR 1-10 Rating of Perceived Exertion Scale. Adapted from "Psychophysical bases of perceived exertion" by G. Borg, 1982, *Med Sci Sports Exerc, 14*(5), p. 380.

Subscale	Anchors	Description
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed or secure, gratified, content, relaxed, and complacent did you feel during the task?

Figure 5. Descriptions of NASA-TLX subscales. Adapted from "NASA TLX: Software for assessing subjective mental workload" by A. Coa, K.K. Chintamani, A.K. Pandya, and R.D. Ellis, 2009, *Behav Res Methods, 41*(1), p. 117. Copyright 2009 by The Psychonomic Society, Inc.

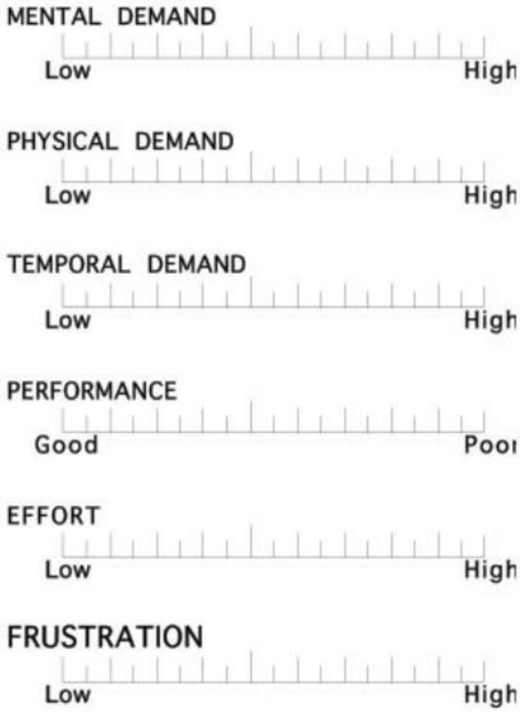


Figure 6. Individual subscales of the NASA-TLX. Adapted from "NASA-Task Load Index (NASA-TLX); 20 years later" by S. Hart, 2006, *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, *50*(9), p. 908.

$$\text{Overall Workload} = \frac{\sum_{i=1}^{6}(\omega_i \cdot R_i)}{15}$$

ω_i = weight of the i-th subscale
R_i = rating value of the i-th subscale

Figure 7. Quantification of NASA-TLX overall workload. Adapted from “Aircraft pilots workload analysis: Heart rate variability objective measures and NASA-Task Load Index subjective evaluation” by A. Alaimo, A. Esposito, C. Orlando, and A. Simoncini, 2020, *Aerospace*, *7*(137), p. 4. Copyright 2018 by the Multidisciplinary Digital Publishing Institute.

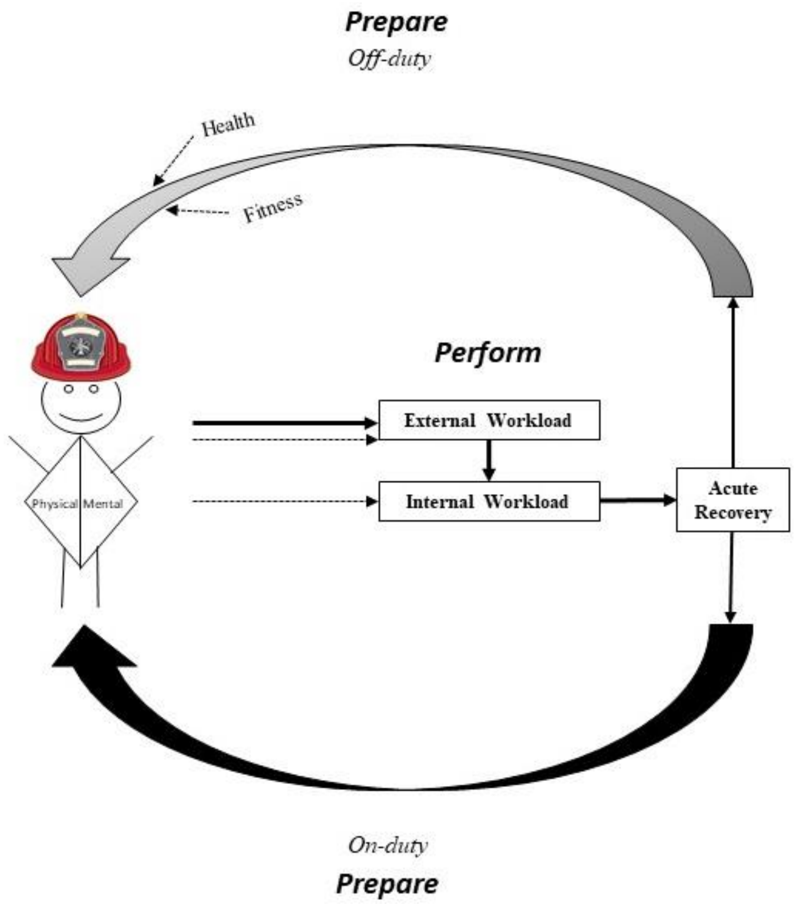


Figure 8. Hypothesized firefighter workload model.

Chapter II: Workloads of different emergency call types

Abstract

The purpose of the present study was to examine differences in external and internal loads across different emergency call types, including medical (MED) and fire (FIRE) emergencies, in active-duty firefighters. Active-duty firefighters (N = 38) completed 4-6 shifts as they regularly would while wearing a chest strap that continuously measured heart rate and triaxial acceleration for the duration of each shift. Following their first MED and all FIRE calls, participants completed a survey to report subjective load measures. For MED and FIRE calls, external load was quantified utilizing Impulse Load, while internal load was quantified physiologically, perceptually, and overall using Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index, respectively. Prior to analysis, FIRE calls were designated as calls that did (FIRE1) or did not (FIRE0) include fire suppression and/or auto-extrication, which resulted in MED, FIRE0, and FIRE1 categories for load comparison. The differences in average loads of the 3 call types were examined via multivariate repeated measures analyses of variance. Results demonstrated that all loads were similar for FIRE0 and MED yet both call types elicited significantly lower workloads than FIRE1. The findings establish workload differences across emergency call types (i.e., MED and FIRE) and provides evidence that FIRE1 calls elicit the greatest workloads, which should inform specificity in preparation and recovery strategies for fire personnel with the greatest exposure to those calls.

Keywords: workload, emergency call, fire suppression

Study 1. This study examined differences in external and internal loads across different emergency call types in active-duty firefighters. External load was quantified utilizing Impulse Load, while internal load was quantified utilizing Edward's Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index. Primary analyses examined for load differences between medical and fire emergency call responses. Following, secondary analyses examined for differences between fire emergencies that included fire suppression and/or auto-extrication (FIRE1), fire emergencies that did not include suppression and/or extrication (FIRE0), and medical (MED) emergencies. This study was the first of its kind to specifically quantify and examine for differences in external and internal load across different types of emergencies in firefighters. As a result, this study has contributed to the literature by determining that the objective job demands (i.e., external load) and physiological, perceived, and overall internal response workloads are substantially greater for fire suppression and/or auto-extrication calls over non-suppressive fire and medical emergency responses.

Methods

Participants

After obtaining approval from the Institutional Review Board (IRB) at the University of Wisconsin-Milwaukee, study recruitment was conducted through use of approved email correspondence, flyer distribution at individual firehouses, and speaking directly to individuals that expressed interest within a Midwest metropolitan fire department. Participants were considered eligible to participate if they were: (a) at least 18 years of age; (b) a non-probationary active-duty firefighter; (c) cleared for full active-duty work; and (d) willing to give written informed consent. Participants were excluded from participating in the proposed study if they:

(a) reported a known cardiovascular or metabolic disease that was currently unmanaged; and/or (b) had been instructed by a physician or the Health Safety Officer to not participate in the study. Upon meeting the eligibility criteria and none of the exclusion criteria, participants that sought enrollment into the study were provided written documentation that outlined all components of the study. Researchers clearly communicated in both the written documentation and verbally that no collected data would be provided to their respective department in an individual format (i.e., non-aggregate format) and participants could withdraw from the study at any time without consequences from the research team or their respective department.

Procedures

The proposed study was broken into two phases for all participants (N=38). Phase 1 of the proposed study consisted of completing the informed consent process and determining descriptive characteristics of the active-duty firefighters prior to continuing into Phase 2 where data were collected while on-duty.

Phase 1. Phase 1 data collection was conducted within the Human Performance & Sport Physiology Laboratory at University of Wisconsin-Milwaukee. After completing a written informed consent, participants completed a health history, exercise history, and job characteristics (i.e., years of experience, rank) survey, and self-reported their age in years (yrs) and biological sex. Following, using a medical grade balance-beam scale and stadiometer (Detecto, Webb City, MO), participant height (cm) and body mass (kg) were measured to the nearest 0.01.

Phase 2. All Phase 2 data were collected at department firehouses or in the field while responding to emergency calls. External load was quantified as Impulse Load and internal load measures included Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the NASA-Task Load Index. Accelerometer and heart-rate data were collected continuously across all shifts and analyzed *post hoc* to quantify Impulse and Edward's Training Impulse for all MED and FIRE calls for each shift. Participants completed surveys after the *first* MED emergency, and all FIRE emergencies, of each shift that were analyzed *post hoc* to quantify Foster's Session Rating of Perceived Exertion and the NASA-Task Load Index for those calls. Participants completed on-duty data collection for at least four shifts and a maximum of six shifts.

Impulse Load. Impulse load (IMPULSE) was measured utilizing the Zephyr™ Bioharness and BioModule™ device (Medtronic, Annapolis, MD). Prior to the start of a shift, each participant was fitted with a Zephyr™ Bioharness™ and BioModule™ device (Figure 11) that continuously collected on-shift IMPULSE (N*s) at a sampling rate of 100 Hz across the duration of each 24-hour shift. Time-stamped (HH:MM:SS) department call logs were used mark the IMPULSE data log for the initiation and completion times of all MED and FIRE emergencies, such that IMPULSE was summed across all MED ($IMPULSE_{MED}$) and FIRE emergency calls with ($IMPULSE_{FIRE1}$) and without ($IMPULSE_{FIRE0}$) fire suppression and/or auto-extrication tasks.

The Zephyr™ system has established validity through very strong relationships between triaxial acceleration measures and oxygen uptake (r = 0.97) and mean step count (r = 0.99) during an incremental treadmill protocol and precision tilt table testing (Johnstone, Ford, Hughes, Watson, & Garrett, 2012a). Additionally, using similar protocols, Johnstone et al. (2012b) demonstrated very strong (ICC ≥ 0.99) between subject, intra-device, and inter-device reliability for Zephyr™ Bioharness accelerometry measures. Further, upon examination of a discontinuous incremental walk-jog-run protocol, Zephyr™ Bioharness accelerometry-derived loads demonstrate excellent precision to oxygen uptake ($r > 0.90$) and very strong inter-device reliability (ICC = 0.93; Johnstone, Ford, Hughes, Watson, Mitchell, et al., 2012). As such, the external load demands of on-duty firefighters, which are typically discontinuous in nature, are adequately represented through impulse load measured via Zephyr™ Bioharness accelerometry.

Edwards' Training Impulse. Edwards' Training Impulse (eTRIMP) was calculated to quantify the physiological internal workload for all MED and FIRE emergency calls from all collected shifts based on the time spent in five predefined heart rate (HR) zones (Sanders et al., 2017). Specifically, the same Zephyr™ Bioharness™ and BioModule™ device that continuously collected IMPULSE also continuously collected HR at a sampling rate of 250 Hz across the duration of each 24-hour shift. The HR data for the entire file were converted from bpm into a percentage of maximal heart rate (HR_{MAX}), which was quantified as: $HR_{MAX} = 208 – 0.7 \times Age$ (Tanaka et al., 2001). Following, time-stamped department call logs were used to *post hoc* mark the HR data per second collected throughout each of the individual MED and FIRE calls into one of the five HR intensity zones and then summed into total duration (HH:MM:SS) spent in each respective zone for the call. The time spent in each HR zone was multiplied by the zone's weighting factor and summed to quantify eTRIMP for all MED ($eTRIMP_{MED}$) and fire emergencies with ($eTRIMP_{FIRE1}$) and without ($eTRIMP_{FIRE0}$) suppression and/or extrication.

Foster's Session Rating of Perceived Exertion. Foster's Session Rating of Perceived Exertion (sRPE) was calculated to quantify the perceived internal load across individual emergency calls. Participant Rating of Perceived Exertion (RPE) from Borg's CR-10 scale for each task multiplied by the time spent in each call response (Sanders et al., 2017) was used to quantify sRPE. The RPE for the *first* MED and all FIRE calls were collected using a Qualtrics Software administered via smart phone immediately upon completion of each call by asking the participants to rate the intensity of the call. Following, time-stamped department call logs were used *post hoc* to identify the initiation and completion of each emergency call to quantify the exact duration (HH:MM:SS) of each MED and FIRE emergency. The duration of each emergency call was multiplied by the respective call RPE to quantify the sRPE for the MED ($sRPE_{MED}$) and FIRE emergencies with ($sRPE_{FIRE1}$) and without ($sRPE_{FIRE0}$) suppression and/or extrication from all survey responses.

National Aeronautics and Space Administration-Task Load Index. The NASA-Task Load Index (NASA-TLX), which has been demonstrated as a valid measure (Hart & Staveland, 1988), was utilized to assess multiple facets of load across the individual calls, including subscales of mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants complete the NASA-TLX using a Qualtrics survey administered via smart phone immediately upon completion of the *first* MED and all FIRE calls for each shift. By completing the NASA-TLX survey, participants rated the task(s) on each subscale within a 100-point range and responded to 15 pairwise comparisons of each subscale to determine their order of relevance to the overall internal load (Hart & Staveland, 1988). The number of times each subscale was selected by the participant as the most relevant to the load was then utilized to weight the score of that subscale, ranging from 0 (no relevance) to 5 (more important than all other factors), for an overall load score for the MED ($NASA\text{-}TLX_{MED}$) and FIRE emergencies with ($NASA\text{-}TLX_{FIRE1}$) and without ($NASA\text{-}TLX_{FIRE0}$) suppression and/or extrication.

Data Processing

Upon completion of HR and IMPULSE collection across each shift via Zephyr™ Bioharness™ and BioModule™, each file was visually inspected. Upon comparison to time-stamped department call logs, any calls that included errored measures (i.e., HR missing, etc.)

during the time of a call response were entirely removed from the data set to avoid inaccurately quantifying the subsequent eTRIMP measures. No filters were applied to the HR or IMPULSE data beyond what is automatically applied within the Zephyr™ manufacturers' design.

All survey responses were also visually inspected prior to quantifying sRPE and NASA-TLX workloads to ensure data accuracy. Any RPE reported as "0" was considered inaccurate due to participants being instructed that a "0" reflects no work at all. Thus, any RPE responses reported as "0" were subsequently replaced with a "0.3" to reflect the lowest possible exertion. Any responses with inaccurate NASA-TLX responses (i.e., NASA-TLX subscales = 0) were removed from the data set and not included in analyses.

Power Analyses

A priori power analyses were conducted to secure a sample to achieve power for all analyses. Utilizing a medium effect size ($f = 0.25$), a 95% confidence interval ($\alpha = 0.05$), and a medium correlation among repeated measures ($r = 0.5$), a sample size of 28 would be required to achieve a power of $1 - \beta = 0.80$ (Faul et al., 2007) for a single group of participants with three measurements (i.e., MED, FIRE0, FIRE1) for a RM ANOVA.

Statistical Analysis

The IMPULSE, eTRIMP, sRPE, and NASA-TLX quantified for all collected MED, FIRE0, and FIRE1 calls were averaged for a single average MED, FIRE0, and FIRE1 call observation per participant. The potential differences in external and internal load between MED, FIRE0, and FIRE1 calls were examined through separate one-way repeated measures multivariate analyses of variance (RM MANOVA) for IMPULSE, eTRIMP, sRPE, and NASA-TLX. Before statistical analysis, the normality of data for each dependent variable (e.g., IMPULSE, eTRIMP, sRPE, NASA-TLX) were examined using visual inspections of univariate

Q-Q plots for the data and *z* tests were performed to identify extreme univariate skewness and kurtosis. No consistent outliers across the dependent variables were identified, thus the normality assumption for the RM MANOVA and *post hoc* calculations was satisfied. Additionally, descriptive statistics of the measurable components that contributed to each load measure were quantified to support identification of potential mechanisms for load differentiations. All statistical analyses were conducted utilizing SAS 9.4 Analytics Software (SAS Institute Inc., Cary, NC). A Bonferroni correction was applied to protect against Type I error, where an alpha of $p < 0.0125$ was utilized to determine statistical significance for all four omnibus RM MANOVA analyses. An additional Bonferroni correction was applied ($p < 0.004$) to examine for the three *post hoc* contrast comparisons of all significant multivariate analyses. Partial eta squared (η^2_p) effect sizes were evaluated for all RM ANOVA analyses with $\eta^2_p < 0.06$, $0.06 \leq \eta^2_p < 0.14$, and $0.14 \leq \eta^2_p$ indicating small, medium, and large effects, respectively (Huck, 2012).

Results

Participant Description

Thirty-eight active-duty members of a metropolitan fire department in the Midwest volunteered to participate in all three studies (34 males, 4 females; 36.45 ± 8.86 yrs; 180.21 ± 6.70 cm; 92.04 ± 13.85 kg), thus satisfying the sample size needed to achieve statistical power. The sample was representative of different ranks within the department and years of experience in the fire service, including Captains (N=7; 16.57 ± 4.85 yrs), Lieutenants (N=11; 12.63 ± 4.88 yrs), and Firefighters (N=20; 8.30 ± 7.92 yrs). Additionally, though this sample of firefighters included 10% females rather than an equal representation of sexes, roughly 5% of career firefighters are female (Fahy et al., 2022) and this sample similarly reflects the population distribution.

Each participant completed data collection for four to six shifts, which resulted in an original data set of 201 shifts. Due to poor signal quality and/or equipment malfunction (i.e., Zephyr Bioharness) during emergency call responses, 19 shifts were eliminated (approximately 10% of original) from data set. Accordingly, 182 shifts were included in the analyses, which represented 1082 medical and 371 fire emergencies (FIRE0= 228, FIRE1=143), as well as 289 completed call surveys. Of the total calls examined (i.e., 1082 + 371 = 1453 calls), approximately 75% were medical, which is slightly above average (67.2%) for fire departments in the Midwest in 2020 (U.S. Fire Administration [USFA], 2022). Additionally, approximately 9.8% of this sample were FIRE1 calls, which is nearly double the average fire call responses in the Midwest (4.1%; USFA, 2022). However, it is unclear whether auto-extrications are included in the midwestern average reported by USFA like the reported in the present results, which may be inflating the response rate in the current sample. All data were collected from shifts that occurred between the months of April 2022 and February 2023. A complete overview of data collected per participant is organized in Appendix A.

External Load

Impulse Load. A single participant did not respond to a FIRE0 call that was captured on the Zephyr Bioharness and Biomodule across their Phase 2 collection period. These data were considered missing completely at random and listwise deleted from this analysis (Table 1). The one-way RM MANOVA identified a large significant effect of call type ($F_{2,35} = 21.17$, $p < 0.001$, $\eta^2_p = 0.525$), such that $\text{IMPULSE}_{\text{MED}}$ (1320.81 ± 221.05 N*s) and $\text{IMPULSE}_{\text{FIRE0}}$ (1330.42 ± 375.76 N*s) were not significantly different ($F_{1,36} = 0.02$, $p = 0.887$), yet $\text{IMPULSE}_{\text{FIRE1}}$ (3857.54 ± 2442.62 N*s) was significantly greater than both $\text{IMPULSE}_{\text{MED}}$ ($F_{1,36}$

= 42.15, $p < 0.001$) and $\text{IMPULSE}_{\text{FIRE0}}$ ($F_{1,36} = 38.60$, $p < 0.001$; Figure 9A). A summary of these results can be found in Table 2.

These outcomes indicate that the objective work (i.e., external load) of FIRE calls that require the complete donning of PPE and SCBA, and fire suppression or the labor of auto-extrication (FIRE1) require nearly three-fold the objective work demands above and beyond MED calls, as well as FIRE calls without suppression (FIRE0). Furthermore, the objective work for FIRE calls without suppression appears to be similar in magnitude as MED calls.

Internal Load

Edwards' Training Impulse. A single participant did not respond to a FIRE0 call that was captured on the Zephyr Bioharness and Biomodule across their Phase 2 collection period. These data were considered missing completely at random and listwise deleted from this analysis (Table 1). The one-way RM MANOVA identified a large significant effect of call type ($F_{2,35}$ = 31.84, $p < 0.001$, $\eta^2_p = 0.569$), such that $\text{eTRIMP}_{\text{MED}}$ (7.66 ± 6.31 AU) and $\text{eTRIMP}_{\text{FIRE0}}$ (8.48 ± 7.28 AU) were not significantly different ($F_{1,36} = 0.09$, $p = 0.349$), yet $\text{eTRIMP}_{\text{FIRE1}}$ (74.33 ± 59.84 AU) was significantly greater than both $\text{eTRIMP}_{\text{MED}}$ ($F_{1,36} = 50.16$, $p < 0.001$) and $\text{eTRIMP}_{\text{FIRE0}}$ ($F_{1,36} = 45.38$, $p < 0.001$; Figure 9B). A summary of these results can be found in Table 2.

These outcomes indicate that the physiological response elicited when completing the work (i.e., external load) of FIRE calls that include fire suppression (FIRE1) is approximately six times greater than MED calls, as well as FIRE calls that do not require suppression (FIRE0). However, the objective work for FIRE calls without suppression (FIRE0) is similar to MED calls.

Foster's Session Rating of Perceived Exertion. Sixteen participants did not complete survey responses for FIRE0 calls, and an additional participant did not complete a survey response for a FIRE1 call, across their Phase 2 collection period. These data were considered missing completely at random and listwise deleted from this analysis (Table 1). The one-way RM MANOVA identified a large significant effect of call type ($F_{2,19} = 14.46$, $p < 0.001$, $\eta^2_p = 0.589$), such that $sRPE_{MED}$ (31.02 ± 37.15 AU) and $sRPE_{FIRE0}$ (23.10 ± 16.01 AU) were not significantly different ($F_{1,20} = 1.17$, $p = 0.292$), yet $sRPE_{FIRE1}$ (187.80 ± 141.06 AU) was significantly greater than both $sRPE_{MED}$ ($F_{1,20} = 28.92$, $p < 0.001$) and $sRPE_{FIRE0}$ ($F_{1,20} = 30.43$, $p < 0.001$; Figure 9C). A summary of these results can be found in Table 2.

These outcomes indicate that the perceived load response to the work (i.e., external load) of FIRE calls that require the complete donning of PPE and SCBA and fire suppression or auto-extrication (FIRE1) is more than six times greater than MED calls, as well as FIRE calls that do not involve fire suppression (FIRE0). Furthermore, the perceived load for FIRE calls without suppression (FIRE0) is similar to MED calls, yet demonstrated a non-significantly lower perceived load on average.

NASA-Task Load Index. Sixteen participants did not complete survey responses for FIRE0 calls, and an additional participant did not complete a survey response for a FIRE1 call, across their Phase 2 collection period. These data were considered missing completely at random and listwise deleted from this analysis (Table 1). The one-way RM MANOVA identified a large significant effect of call type ($F_{2,19} = 24.70$, $p < 0.001$, $\eta^2_p = 0.536$), such that NASA-TLX_{MED} (17.77 ± 16.08 AU) and NASA-TLX_{FIRE0} (15.33 ± 10.42 AU) were not significantly different ($F_{1,20} = 0.77$, $p = 0.389$), yet NASA-TLX_{FIRE1} (34.17 ± 15.74 AU) was significantly greater than both NASA-TLX$_{MED}$ ($F_{1,20}$ = 20.99, $p < 0.001$) and NASA-TLX$_{FIRE0}$ ($F_{1,20}$ = 51.99, $p < 0.001$; Figure 9D). A summary of these results can be found in Table 2.

These outcomes indicate that the overall internal load response to the work (i.e., external load) of FIRE calls that require donning PPE and SCBA for fire suppression or auto-extrication (FIRE1) is two-fold more than MED calls, as well as FIRE calls that do not involve fire suppression (FIRE0). Additionally, the overall demands of FIRE calls without suppression (FIRE0) appeared similar in magnitude compared to MED calls.

Results Summary

Collectively, these results indicate that the objective work, and subsequent physiological, perceived, and overall internal load for FIRE1 calls that require fire suppression and/or auto-extrication, are significantly greater than MED calls and any FIRE0 call that does not include suppression or extrication. Further, external and internal loads of FIRE0 are not different from MED calls. Together, these results demonstrate that FIRE calls that include fire suppression and/or auto-extrication (i.e., FIRE1) require firefighters to complete approximately three times more work, which elicits heightened intrinsic responses above and beyond what is required for MED calls and non-suppression FIRE calls. Descriptive data for the components that inform the load calculations (i.e., call duration, etc.) are provided in Table 3.

Discussion

The purpose of Study 1 was to examine differences in external and internal workloads across different emergency call types in active-duty firefighters. This study is the first of its kind to specifically quantify, and examine for, differences in workload across different types of emergency call responses utilizing both external and internal load metrics.

Impulse Load. The results of this study indicate that the objective work (i.e., external load) that is completed for individual call job demands is approximately three-fold greater for fire call emergency responses that involve fire suppression and/or auto-extrication when compared to medical emergency and non-suppressive fire emergency call demands. Upon further investigation, the results also suggest that medical emergencies and fire emergencies without suppression and/or extrication require similar external and internal workloads.

The results of this study are challenging to compare to the single study that has measured external load in the fire service during a simulated task (Marcel-Millet et al., 2020) because the measures utilized are different. However, the external load measure utilized by Marcel-Millet et al. (2020) to examine the influence of various PPE and SCBA equipment combinations on a simulated rescue task suggested PPE without a SCBA and/or breathing tank air elicited significantly greater job demands. Marcel-Millet et al.'s (2020) findings demonstrate contradictory trends from the present results where FIRE1 calls exhibited significantly greater job demands than the other call types despite being the only call category that required firefighters to fully don PPE and SCBA, as well as breathe on air. Although this is of interest to note, the heightened load in FIRE1 calls with PPE and SCBA in the present study are likely due to the change in overall task demands rather just the addition of the SCBA and breathing on air. Specifically, Marcel-Millet et al.'s (2020) simulated rescue may have required work (e.g., carrying hoses, stair climbing, victim rescue) similar to the physical labor of a FIRE1 fire suppression call, however the duration of the simulation is shorter (~13 min) than FIRE1 of the present study (~42 min). These differences in duration may explain, in part, why FIRE1 in the present study elicited a greater external workload than the other call types despite PPE and SCBA donned similarly to the condition with the lowest external load in Marcel-Millet et al.

(2020). However, it is also possible that, if the durations were similar, the quantity of objective work in a simulated setting may still be less than that of a live emergency response. Future researchers should seek to quantify if such differences in objective work exist.

The majority of the literature that has utilized impulse load to quantify external load demands has done so in sport-athlete populations and, given the lack of published literature available to compare to the present data, we can turn to the sport literature where the load demands of sport activities are well established. Specifically, the more substantial load demands of the fire suppression and/or auto-extrication calls (i.e., FIRE1) are similar to the external load of running related movement (4534.12 ± 3552.79 N*s) during ROTC training sessions (Zadeh et al., 2020), as well as the positional demands of a collegiate defensive specialist (6122 ± 1972 N*s) during a volleyball match (Coniglio et al., 2018). In contrast, the impulse load of the job demands for all call response types (i.e., MED, FIRE0, and FIRE1) are substantially less than the load of a women's collegiate soccer match (~20,000 N*s; Gentles, Coniglio, Besemer et al., 2018) and a period of U16 male soccer (~40,000 N*s; Gómez-Carmona et al., 2019). This suggests that a measure such as IMPULSE is capable of quantifying work demands in occupational populations, but that the physical work completed is less than running-based sport athletes. Given this understanding, it is critical to continue developing insight for occupational athlete workloads independent of sport-athlete populations. Specifically, it is crucial to further investigate the use of external load metrics within occupational work of firefighters as establishing a compendium of occupational athlete workload may lead to improved, targeted preparation of fire service members and mitigation of associated preventable injury risk.

The difference in external load demands across the emergency call types is likely the result of varying task-specific characteristics (e.g., task duration, equipment demands, physical labor). The duration of FIRE1 calls (42.75 ± 23.67 min) was greater than MED (21.15 ± 3.42 min) and FIRE0 (14.30 ± 5.86 min), which allowed for greater time to accumulate work. Additionally, unlike the MED and FIRE0 calls, FIRE1 calls include the complete donning of PPE and SCBA that adds approximately 22.4 kg (~50lbs) of mass the firefighter must maneuver (NFPA, 2022). Although prior research in a simulated setting suggests that the added SCBA reduced the external load demands (Marcel-Millet et al., 2020), an on-duty setting is highly uncontrolled and it is possible that the added gear influenced the external load demands differently from the simulated scenario. Additionally, MED and FIRE0 calls likely require firefighters to cover less distance (i.e., walking from rig to emergency location within structure) compared to FIRE1 calls that often include sizeable scenes (i.e., an entire single-family dwelling, apartment complex, etc.). The added distance to traverse, in combination with the demanding physical actions completed on scene (e.g., crawling, use of heavy tools, raising ladders, overhead work, climbing; Gledhill & Jamnik, 1992; NFPA, 2022) and post-suppression clean-up (e.g., repacking hose, storing equipment back on rig) likely also contribute to the larger IMPULSE. Of note, all of the emergencies including FIRE1 required substantially lower external loads when compared to sport-athlete populations. Due to sporting events often requiring running-related movement across larger distances (e.g., soccer), as compared to walking and power-based overhead movements of firefighting where efficient and quick movement (i.e., shorter duration) is paramount, it makes sense that the objective work quantified by an accelerometer donned around the upper trunk suggests IMPULSE is greater in sport-athlete populations than structural firefighters. It may be advantageous for future researchers to examine whether a different accelerometer location enhances the ability to measure IMPULSE in firefighters, such as on the arm or wrist where many power-based movements elicit motion.

Edwards' Training Impulse. The results of this study indicate that the physiological workload response elicited when completing the job demands (i.e., external load) of fire calls that include suppression and/or auto-extrication is six times greater than other calls and indicates that job demands of suppression and/or extrication elicit substantially greater physiological workloads than non-suppressive fire calls and medical emergencies. Interestingly, the job demands of non-suppressive fire calls and medical emergencies elicited similar physiological loads.

A single study has examined on-duty physiological responses in firefighters but measured physiological load using Banister's Training Impulse (bTRIMP; Bouzigon et al., 2015), which utilizes an average heart rate response unlike the present study that accounts for time spent in various intensity zones (i.e., eTRIMP). Bouzigon et al., (2015) demonstrated that the bTRIMP of different rescue tasks completed throughout a 10-hour shift were similar (Bouzigon et al., 2015). Although a direct comparison between Bouzigon et al. (2015) and the present study cannot be made due to differences in physiological load quantification (i.e., overall average heart rate response [bTRIMP] vs. time spent in five heart rate zones [eTRIMP]), the present results are inconsistent with Bouzigon et al.'s (2015) due to differences being identified between eTRIMP for FIRE1 and MED as well as FIRE0 call types. In a separate study that utilized simulated rescue tasks, eTRIMP was demonstrated to be sensitive in differentiating between conditions that utilized PPE alone and PPE with an SCBA (Marcel-Millet et al., 2020). Specifically, Marcel-Millet et al. (2020) demonstrated that the eTRIMP of a simulated rescue in PPE alone (584.3 ± 83.3 AU) elicited a significantly lower physiological load than conditions that included an SCBA without facemask (707 ± 131.6 AU) and an SCBA while on air (754.7 ± 121.1 AU). Although direct comparisons cannot be made to the present results as Marcel-Millet et al. (2020) quantified eTRIMP using a different unit of time, the present study also demonstrates that FIRE1 calls, which utilize PPE and SCBA, similarly elicit the greatest physiological load.

Due to eTRIMP being primarily utilized in sport-athlete populations to date, it is possible to compare the on-duty call responses of firefighters to the magnitude of physiological load elicited during athletic events. Likely as a result of the similar interval-like work experienced on the fireground, $eTRIMP_{FIRE1}$ (74.17 ±59.93 AU) appears to elicit physiological loads similar to high-intensity functional training (HIFT; 77.7 + 4.9 AU) that included five upper- and lower-body power-based exercises (i.e., push-press, sumo deadlift high-pull, etc.) to be completed in 5-minute segments for three total circuits (Tibana et al., 2018). On the contrary, a different HIFT session that was shorter in duration (4 min) than MED and FIRE0 elicited a substantially greater physiological load (19.8 + 8.4 AU) than $eTRIMP_{MED}$ (7.66 ± 6.31 AU) and $eTRIMP_{FIRE0}$ (8.58 ± 7.24 AU) thus demonstrating that load in a single MED or FIRE0 call appears to be less than a short bout of high-intensity exercise. Aside from HIFT, the physiological load of all call types examined in the present study are substantially lower than other sport-athlete populations, including single training sessions for men's semipro soccer (216.3 ± 72.6 AU; Casamichana et al., 2013) and young men's club soccer (approximately 200 – 400 AU; Impellizzeri et al., 2004), as well as the average weekly load for men's rugby training (360 ± 104 AU; Taylor et al., 2018).

As a result of the greater amount of work (i.e., external load) conducted during FIRE1 compared to MED or FIRE0, the physiological demands placed on the body to meet such work demands is heightened and likely reflects changes in autonomic nervous system (ANS) activity. It is well-established that the ANS drives the physiological responses to firefighter work demands (Kesler et al., 2018; Smith et al., 2016), like increasing heart rate, through withdrawal of the parasympathetic nervous system (PSNS) branch (i.e., rest and digest) and increasing control of the sympathetic nervous system (SNS) branch (i.e., fight or flight). To meet greater oxygen demands in the musculoskeletal system during higher intensity tasks, the ANS will shift to greater SNS control to stimulate further increases in heart rate necessary meet task demands (Hughson et al., 2001). The initiation of this shift in the ANS is known to begin at the sound of the alarm that calls firefighters to an emergency and prior research has established that a fire alarm stimulates a greater SNS response to elicit a higher heart rate response than the alarm for a medical emergency (Marciniak, Tesch, et al., 2021). Thus, each of the call types (i.e., MED, FIRE0, and FIRE1) elicit some form of physiological load as a result of PSNS withdrawal and heightened SNS activity beginning at the sound of the alarm and throughout the emergency, which is then quantified into physiological workload.

The heightened SNS activity during each of the emergency call types is carried throughout the remainder of the job demands but to a greater extent for FIRE1. Of particular interest, despite the known heart rate response at the sound of the alarm for all fire emergencies, the heightened SNS activity throughout the remainder of the call seems to only occur in FIRE1, as evidenced by accumulated time in higher heart rate intensity zones compared to FIRE0 calls (Table 2). The prolonged elevation in SNS activity for FIRE1 may be informed by the initial job demands when arriving on-scene, which can include time-sensitive tasks (i.e., victim rescue) and other fast-paced demands that may drive SNS response to the higher-intensity zones (e.g., ZONE4-5). Following suppression and/or auto-extrication, the objective work demands for FIRE1 calls shift to other types of objective work where less SNS demand is likely elicited, such as post-fire suppression clean up demands (e.g., repacking hose, returning equipment to rig), and accumulate external loads at lower-intensity zones similar to FIRE0 and MED. In addition to the job demands (i.e., external load) completed for FIRE1 that were measured via IMPULSE, prior research demonstrates that the environmental temperature of fireground operations, and the duration of exposure to such operations, also supports greater SNS drive to elevate firefighter heart rate responses (Horn et al., 2013; Smith et al., 2016). Therefore, it is possible that, in addition to the greater objective work demands, some of the physiological load of FIRE1 calls may be supported in part by the temperature of the emergency environment. Given these factors, it is evident that there are likely several components that are driving up the SNS response of FIRE1 calls and informing the resultant eTRIMP.

The elevated SNS activity of fire calls with suppression and/or auto-extrication (i.e., FIRE1) prolonged the duration spent at lower-intensity heart rate zones above MED and FIRE0, as well as uniquely elicited responses at the higher-intensity heart rate zones, that accumulated into an eTRIMP roughly six times greater than other calls. Specifically, large portions of FIRE1 responses were spent in ZONE1 (8.51 ± 6.98 min), which was nearly twice that of MED and FIRE0 calls (4.63 ± 3.31 and 3.94 ± 2.75 min, respectively); despite the lowest-intensity zone (i.e., ZONE1) primarily contributing to the physiological load of MED and FIRE0, the totality of the duration in this low-intensity for both call types was nearly half that of FIRE1. A similar trend was exhibited for FIRE1 in ZONE2 (8.58 ± 7.31 min) and ZONE3 (6.23 ± 5.23 min) when compared to the shorter durations in the respective zones for MED (1.15 ± 1.25 and 0.21 ± 0.30 min) and FIRE0 (1.45 ± 1.53 and 0.46 ± 0.76 min). Thus, the lengthier durations of the FIRE1 calls in ZONE1-ZONE3 due to prolonged SNS activity contributed to the heightened physiological load over MED and FIRE0. Additionally, the SNS also evoked higher-intensity responses for FIRE1 in ZONE4 (4.38 ± 4.86 min) and ZONE5 (2.47 ± 4.43 min) compared to the minimal times spent in ZONE4 (0.03 ± 0.05 and 0.08 ± 0.16 min, respectively) and ZONE5 (0.01 ± 0.02 and 0.01 ± 0.03 min) for MED and FIRE0, respectively. As such, the accumulated times in ZONE4 and ZONE5, in tandem with the larger weighting factors that are applied to the each when quantifying the physiological load (i.e., eTRIMP), bolstered the SNS-driven physiological load for fire suppression and auto-extrication call responses (i.e., FIRE1) above and beyond medical emergencies (i.e., MED) and non-suppression fire calls (i.e., FIRE0).

Although this is the first study of its kind to utilize traditional training load measures to quantify the intrinsic load demands accumulated across time (i.e., eTRIMP) for on-duty call responses, the results of this study build on the foundational knowledge of previous research that has quantified peak cardiovascular demands (i.e., peak heart rate response) of fire suppression. Specifically, Horn et al. (2013) demonstrated that during live-fire training operations (~15-30 min), firefighters achieved a peak cardiovascular response of *at least* 95% of their predicted maximal heart rate, which is similar to the maximal cardiovascular demands achieved in other training settings that included live-fire operations (Colburn et al., 2011; Smith et al., 2005). In an on-duty setting, fire suppression tasks (e.g., pike pole ventilation, victim rescue, ladder climbing) have elicited heart rate intensities up to 97% maximal heart rate (Sothmann et al., 1992). The results of the present study build on this foundational literature by demonstrating that in an on-duty fire suppression setting, maximal heart rate responses are elicited *and* sustained for an average accumulation of 2.47 ± 4.43 min (i.e., ZONE5). As such, it is evident that firefighters need to be capable of meeting *and* sustaining the maximal capacity of the cardiovascular system to meet the job demands of fire suppression and/or auto-extrication emergency responses (i.e., FIRE1). Given these findings, future researchers should consider reporting peak heart rate responses, and duration of responses in such zones, to support the identification of the unique capacity needs required to sustain the maximal intensity workload of firefighting.

Foster's Session Rating of Perceived Exertion. The results of the present study indicate that perceived load response to complete the job demands (i.e., external load) of FIRE1 calls that require the complete donning of PPE and SCBA and fire suppression or auto-extrication is more than six times MED calls and FIRE0 calls that do not involve fire suppression. Additionally, although not of statistical significance, the perceived exertion of MED calls appears slightly greater than FIRE0 calls that do not involve suppression or extrication.

The results of the present study are comparable to those in prior studies conducted within the fire service. The perceived exertional load quantified by Bouzigon et al. (2015) for an on-duty "person rescue" intervention (157.8 ± 117.2 AU) is similar in magnitude to the sRPE of a FIRE1 response in the present study (187.80 ± 141.06 AU) and similarly greater than the perceived exertional load of MED (31.02 ± 37.15 AU) and FIRE0 (23.10 ± 16.01 AU). However, FIRE1 exhibited greater perceived loads when compared to a simulated rescue intervention while donning PPE alone (66.2 ± 17.0 AU), PPE and SCBA yet off air (89.5 ± 14.4 AU), and PPE and SCBA while on air (106.8 ± 21.5 AU; Marcel-Millet et al., 2020). The duration of Marcel-Millet et al.'s (2020) simulated intervention (~13 min) was longer than MED and FIRE0, yet much shorter than FIRE1, which may explain why MED and FIRE0 exhibited lower perceived loads and FIRE1 exhibited higher perceived loads.

Similar to the physiological load of in an athletic population, FIRE1 exhibited perceived loads to equate to a bout of HIFT (~160 AU; Tibana et al., 2018). It is likely that the loads are similar due to a higher RPE during the HIFT (9.6 AU) than FIRE1 (3.5 AU), in combination with the lengthier duration of the average FIRE1 (42.75 min) than the HIFT (17 min; Tibana et al., 2018); the load of FIRE1 is likely comparable to a bout of HIFT as a result of a longer duration rather than the tasks exhibiting similar perceived intensities. Unlike the physiological load, a shorter HIFT bout (4 min) examined by Tibana et al. (2018) elicited a perceived load (~35 AU) that was similar to the average MED (31.02 ± 37.15 AU) and FIRE0 (23.10 ± 16.01 AU) calls. However, similar to FIRE1, it is likely that the loads are similar due to a higher RPE during the HIFT (8.7 AU) than MED and FIRE0 (1.06 and 1.38 AU, respectively; Table 2), in combination with the lengthier duration of the average MED and FIRE0 than the HIFT bout (4 min; Tibana et al., 2018); these similarities are likely the result of MED and FIRE0 having lengthier durations than the 4-minute HIFT session rather than the tasks exhibiting similar perceived intensities. Aside from HIFT, the perceived load of FIRE1 is also similar to the perceived demands of a 75-minute collegiate women's soccer practice (143.30 ± 123.50 AU; Gentles, Coniglio, Besemer et al., 2018), but substantially less than elite women's (892.50 ± 358.50 AU; Gentles, Coniglio, Besemer et al., 2018) and men's (646.52 ± 192.88 AU; Enes et al., 2021) soccer match play.

Prior research has demonstrated links between various mechanisms that may heighten the perceived load experienced during a task like that of the call responses in the present study. Gentles, Coniglio, Besemer et al. (2018) established that perceived load is strongly positively correlated to external load when measured as IMPULSE. As such, the perceived load of each of the emergency call types, including MED, FIRE0, and FIRE1, are likely directly informed by the job demands (i.e., external load) required of the respective emergency calls, which is supported in the mirrored magnitudes of the external and perceived load responses (Figure 1). It is also possible that, due to the established links between RPE and physiological measures like heart rate (Borg, 1982), the perceived exertional loads of each of the call types may similarly reflect varying physiological loads of the call responses. This is evidenced by the heightened SNS activation eliciting greater heart rate responses in FIRE1 calls and, in turn, a considerably larger physiological load (i.e., eTRIMP) that is mirrored by a similarly substantial perceived load (i.e., sRPE) response over MED and FIRE0 call types. (Figure 1).

Beyond the job demands and physiological response to such demands, it is also possible that psychological factors contributed to the perceived loads of the call types examined. Specifically, as it relates to the distinct differences in perceived loads for FIRE1 compared to the other call types, the presence of a live fire is known to increase the RPE and cardiovascular response in firefighters conducting simulated fireground operations (Smith et al., 1996) and it is plausible that the live fires at scenes involving fire suppression for FIRE1 increased the RPE's reported for those calls. Additionally, while objective work was completed in response to all emergency calls, it is also plausible that psychological stress in response to the emergency scenes and/or traumas may contribute to the perceived exertional loads (Barnes, 2000).This notion is supported by some of the self-reported MED call feedback, where one participant indicated that a "12 y/o [year old]…girl [experiencing an] active seizure. I gathered information, vitals, and provided Med unit with radio report." In a separate incident, a different participant described "Psych patient where patient had to be restrained and drugged. Forced entry in *[sic]* building. Vitals. Report writing." The added critical-thinking and patient care, particularly for MED emergencies, may also inform why the perceived load for MED emergencies was slightly, though non-significantly, greater than fire emergencies without suppression or extrication (i.e., FIRE0). These findings would support future research to identify the psychological components that drive perceived demands across different emergency call responses.

NASA Task Load Index. The results of the present study indicate that the subjective overall load for fire emergency responses that involve fire suppression or auto-extrication is two times greater than fire emergency responses that do not include suppression or extrication and medical emergencies. Additionally, although not of statistical significance, the subjective overall load of MED calls appears slightly greater than FIRE calls that do not involve suppression or extrication.

The NASA-TLX was established for use within pilot populations and has bridged into load quantification in other athletic populations. In comparison to pilot populations, the overall load of all the call types (i.e., MED, FIRE0, and FIRE1) in the present study are substantially less than the subjective overall load of takeoff (~58 AU) and landing (~62 AU) during a flight simulation (Alaimo et al., 2020). However, the subjective overall loads for MED and FIRE0 calls (17.77 ± 16.08 and 15.33 ± 10.42 AU) and FIRE1 calls (34.17 ± 15.74 AU) are respectively similar to the overall loads of entire flight simulations in high- (14.93 ± 6.42 AU) and low- (39.04 ± 7.86 AU) performing Finnish Air Force pilots (Mansikka et al., 2019). Aside from occupational populations, the subjective overall loads of all call types in this study are much less than the subjective overall load of a 20-minute maximal cycling bout (~70 AU) in recreational and competitive cyclists (Kesisoglou et al., 2021).

In comparison to prior research conducted in firefighter populations, the results of this study demonstrate significantly lower subjective overall loads for all call types compared to a computer-simulation emergency scenario. A single study conducted by Webb et al. (2010) examined the overall load of the computer-based Fire Strategies and Tactics Drill, which is a forced-choice decision making challenge that utilizes two emergency scenarios with corresponding questions common to fire suppression, and demonstrated that completing the computer-based task while exercising (68.75 ± 5.88 AU) or without concurrent exercise (52.83 ± 5.05 AU). The scenarios exhibited NASA-TLX scores significantly higher than all on-duty call response types in the present study, which suggests that the subjective overall load is heightened in a simulated scenario, but upon movement to active emergency scenes and scenario demands, the overall load declines. The sizeable differences in the overall loads of all call types in the present study and the emergency scenario simulations previously conducted within a firefighter population suggests that the use of the NASA-TLX in an on-duty setting within the fire service may need deeper evaluation to better understand the measures validity within this occupational sample. Specifically, future researchers should determine if the NASA-TLX accurately reflects overall workload in both simulated and on-duty settings, thus confirming that this measure can be utilized to determine if computer-based training scenarios truly reflect firefighter readiness to meet expected workload demands in the field.

Unique to the NASA-TLX in comparison to other load measures is the quantification of subjective overall load without consideration for the task duration, thus allowing for an examination of contributions from each subscale across tasks of different durations, like the MED, FIRE0, and FIRE1 emergency responses in this study. For MED, the greatest contribution to the subjective overall load (Table 2) was from the mental demand (27.88%), or magnitude of perceptual activity (e.g., thinking, deciding). Additionally, upon considering the slight elevation in perceived load for medical emergencies (i.e., sRPE) compared to FIRE0 emergencies, the greater mental demand contributions to the overall load of medical emergencies supports the notion that psychological stress is likely a strong contributor to the workload of medical emergencies. On the contrary, the contribution of the mental demand to the overall subjective load of FIRE0 and FIRE1 calls are decreasingly impactful (22.92% and 20.55%, respectively). However, interestingly, the contribution of temporal demands (i.e., time pressure) increasingly contributes to FIRE0 calls without suppression and/or auto-extrication (20.58%) and FIRE1 calls with suppression and/or extrication (21.69%). Taken together, it appears that the cognitive stressors for medical calls are the result of more decision-making based demands where fire calls in general are the result of more time-based demands. For contributions of performance (i.e., personal level of success in accomplishing task goals), medical emergencies participants attributed a greater contribution of overall load to performance (21.80%) compared to FIRE0 or FIRE1 calls (17.84% and 12.20%, respectively), thus suggesting that individual performance on-scene is perceived to be more influential during MED than all fire call tone emergencies. Finally, in alignment with the physiological load (i.e., eTRIMP) outcomes, the greatest contributor to the overall load of FIRE1 calls is the physical demand (23.57%), or the magnitude of physical activity requirements, when compared to MED (7.79%) and FIRE0 (13.20%).

Limitations and Future Research. It is important to consider these results within the confines of the study limitations. This study is representative of a sample of structural firefighters from a large, metropolitan fire department in the Midwest and therefore may not entirely represent the workload demands of a shift among other fire service subpopulations (e.g., volunteer firefighters, wildland firefighters). Specifically, for Midwestern department emergency responses, the reported sample distribution in medical call types reflects the average response profile, however the fire call responses of this sample are approximately double the Midwest average, according to the USFA (USFA, 2022). Therefore, it is possible that these results mirror expected workloads in the Midwest, especially in relation to MED call responses, but may not represent other areas of the United States. Finally, it should also be noted that the surveys to quantify sRPE and NASA-TLX were administered while returning, or once returned, to the station following a call. While this limitation is relatively unavoidable in trying to capture the workloads of calls while on-duty, an avenue of future research could examine if survey timing (i.e., on-scene vs. once returned to station) influences the subjective loads being measured as well as examine if physiological, perceived, and/or overall load metrics are different at different times of a shift (i.e., day vs. night).

Conclusions. Through the completion of this study, there is now an enhanced understanding of the external load, and various internal loads, across different emergency call types in structural firefighters. It is evident that the magnitude of objective work required for fire emergency responses that include fire suppression and/or auto-extrication is approximately three times greater than medical and other fire emergency (i.e., no suppression or extrication) responses. Further, the yielded intrinsic loads when accomplishing objective job demands of a fire suppression and/or auto-extrication call are physiologically and perceptually six times greater, and double overall, in comparison to the workloads of medical and other fire emergency responses (i.e., no suppression or extrication). Additionally, the workload demands of medical calls are seemingly influenced by the mental demands of the task as evidenced by the larger contributions of this subscale to the NASA-TLX and slight elevation in sRPE over FIRE0. In contrast, the workload of fire calls, particularly those that require suppression and/or extrication, appear to be driven to a greater extent by physical and temporal demands, as evidenced by the resultant physiological load (i.e., eTRIMP) and contributions of these subscales to the NASA-TLX. In consideration for the unique differences in workload across medical and fire emergency calls, it is likely that the workloads of individual firefighters are unique to the call types they respond to on-duty. Targeted preparation and recovery strategies that reflect the specific call responses of individual companies, as well as individual firefighters, should be considered for injury mitigation and personnel wellness strategies. Additionally, future researchers should examine the influence of different call types, particularly fire calls that require suppression and/or auto-extrication, on the workloads of 24-hour shifts.

Figures & Tables

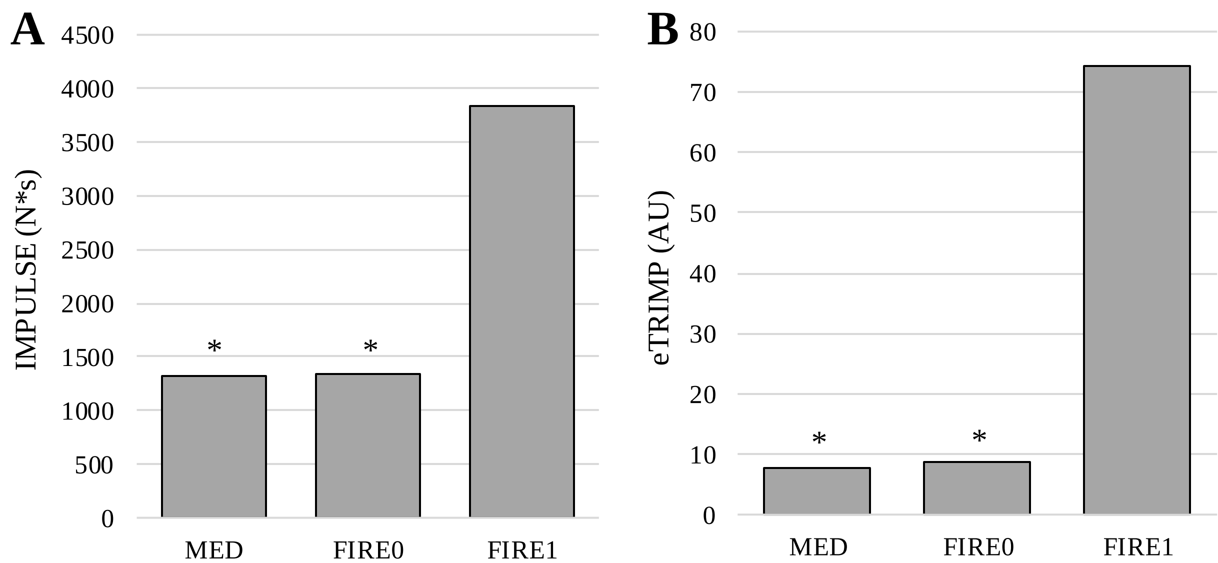


Figure 9. Differences in external and internal workloads across emergency call types. A, Impulse; B, Edward's Training Impulse; C, Foster's Session Rating of Perceived Exertion; D, NASA- Task Load Index; *, significantly different from FIRE1.

Table 1

Study 1 Analysis Sample Sizes

	MED	**FIRE0**	**FIRE1**	**RM ANOVA Sample Size**
IMPULSE	38	37	38	37
ETRIMP	38	37	38	37
SRPE	38	22	37	21
NASA-TLX	38	22	37	21

Table 2

Results summary of omnibus test results and least significant differences

Omnibus Test Results	Call Type (Mean ± SD)		
Wilks' Lambda F value (*p* value)	**MED**	**FIRE0**	**FIRE1**
Impulse (N*s)			
21.17 (<.001)	1320.81 ± 221.05	1330.42 ± 375.76	3857.54 ± 2442.62[ab]
eTRIMP (AU)			
31.84 (<.001)	7.67 ± 6.31	8.48 ± 7.28	74.33 ± 59.84[ab]
sRPE (AU)			
14.46 (<.001)	31.02 ± 37.15	23.11 ± 16.01	187.80 ± 141.06[ab]
NASA-TLX (0-100)			
24.70 (<.001)	17.77 ± 16.08	15.33 ± 10.42	34.17 ± 15.74[ab]

a, significantly different from MED; b, significantly different from FIRE0.

Table 3

Descriptive statistics (Mean ± SD) of load components across emergency call types

Component	**MED**	**FIRE0**	**FIRE1**
Call Duration (min)	21.15 ± 3.42	14.30 ± 5.86	42.75 ± 23.67
RPE (AU)	1.06 ± 0.84	1.38 ± 0.85	3.53 ± 1.22
Heart Rate Zones (min)			
ZONE1	4.63 ± 3.31	3.94 ± 2.75	8.51 ± 6.98
ZONE2	1.15 ± 1.25	1.45 ± 1.53	8.58 ± 7.31
ZONE3	0.21 ± 0.30	0.46 ± 0.76	6.23 ± 5.23
ZONE4	0.03 ± 0.05	0.08 ± 0.16	4.38 ± 4.86
ZONE5	0.01 ± 0.02	0.01 ± 0.03	2.47 ± 4.43
NASA-TLX Raw Scores (0-100)			
Mental Demand	16.95 ± 15.97	12.89 ± 8.22	38.20 ± 23.71
Physical Demand	11.10 ± 12.21	12.18 ± 7.92	43.69 ± 23.31
Temporal Demand	14.57 ± 18.04	11.70 ± 8.37	39.28 ± 22.81
Performance	22.32 ± 31.14	20.46 ± 31.52	24.63 ± 29.14
Effort	13.86 ± 13.11	13.75 ± 9.55	40.72 ± 22.84
Frustration	12.84 ± 13.85	6.42 ± 5.26	16.02 ± 10.48
NASA-TLX Weighted Contribution (%)			
Mental Demand	27.88 ± 17.40	22.92 ± 13.81	20.55 ± 14.16
Physical Demand	7.79 ± 10.26	13.20 ± 12.62	23.57 ± 13.44
Temporal Demand	14.88 ± 12.20	20.58 ± 12.80	21.69 ± 12.72
Performance	21.80 ± 22.56	17.84 ± 15.12	12.20 ± 13.53
Effort	14.30 ± 9.48	18.30 ± 9.99	18.99 ± 9.44
Frustration	13.35 ± 13.69	7.15 ± 8.92	3.00 ± 4.89

Chapter III: Influence of Fire Suppression and/or Auto-Extrication on Shift Workload

Abstract

The purpose of the present study was to examine differences in external and internal loads across 24-hour shifts with (SHIFT-FIRE1) or without (SHIFT-NOFIRE1) at least one fire suppression and/or auto-extrication call response in active-duty firefighters. Active-duty firefighters (N = 38) completed 4-6 shifts as they regularly would while wearing a chest strap that continuously measured heart rate and triaxial acceleration for the duration of each shift. At shift completion, participants completed a survey to report subjective load measures. For SHIFT-FIRE1 and SHIFT-NOFIRE1, external load was quantified utilizing Impulse Load, while internal load was quantified physiologically, perceptually, and overall using Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index, respectively. Call volume and shift duration similarities between the shift types were confirmed prior to examining for differences between the average loads for SHIFT-FIRE1 and SHIFT-NOFIRE1 using paired *t*-tests. Results demonstrated that SHIFT-FIRE1 require greater external loads (i.e., objective work) and physiological, perceptual, and overall internal response loads than SHIFT-NOFIRE1, indicating that the presence of at least one fire suppression and/or auto-extrication call response significantly increases the workload of a 24-hour shift with a similar total call volume. The findings establish that despite similar call volumes, the workload elicited for FIRE1 calls exacerbates the shift load, which should inform specificity in preparation and recovery strategies for fire personnel particularly after shifts that included suppression and/or extrication responses.

Keywords: workload, shift load, shiftwork, fire suppression

Methods

Study 2. The second study sought to quantify the external and internal loads across 24-hour shifts in active-duty firefighters and examine the influence of a structural fire emergency on shift workload. Similar to Study 1, external load was quantified utilizing Impulse Load, while internal load was quantified utilizing Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index. After confirming similar call volumes and shift durations, paired *t*-tests examined for load differences between shifts with and without at least one fire suppression and/or auto-extrication response. This study was the first of its kind to quantify external and internal loads in tandem across a 24-hour shift within the active-duty firefighter population, as well as the first to account for potential job factors, like call volume, that may increase the load. As a result, this study has contributed to the literature by determining that the objective job demands (i.e., external load) and physiological, perceived, and overall internal response loads that are known to be substantially greater for fire suppression and/or auto-extrication calls over non-suppressive fire and medical emergency responses (Study 1), result in significantly heightened shift workloads overall.

Participants

After obtaining approval from the Institutional Review Board (IRB) at the University of Wisconsin-Milwaukee, study recruitment was conducted through use of approved email correspondence, flyer distribution at individual firehouses, and speaking directly to individuals that expressed interest within a Midwest metropolitan fire department. Participants were considered eligible to participate if they were: (a) at least 18 years of age; (b) a non-probationary active-duty firefighter; (c) cleared for full active-duty work; and (d) willing to give written informed consent. Participants were excluded from participating in the proposed study if they: (a) reported a known cardiovascular or metabolic disease that was currently unmanaged; and/or (b) had been instructed by a physician or the Health Safety Officer to not participate in the study. Upon meeting the eligibility criteria and none of the exclusion criteria, participants that sought enrollment into the study were provided written documentation that outlined all components of the study. Researchers clearly communicated in both the written documentation and verbally that no collected data would be provided to their respective department in an individual format (i.e., non-aggregate format) and participants could withdraw from the study at any time without consequences from the research team or their respective department.

Procedures

The proposed study was broken into two phases for all participants (N=38). Phase 1 of the proposed study consisted of completing the informed consent process and determining the descriptive characteristics of the active-duty firefighters prior to continuing into Phase 2 where data were collected while on-duty. This study was part of a larger study and therefore follows protocols similar to prior research (Study 1).

Phase 1. Phase 1 data collection was conducted within the Human Performance & Sport Physiology Laboratory at University of Wisconsin-Milwaukee. After completing a written informed consent, participants completed a health history, exercise history, and job characteristics (i.e., years of experience, rank) survey and self-reported their age in years (yrs) and biological sex. Following, using a medical grade balance-beam scale and stadiometer (Detecto, Webb City, MO), participant height (cm) and body mass (kg) were measured to the nearest 0.01.

Phase 2. All Phase 2 data were collected at department firehouses, or in the field while responding to emergency calls. External load was quantified as Impulse Load and internal load measures included Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the NASA-Task Load Index. Accelerometer and heart-rate data were collected continuously across all shifts and analyzed *post hoc* to quantify Impulse and Edwards' Training Impulse for each shift. Participants completed a survey upon shift completion that were analyzed *post hoc* to quantify Foster's Session Rating of Perceived Exertion and the NASA-Task Load Index. Participants completed on-duty data collection for at least 4 shifts and a maximum of 6 shifts.

Impulse Load. Impulse load (IMPULSE) was measured utilizing the Zephyr™ Bioharness and BioModule™ device (Medtronic, Annapolis, MD). At the start of a shift, each participant was fitted with a Zephyr™ Bioharness™ and BioModule™ device that continuously collected on-shift IMPULSE (N•sec) at a sampling rate of 100 Hz across the duration of the 24-hour shift. Time-stamped (HH:MM:SS) department call logs were used to mark the IMPULSE data log for the shift initiation and completion times to sum IMPULSE across the shift duration ($IMPULSE_{SHIFT}$).

As previously reported (Study 1), the Zephyr™ system has established validity during an incremental treadmill protocol and precision tilt table testing (Johnstone, Ford, Hughes, Watson, & Garrett, 2012a). Additionally, using similar protocols, Johnstone et al. (2012b) demonstrated very strong (ICC $\geq$ 0.99) between subject, intra-device, and inter-device reliability for Zephyr™ Bioharness accelerometry measures. Further, upon examination of a discontinuous incremental walk-jog-run protocol, Zephyr™ Bioharness accelerometry-derived loads presented with excellent precision to oxygen uptake ($r > 0.90$) and very strong inter-device reliability (ICC = 0.93; Johnstone, Ford, Hughes, Watson, Mitchell, et al., 2012). Therefore, impulse load measured via Zephyr™ Bioharness accelerometry is likely an adequate measure to reflect the external load demands of on-duty firefighters, which are typically discontinuous in nature.

Edwards' Training Impulse. Edwards' Training Impulse (eTRIMP) was calculated to quantify the physiological internal workload across a 24-hour shift based on the time spent in 5 predefined heart rate (HR) zones (Sanders et al., 2017). Specifically, the same Zephyr™ Bioharness™ and BioModule™ device that continuously collected on-shift IMPULSE also continuously collected HR at a sampling rate of 250 Hz across the duration of a 24-hour shift. The HR data for the entire file was converted from bpm into a percentage of maximal heart rate (HR_{MAX}), which was quantified as: $HR_{MAX} = 208 – 0.7 x Age$ (Tanaka et al., 2001). Following, time-stamped department call logs were used to *post hoc* mark the HR data per second collected throughout the entirety of the shift into one of the five HR intensity zones and then summed into total duration (HH:MM:SS) spent in each respective zone for the shift. The time spent in each HR zone was multiplied by the zone's weighting factor and summed to quantify eTRIMP for each shift ($eTRIMP_{SHIFT}$). An example of HR data sampled across a shift via Zephyr™ Bioharness™ and BioModule™ device is provided in Figure 10 to demonstrate how each shift was an accumulated physiological workload across calls and the time between calls.

Foster's Session Rating of Perceived Exertion. Foster's Session Rating of Perceived Exertion (sRPE) was calculated to quantify the psychological internal workload across a 24-hour shift. The Rating of Perceived Exertion (RPE) from Borg's CR-10 scale for each 24-hour shift was collected using a Qualtrics survey administered via smart phone upon completion of the shift and asked the participants to rate the intensity of the shift. Following on-duty RPE collection, time-stamped department call logs were used *post hoc* to identify the initiation and completion of each shift to quantify the exact duration (HH:MM:SS) of each 24-hour shift. The duration of each shift was multiplied by the shift RPE to quantify the shift sRPE ($sRPE_{SHIFT}$).

National Aeronautics and Space Administration-Task Load Index. The NASA-Task Load Index (NASA-TLX), which has been demonstrated as a valid measure (Hart & Staveland, 1988), was utilized to assess multiple facets of load across a 24-hour shift. The NASA-TLX includes subscales of mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants completed the NASA-TLX using a Qualtrics survey that was administered via smartphone at the completion of each shift. By completing the NASA-TLX survey, participants rated the shift on each subscale within a 100-points range and responded to 15 pairwise comparisons of each subscale to determine their order of relevance to the overall load (Hart & Staveland, 1988). The number of times each subscale was selected by the participant as the most relevant to the load was utilized to weight the score of that subscale, ranging from 0 (no relevance) to 5 (more important than all other factors), for an overall load score (Figure 5) for the shift ($NASA\text{-}TLX_{SHIFT}$).

Data Processing

Upon completion of HR and IMPULSE collection across each shift via Zephyr™ Bioharness™ and BioModule™, each file was visually inspected. Upon comparison to time-stamped department call logs, any shifts that included errored measures (i.e., HR missing, etc.) during the time of a call response were entirely removed from the data set to avoid inaccurately quantifying the subsequent eTRIMP measures. Additionally, any files with errored measures (i.e., HR missing, etc.) between call responses were also removed from the data set. Finally, while the objective of this study was to capture entire 24-hour shifts, there were some circumstances (i.e., participants donning puck later into the shift, etc.) where the collected data files were shorter than 24-hours in length. To protect the accuracy of analyzing and reporting outcomes that reflect an entire shift, all files less than 22 hours in length were entirely removed from the data set. No filters were applied to the HR or IMPULSE data beyond what is automatically applied within the Zephyr™ manufacturers' design.

All survey responses were also visually inspected prior to quantifying sRPE and NASA-TLX workloads to ensure data accuracy. Any RPE reported as "0" was considered inaccurate due to participants being instructed that a "0" reflects no work at all. Thus, any RPE responses reported as "0" were subsequently replaced with a "0.3" to reflect the lowest possible exertion. Any responses with inaccurate NASA-TLX responses (i.e., NASA-TLX subscales = 0) were removed from the data set and not included in analyses.

Power Analyses

A priori power analyses were conducted to secure a sample to achieve power for the dependent *t*-tests. Utilizing a large effect size ($\rho = 0.5$) indicated a sample size of 34 participants would be required to achieve a power of $1 - \beta = 0.80$ (Faul et al., 2007) for each dependent *t*-test.

Statistical Analysis

Differences of external and internal load across 24-hour shifts with (SHIFT-FIRE1) and without (SHIFT-NOFIRE1) fire suppression or auto-extrication among active-duty firefighters were examined through separate dependent *t*-tests for IMPULSE, eTRIMP, sRPE, and NASA-TLX. Participants completed four to six shifts that were designated as SHIFT-FIRE1 or SHIFT-NOFIRE1. The observations within the SHIFT-FIRE1 and SHIFT-NOFIRE1 categories for participants with multiple observations were averaged into a single observation and resulted in a single average of each measure fore SHIFT-FIRE1 (i.e., $\text{IMPULSE}_{\text{SHIFT-FIRE1}}$, $\text{eTRIMP}_{\text{SHIFT-FIRE1}}$, $\text{sRPE}_{\text{SHIFT-FIRE1}}$, and $\text{NASA-TLX}_{\text{SHIFT-FIRE1}}$) and SHIFT-NOFIRE1 (i.e., $\text{IMPULSE}_{\text{SHIFT-NOFIRE1}}$,

$eTRIMP_{SHIFT\text{-}NOFIRE1}$, $sRPE_{SHIFT\text{-}NOFIRE1}$, and $NASA\text{-}TLX_{SHIFT\text{-}NOFIRE1}$). Before statistical analysis, the normality of data for each dependent variable (e.g., IMPULSE, eTRIMP, sRPE, NASA-TLX) were examined using visual inspections of univariate Q-Q plots for the data and *z* tests were performed to identify extreme univariate skewness and kurtosis. No consistent outliers across the dependent variables were identified, thus normality was satisfied. Additional dependent *t*-tests examined for differences in call volume and duration between SHIFT-FIRE1 and SHIFT-NOFIRE1 shifts. Separate bivariate Pearson correlations examined for relationships between the external (i.e., IMPULSE) and internal loads (i.e., eTRIMP, sRPE, NASA-TLX) for SHIFT-FIRE1 and SHIFT-NOFIRE1. All statistical analyses were performed using IBM SPSS 28 software (IBM Corp., Armonk, NY). A Bonferroni correction was applied to protect against Type I error, where an alpha of $p < 0.0125$ was utilized to determine statistical significance for all four omnibus analyses. Eta squared (η^2) effect sizes were evaluated for all dependent *t*-test analyses with $0.01 \leq \eta^2 < 0.06$, $0.06 \leq \eta^2 < 0.14$, and $0.14 \leq \eta^2$ interpreted as small, medium, and large effects, respectively (Richardson, 2011).

Results

Participant Description

Each participant from the original 38 participants completed data collection for four to six shifts, which resulted in an original data set of 201 shifts. Due to poor signal quality and/or equipment malfunction (i.e., Zephyr Bioharness) during emergency call responses, 19 shifts were eliminated (approximately 10% of original) from data set. An additional 41 shifts (approximately 20% of original) were eliminated due to poor signal quality between calls and/or equipment malfunctions during non-call response times. Therefore, for Study 2 and 3, 141 shifts were included in the analyses, as well as 138 completed shift surveys. All data were collected from shifts that occurred between the months of April 2022 and February 2023. A complete overview of data collected per participant is organized in Appendix A.

From the original 38 participants, one participant did not perform a FIRE1 response while wearing the Zephyr Bioharness and did not complete a survey for the response, and therefore did not have any load observations for SHIFT-FIRE1. Four additional participants did not complete shifts without FIRE1 responses (i.e., all shifts included at least 1 FIRE1 call), and therefore did not have any load observations for SHIFT-NOFIRE1. These five participants were listwise deleted from the analysis, which resulted in a sample of N=33 contributing to all shifts utilized for all statistical testing (Table 4).

Call Volume

A non-significant difference in call volume was identified between SHIFT-FIRE1 and SHIFT-NOFIRE1 (7.74 ± 3.66 = 7.90 ± 4.05 calls; $t = -0.282$, $p = 0.780$, $\eta^2 = 0.002$; Table 5). A non-significant difference in shift duration was identified between SHIFT-FIRE1 and SHIFT-NOFIRE1 (1381.51 ± 27.54 = 1388.75 ± 25.52 min; $t = -1.147$, $p = 0.260$, $\eta^2 = 0.039$; Table 5). A moderate positive relationship was identified between $IMPULSE_{SHIFT-FIRE1}$ and $eTRIMP_{SHIFT-FIRE1}$ ($r = 0.591$, $p < 0.001$), however $IMPULSE_{SHIFT-FIRE1}$ was non-significantly related to $sRPE_{SHIFT-FIRE1}$ ($r = 0.157$, $p = 0.353$) and $NASA\text{-}TLX_{SHIFT-FIRE1}$ ($r = 0.237$, $p = 0.158$; Table 6). Similarly, a moderate positive relationship was identified between $IMPULSE_{SHIFT-NOFIRE1}$ and $eTRIMP_{SHIFT-NOFIRE1}$ ($r = 0.407$, $p = 0.019$), however $IMPULSE_{SHIFT-NOFIRE1}$ was non-significantly related to $sRPE_{SHIFT-NOFIRE1}$ ($r = 0.079$, $p = 0.664$) and $NASA\text{-}TLX_{SHIFT-NOFIRE1}$ ($r = 0.034$, $p = 0.849$; Table 6).

External Load

Impulse Load. A large significant difference was identified between the external load demands of SHIFT-FIRE1 and SHIFT-NOFIRE1, such that $IMPULSE_{SHIFT\text{-}FIRE1}$ was significantly greater than $IMPULSE_{SHIFT\text{-}NOFIRE1}$ (52,982.29 ± 16,800.51 > 45,617.71 ± 12,939.82 N*s; $t = 3.089$, $p = 0.004$, $\eta^2 = 0.230$; Figure 10A). This outcome suggests the objective work completed throughout shifts with at least one fire suppression and/or auto-extrication response is approximately 16% greater than shifts with no fire suppression responses.

Internal Load

Edwards' Training Impulse. A large significant difference was identified between the physiological internal load demands of SHIFT-FIRE1 and SHIFT-NOFIRE1, where $eTRIMP_{SHIFT\text{-}FIRE1}$ was significantly greater than $eTRIMP_{SHIFT\text{-}NOFIRE1}$ (417.09 ± 333.77 > 295.02 ± 230.95 AU; $t = 2.745$, $p = 0.010$, $\eta^2 = 0.191$; Figure 10B). This outcome suggests the physiological load elicited in response to the work completed (i.e., external load) when at least one fire suppression response is required is approximately 40% greater than shifts with no fire suppression responses.

Foster's Session Rating of Perceived Exertion. A large significant difference was identified between the perceived internal load demands of SHIFT-FIRE1 and SHIFT-NOFIRE1, where $sRPE_{SHIFT\text{-}FIRE1}$ was significantly greater than $sRPE_{SHIFT\text{-}NOFIRE1}$ (4814.22 ± 2273.14 > 2969.22 ± 1529.60 AU; $t = 5.666$, $p < 0.001$, $\eta^2 = 0.501$; Figure 10C). This outcome suggests the perceived exertional load elicited in response to the work completed (i.e., external load) when at least one fire suppression response is required are approximately 60% greater than shifts with no fire suppression responses.

NASA-Task Load Index. A large significant difference was identified between the overall internal load demands of SHIFT-FIRE1 and SHIFT-NOFIRE1, where NASA-$TLX_{SHIFT\text{-}FIRE1}$ was significantly greater than NASA-$TLX_{SHIFT\text{-}NOFIRE1}$ (32.40 ± 16.83 > 21.60 ± 13.85 AU; $t = 4.227$, $p < 0.001$, $\eta^2 = 0.358$; Figure 10D). This outcome suggests the subjective overall load elicited in response to the work completed (i.e., external load) when at least one fire suppression call response is required is nearly 50% more than a shift with no fire suppression responses.

Results Summary

In summary, these results suggest a shift that includes at least one fire suppression call requires about 16% more objective work than a shift without suppression. Further, the heightened external loads required of shifts that include at least one fire suppression and/or auto-extrication elicit even greater physiological, perceived, and overall internal loads. Additionally, for shifts with or without suppression, the physiological load elicited is positively related to, or reflects, the objective work completed across the shift, however the perceived load (i.e., sRPE) and overall internal load (i.e., NASA-TLX) are unrelated to the objective job demands, suggesting that additional factors may be influencing the subjective interpretation of loads across a shift among fire service personnel.

Discussion

The purpose of Study 2 was to examine differences in external and internal loads across 24-hour shifts with and without at least one fire suppression and/or auto-extrication emergency (i.e., FIRE1) call response in active-duty firefighters. This study is the first of its kind to specifically quantify, and examine for, the influence of the emergency call type that elicits the greatest workload response (i.e., FIRE1), on the workload of a 24-hour shift utilizing external and internal load metrics. Furthermore, the most common measure of workload in the fire service to date (i.e., call volume) is similar across the designated shift groups, thus allowing for an objective examination of load when different call types are responded to across the shift.

Impulse Load. The results of this study indicate that the objective workload (i.e., external load) that is completed for a shift that includes at least one fire suppression and/or auto-extrication emergency call response (i.e., SHIFT-FIRE1) is 16% more than a shift that does not include a suppression call response (i.e., SHIFT-NOFIRE1). External load metrics have been primarily utilized in sport-athlete populations and given the lack of published literature in the fire service for comparison to the present study, it is possible to compare the objective work completed across a shift with and without a FIRE1 call response to such populations. The objective work performed across SHIFT-FIRE1 (52,982.29 ± 16,800.51 N*s) and SHIFT-NOFIRE1 (45,617.71 ± 12,939.82 N*s) are greater than an average men's collegiate singles tennis match (31,310 ± 8,640 N*s; Gentles, Coniglio, Mahnken et al., 2018) as well as an average women's collegiate soccer match (20,120 ± 8,609 N*s; Gentles, Coniglio, Besemer et al., 2018). However, the loads of both shift types are similar to the objective work of an average boys U16 soccer match (~54,000 N*s; Gómez-Carmona et al., 2019), and diverge into similarities with specific positions in women's collegiate volleyball 3-day tournament play, where SHIFT-FIRE1 and SHIFT-NOFIRE1 are similar to the total external loads of a libero (60,752 ± 0 N*s) and an outside hitter (46,538 ± 9,456 N*s), respectively (Coniglio et al., 2018). Given this information, it is clear the shiftwork demands of firefighting may be comparable to some sporting event demands, however the discrepancies with sport-athlete work demands support the continuation of examining the workloads of occupational athletes, such as firefighters, as independent populations.

Prior research has not been conducted utilizing external load measures in an on-duty setting among fire personnel, however, researchers have quantified the objective work demands in other occupational athlete settings. In particular, the objective job demands of SHIFT-FIRE1 and SHIFT-NOFIRE1 in the present study are seemingly greater than the summed external load of training sessions (~77 min) conducted three times weekly across 12 weeks for Army Reserve Officers' Training Corps (~15,300 N*s; Zadeh et al., 2020). The amount of training time (~2,772 min [77 min x 3 d x 12 wks]) where Zadeh et al., (2020) quantified the external load is nearly double that of the present SHIFT-FIRE1 (1,381.51 ± 27.54 min) and SHIFT-NOFIRE1 (1,388.75 ± 25.52 min) durations. Thus, it is likely that despite the longer duration of total task time, the physical work completed during training in this sample of Army Reserve Officers' Training Corps is substantially less than the objective work completed during a shift in the fire service, particularly when the shift includes a FIRE1 call response.

The differences in the objective work completed throughout shifts with and without a fire suppression and/or auto-extrication call (i.e., FIRE1) emergency call is likely the result of several factors. Prior research (Study 1) has demonstrated that the heightened job demands of fire suppression and/or auto-extrication calls may be due to the greater physical demands required for such calls, including longer durations of call responses (42.75 ± 23.67 min) in comparison to medical (21.15 ± 3.42 min) and non-suppression fire call responses (14.30 ± 5.86 min). As it relates to shift differences, the durations of the quantified shifts in the present study (i.e., SHIFT-FIRE1 and SHIFT-NOFIRE1) were similar and therefore, it is unlikely that the differences in workload are the result of differences in time spent on-duty. Additionally, the established measure of workload currently utilized in the fire service is call volume (Blackwell et al., 2011; Watkins et al., 2021), however, SHIFT-FIRE1 and SHIFT-NOFIRE1 required similar volumes of total call responses (7.74 ± 3.66 and 7.90 ± 4.05 calls, respectively) and therefore, it is unlikely that the differences in objective work requirements are due to the total call volume. As such, it is probable that the significantly greater job demands of a fire suppression and/or auto-extrication, including the lengthier call time and greater physical work demands of the call (Study 1), for SHIFT-FIRE1 are substantially increasing the objective work completed across a shift. Specifically, fire suppression and/or auto-extrication calls often include sizeable response areas, and subsequent distance coverage (i.e., an entire apartment complex, etc.), as well as physically demanding actions (e.g., crawling, use of heavy equipment, raising ladders, climbing, overhead work; Gledhill & Jamnik, 1992; National Fire Protection Association, 2022), that contribute the objective workload of SHIFT-FIRE1 being heightened above SHIFT-NOFIRE1. In addition to the objective work completed during the actual call response, the National Fire Protection Association (NFPA) requires firefighters to complete cleaning protocols following fire suppression responses to uphold the integrity and cleanliness of personal protective ensembles (PPE; NFPA, 2020b), self-contained breathing apparatuses (SCBA; NFPA, 2019), and other emergency equipment (NFPA, 2020c). Examples of the cleaning completed upon return to the station may include decontamination of PPE, equipment (e.g., radio, tools, fire hose), and the apparatus cab, as well as returning the cab to a state of readiness and taking a shower to reduce exposure to carcinogens and products of combustion. Taking into account the lower-intensity, yet active work of post-suppression cleaning, as well as the objective work demands of the call response(s) themselves, the greater accumulated external load of SHIFT-FIRE1 is likely the result of the combined work completed at the emergency scene and upon return to the fire station; shifts that include FIRE1 calls may require more time spent in a state of physical exertion compared to a non-suppression shift. Future researchers should investigate further how much of the objective work demands of a shift with a FIRE1 response are accumulated separately across the call-response and post-call cleaning obligations.

Edwards' Training Impulse. The results of this study indicate that the physiological internal load is approximately 40% greater for a shift that includes at least one fire suppression and/or auto-extrication emergency call response (i.e., SHIFT-FIRE1) than a shift that does not include a suppression call response (i.e., SHIFT-NOFIRE1). Additionally, it is likely that the physiological loads of both shifts reflect the magnitude of objective work conducted across each shift as the physiological load demonstrated a significant positive relationship to the job demands (i.e., IMPULSE).

Researchers have established eTRIMP as a measure of physiological internal load mainly within sport-athlete populations and due to the duration of such events or competitions being short relative to the 24-hour duration of a single shift in the fire service, it is not surprising to see that the physiological load for SHIFT-FIRE1 (417.09 ± 333.77 AU) and SHIFT-NOFIRE1 (295.02 ± 230.95 AU) are significantly greater than most athletic populations. Specifically, the physiological loads for both shift designations were substantially greater than a 4-min and 17-min high-intensity functional training sessions (19.8 ± 8.4 and 77.7 ± 4.9 AU, respectively; Tibana et al., 2018), as well as for a 30-min exercise bout termed functional fitness training (93.1 ± 9.5 AU; Falk Neto et al., 2020). Similarly, both shift designations exhibited physiological loads greater than the average load of professional men's soccer training sessions (169.2 ± 54.0 AU; Scott et al., 2013). However, upon considering the range of training session loads in the same sample (50.8 - 367.5 AU), similarities do emerge between the load of SHIFT-NOFIRE1 and the soccer athletes that acquired higher loads during the training duration (~73 min; Scott et al., 2013), which suggests that across the duration of a 24-hour shift that does not include fire suppression and/or auto-extrication, firefighters may accumulate a similar physiological load as soccer athletes during a high-intensity soccer practice. In all, the results of the present study demonstrate that the physiological loads elicited by shifts with (i.e., SHIFT-FIRE1) and without (i.e., SHIFT-NOFIRE1) fire suppression and/or auto-extrication are generally greater than the demands exhibited during athletic tasks, however it is possible for the lower load of a shift without fire suppression and/or auto-extrication to accumulate a physiological load similar quantify to a single, higher-intensity soccer training session.

Beyond use among sport-athletes, researchers have recently bridged use of eTRIMP into monitoring the physiological load within occupational athletes to quantify daily workloads. Specifically, within a sample of Australian Army Recruits completing 14-hours of daily basic military training (e.g., physical training, marching, military education, field exercises, drill), the average daily eTRIMP across a 6-day period ranged from 274 to 709 AU, and equated to an average of approximately 467 AU daily (Gibson et al., 2022). In comparison, the physiological load of a shift in the fire service that includes at least one response to a fire suppression and/or auto-extrication call (i.e., SHIFT-FIRE1) is seemingly similar to an average day of basic military training, however, a shift without a FIRE1 call response is most similar to the lower range of eTRIMP training demands in army recruits. Future researchers should examine if other similarities exist between the physiological occupational demands of a shift in the fire service, and other shiftwork demands (i.e., police, military).

The autonomic nervous system (ANS) is known to drive the physiological responses to firefighter work demands (Kesler et al., 2018; Smith et al., 2016) through increasing heart rate through withdrawal of the parasympathetic nervous system (PSNS) and subsequent stimulation of the sympathetic nervous system (SNS). Prior research demonstrates that the heart rate response to an emergency begins at the sound of the tone (Barnes, 2000; MacNeal et al., 2016; Marciniak, Tesch, et al., 2021) and is carried throughout an emergency response to elicit a physiological load regardless of the emergency call type (Study 1). Further, it is known that the physiological load of a fire call response that includes fire suppression and/or auto-extrication (i.e., FIRE1) significantly increase SNS activation and, in turn, eTRIMP responses over non-suppression fire calls (i.e., FIRE0) and medical (i.e., MED) emergencies (Study 1). Therefore, given that the total call volumes of SHIFT-FIRE1 and SHIFT-NOFIRE1 were similar, the types of calls that were responded to for each shift should be considered for their influence on the physiological load across the shifts. Specifically, throughout SHIFT-FIRE1 and SHIFT-NOFIRE1, the participants responded to a similar number of FIRE0 calls on average (0.97 ± 0.84 and 0.96 ± 0.97 calls, respectively). However, for SHIFT-FIRE1, participants appear to respond to fewer MED calls which are replaced by FIRE1 responses, such that the response includes an average FIRE1 (1.39 ± 0.51 calls) and MED responses (5.33 ± 3.75 calls) in comparison to the FIRE1 and MED responses (0.00 ± 0.00 and 6.94 ± 4.12, respectively) for SHIFT-NOFIRE1. As such, given that the total call volumes of SHIFT-FIRE1 and SHIFT-NOFIRE1 were similar, the work conducted in response to the FIRE1 calls in place of the MED calls in SHIFT-FIRE1 are likely contributing to the differences in physiological load demands between the shift designations in the present study. This notion is further supported by the stronger relationship demonstrated between the measured objective work (i.e., IMPULSE) and the elicited physiological load (i.e., eTRIMP) for SHIFT-FIRE1 (r = 0.591) compared to SHIFT-NOFIRE1 (r = 0.407).

The additional physiological load elicited for shifts that include at least a fire suppression and/or auto-extrication emergency response (i.e., SHIFT-FIRE1) is due to greater SNS activation necessary to increase heart rate to meet task demands, and in turn, accumulating greater amounts of time in each heart rate zone (i.e., ZONE1-ZONE5) than non-suppression shifts (i.e., SHIFT-NOFIRE1). Due to the known objective work for FIRE1 calls being significantly greater than MED and FIRE0 (Study 1), it is not surprising to see that the SNS-driven cardiovascular intensity of such calls resulted in nearly double the time in higher-intensity zones respectively for SHIFT-FIRE1 over SHIFT-NOFIRE1, including ZONE3 (22.62 ± 19.89 > 11.06 ± 10.98 min), ZONE 4 (12.42 ± 11.75 > 7.01 ± 7.69 min), and ZONE5 (6.03 ± 11.36 > 3.42 ± 5.01 min). However, it is interesting to note that SHIFT-FIRE1 also exhibited greater overall time than SHIFT-NOFIRE1 at the lower-intensity zones like ZONE1 (165.34 ± 116.65 > 149.43 ± 124.04 min) and ZONE2 (52.02 ± 48.31 > 33.65 ± 34.23 min). Due to the NFPA post-suppression cleaning standards, described specifically in the previous section (i.e., IMPULSE), it is possible that cardiovascular demands (i.e., eTRIMP) of fire call responses (Study 1) may extend into prolonged heart rate responses above 50% HR_{MAX} (i.e., ZONE1 and ZONE2) following calls, especially as it relates to FIRE1 calls. Future research should examine the timeline to recovery following the workload of individual call responses, particularly following fire suppression and/or auto-extrication calls, as targeted SNS recovery strategies may be designed to support recovery of firefighter post-call heart rates and reductions in cardiovascular risk.

Foster's Session Rating of Perceived Exertion. The results of the present study demonstrate that a shift that includes a fire suppression and/or auto-extrication is not only physiologically more demanding for firefighters, but also elicits nearly 60%greater perceived load, than a non-suppression shift. In comparison to sport-athlete populations where this measure (i.e., sRPE) has been primarily utilized, the perceived load of a shift, including with and without a fire suppression and/or auto-extrication, is substantially greater than the load of many athletic tasks. The daily perceived load of a national soccer training camp (609 – 1153.3 AU; Clemente et al., 2020) and a match of collegiate women's soccer (892.50 ± 358.50 AU; Gentles, Coniglio, Besemer et al., 2018) are much less than SHIFT-FIRE1 and SHIFT-NOFIRE1 (4814.22 ± 2273.14 and 2969.22 ± 1529.60 AU, respectively), which is likely due to both tasks requiring less time than a 24-hour shift. In contrast, when quantifying the perceived load across time, such as Conte and Kamarauskas' (2022) quantification of a week of training from 88-min daily sessions of national men's soccer practice (3645 ± 950 AU) and 116-min daily sessions of European men's soccer practice (4877 ± 1390 AU), which are nearly equivalent to the load of SHIFT-FIRE1. Together, these trends support the notion that the perceived load of a shift in the fire service is greater than a single sporting-event or task, particularly as it relates to soccer, however the accumulation of load across multiple events is increasingly similar to the job demands of a single shift.

In comparison to other occupational athletes, such as the average daily training load of army recruits attending basic military training where the physiological loads were similar to SHIFT-FIRE1, but slightly greater than SHIFT-NOFIRE1, the perceived exertion (i.e., RPE) of training followed a similar trend (Gibson et al., 2022). Specifically, the average perceived exertion for a day of basic military training (3.83 AU; Gibson et al., 2022) was similar to that of SHIFT-FIRE1 (3.48 AU), yet greater than SHIFT-NOFIRE1 (2.17 AU) in the present study. Although sRPE was not quantified by Gibson et al. (2022), if we estimate the perceived load from the product of the duration of an average training day (960 min) and the average perceived exertion (3.83 AU), the load of daily training in an army recruit population (~3676.8 AU) is still greater than SHIFT-NOFIRE1, yet exhibits a lesser perceived load than SHIFT-FIRE1, likely due to the longer shift durations in the fire service.

There are a multitude of factors that are likely contributing to the heightened perceived load that was experienced by firefighters completing shifts that included a fire suppression and/or auto-extrication call response. Strong positive relationships between perceived load (i.e., sRPE) and the objective job demands (i.e., IMPULSE) have been established (Gentles, Coniglio, Besemer et al., 2018), however, in the present study, the perceived load was non-significantly related to the IMPULSE of SHIFT-FIRE1 (r = 0.157) and SHIFT-NOFIRE1 (r = 0.079). Accordingly, the perceived loads of both shifts in this case appear to be relatively uninformed by the job demands conducted across the shift. Aside from links to external loads, physiological measures like heart rate have also been tied to RPE (Borg, 1982) and it is plausible that the heightened cardiovascular drive that resulted in a greater eTRIMP for SHIFT-FIRE1 also contributed to the greater perceived load. This notion is supported by the presence of a moderate relationship between sRPE and eTRIMP for SHIFT-FIRE1 (r = 0.426). However, a weak relationship was identified between sRPE and eTRIMP for SHIFT-NOFIRE1 (r = 0.111) suggesting that perceived load across a shift with a lesser heart rate response may be less informed by cardiovascular demands, or lack thereof, across the shift. Finally, and particularly as it relates to emergency calls that require fire suppression, firefighters are known to be at risk of dehydration as a result of encapsulating PPE and environmental temperatures (Walker et al., 2016) and prior research suggests the magnitude of body water lost during exercise is related to increased perceived loads (Cesanelli et al., 2021). Taken together, it is likely that the perceived load of both shift designations was minimally informed by the objective work but rather influenced to a greater extent by physiological loads experienced across the shift, particularly as it relates to SHIFT-FIRE1.

Aside from potential influences of the other loads measured across the shifts, there are also several other mechanisms that are known to increase perceptions of exertion that may have a role in the perceived load responses of this study, particularly as it relates to the perceived load of non-suppression shifts (i.e., SHIFT-NOFIRE1). While the demands of each emergency call elicit a perceived load, and to a greater extent in FIRE1 over MED and FIRE0 (Study 1), anticipation of an emergency response or hyper-vigilance is known to occur between calls (Barnes, 2000), which may also increase the perceived shift loads. It is possible that the completion of a 24-hour shift without a FIRE1 response may elicit hyper-vigilance and contribute to the perceived load experienced in SHIFT-NOFIRE1. Additionally, it is known that due to the unpredictable timing of emergency calls throughout a shift, sleep disruptions and low-quality sleep often occur (Billings & Focht, 2016) and negatively influence cognitive functioning among firefighters (Stout et al., 2021). Further, bouts of moderate-to high intensity exercise on consecutive days have been linked to accumulated fatigue measured via sRPE (Fusco et al., 2020). Taken together, it is possible that between-call hyper-vigilance, particularly for SHIFT-NOFIRE1, and the perceived load of consecutive calls across the shift duration in combination with poor sleep quality, may contribute to the perceived shift loads.

NASA-TLX. In step with the other internal load measures of the present study, the NASA-TLX results indicate that the overall load of a shift that includes a fire suppression and/or auto-extrication call is 50% more than a non-suppression shift. Due to the established use of the NASA-TLX for use within occupational populations, primarily pilots, there are several comparisons to be made between the results of the present study and other occupational athletes. The overall load of a flight simulation in pilots, including both high- and low-performers (14.93 ± 6.42 and 39.04 ± 7.86 AU, respectively; Mansikka et al., 2019), were respectively comparable to the loads of SHIFT-NOFIRE1 (21.60 ± 13.85 AU) and SHIFT-FIRE1 (32.40 ± 16.83 AU). However, in a separate, military pilot population, the overall loads of the take-off (~57 AU) and landing phases of flight (~62 AU) are much greater than the load of either shift designation in the present study (Alaimo et al., 2020). When quantifying the load of a shift in law enforcement officers, the overall loads of a day (34.74 ± 17.26 AU) and night (37.69 ± 11.16 AU) shift are similar to the SHIFT-FIRE1, yet much greater than SHIFT-NOFIRE1. Given this information, the NASA-TLX may allow for comparisons across occupations when comparing the overall load of work demands, particularly when comparing the shift loads of tactical populations (i.e., fire service and law enforcement). However, without examining the individual subscales of the measure, it is difficult to identify how the similar loads across populations may in fact elicit different subscale ratings and future researchers should examine subscale comparisons further before confirming that overall loads are similar for tactical personnel.

Interestingly, while the magnitudes of physiological and perceived loads appear to surpass that of tasks completed in various sport-athlete populations, the NASA-TLX results of the present study are comparable with prior sport-athlete measures and in some cases, significantly less in overall load magnitude. In a sample of male cyclists (Kesisoglou et al., 2021), it appears that a 5-min (~68 AU) and 20-min (~70 AU) maximal intensity timed trial, and a 20-min (~42 AU) submaximal intensity timed trial, require greater overall loads then both shift designations in the present study. Further, when examining the average ratings (0 – 100) assigned to each individual subscale by elite rugby players (Mullen et al., 2021), including mental demand (~73 AU), physical demand (~77 AU), temporal demand (~67 AU), performance (~43 AU), effort (~75 AU), and frustration (~60 AU), all of the scales are assigned a greater rating compared to the individual scales for each shift type in the present study (Table 5). As such, despite the physiological and perceived loads of both shift designations eliciting magnitudes that were greater than some sport-athlete populations, the overall shift loads as measured by the NASA-TLX are seemingly contradictory of the other internal load measures (i.e., eTRIMP and sRPE) and demonstrate the overall loads of shifts are generally less than sporting tasks. However, prior research suggests that the activities and tasks that commonly utilize the NASA-TLX are relatively intense yet short in duration (e.g., athletic events, flight simulations; Hart, 2006). Therefore, it is possible that the differences in overall load quantifications may be due to the length of the task being recalled in the present study (i.e., 24-hours), where periods of high-intensity work are intermittently disbursed between lower-intensity time at the station throughout the 24-hour shift. This notion is supported by the similarities between the overall loads in the present study to shiftwork in law enforcement officers, but the distinct differences with other studies that include shorter tasks/events. Future research should evaluate the use of the NASA-TLX across sport-athlete and tactical populations to determine if loads across populations are equally quantifiable and comparable.

While the differences in overall load for SHIFT-FIRE1 and SHIFT-NOFIRE1 are likely the result of the magnitude of ratings being greater for the former, the variables that contributed most to overall load also appear different across shift designations. Upon examining the magnitudes (Raw Score 0-100) of all six subscales for both shifts (Table 5), the magnitude of mental demand (i.e., how much mental activity [e.g., thinking, deciding, etc.] was required), physical demand (i.e., how much physical activity [e.g., pushing, pulling, etc.] was required), temporal demand (i.e., how much time pressure was felt), performance (i.e., level of success or accomplishment), effort (i.e., how hard did the participant work), and frustration (i.e., level of discouragement, stress) were all greater for SHIFT-FIRE1 than SHIFT-NOFIRE1. Further differences between the overall load demands emerge when comparing the contributions of the primary subscales to SHIFT-FIRE1 and SHIFT-NOFIRE1 overall load. Accordingly, although the mental demand for both shift designations were similar, the overall load of SHIFT-FIRE1 had greater contributions from physical demand (15.77%) and effort (20.14%) than SHIFT-NOFIRE1 (9.74 and 15.54%, respectively). This suggests that the added objective work of a fire suppression and/or auto-extrication call to the shift elicited greater contributions of physical strain and effort to accomplish performance demands of overall load, which is supported by the moderate relationship between the physiological load (i.e., eTRIMP) and overall load (i.e., NASA-TLX) for SHIFT-FIRE1 (r = 0.361). In contrast, the smaller contributions of physical demand and effort to SHIFT-NOFIRE1 likely explain the lack of relationship between eTRIMP and NASA-TLX (r = 0.038) for that shift designation. SHIFT-FIRE1 also exhibited lesser contributions from temporal demand (12.91%), performance (16.76%), and frustration (10.84%) than SHIFT-NOFIRE1 (16.55, 20.16, and 14.90%, respectively). Suggesting that despite the added contributions in physical demands and effort required across the shift, the time pressure or pace of the shift was slowed (i.e., temporal demands), the level of success with personal performance was improved (i.e., performance), and the gratification during shift was enhanced (i.e., frustration) with the addition of at least one fire suppression and/or auto-extrication call to the shift. Taken together, while the magnitude of the overall load required to complete the shiftwork demands when including a fire suppression and/or auto-extrication call is amplified, the profile of the load seems to rely more heavily on physical demands and effort, while enhancing some of the positive characteristics of shiftwork.

Comparison of Load Measures. Due to an impactful strength of the present study being the utilization of external load in tandem with multiple measures of internal load across the duration of an entire 24-hour shift in the fire service, a comparison of the measures in use is warranted. The use of an external load measure to quantify the objective work completed across a shift in this study was to quantify the job demands completed and in turn, inform a greater understanding for the intrinsic load responses similar to the established, traditional use of such measures in sport-athletes (Bourdon et al., 2017; Impellizzeri et al., 2019). Of the objective work quantified via accelerometer-derived IMPULSE, the only internal load metric with a significant relationship to the objective work, thereby reflecting the intrinsic load as a direct response of the objective work conducted for SHIFT-FIRE1 and SHIFT-NOFIRE1, was the physiological load, or eTRIMP. The perceived load (i.e., sRPE) was seemingly unrelated to the objective work (i.e., IMPULSE) completed across the shift for SHIFT-FIRE1 (r = 0.157) and SHIFT-NOFIRE1 (r = 0.079), and only reflected the physiological load of SHIFT-FIRE1 (r = 0.426) yet remained unrelated to SHIFT-NOFIRE1 (r = 0.111). Similarly, the overall load (i.e., NASA-TLX) was also non-significantly related to the objective work (i.e., IMPULSE) for SHIFT-FIRE1 (r = 0.237) and SHIFT-NOFIRE1 (r = 0.034) and only reflected the physiological load of SHIFT-FIRE1 (r = 0.361) yet was unrelated to SHIFT-NOFIRE1 (r = 0.038). Taken together, these relationships, or lack thereof, indicate that the sRPE and the NASA-TLX are unlikely to reflect the magnitude of objective work completed or the physiological response to such work, across a shift and in turn, may not be well-suited to independently inform the physical recovery needs of post-shift fire personnel. However, it is evident that sRPE and the NASA-TLX indicate other, non-physical characteristics of shiftwork and may inform other needs of recovery, such as those related to mental recovery and wellness. Finally, as a result of the strong relationships between the NASA-TLX and sRPE, it is likely that use of both measures is redundant and only one of these measures may be necessary to determine the magnitude of non-physical recovery needs post-shift. As such, the selection of either measure should be considered with its strengths. Due to its shorter time requirements and/or ease of use with minimal equipment and methods of calculation, sRPE may be better-suited for use. However, the NASA-TLX should be considered if seeking to better understand the direct contributions of specific characteristics, or subscales, across specific tasks (i.e., training scenarios, etc.). To conclude, each of the internal load measures utilized in this study demonstrated meaningful purposes in better understanding the shiftwork demands of firefighting and should be considered for use in future research, and in applied settings, based on the direct needs (i.e., physical, mental, etc.) of the fire service personnel.

Limitations and Future Research. While the strengths of the present study are impactful, it is important to consider these results within the confines of the Study limitations. This study is representative of a sample of structural firefighters from a large, metropolitan fire department and therefore may not entirely represent the workload demands of a shift among other fire service subsets, such as volunteer firefighters. Specifically, for Midwest department emergency responses, the reported sample distribution in medical call types reflects the average response profile, however the fire call responses of this sample are approximately double the Midwest average, according to the USFA (USFA, 2022). Therefore, it is possible that these results mirror expected workloads in the Midwest, especially in relation to MED call responses, but may not represent other areas of the United States. Additionally, as population density increases the ratio of firefighters to civilians decreases (Fahy et al., 2022). Thus, it is likely that the rate of call responses across a shift in this sample from a larger metropolitan area may be greater than call experiences in communities with smaller populations. Additionally, despite the call volume across the shifts in comparison not demonstrating statistical differences, the exact amount of time spent in response to calls vs. at the station was not quantified and future researchers should examine for specific contributions of call response time and non-call time to overall shift load, particularly as it relates to post-suppression cleaning demands. It should also be noted that the surveys to quantify sRPE and NASA-TLX were administered upon shift completion during which the participants may have been fatigued from shift demands (i.e., sleep deprivation, etc.). While this limitation is relatively unavoidable in trying to quantify shift workload, an avenue of future research could examine if survey timing influences the subjective loads being measure, as well as examine if physiological, perceived, and/or overall load metrics are different at different times of a shift (i.e., day vs. night). Finally, while the NASA-TLX has an established use within occupational populations, future researchers should examine if the duration of the task being recalled (i.e., 24-hour shift) influences the accuracy of overall load scores.

Conclusions. Through the completion of this study, there is an understanding of the quantifiable external and internal load demands required of structural firefighters across 24-hour shifts. Furthermore, it is evident that for shifts of similar call volumes, the objective work demands (i.e., IMPULSE) and subsequent physiological (i.e., eTRIMP), perceived (i.e., sRPE), and overall (i.e., NASA-TLX) load responses are significantly increased when there is at least one emergency response that includes fire suppression and/or auto-extrication. In turn, the recovery needs of firefighters following shifts that included suppression may be elevated and, to address the potential cardiovascular injury concerns beyond improving individual fitness and preparation, it may be important to create recovery protocols specific for shifts that included fire suppression and/or auto-extrication. Physical recovery needs from a 24-hour shift are likely best informed by a physiological load measure such as eTRIMP. However, subjective measures of internal load like sRPE and NASA-TLX may inform recovery needs beyond physical components and in turn, each measure should be considered for use in the fire service based on the specific needs (i.e., physical recovery, mental recovery) of the personnel of interest. Finally, while call volume is currently the most established and utilized metric of workload in the fire service, it appears that the workload of shifts with similar volumes are not necessarily equal and quantification of workload should consider other objective work parameters (i.e., FIRE1 call volume, total time responding to calls, etc.) to quantify the job demands more specifically of these occupational athletes.

Figures & Tables

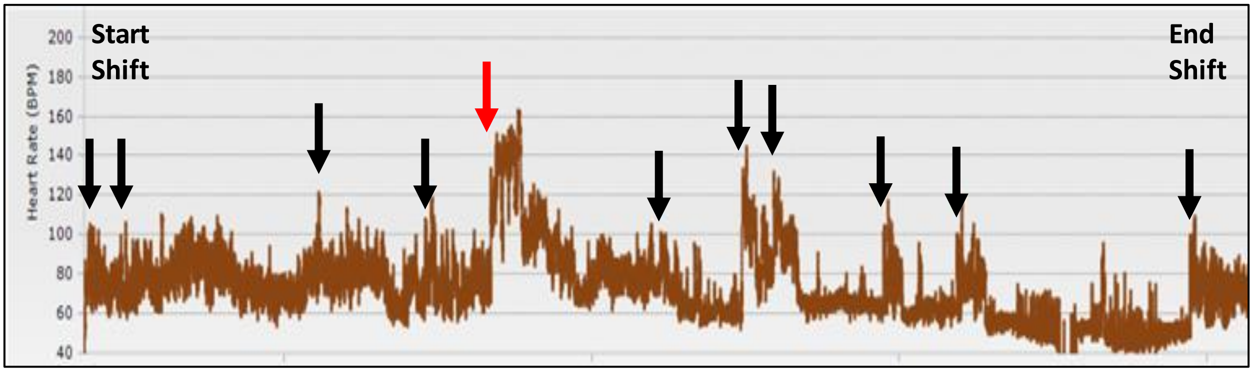


Figure 10. Example of heart rate sampled continuously across a 24-hour shift using Zephyr™ Bioharness™ and BioModule™. Arrows indicate the alarm sounding to call firefighter to an emergency. Black arrow, not fire suppression and/or auto-extrication; Red arrow, fire suppression and/or auto-extrication.

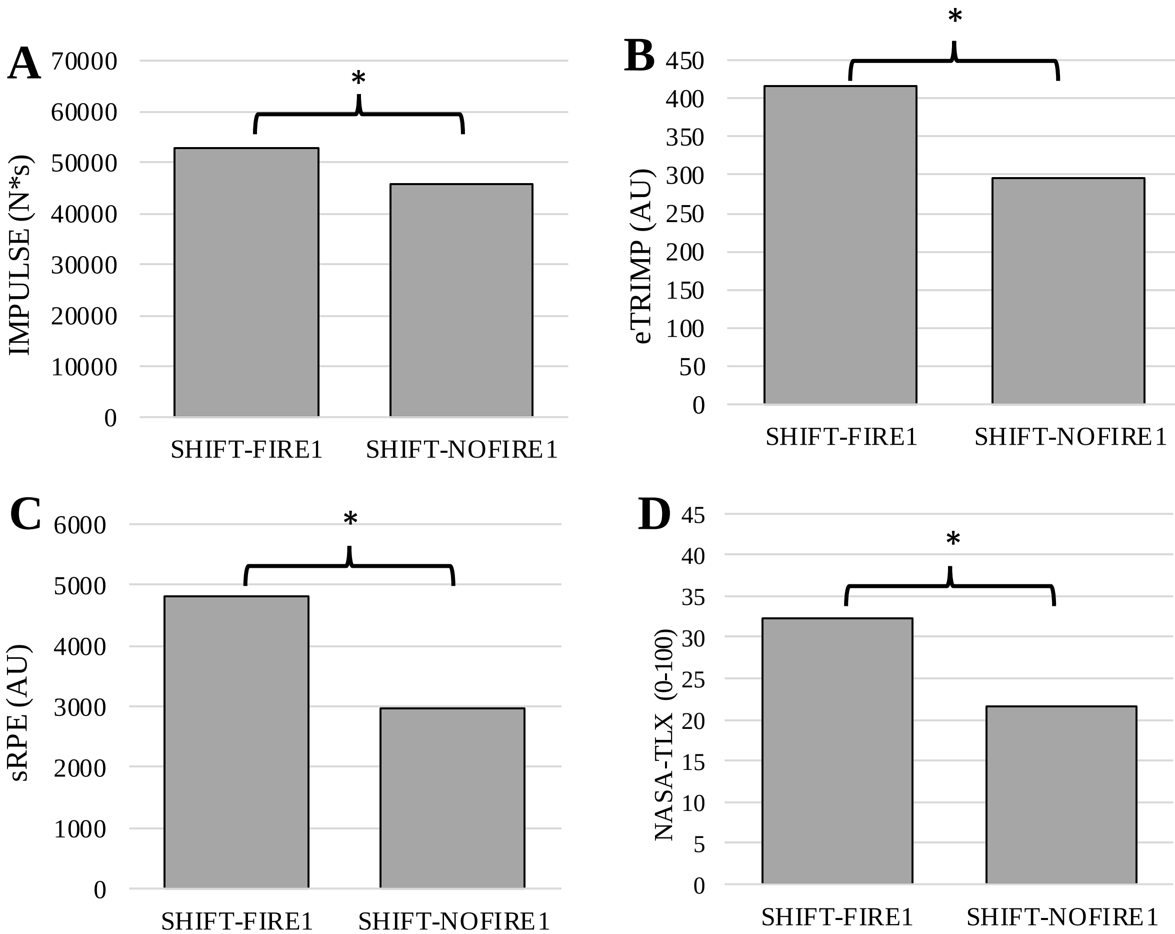


Figure 11. Differences in external and internal workloads across shifts with and without FIRE1 call responses. A, Impulse; B, Edward's Training Impulse; C, Foster's Session Rating of Perceived Exertion; D, NASA- Task Load Index; *, significantly different ($p < 0.05$).

Table 4

Study 2 Analysis Sample Sizes

	SHIFT FIRE1	**SHIFT NOFIRE1**	**Paired *t*-test Sample Size**
IMPULSE	37	34	33
ETRIMP	37	34	33
SRPE	37	34	33
NASA-TLX	37	34	33

Table 5

Descriptive statistics (Mean ± SD) of load components across shifts with and without fire suppression

Component	**SHIFT-FIRE1**	**SHIFT-NOFIRE1**
Call Volume (Count)	7.74 ± 3.66	7.90 ± 4.05
Shift Duration (min)	1381.51 ± 27.54	1388.75 ± 25.52
RPE (AU)	3.48 ± 1.64	2.17 ± 1.10
Heart Rate Zones (min)		
ZONE1	165.34 ± 116.65	149.43 ± 124.04
ZONE2	52.02 ± 48.31	33.65 ± 34.23
ZONE3	22.62 ± 19.89	11.06 ± 10.98
ZONE4	12.42 ± 11.75	7.01 ± 7.69
ZONE5	6.03 ± 11.36	3.42 ± 5.01
NASA-TLX Raw Score (0-100)		
Mental Demand	32.11 ± 22.00	21.09 ± 16.39
Physical Demand	33.23 ± 20.91	17.32 ± 11.39
Temporal Demand	26.18 ± 19.26	17.49 ± 15.24
Performance	26.74 ± 27.96	24.57 ± 29.69
Effort	35.52 ± 20.69	20.41 ± 13.90
Frustration	18.76 ± 15.28	16.84 ± 14.13
NASA-TLX Weighted Contribution (%)		
Mental Demand	23.59 ± 12.03	24.11 ± 12.90
Physical Demand	15.77 ± 13.16	9.74 ± 12.87
Temporal Demand	12.91 ± 10.52	16.55 ± 11.43
Performance	16.76 ± 17.10	20.16 ± 17.56
Effort	20.14 ± 11.35	14.54 ± 8.59
Frustration	10.84 ± 15.41	14.90 ± 17.63

Table 6

Relationships between external and internal loads for shifts with and without fire suppression

	SHIFT-FIRE1			**SHIFT-NOFIRE1**		
	Impulse	eTRIMP	sRPE	Impulse	eTRIMP	sRPE
eTRIMP	.591**	---	---	.407*	---	---
sRPE	.157	.426**	---	.079	.111	---
NASA-TLX	.237	.361*	.564**	.034	.038	.415*

eTRIMP, Edward's Training Impulse; sRPE, Foster's Session Rating of Perceived Exertion; NASA-TLX, NASA-Task Load Index; *, $p < .05$, **, $p < .001$.

Chapter IV: Predictors of Shift Workload

Abstract

The purpose of the present study was to identify health and fitness factors, in combination with established measures of load in the fire service, that significantly predict the workload of 24-hour shifts in active-duty firefighters. Active-duty firefighters (N = 38) completed a single laboratory session to quantify body mass index (BMI), waist circumference (WC), and peak aerobic capacity (VO_{2PEAK}). Participants then completed 4-6 shifts as they regularly would while wearing a chest strap that continuously measured heart rate and triaxial acceleration for the duration of each shift. At shift completion, participants completed a survey to report subjective load measures. For all shifts, external load was quantified utilizing Impulse Load, while internal load was quantified physiologically, perceptually, and overall using Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index, respectively. Total call volume ($VOLUME_{OVERALL}$) and volume of fire suppression and/or auto-extrication calls ($VOLUME_{FIRE1}$) were quantified for all shifts. Independent variables were examined as predictors of external and internal load by progressively entering each variable into multiple linear regression analyses. Results demonstrated that for the average 24-hour shift, $VOLUME_{OVERALL}$ is a predictor of objective workload, $VOLUME_{FIRE1}$ and VO_{2PEAK} are predictors of physiological workload, and $VOLUME_{FIRE1}$ is a predictor of perceived workload. The findings establish that call volume is indicative of the external workload experienced across a shift, yet the volume of FIRE1 calls specifically is indicative of the physiological workload, which is exacerbated in lower-fit individuals.

Keywords: workload, shiftwork, fitness, aerobic capacity, call volume

Study 3. This study sought to identify health and fitness factors, in combination with established measures of load in the fire service, that significantly predict the workload of 24-hour shifts. The health and fitness factors that were measured include obesity and cardiovascular fitness measures. The established measures of load included overall call volume (i.e., total medical and fire calls combined) and fire call volume of 24-hour shifts. Using standard multiple regression, these factors were analyzed for potential contributions to external load, quantified utilizing Impulse Load, and internal load, quantified utilizing Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the National Aeronautics and Space Administration-Task Load Index, of 24-hour shifts. This study is the first of its kind to identify controllable health and fitness factors, in combination with established load measures in the fire service, that predict the external and internal load demands of firefighting and inform future research on workload reduction and/or preparation among active-duty firefighters. As a result, this study contributes to the literature by determining that the objective job demands (i.e., external load) are significantly predicted by total call volume across a shift independent of firefighter fitness. More specifically, fire suppression and/or auto-extrication call volume is indicative of physiological workload, which is exacerbated in individuals with lower-aerobic capacities. Volume of fire suppression and/or auto-extrication calls also informs perceived workload, but due to a lack of sensitivity to fitness measures, this measure of workload (i.e., sRPE) may be limited for use independent of other workload measures (i.e., eTRIMP). Finally, the overall internal workload is unrelated to all objective workload and fitness characteristics examined in this study and may also be limited as a measure of overall workload in the fire service.

Methods

Participants

After obtaining approval from the Institutional Review Board (IRB) at the University of Wisconsin-Milwaukee, study recruitment was conducted through use of approved email correspondence, flyer distribution at individual firehouses, and speaking directly to individuals that expressed interest within a Midwest metropolitan fire department. Participants were considered eligible to participate if they were: (a) at least 18 years of age; (b) a non-probationary active-duty firefighter; (c) cleared for full active-duty work; and (d) willing to give written informed consent. Participants were excluded from participating in the proposed study if they: (a) reported a known cardiovascular or metabolic disease that was currently unmanaged; and/or (b) had been instructed by a physician or the Health Safety Officer to not participate in the study. Upon meeting the eligibility criteria and none of the exclusion criteria, participants that sought enrollment into the study were provided written documentation that outlined all components of the study. Researchers clearly communicated in both the written documentation and verbally that no collected data would be provided to their respective department in an individual format (i.e., non-aggregate format) and participants could withdraw from the study at any time without consequences from the research team or their respective department.

Procedures

The proposed study was broken into two phases for all participants (N=38). Phase 1 of the proposed study consisted of completing the informed consent process and determining the fitness characteristics of the active-duty firefighters prior to continuing into Phase 2 where data were collected while on-duty. This study was part of a larger study and therefore follows protocols similar to prior research (Study 2).

Phase 1. Phase 1 data collection was conducted within the Human Performance & Sport Physiology Laboratory at University of Wisconsin-Milwaukee. After providing written informed consent, participants completed a health history, exercise history, and job characteristics (i.e., years of experience, rank) survey. Following, the data were collected in the following order: anthropometric, obesity, and cardiovascular fitness measures.

Anthropometric Measures. Anthropometric measures were collected and calculated following American College of Sports Medicine (ACSM) guidelines (ACSM, 2018).

Age and biological sex. All participants self-reported their age in years (yrs) and biological sex.

Height and body mass. Using a medical grade balance-beam scale and stadiometer (Detecto, Webb City, MO), participant height (cm) and body mass (kg) were measured to the nearest 0.01.

Obesity Measures. Obesity was measured as body mass index (BMI) and waist circumference (WC), which were collected and calculated following ACSM guidelines (ACSM, 2018). BMI was calculated by dividing participant body mass by height squared (kg/m^2). WC (cm) was measured horizontally at the narrowest part of the torso above the umbilicus and below the xiphoid process to the nearest 0.1 cm using a cloth Gulick tape measure (Creative Health Care Products, Inc., Ann Arbor, MI, USA).

Cardiovascular Fitness. Cardiovascular fitness was quantified as peak aerobic capacity (VO_{2PEAK}), which was assessed through the completion of the Wellness Fitness Initiative (WFI) maximal treadmill test (WFI-TM). Prior to beginning the WFI-TM protocol, participants were fitted with a sealed mask that carried their expired air to a portable metabolic analysis unit (COSMED Fitmate MED, Rome, Italy) that collected breath-by-breath oxygen consumption throughout the entirety of the test. Before the start of the test, participants were also fitted with a Zephyr™ Bioharness™ strap and BioModule™ device (Medtronic, Annapolis, MD) that continuously collected heart rate (HR) in beats per minute (bpm). The WFI-TM protocol began with a 3-min warm up of 3 mph at 0% gradient followed by an increase in speed to 4.5 mph for 1 min. The remainder of the protocol then alternated increases in percent gradient by 2% and speed by 0.5 mph at each 1-min interval (i.e., increase to 2% gradient at 4-min, increase by 0.5 mph at 5-min, etc.). The WFI-TM protocol continued until at least two of the following three criteria were achieved: (a) a target maximal HR was achieved or exceeded for more than 15 sec, (b) the participant reported a rating of perceived exertion ≥7 from Borg's CR-10 scale, and/or (c) the participant volitionally terminated the test. Target HR was defined as 100% of HR_{MAX} (HR_{MAX} = 208 – 0.7 x Age; Tanaka et al., 2001). Participant VO_{2PEAK} (mL/kg/min) was quantified as the peak rate of oxygen consumption achieved at the time of termination of the WFI-TM protocol.

Phase 2. All Phase 2 data were collected at department firehouses or in the field while responding to emergency calls. External load was quantified as Impulse Load and internal load measures included Edwards' Training Impulse, Foster's Session Rating of Perceived Exertion, and the NASA-Task Load Index. Accelerometer and heart-rate data were collected continuously across all shifts and analyzed *post hoc* to quantify Impulse and Edwards' Training Impulse for each shift. Participants completed a survey upon shift completion that was analyzed *post hoc* to quantify Foster's Session Rating of Perceived Exertion and the NASA-Task Load Index. The total volume of all call responses (i.e., medical and all fire emergencies), as well as the total volume fire suppression and/or auto-extrication call responses, were quantified for each shift. Participants completed on-duty data collection for at least four shifts and a maximum of six shifts.

Impulse Load. Impulse load (IMPULSE) was measured utilizing the Zephyr™ Bioharness and BioModule™ device (Medtronic, Annapolis, MD). At the start of a shift, each participant was fitted with a Zephyr™ Bioharness™ and BioModule™ device that continuously collected on-shift IMPULSE (N*sec) at a sampling rate of 100 Hz across the duration of the 24-hour shift. Time-stamped (HH:MM:SS) department call logs were used to mark the IMPULSE data log for the shift initiation and completion times to sum IMPULSE across the shift duration ($IMPULSE_{SHIFT}$).

As previously reported (Study 1 and Study 2), the Zephyr™ system has established validity during an incremental treadmill protocol and precision tilt table testing (Johnstone, Ford, Hughes, Watson, & Garrett, 2012a). Additionally, using similar protocols, Johnstone et al. (2012b) demonstrated very strong (ICC ≥ 0.99) between subject, intra-device, and inter-device reliability for Zephyr™ Bioharness accelerometry measures. Further, upon examination of a discontinuous incremental walk-jog-run protocol, Zephyr™ Bioharness accelerometry-derived loads presented with excellent precision to oxygen uptake ($r > 0.90$) and very strong inter-device reliability (ICC = 0.93; Johnstone, Ford, Hughes, Watson, Mitchell, et al., 2012). Therefore, $IMPULSE_{SHIFT}$ measured via Zephyr™ Bioharness accelerometry is likely an adequate measure to reflect the external load demands of on-duty firefighters, which are typically discontinuous in nature.

Edwards' Training Impulse. Edwards' Training Impulse (eTRIMP) was calculated to quantify the physiological internal workload across a 24-hour shift based on the time spent in 5 predefined HR zones (Sanders et al., 2017). Specifically, the same Zephyr™ Bioharness™ and BioModule™ device that continuously collected on-shift IMPULSE also continuously collected HR at a sampling rate of 250 Hz across the duration of a 24-hour shift. The HR data for the entire file will was converted from bpm into a percentage of HR_{MAX}. Following, time-stamped department call logs were used to *post hoc* mark the HR data per second collected throughout the entirety of the shift into one of the five HR intensity zones and then summed into total duration (HH:MM:SS) spent in each respective zone for the shift. The time spent in each HR zone was multiplied by the zone's weighting factor and summed to quantify eTRIMP for each shift ($eTRIMP_{SHIFT}$).

Foster's Session Rating of Perceived Exertion. Foster's Session Rating of Perceived Exertion (sRPE) was calculated to quantify the perceived internal workload across a 24-hour shift. The Rating of Perceived Exertion (RPE) from Borg's CR-10 scale for each 24-hour shift was collected using a Qualtrics survey administered via smart phone upon completion of the shift and asked the participants to rate the intensity of the shift. Following on-duty RPE collection, time-stamped department call logs were used *post hoc* to identify the initiation and completion of each shift to quantify the exact duration (HH:MM:SS) of each 24-hour shift. The duration of each shift was multiplied by the shift RPE to quantify the shift sRPE ($sRPE_{SHIFT}$).

National Aeronautics and Space Administration-Task Load Index. The NASA-Task Load Index (NASA-TLX), which has been demonstrated as a valid measure (Hart & Staveland, 1988), was utilized to assess multiple facets of load across as 24-hour shift. The NASA-TLX includes subscales of mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants completed the NASA-TLX using a Qualtrics survey that was administered via smartphone at the completion of each shift. By completing the NASA-TLX survey, participants rated the shift on each subscale within a 100-points range and responded to 15 pairwise comparisons of each subscale to determine their order of relevance to the overall load (Hart & Staveland, 1988). The number of times each subscale was selected by the participant as the most relevant to the load was utilized to weight the score of that subscale, ranging from 0 (no relevance) to 5 (more important than all other factors), for an overall load score for the shift ($NASA\text{-}TLX_{SHIFT}$).

Total Call Volume. Due to the current use of call volume as an established measure of workload in the fire service, the total call volume responded to by the participant across the duration of each 24-hour shift ($VOLUME_{OVERALL}$) was quantified as a potential predictor of workload. $VOLUME_{OVERALL}$ was calculated as the summed call responses, including all medical and all fire emergencies, across each shift and averaged as a single observation for each participant.

Fire Call Volume. As a reflection of the influence of fire calls on shift load, corresponding to the greatest loads being previously reflected in fire suppression and/or auto-extrication calls (FIRE1), fire call volume was quantified in addition to $VOLUME_{OVERALL}$. The summed total of all FIRE1 calls across each shift was averaged into a single observation per participant ($VOLUME_{FIRE1}$) and examined as a potential predictor.

Data Processing

Upon completion of HR and IMPULSE collection across each shift via Zephyr™ Bioharness™ and BioModule™, each file was visually inspected. Upon comparison to time-stamped department call logs, any shifts that included errored measures (i.e., HR missing, etc.) during the time of a call response were entirely removed from the data set to avoid inaccurately quantifying the subsequent eTRIMP measures. Additionally, any files with errored measures (i.e., HR missing, etc.) between call responses were also removed from the data set. Finally, while the objective of this study was to capture entire 24-hour shifts, there were some circumstances (i.e., participants donning puck later into the shift, etc.) where the collected data files were shorter than 24-hours in length. To protect the accuracy of analyzing and reporting outcomes that reflect an entire shift, all files less than 22 hours in length were entirely removed from the data set. No filters were applied to the HR or IMPULSE data beyond what is automatically applied within the Zephyr™ manufacturers' design.

All survey responses were also visually inspected prior to quantifying sRPE and NASA-TLX workloads to ensure data accuracy. Any RPE reported as "0" was considered inaccurate due to participants being instructed that a "0" reflects no work at all. Thus, any RPE responses reported as "0" were subsequently replaced with a "0.3" to reflect the lowest possible exertion. Any responses with inaccurate NASA-TLX responses (i.e., NASA-TLX subscales = 0) were removed from the data set and not included in analyses.

Power Analyses

A priori power analyses were conducted to secure an adequate sample to achieve power for the regression analyses. An *a priori* power analysis utilizing a large effect size ($f = 0.33$) was utilized due to pilot data establishing correlations between Banister's TRIMP and sRPE of submaximal and maximal tasks with BMI and VO_{2PEAK} resulting in R^2 estimates ranging from 0.29 to 0.59. From this range of values, we utilized a conservative R^2 value ($R^2 = 0.25$) to estimate the effect size (f) utilized in the *a priori* power analysis with up to 4 predictor variables (BMI or WC, VO_{2PEAK}, $VOLUME_{CALL}$, $VOLUME_{FIRE1}$) to indicate a sample size of 42 participants is required to achieve a power of $1 - \beta = 0.80$ (Faul et al., 2009) for a regression. *A priori* analyses for regression analyses with similar parameters utilizing up to 3, 2 or 1 predictor variable(s) each respectively require a sample size of 38, 33, or 26 participants to achieve power.

Statistical Analysis

The purpose of the following regression analyses were to identify the significant predictor(s) of each 24-hour shift workload (i.e., IMPULSE, eTRIMP, sRPE, and NASA-TLX) from the health and fitness variables and established measures of workload in the fire service. For each participant, the completed shifts were averaged into a single observation of IMPULSE, eTRIMP, sRPE, and NASA-TLX. All potential predictors, including BMI or WC, VO_{2PEAK}, $VOLUME_{OVERALL}$, and $VOLUME_{FIRE1}$, were initially examined utilizing bivariate Pearson correlations to identify significant relationships between any of the aforementioned variables and participants' average shift IMPULSE, eTRIMP, sRPE, and NASA-TLX, as well as to identify any relationships between predictors that may require further examination for multicollinearity. The obesity measure (e.g., BMI, WC) with the stronger correlation to each dependent variable was selected for entry into the respective regression analyses. The potential predictors were entered progressively into multiple regression models based on their bivariate correlation strength until all variables were entered into the models. All statistical analyses were performed using IBM SPSS 28 software (IBM Corp., Armonk, NY). An alpha level of 0.05 was utilized to determine statistical significance for all analyses.

Results

All descriptive statistics for average shift workloads and potential predictors are provided in Table 7. The correlational analyses conducted between potential predictors, as well as between potential predictors and the outcome workload measures, are provided in Table 8.

External Load

Impulse Load. A visual inspection of the Normal Probability Plot (P-P) of the Regression Standardized Residuals and Scatterplot confirmed that no outliers were present for IMPULSE and the assumptions of normality, linearity, homoscedasticity, and independence of residuals were achieved. According to the strength of the bivariate Pearson correlations (Table 8) identified between the independent variables and IMPULSE, the predictors for this analysis were entered progressively in the following order: $VOLUME_{OVERALL}$, $VOLUME_{FIRE1}$, BMI, and VO_{2PEAK}. Based on these analyses, the regression model with only $VOLUME_{OVERALL}$ significantly predicted IMPULSE ($F_{1,36} = 4.565$, $p = 0.039$), where $VOLUME_{OVERALL}$ accounted for 11.3% of the total variance ($R^2 = 0.113$). This also implies that for every 1-unit increase in $VOLUME_{OVERALL}$ there is roughly a 1090 N*s predicted increase in IMPULSE for the shift ($B = 1090.31$). The model summaries, multicollinearity statistics, and the significance test results for regression coefficients are presented in Table 9.

Internal Load

Edwards' Training Impulse. A visual inspection of the Normal Probability Plot (P-P) of the Regression Standardized Residuals and Scatterplot confirmed that no outliers were present for eTRIMP and the assumptions of normality, linearity, homoscedasticity, and independence of residuals were achieved. According to the strength of the bivariate Pearson correlations (Table 8) identified between the independent variables and eTRIMP, the predictors for this analysis were entered progressively in the following order: VO_{2PEAK}, $VOLUME_{OVERALL}$, BMI, and $VOLUME_{FIRE1}$. Based on these analyses, the regression model with all 4 predictors significantly predicted eTRIMP ($F_{4,33} = 7.652$, $p < 0.001$), accounting for 48.1% of the total variance ($R^2 = 0.481$). However, based on the non-significant R^2 change statistics when adding BMI to Model 2 to create Model 3 (R^2 change = 0.000) and BMI not emerging as a significant predictor in Model 4, Model 5 was created to include all predictors except BMI. Accordingly, Model 5 significantly predicted eTRIMP ($F_{3,34} = 10.376$, $p < 0.001$), accounting for 47.8% of the total variance ($R^2 =

0.478), which was a non-significant reduction in variance from Model 4 (R^2 change = 0.003). Based on this more parsimonious model, VO_{2PEAK} and $VOLUME_{FIRE1}$ emerged as significant predictors and respectively account for 28.1% and 13.9% of the variance in shift eTRIMP. This also implies that after accounting for the relationship between eTRIMP and $VOLUME_{FIRE1}$ as well as $VOLUME_{OVERALL}$, for every 1-unit increase in VO_{2PEAK} there is roughly a 22 AU predicted decrease in eTRIMP for the shift (B = 22.40). Additionally, after accounting for the relationship between eTRIMP and VO_{2PEAK} as well as $VOLUME_{OVERALL}$, for every 1-unit increase in $VOLUME_{FIRE1}$ there is roughly a 200 AU predicted increase in eTRIMP for the shift (B = 203.61). The model summaries, multicollinearity statistics, and the significance test results for regression coefficients are presented in Table 10.

Foster's Session Rating of Perceived Exertion. A visual inspection of the Normal Probability Plot (P-P) of the Regression Standardized Residuals and Scatterplot confirmed that no outliers were present for sRPE and the assumptions of normality, linearity, homoscedasticity, and independence of residuals were achieved. According to the strength of the bivariate Pearson correlations (Table 8) identified between the independent variables and sRPE, the predictors for this analysis were entered progressively in the following order: $VOLUME_{FIRE1}$, $VOLUME_{OVERALL}$, WC, and VO_{2PEAK}. Based on these analyses, the regression model with only $VOLUME_{FIRE1}$ significantly predicted sRPE ($F_{1,36}$ = 9.039, p = 0.005), where $VOLUME_{FIRE1}$ accounted for 20.1% of the total variance (R^2 = 0.201). This also implies that after accounting for every 1-unit increase in $VOLUME_{FIRE1}$ there is roughly a 1440 AU predicted decrease in sRPE for the shift (B = 1436.76). The model summaries, multicollinearity statistics, and the significance test results for regression coefficients are presented in Table 11.

NASA-Task Load Index. A visual inspection of the Normal Probability Plot (P-P) of the Regression Standardized Residuals and Scatterplot confirmed that no outliers were present for NASA-TLX and the assumptions of normality, linearity, homoscedasticity, and independence of residuals were achieved. According to the strength of the bivariate Pearson correlations (Table 8) identified between the independent variables and NASA-TLX, the predictors for this analysis were entered progressively in the following order: BMI, VO_{2PEAK}, $VOLUME_{OVERALL}$, and $VOLUME_{FIRE1}$. Based on these analyses, none of the regression models significantly predicted NASA-TLX. The absence of relationships between IMPULSE and any of the independent variables suggests that the NASA-TLX may quantify the overall load of a shift independent of the health and fitness, and shift volume characteristics, included in this study. The model summaries, multicollinearity statistics, and the significance test results for regression coefficients are presented in Table 12.

Collectively, these results indicate several key findings. The first key finding indicates that the objective workload (i.e., IMPULSE) firefighters complete across a 24-hour shift remains uninfluenced by individual fitness characteristics. Specifically, 11% of the external load of the job across 24-hour shifts is uniquely accounted for by the total call volume across that shift. The second key finding indicates that the physiological response load elicited across a 24-hour shift is more specifically influenced by volume of FIRE1 calls, as well as individual aerobic capacity ability, which respectively account for 13.9% and 28.1% of the cardiovascular load of a shift. Third, similar to the physiological load response to job demands, the perceived workload of a shift is also predicted by the total amount of FIRE1 calls in a shift, which accounts for approximately 20% of the perceived load of a 24-hour shift. Lastly, while the NASA-TLX is indicative of the overall load of individual emergency calls (Study 1) and able to differentiate overall loads for shifts with and without FIRE1 call responses (Study 2), it is not significantly predicted by the examined individual fitness characteristics, total call volume, and/or FIRE1 call volume factors examined in this study. This indicates that the NASA-TLX as an overall load measure may not be sensitive to quantifying shift load across varying levels of fitness and further, may not be indicative of shift-work demands in the fire service.

Discussion

The purpose of this study was to identify health and fitness factors, in combination with established measures of load in the fire service, that significantly predict the workload of 24-hour shifts. Accordingly, the results of this study indicate that the total call volume of the shift (i.e., $VOLUME_{OVERALL}$ is a significant predictor of the objective job demands (i.e., IMPULSE) for a shift. However, the physiological response load (i.e., eTRIMP) to the job demands across a 24-hour shift is more specifically predicted by the total volume of FIRE1 call responses, as well as individual aerobic capacity. The perceived workload (i.e., sRPE) of a shift is similarly predicted by the quantity of responses to fire suppression and/or auto-extrication calls. Finally, none of the potential predictors in the present study are indicative of overall internal load for a shift as measured by the NASA-TLX.

Impulse Load. Call volume, or total calls responded to, across a 24-hour shift has been an established metric of workload quantification within the fire service (Blackwell et al., 2011; Watkins et al., 2021), however it remained unclear if the absolute quantity of call responses is indicative of the objective work completed (i.e., IMPULSE) in that period. Therefore, the results of this study are impactful as they indicate that the total call volume (i.e., $VOLUME_{OVERALL}$) is, in fact, predictive of the external job demands across a shift. These results align with previous findings that demonstrate that the response to all emergency call types, including medical calls, as well as fire calls with and without suppression demands, require some magnitude of objective work (Study 1). However, despite the job demands of individual calls being greatest in fire calls that include suppression and/or auto-extrication (i.e., FIRE1; Study 1), and the inclusion of at least a single FIRE1 call significantly increasing the job demands of that shift (Study 2), $VOLUME_{FIRE1}$ demonstrated a weak, yet non-significant, relationship to IMPULSE (r = 0.208) and did not emerge as a significant predictor in any of the examined models. Due to most participants responding to shifts where approximately only half included FIRE1 call responses (Appendix A), it is possible that the $VOLUME_{FIRE1}$, or average FIRE1 response per shift, was deflated and in turn, not found to be a predictor of the average IMPULSE response across a shift. However, the inclusions of total FIRE1 calls were included in the summated $VOLUME_{OVERALL}$ as a predictor and in turn, contributed to the 11% of variance accounted for by total call volume in the objective work demands of a shift. Although a significant finding, these results suggest that a most of the work (~90%) completed by firefighters on duty must be accounted for by other factors. Thus, call volume may establish an initial, or foundational, understanding of the physical work conducted on-duty, yet leaves room for future researchers to determine additional factors that drive objective shiftwork demands.

Unlike call volume, which is relatively unpredictable, there are controllable factors like individual health and fitness that may be manipulated through training to attempt reductions in firefighter workload. However, it appears the selected WFI-supported measures included in the present study are unrelated to the amount of objective work completed across a shift. In particular, despite known links between risk of on-duty cardiovascular injury and firefighter aerobic capacity (Poplin et al., 2014) and obesity (Smith et al., 2016), no significant relationships were identified between VO_{2PEAK}, BMI, or WC and the accumulated shift IMPULSE and no significant models with such predictors emerged. This suggests that the objective work of firefighting across a 24-hour shift is relatively uninfluenced by the unique health and fitness status of the department member; firefighters will complete the physical job demands of 24-hour shifts regardless of individual obesity status or aerobic capacity capabilities. Completing the same objective work despite poorer obesity status may explain, in part, why musculoskeletal injury risks are heightened for firefighters with an elevated obesity status. Prior research indicates that obesity is related to poorer balance ability (Marciniak, Ebersole, et al., 2021) and movement quality (Cornell et al., 2016) in firefighter recruits, and due to the completion of the same objective work demands with additional body mass, this may inform portions of heightened risk for slip, trip, and fall related injuries in the fire service (Kong et al., 2013). Future researchers should examine the relationships between objective work completed across a shift in firefighters of ranging obesity levels and musculoskeletal injury risk.

Edwards' Training Impulse. Due to previously established relationships between the objective work demands (i.e., IMPULSE) and the physiological response load (i.e., eTRIMP) of shifts with and without fire suppression and/or auto extrication call responses (Study 2), it is not surprising that both measures are predicted by metrics of call volume. However, the two measures diverge with IMPULSE predicted by $\text{VOLUME}_{\text{OVERALL}}$, while eTRIMP is more specifically predicted by $\text{VOLUME}_{\text{FIRE1}}$. These eTRIMP results align with prior research that demonstrated all emergency call types elicit some magnitude of physiological load in response to completing objective work, however the workload is greatest in response to FIRE1 calls (Study 1). Additionally, the inclusion of at least a single FIRE1 call to the responses across a 24-hour shift is known to significantly increase physiological shift load (Study 2). Therefore, the results of this study extend the findings of Study 1 and 2 by demonstrating that when controlling for

$VOLUME_{OVERALL}$, as well as VO_{2PEAK} as another factor in the model, $VOLUME_{FIRE1}$ accounts for nearly 14% of the physiological load accumulated across a 24-hour shift; these results suggest that regardless of individual fitness ability and comparing shifts with similar total call volumes, the workload required by the cardiovascular system is significantly increased with the inclusion of FIRE1 call response(s) to the shift. Thus, the physiological demands of a shift are escalated in response to FIRE1 calls and firefighters regularly exposed to such calls may have unique preparation and recovery needs for duty.

In addition to the influence of FIRE1 call volume, aerobic capacity accounted for two-fold the variance in the physiological response loads across a 24-hour shift. Specifically, nearly one-third (28.1%) of the physiological load elicited across a 24-hour shift was accounted for by the individual's ability to consume oxygen, such that when holding the total and FIRE1 call volumes of a shift constant, for each 1-unit (mL/kg/min) decrease in in individual VO_{2PEAK} there is roughly a 22 AU predicted increase in eTRIMP for the shift to complete the same objective work. However, the heightened cardiovascular response to the objective work of a shift was not predicted by obesity status, as measured by BMI, where despite a significant relationship with shift eTRIMP, BMI did not emerge as a significant predictor of physiological load. This suggests that in the fire service, an individual's ratio of body mass to their height does not predict the cardiovascular load that is elicited in response to the job demands of a 24-hour shift. Therefore, it is more important that firefighters train to efficiently consume oxygen through an increased aerobic capacity to minimize the cardiovascular load accumulated through job demands.

These findings, in tandem with the IMPULSE results demonstrating that firefighters complete the same objective work (i.e., IMPULSE) regardless of their aerobic capacity (i.e., VO_{2PEAK}) ability, suggest that lower-fit firefighters complete the same job demands but at the cost of heightened physiological loads on the cardiovascular system, as evidenced by a greater eTRIMP. Greater accumulated eTRIMP across the course of a shift is the result of heightened cardiovascular responses (i.e., HR) across the 24-hour shift period, which is known to be elicited in response to greater sympathetic nervous system (SNS) input from the autonomic nervous system (ANS; Kesler et al., 2018; Smith et al., 2016). The link between aerobic capacity and eTRIMP in the present study suggests that individuals with lower aerobic capacities elicit greater HR responses as a result of heightened SNS activation throughout a 24-hour shift. It is possible that the greater SNS activation in lower-fit firefighters occurs during call response times as it has been established that all types of emergency responses elicit cardiovascular loads (Study 1), however, it is also possible that physiological loads (i.e., eTRIMP) are accumulated following call response. Cardiovascular recovery, as measured by HR recovery to a rested state following a task, has been utilized to better understand ANS recovery, or withdrawal of SNS activity, in firefighters (Ebersole et al., 2020). Additionally, prior research has established that lower-fit firefighters (VO_{2PEAK} < 42 mL/kg/min) may have suboptimal recoveries due to their prolonged HR recovery profiles (i.e., longer time to resting status) following submaximal tasks (Cornell et al., 2020). Due to the average total calls (8.32 calls) responded to throughout the shifts being mostly medical or non-suppression fire calls (6.46 and 1.07 calls, respectively),which elicit submaximal cardiovascular loads (Study 1) as compared to maximal fire suppression and/or auto-extrication calls (0.78 calls), the post-call HR recovery profiles may be poorer in lower-fit firefighters for the majority of calls responded to across a shift and account for the higher accumulated HR responses and subsequent eTRIMP. Further, due to the known links between poor HR recovery and risk of sudden cardiac death (Curtis & O'Keefe, 2002; Hernesniemi et al., 2020; Peçanha et al., 2014), the association between lower aerobic capacity and greater physiological loads (i.e., eTRIMP) may support further mechanistic evaluation for cardiac risk and injury prevention in the fire service.

Obesity status, particularly as it relates to distribution of mass across the body, did not emerge as a predictor for cardiovascular load across a 24-hour shift. An initial relationship between BMI and shift eTRIMP was identified, however, BMI was not established to be a significant predictor of eTRIMP. Prior research suggests that BMI is related to the submaximal heart rate response of firefighters to the alert tone of a medical emergency, but that this relationship is not present in response to the alert tone of fire emergencies, including calls with and without suppression (Marciniak, Tesch, et al., 2021). However, it appears that BMI does not influence the objective work completed in response to such calls across a shift, nor the physiological load in response to that work, to a great enough extent to emerge as a predictor of physiological shift load. It is possible that, due to more accumulated non-call time in comparison to time spent in response to calls during a shift, BMI may not have influenced enough call time across the shift to emerge as a significant predictor of the accumulated shift eTRIMP. Cornell et al. (2021) previously demonstrated that BMI does not influence autonomic nervous system recovery measured via HR recovery from a submaximal stepping task. Due to the largely accumulated non-call response times in the present study likely reflecting the lower-intensity cardiovascular responses similar to the submaximal heart rate recovery measures reported by Cornell et al. (2021), it makes sense that BMI did not significantly predict eTRIMP in this study. WC has demonstrated a similar lack of influence on ANS recovery, as well (Cornell et al., 2021). However, despite the minimal influence of BMI and WC on the physiological load (i.e., eTRIMP) in this study, both factors still warrant consideration in the health profile of fighters. Specifically, BMI and WC have been previously identified as predictors of aerobic capacity

(Barry et al., 2019) and despite the lack of direct contributions to the physiological load of a 24-hour shift, they may indirectly support reductions in physiological shift load through enhanced aerobic capacity.

Finally, despite the variance significantly accounted for by each of the predictors identified for eTRIMP, approximately half of the variance in the average physiological load of a 24-hour shift remains unaccounted for. Specifically, with the inclusion of $VOLUME_{OVERALL}$, VO_{2PEAK}, and $VOLUME_{FIRE1}$ in the fitted model (Model 5), which accounted for 47.8% of the variance in eTRIMP, over 50% of the variance in physiological load remained unexplained. It is possible that other health and fitness factors that have been addressed by the WFI as characteristics to uphold firefighter wellness, such as muscular strength and endurance (IAFF, 2018), may support firefighter efficiency in completing job demands at a lower physiological load. For example, recent research suggests that maximal lower-body strength is positively related to acute measures of the ANS status, which is related to enhanced firefighter performance in a simulated fireground test (Lesniak et al., 2022). Future researchers should examine additional components of health and fitness for their contributions to physiological response load to job demands.

Foster's Session Rating of Perceived Exertion. Unlike IMPULSE and eTRIMP, the perceived load (i.e., sRPE) of an average 24-hour shift was unrelated to total call volume (i.e., $VOLUME_{OVERALL}$), but rather informed by total fire suppression and/or auto-extrication call responses (i.e., $VOLUME_{FIRE1}$). Prior research suggests that for a shift that includes at least one fire suppression and/or auto-extrication call response, sRPE is significantly related to the quantified physiological load (i.e., eTRIMP), however for a shift without a suppression or extrication response, that relationship dissolves (Study 2). This suggests that sRPE as a measure of perceived load across an entire 24-hour shift is likely influenced by the maximal cardiovascular demands, or lack thereof, elicited in response to FIRE1 emergencies, which require the greatest job demands (i.e., IMPULSE) and physiological response load (Study 1). Our findings support this notion whereby volume of FIRE1 calls, which are known to elicit the greatest physiological loads across call types (Study 1), is a significant predictor of shift sRPE and accounts for 20% of the variance in perceived load. Further, prior research suggests sRPE is unrelated to the objective job demands (i.e., IMPULSE) of shifts regardless of FIRE1 call response (Study 2). Therefore, it makes sense that in the present study, shift sRPE is seemingly unrelated to total call volume while this metric is indicative of shift IMPULSE. Taken together, this information suggests that, as a measure of an entire 24-hour shift in the fire service, sRPE as a measure of perceived load is likely influenced by the physiological load, especially as it relates to fire suppression and/or auto-extrication, and independently may not reflect the internal load responses to the external load (i.e., job demands) completed across the shift.

It also appears that perceived load is unrelated to measures of obesity or aerobic capacity, which may negatively impact the identification of firefighters with unique recovery needs. The absence of relationships between BMI and WC with perceived load (i.e., sRPE) are not concerning as this aligns with our eTRIMP findings that suggest body mass distribution does not predict the HR driven physiological load. However, due to the significant influence of lower aerobic capacity (i.e., VO_{2PEAK}) to increase the physiological load of a shift, it would be expected that the shift sRPE would similarly mirror this outcome, particularly due to previously established links between sRPE and eTRIMP in shifts that include fire suppression and/or auto-extrication responses (Study 2). In contrast, the independence demonstrated between sRPE and aerobic capacity suggests that the perceived workload of a shift is likely to be similar across firefighters of ranging fitness levels; the elevated physiological load accumulated across a shift for less-fit individuals is unlikely to be perceived as a greater load. Thus, it is possible that sRPE as an independent internal load measure for shiftwork in the fire service may result in individuals that require additional recovery strategies (i.e., lower-fit firefighters) to go undetected and remain at an elevated risk of injury.

Similar to eTRIMP, a majority of the variance in the average perceived load of a 24-hour shift remained unaccounted for. Specifically, 20% of the perceived load may be accounted for in volume of FIRE1 calls, which leaves 80% of the variance unexplained. It is possible that aside from the obesity and aerobic capacity factors examined, other health and fitness factors indicated by the WFI to be important for firefighter wellness (IAFF, 2018) may inform the perceived load of 24-hour shifts. However, it is also important to consider the potential difficulties in discriminating perceptions of exertion. The participants in this study reported ratings of perceived exertion (2.98 ± 1.15) that tended to saturate around the group average without much discrimination between low and high shift demands, which may explain why other significant relationships with the quantified sRPE did not emerge. Additionally, consideration should be given to the various psychological factors suggested to influence on-duty experiences, such as the anticipation of an emergency response or hyper-vigilance that is known to occur between calls (Barnes, 2000). The unpredictable timing of emergency calls also elicits sleep disruptions and low-quality sleep (Billings & Focht, 2016), which have been demonstrated to negatively influence cognitive functioning among firefighters (Stout et al., 2021). Thus, it may be important for researchers to target deeper examination into the factors that inform the perception of the load of 24-hour shifts in the fire service beyond traditional volume-based metrics of calls and individual health and fitness characteristics.

NASA-Task Load Index. As an indicator of overall internal load demands across a 24-hour shift, it appears that the NASA-TLX does not reflect the quantity of objective work completed using established measures of workload in the fire service nor diverge by fitness status. Therefore, the validity of use of the NASA-TLX as an overall internal load measure may be questionable as the measure does not reflect the job demands using the established workload measures of $VOLUME_{OVERALL}$ or $VOLUME_{FIRE1}$ despite one of the primary purposes of measuring internal load is to be able to understand such responses to objective work demands. Further, the lack of influence by fitness measures, particularly VO_{2PEAK} given that it significantly contributes to the physiological load (i.e., eTRIMP) of a shift, demonstrates that the overall load quantified by the NASA-TLX is unable to differentiate across individuals that may have experienced greater cardiovascular responses and likely require additional post-shift recovery needs. These findings are similar to prior research that has identified the NASA-TLX is unrelated to job demands (i.e., IMPULSE) and the physiological response loads (i.e., eTRIMP) for shifts regardless with and without fire suppression and/or extrication responses (Study 2). From these findings, we can conclude that the NASA-TLX as a measure of overall internal load may not reflect the intrinsic load of a shift in reflection of the shiftwork job demands. However, prior research has indicated that use of the individual subscales that contribute to the overall NASA-TLX score may inform the various characteristics that contribute to overall internal loads. Future research should examine further if the individual subscales are more reflective of shiftwork load demands and if they are more informative to the objective work completed than the customary, composite NASA-TLX score.

Limitations. It is important to consider these results with respect to the study limitations. This study is representative of a sample of structural firefighters from a large, metropolitan fire department and therefore may not entirely represent the workload demands of a shift among other fire service subsets, such as volunteer firefighters. Specifically, the reported distribution in call types across a shift in this sample are similar to the average Midwest department according to the USFA (USFA, 2022) yet may not reflect other areas of the United States. Additionally, as population density increases the ratio of firefighters to civilians decreases (Fahy et al., 2022). Thus, it is likely that the rate of call responses in this sample from a larger metropolitan area may be greater than call experiences in communities with smaller populations. Additionally, the surveys to quantify sRPE and NASA-TLX were administered upon shift completion during which the participants may have been fatigued from shift demands (i.e., sleep deprivation, etc.). While this limitation is relatively unavoidable in trying to capture the entire load a shift, an avenue of future research could examine if survey timing influences the subjective load measures, as well as examine if physiological, perceived, and/or overall load metrics change across a shift in accordance with sleep and/or fatiguing factors. Finally, it is possible that averaging the shift results into a single observation may have suppressed the influence of high intensity demands on the shift load, particularly as it relates to FIRE1 calls, thus future researchers should consider re-examining these findings using a statistical strategy that includes each shift as a separate observation.

Conclusions. In summary, the results of this study identified several health and fitness factors and established measures of workload as predictors of external and internal load across 24-hour shifts in the fire service. Total volume of call responses across a shift significantly predicts the amount of objective work (i.e., IMPULSE) completed across 24-hour shifts that is similar in magnitude for firefighters independent of the health and fitness measures examined in this study. However, it is evident that firefighters with a lower aerobic capacity will complete the objective job demands at a higher physiological load, which should be considered with developing post-shift recovery strategies for lower-fit firefighters. Further, obesity status may not directly inform the physiological load of a shift but should be considered in the health and fitness profile of a firefighter as lower-obesity status may support higher aerobic capacities and subsequently lessen physiological shift loads. As a measure of perceived internal load, sRPE appears to be limited in identifying the influence of aerobic capacity on shift demands and as a stand-alone measure of shift load may allow individuals that require additional cardiovascular recovery strategies to go unidentified and remain at risk for injury. Similarly, the NASA-TLX score as an overall load metric does not reflect the external or other physiological load demands of 24-hour shifts quantified in this study. In conjunction, the results of this study suggest firefighters perform similar job demands across a 24-hour shift, however, the cost of such work appears to be greater in firefighters with lower aerobic capacities. Due to the influence of aerobic capacity on physiological load, particularly as measured by eTRIMP, it is suggested that this direct physiological load metric may be the most equipped in differentiating loads experienced across different fire service personnel and may best identify individuals that have greater recovery needs.

Figures & Tables

Table 7

Descriptive Statistics of Shift Loads and Potential Predictors

	MEAN	**SD**
IMPULSE (N*s)	49975.76	12278.03
eTRIMP (AU)	357.93	259.03
sRPE (AU)	4111.37	1634.16
NASA-TLX (0-100)	29.03	15.96
BMI (kg/m^2)	28.29	3.61
WC (cm)	91.07	10.28
VO_{2PEAK} (mL/kg/min)	46.16	6.59
$VOLUME_{OVERALL}$	8.32	3.78
$VOLUME_{FIRE1}$	.78	.51

Table 8

Relationships between potential predictors and load measures

	IMPULSE	ETRIMP	SRPE	NASA-TLX	WC	VO_{2PEAK}	$VOLUME_{OVERALL}$	$VOLUME_{FIRE1}$
BMI	.180	.353*	-.010	.302	.888**	-.666**	.160	-.259
WC	.022	.209	.074	.266	---	-.560**	-.019	-.222
VO_{2PEAK}	.000	-.495*	.014	-.082	---	---	-.179	.283
$VOLUME_{OVERALL}$	.335*	.390*	.170	.227	---	---	---	.177
$VOLUME_{FIRE1}$	.208	.277	.448*	.220	---	---	---	---

*, $p < .05$; **, $p < .001$

Table 9

IMPULSE load model summary and significant test results for regression coefficients

Model Summary	R^2	*Adj. R^2*	SEE	*F*	*df*	*p*	R^2 Change	*F* Change (*p*)
Model 1	**.335**	**.113**	**11726.06**	**4.565**	**1,36**	**.003**	**.113**	**4.565 (.039)**
Model 2	.368	.135	11737.63	2.743	2,35	<.001	.023	0.929 (.343)
Model 3	.410	.168	11681.14	2.293	3,34	.096	.033	1.339 (.255)
Model 4	.440	.194	11673.81	1.982	4,33	.120	.025	1.043 (.315)

Variable	*B*	*SE B*	*β*	*t*	*p*	Zero	Partial	Part	Tolerance	VIF
Model 1 (Constant)	40909.43	4650.01		8.798	<.001					
$VOLUME_{OVERALL}$	**1090.31**	**510.29**	**.335**	**2.137**	**.039**	**.335**	**.335**	**.335**	**1.000**	**1.000**
Model 2 (Constant)	38748.82	5166.32		7.500	<.001					
$VOLUME_{OVERALL}$	1001.74	518.99	.308	1.930	.062	.335	.310	.303	.969	1.032
$VOLUME_{FIRE1}$	3708.86	3847.88	.154	.964	.342	.208	.161	.151	.969	1.032
Model 3 (Constant)	20289.63	16758.26		1.211	.234					
$VOLUME_{OVERALL}$	869.25	529.03	.267	1.643	.110	.335	.271	.257	.923	1.083
$VOLUME_{FIRE1}$	5081.96	4008.95	.211	1.268	.214	.208	.212	.198	.884	1.131
BMI	653.46	564.64	.192	1.157	.255	.180	.195	.181	.889	1.125
Model 4 (Constant)	-11436.98	35296.73		-.324	.748					
$VOLUME_{OVERALL}$	945.17	533.90	.291	1.770	.086	.335	.295	.277	.905	1.105

$VOLUME_{FIRE1}$	4326.24	4074.22	.180	1.062	.296	.208	.182	.166	.855	1.170
BMI	1108.92	719.28	.326	1.542	.133	.180	.259	.241	.547	1.827
VO_{2PEAK}	407.31	398.89	.219	1.021	.315	.000	.175	.160	.533	1.877

Table 10

eTRIMP load model summary and significant test results for regression coefficients

Model Summary	R^2	*Adj.* R^2	SEE	*F*	*df*	*p*	R^2 Change	*F* Change (*p*)
Model 1	.245	.225	228.11	11.713	1,36	.002	.245	11.71 (.002)
Model 2	.339	.301	216.53	8.975	2,35	<.001	.094	4.951 (.033)
Model 3	.339	.281	219.66	5.817	3,34	.003	.000	.010 (.923)
Model 4	.481	.418	197.56	7.652	4,33	<.001	.142	9.035 (.005)
Model 5	**.478**	**.432**	**197.56**	**10.376**	**3,34**	**<.001**	**.003**	**.207 (.652)**

Variable	*B*	*SE B*	*β*	*t*	*p*	Zero	Partial	Part	Tolerance	VIF
Model 1 (Constant)	1256.55	265.16		4.739	<.001					
VO_{2PEAK}	-19.47	5.69	-.495	-3.422	.002	-.495	-.495	-.495	1.000	1.000
Model 2 (Constant)	978.31	281.06		3.481	<.001					
VO_{2PEAK}	-17.28	5.49	-.440	-3.148	.003	-.495	-.470	-.433	.968	1.033
$VOLUME_{OVERALL}$	21.31	9.58	.311	2.225	.033	.390	.352	.306	.968	1.033
Model 3 (Constant)	919.78	663.85		1.386	.175					
VO_{2PEAK}	-16.81	7.38	-.428	-2.277	.029	-.495	-.364	-.317	.551	1.815
$VOLUME_{OVERALL}$	21.26	9.73	.310	2.185	.036	.390	.351	.305	.965	1.036
BMI	1.31	13.44	.018	.098	.923	.353	.017	.014	.555	1.803

Model 4 (Constant)	864.38	597.33		1.447	.157					
VO_{2PEAK}	-20.49	6.75	-.522	-3.036	.005	-.494	-.467	-.381	.533	1.877
$VOLUME_{OVERALL}$	14.51	9.04	.212	1.606	.118	.390	.269	.201	.905	1.105
BMI	5.55	12.17	.077	.456	.652	.353	.079	.057	.547	1.827
$VOLUME_{FIRE1}$	207.42	68.95	.408	3.006	.005	.277	.464	.377	.855	1.170
Model 5 (Constant)	1109.30	257.14		4.314	<.001					
VO_{2PEAK}	**-22.40**	**6.75**	**-.570**	**-4.280**	**<.001**	**-.495**	**-.592**	**-.530**	**.866**	**1.155**
$VOLUME_{OVERALL}$	**14.85**	**8.90**	**.217**	**1.669**	**.104**	**.390**	**.275**	**.207**	**.911**	**1.097**
$VOLUME_{FIRE1}$	**203.61**	**67.68**	**.401**	**3.008**	**.005**	**.277**	**.458**	**.373**	**.866**	**1.154**

Table 11

sRPE load model summary and significant test results for regression coefficients

Model Summary	R^2	*Adj.* R^2	SEE	*F*	*df*	*p*	R^2 Change	*F* Change (*p*)
Model 1	**.201**	**.178**	**1481.16**	**9.039**	**1,36**	**.005**	**.201**	**9.039 (.005)**
Model 2	.209	.164	1494.15	4.630	2,35	.016	.009	.377 (.543)
Model 3	.240	.173	1486.19	3.578	3,34	.024	.031	1.376 (.249)
Model 4	.240	.148	1508.53	2.605	4,33	.054	.000	.000 (.983)

Variable	*B*	*SE B*	*β*	*t*	*p*	Zero	Partial	Part	Tolerance	VIF
Model 1 (Constant)	2989.06	443.94		6.733	<.001					
$\text{VOLUME}_{\text{FIRE1}}$	**1436.76**	**477.89**	**.448**	**3.006**	**.005**	**.448**	**.448**	**.448**	**1.000**	**1.000**
Model 2 (Constant)	2693.40	657.65		4.095	<.001					
$\text{VOLUME}_{\text{FIRE1}}$	1383.52	489.82	.431	2.825	.008	.448	.431	.425	.969	1.032
$\text{VOLUME}_{\text{OVERALL}}$	40.56	66.07	.064	.614	.543	.170	.103	.920	.969	1.032
Model 3 (Constant)	.07	2387.30		.000	1.000					
$\text{VOLUME}_{\text{FIRE1}}$	1513.53	499.65	.472	3.029	.005	.448	.461	.453	.921	1.086
$\text{VOLUME}_{\text{OVERALL}}$	38.94	65.73	.090	.593	.557	.170	.101	.089	.968	1.033
WC	28.61	24.39	.180	1.173	.249	.074	.197	.175	.950	1.052
Model 4 (Constant)	78.43	4452.09		.018	.986					
$\text{VOLUME}_{\text{FIRE1}}$	1516.25	523.50	.473	2.896	.007	.448	.450	.440	.864	1.157

$VOLUME_{OVERALL}$	38.55	69.37	.089	.556	.582	.170	.096	.084	.896	1.116
WC	28.27	29.47	.178	.959	.344	.074	.165	.146	.671	1.491
VO_{2PEAK}	-1.01	48.14	-.004	-.021	.983	.014	-.004	-.003	.611	1.638

Table 12

NASA-TLX load model summary and significant test results for regression coefficients

Model Summary	R^2	*Adj.* R^2	SEE	*F*	*df*	*p*	R^2 Change	*F* Change (*p*)
Model 1	.091	.065	15.428	3.512	1,35	.069	.091	3.512 (.069)
Model 2	.117	.065	15.431	2.250	2,34	.121	.026	.989 (.327)
Model 3	.156	.079	15.312	2.033	3,33	.128	.039	1.528 (.225)
Model 4	.217	.119	14.977	2.216	4,34	.089	.061	2.492 (.124)

Variable	*B*	*SE B*	*β*	*t*	*p*	Zero	Partial	Part	Tolerance	VIF
Model 1 (Constant)	-8.26	20.06		-.412	.683					
BMI	1.32	.70	.302	1.874	.069	.302	.302	.302	1.000	1.000
Model 2 (Constant)	-49.65	46.19		-1.075	.290					
BMI	1.94	.94	.445	2.060	.047	.302	.333	.332	.556	1.798
VO_{2PEAK}	.51	.52	.215	.995	.327	-.082	.168	.160	.556	1.798
Model 3 (Constant)	-57.59	46.29		-1.244	.222					
BMI	1.88	.94	.430	2.002	.054	.302	.329	.320	.554	1.804
VO_{2PEAK}	.58	.52	.241	1.118	.272	-.082	.191	.179	.551	1.815
$VOLUME_{OVERALL}$	.84	.68	.201	1.236	.225	.227	.210	.198	.965	1.036
Model 4 (Constant)	-60.41	45.31		-1.333	.192					
BMI	2.07	.93	.473	2.234	.033	.302	.367	.349	.545	1.835

VO_{2PEAK}	.43	.51	.178	.830	.413	-.082	.145	.130	.532	1.880
$VOLUME_{OVERALL}$	.54	.69	.128	.772	.446	.227	.135	.121	.889	1.124
$VOLUME_{FIRE1}$	8.64	5.47	.270	1.579	.124	.220	.269	.247	.834	1.199

Chapter V: Dissertation Summary

Due to the extremely hazardous and strenuous job demands of firefighting, firefighters are at a high-risk for occupation-related injuries (Kurlick, 2012). Most firefighter injuries are driven by over-exertion, which results in musculoskeletal strain, sprain, or muscular pain (Campbell & Evarts, 2020), and in extreme cases, on-duty sudden cardiac death (SCD; Fahy and Petrillo, 2022). Research has also established that firefighter injury risk is greatest on the fireground (Campbell & Evarts, 2020) and SCD risk is disproportionately high following strenuous activity like fire suppression (Farioli et al., 2014; Haller & Smith, 2019). In sport-athlete populations, where over-exertion injuries are also prevalent, paired use of external load (i.e., "stimulus") and internal load (i.e., "response") measures have been utilized to quantify training load and inform injury prevention strategies (Bourdon et al., 2017; Gabbett et al., 2014). While some research has been conducted among firefighters in attempt to apply measures of training load within this subset of occupational athletes (Bouzigon et al., 2015; Marcel-Millet et al., 2020; Webb et al., 2010), minimal research has been conducted to quantify *workload* specific to on-duty demands. Additionally, despite links between firefighter injury risk and various health and fitness factors (Poplin et al., 2014; Poston, Jitnarin, et al., 2011), as well as the established measure of workload in the fire service, or call volume across a 24-hour shift (Blackwell et al., 2011; Watkins et al., 2021), no research to date has directly examined for predictors of firefighter workload. To address these gaps, the purposes of the present research were to: (a) identify differences in external and internal loads of emergency call types, (b) examine the influence of at least one fire suppression and/or auto-extrication call response on shift workload, and (c) identify health and fitness factors, as well as established workload measures in the fire service, that significantly predict workload.

Summary of Dissertation Results

Through the achievement of the first purpose, the comparison of the external and internal loads across different emergency call types in structural firefighters, it is evident that the workload of fire emergency responses that include fire suppression and/or auto-extrication are substantially greater than medical and other fire emergency (i.e., no suppression or extrication) responses. Specifically, the objective work and subsequent physiological, perceived, and overall internal workloads are greatest for suppression and extrication calls above medical and non-suppression fire calls which elicit similar magnitudes across all load measures. For medical emergencies, the workload demands appear to be influenced predominantly by the mental demands of the task. In contrast, the workload of fire calls, particularly those that require suppression and/or extrication, appear to be driven more so by physical and temporal demands. In consideration for the unique differences in workload across medical and fire emergency calls, it is likely that the accumulated workloads of individual firefighters are unique to the call types they respond to on-duty.

In accordance with the second study purpose, these results indicate that shifts with at least one fire suppression and/or auto-extrication emergency call response elicit significantly greater workloads than shifts without a suppression or extrication response. The elevated workload of shifts with a suppression or extrication call response is demonstrated through heightened objective work (i.e., external load), as well as greater physiological, perceived, and overall internal workloads. Additionally, for all shifts regardless of suppression or extrication call response inclusion, the physiological workload elicited is positively related to, or reflects, the objective work completed across the shift. However, the perceived workload (i.e., sRPE) and overall internal workload (i.e., NASA-TLX) did not demonstrate direct reflections of objective job demands, suggesting that beyond the completed physical work, additional factors may influence the subjective interpretation of shift workload among fire service personnel. Finally, these results support the notion that despite call volume being an established measure of workload in the fire service, the external and internal workloads of shifts with similar volumes are not equal and quantification of workload should consider other objective work parameters beyond call volume alone.

Finally, in alignment with the third purpose of this study, cardiovascular fitness and established measures of workload have been identified as predictors of external and internal workload across 24-hour shifts in the fire service. Total volume of call responses across a shift account for approximately 11% of the variance and significantly predicts the amount of objective work (i.e., IMPULSE) completed across 24-hour shifts. More specifically, the call volume of fire suppression and/or auto-extrication calls account for approximately 14% of the variance in the physiological response load to the job demands. Further, the objective work completed across a 24-hour shift is similar for firefighters with ranging obesity statuses and aerobic capacities, however, it is evident that firefighters with a lower aerobic capacity will complete the objective job demands at a higher physiological load. Namely, aerobic capacity accounts for nearly one-third of the physiological response load across a shift. As a measure of perceived internal load, sRPE is significantly informed by total volume of fire suppression and/or auto-extrication call responses in particular but appears to be limited in identifying the influence of aerobic capacity on shift demands. Therefore, as a stand-alone measure of shift workload, sRPE may allow individuals that require additional cardiovascular recovery strategies to go undetected and remain at an elevated risk for injury. Finally, the NASA-TLX score as an overall workload metric does not reflect the external, or other physiological load demands, of 24-hour shifts quantified in this study, nor are any of the variables (i.e., fitness or call volume) examined in this study indicative of overall internal load. As such, similar to sRPE, the NASA-TLX may be limited in quantifying workload demands if utilized as a stand-alone measure. Given these findings in conjunction, the cost of the workload across a 24-hour shift appears to be greater in firefighters with lower aerobic capacities and, due to the sensitivity of eTRIMP to the influence of aerobic capacity on workload, it is suggested that this direct physiological load metric may be the most equipped in differentiating loads experienced across different fire service personnel and may best identify individuals that have elevated recovery needs.

The collective findings of this study strongly contribute to the foundational use of *workload* measures in an on-duty firefighter setting due to multi-system examination of different emergency call types and 24-hour shifts, in tandem with consideration for call volume as an established measure of load in the fire service and the included examination of individual health and fitness characteristics supported by the WFI on workload. The use of external and internal loads concurrently for medical and fire emergency responses throughout a 24-hour shift, as well as consideration for physiological, perceived, and overall internal loads, expands on previous studies where similar measures have been utilized in simulated rescue scenarios (Marcel-Millet et al., 2020; Webb et al., 2010) or in measurement of a partial on-duty shift (Bouzigon et al., 2015). Additionally, the current state of the literature and practice utilize call volume for a 24-hour shift to infer the amount of work conducted across shifts in the fire service (Blackwell et al., 2011; Watkins et al., 2021). The findings of this study confirm that, in part, call volume is a predictor of the objective work completed on-duty. However, the findings indicate that further consideration should be given to the types of calls responded to, as the workload is greatest for fire suppression and/or auto-extrication calls where a single FIRE1 call response significantly increases the shift workload across physiological and perceptual systems. Finally, it appears that firefighters will complete their job demands on-duty to a similar magnitude, regardless of aerobic capacity abilities, however, the physiological load of the work is significantly escalated for lower-fit firefighters. The types of call responses, typical volume of call responses, and individual aerobic capacity of firefighters should all be considered for contributions to the *workload* of firefighting and inform the necessary, multi-system preparation and recovery strategies required to mitigate preventable injury.

Limitations & Directions for Future Research

Although the outcomes of this dissertation study are impactful for the foundational and strategic use of workload measures in the fire service, there are several limitations to consider that may inform future research objectives. First, the recruited sample of firefighters in this study are from a single, metropolitan structural fire department that are representative of one of the busiest departments in the nation. Therefore, the workloads quantified in this study may not represent the workloads experienced at other departments, including smaller metropolitan and/or rural departments. Additionally, this sample is only representative of career structural firefighters and these findings may not reflect the demands, or relationships to fitness, that are experienced in volunteer structural or wildland firefighters. It is also important to consider that although roughly 5% of career firefighters are female (NFPA, 2022) and this sample similarly reflects the population distribution the participants in all three studies included 10% female representation rather than an equal representation of sexes. Future research should apply this methodology within other firefighter populations to determine how workload varies across different subsets of firefighters and establish specific applications of the findings as necessary.

These findings are also limited by the cross-sectional, methodological design of this dissertation study. The data collection for all aims was conducted across consecutive shifts, such that the four to six shifts collected for each participant represent the workload of approximately 3-weeks of the individuals' calendar year. It is possible that if measured longitudinally, the workloads measured for individual calls and/or shifts may be influenced by various environmental or individual characteristics. As such, future researchers should examine the influence of time on firefighter workload to determine if other factors should be considered as influential on the demands of firefighting.

It is also essential to consider the limitations of quantifying objective work utilizing call volume across a 24-hour shift. Although call volume is an established measure of workload, and was accordingly selected for use in this study, the measure of volume does not independently account for durations (min) spent in response to individual calls or accumulate call-response durations across a shift. Therefore, despite call volume being predictive of the objective work and physiological response load of a shift, as well as fire call volume indicating perceived response loads of a shift, future researchers should examine the use of load measures with greater specificity for the on-duty work performed. Specifically, the duration of individual call responses, as well as the total time spent responding to calls throughout a shift, may serve as more specific predictors of workload responses and should be examined in future iterations of workload research in the fire service.

Finally, the multi-system examination of internal workload responses (i.e., physiological, perceptual, and overall) to the job demands of firefighting supports foundational knowledge of the intrinsic responses to firefighting, yet also establishes a need for further, integrative examination of the job demands in the fire service. Given the lack of relationships demonstrated between the perceived shift load (i.e., sRPE) and the individual characteristics examined in this study (i.e., aerobic capacity, obesity), it is evident that other factors may influence the perceived demands of firefighting. Based on the evidence supporting the differences in contribution of perceptual demands in the workload of individual call types, in addition to the variance in perceived load across 24-hour shifts with and without fire suppression and/or auto-extrication call responses, future researchers should target a deeper understanding of factors that influence the perceptual demands of firefighting.

Implications for Policy and Practice

The results of this dissertation study are influential on the practical applications of exercise science as it applies to the occupational health and wellness of firefighters. First, the findings of this research suggest that individual call responses, particularly those in response to fire suppression and/or auto-extrication, elicit substantially greater workloads. As such, inadequate recovery following the demands of fire suppression may decrease the readiness of a firefighter to respond to subsequent emergencies and heighten injury risk across a shift. Due to the links between overexertion of the cardiovascular and musculoskeletal systems and injury, practitioners should give particular attention to the recovery strategies implemented following individual call responses to maximize firefighter health and readiness to meet workload demands upon the sounding of the next alarm; practitioners should consider recovery strategies specific to the demands required of individual firefighters unique to the call type(s) encountered on-duty. From a policy perspective, departments should consider implementing, or extending, post-call recovery time periods to allow firefighters to manage their recovery needs. Additionally, resource allocation to education on the importance of recovery to wellness and job performance, as well as training on strategies that enhance recovery efficacy, may improve outcome quality.

Workload in the fire service has been inferred through the measurement of call volume, which is confirmed by this study to significantly contribute to the objective workload of a shift. Attention should be paid to post-shift recovery strategies, especially following shifts that include higher-call volumes. However, due to differences in workload across shifts with and without the inclusion of maximal-intensity fire-suppression and/or auto-extrication demands despite similar call volumes, shifts that include such responses should also be targeted with greater recovery strategies regardless of call volume across the shift. Firefighters at stations with higher call volumes on average, as well as fire suppression and/or auto-extrication call volumes specifically, may require the greatest implementation of recovery strategies following call responses and 24-hour periods of shiftwork. To address these findings and subsequent recommendations, departments should consider utilizing volume of fire suppression and/or auto-extrication across a shift, in tandem with overall call volume, to inform firefighter recovery protocols and implement necessary policy change to create time for such protocols on-duty.

While it is established that the cardiovascular response to a fire alarm tone is greater than a medical emergency alarm (Marciniak, Tesch, et al., 2021), the results of this study suggest that the overall workload of non-suppression and/or auto-extrication calls following a fire alarm are similar to medical emergency responses. It is likely that re-categorization of fire calls that do not include fire suppression and/or auto-extrication into the grouped calls alerted via medical emergency alarm may reduce some unnecessary perturbation on firefighters' cardiovascular systems. Departments should consider implementing a policy change that transitions all non-fire suppression and/or auto-extrication to the medical alarm tone grouping in the emergency alert system.

Although preparation for specific call demands on-duty is difficult due to the unpredictable nature of calls types and volumes, off-duty preparation should be utilized and target the fitness needs of firefighters. It is evident from these results that the physiological response load to job demands is substantially influenced by aerobic capacity. Therefore, targeted training to enhance aerobic capacity may support reductions in workload. Additionally, the importance of aerobic capacity abilities is greater for firefighters assigned to higher-volume stations as the physiological loads will be greater than lower-volume houses and likely exacerbated in individuals with lower oxygen consumption efficiencies. Finally, due to the findings of this study demonstrating that maximal intensities are achieved *and* sustained across time during call fire suppression and/or auto-extrication call responses, practitioners should consider implementing training that supports greater aerobic capacity abilities, as well as challenges firefighter capacities to sustain maximal intensity exercise across time. Prior research has demonstrated that interval based training is effective at enhancing aerobic capacity and is well-suited for specificity to tasks required of firefighters (Abel et al., 2011). Given these recommendations, departments should consider allocating resources to provide effective training opportunities (i.e., interval training) to personnel, as well as education on the importance of individual wellness towards job performance.

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Appendix A: Participant Descriptive Data

Descriptive Data					Aim 1 Call Frequencies				Aim 2 & 3 Shift Frequencies					
					Zephyr Data		Survey Data		Zephyr Data			Survey Data		
ID	Age	Sex	Ethn	Rank (Exp)	MED	FIRE0/1	MED	FIRE0/1	TOTAL	NOFIRE1	FIRE1	TOTAL	NOFIRE1	FIRE1
1	39	0	---	LT (11.5)	47	6/5	4	1/2	3	2	1	3	2	1
2	26	0	W	FF (4.4)	18	8/5	3	5/3	4	1	3	4	1	3
3	43	0	W	FF (3.0)	37	9/2	3	4/2	4	3	1	4	3	1
4	53	0	W	FF (21.5)	7	0/1	3	0/1	4	3	1	4	3	1
5	39	0	W	FF (3.7)	10	18/6	4	3/4	5	1	4	5	1	4
6	44	0	W	FF (16.5)	31	6/3	4	4/2	3	2	1	3	2	1
7	38	0	W	CPT (12.5)	25	3/2	6	2/2	5	3	2	5	3	2
8	40	0	W	LT (11.8)	38	7/5	5	7/3	5	1	4	5	1	4
9	35	0	H	FF (5.7)	36	6/3	6	1/2	3	2	1	3	2	1
10	57	0	W	LT (23.0)	6	9/3	4	1/4	5	2	3	5	2	3
11	45	0	W	FF (26.6)	8	1/1	3	1/1	2	1	1	2	1	1
12	36	0	W	LT (9.4)	27	3/2	5	0/1	4	3	1	4	3	1
13	24	1	H	FF (2.8)	26	5/3	4	0/1	4	2	2	4	2	2
14	52	0	W	CPT (24.2)	13	8/6	2	0/3	4	1	3	4	1	3
15	34	1	W	FF (16.4)	34	3/2	4	1/1	3	1	2	3	1	2
16	41	0	W	LT (10.5)	15	3/1	4	0/1	4	2	2	4	2	2

17	35	1	W	FF (1.9)	11	10/11	2	0/6	4	0	4	4	0	4
18	37	0	W	LT (9.5)	49	7/3	4	3/2	4	3	1	4	3	1
19	37	0	W	LT (19.4)	43	13/2	5	0/1	5	3	2	5	3	2
20	38	0	B/W	CPT (18.8)	10	11/1	2	3/1	4	3	1	4	3	1
21	35	0	B	CPT (12.8)	53	4/4	1	0/1	1	1	0	1	1	0
22	22	1	L	FF (1.5)	54	7/5	5	0/2	5	2	3	5	2	3
23	32	0	AA	FF (5.5)	61	4/4	3	0/0	2	0	2	1	0	1
24	43	0	W	LT (6.1)	45	8/4	6	7/3	3	2	1	3	2	1
25	21	0	W	FF (1.4)	19	5/1	4	5/0	5	4	1	5	4	1
26	28	0	AA	FF (4.1)	55	8/8	5	3/4	5	1	4	5	1	4
27	25	0	---	FF (5.0)	28	2/2	3	1/2	3	1	2	3	1	2
28	33	0	W	LT (15.2)	60	5/6	4	4/5	4	1	3	4	1	3
29	34	0	W	LT (12.8)	10	5/8	4	0/1	3	1	2	3	1	2
30	25	0	---	FF (4.1)	24	5/3	3	0/2	3	0	3	3	0	3
31	24	0	AI	FF (4.2)	14	1/5	4	0/4	3	1	2	3	1	2
32	51	0	W	CPT (21.5)	16	6/8	1	2/6	4	2	2	4	2	2
33	37	0	---	LT (9.8)	34	2/3	2	0/1	2	1	1	2	1	1
34	32	0	W	FF (12.4)	26	3/4	3	4/4	4	2	2	3	2	1

35	41	0	W	CPT (13.1)	41	2/1	4	2/1	4	3	1	4	3	1
36	24	0	W/AI	FF (3.2)	3	13/4	2	0/2	5	2	3	5	2	3
37	41	0	AA	CPT (13.3)	43	1/2	3	0/2	3	2	1	3	2	1
38	42	0	---	FF (22.3)	5	11/4	1	2/2	3	0	3	2	0	2

Age, years; Sex, 0=Male, 1=Female; Ethnicity, AA=African American, AI=American Indian, B=Black, H=Hispanic, L=Latino, W=White, ---=Not response; Rank, FF=Firefighter, LT=Lieutenant, CPT=Captain.

Appendix B: Institutional Review Board Protocol Approval

UNIVERSITY of WISCONSIN
UWMILWAUKEE
Institutional Review Board

uwm.edu/irb
irbinfo@uwm.edu
414-662-3544

Date: February 10, 2022

To: Kyle Ebersole
Dept: Rehabilitation Sciences and Technology
CC: Kyle Ebersole - Investigator,Rudi Marciniak - Co-Inv (Full Access w/Notify)

IRB #: 22.158
Title: Quantifying On-Duty Workload in Active-Duty Firefighters

The University of Wisconsin-Milwaukee Institutional Review Board has approved your protocol as minimal risk under Expedited Category 2, 4, 6, 7 as governed by 45 CFR 46.110. This protocol has been approved on **February 10, 2022** and IRB approval will expire on **February 9, 2023**. Before the expiration date, you will receive an email explaining how to either keep the study open or close it.

Any proposed changes to the protocol must be reviewed by the IRB before implementation, unless the change is specifically necessary to eliminate apparent immediate hazards to the subjects.

It is your responsibility to:

- promptly report unanticipated problems to the IRB
- maintain proper documentation of study records
- ensure that all study staff receive appropriate training as outlined in the approved protocol
- adhere to the policies and guidelines set forth by the IRB, UWM, and the UW System, and to all applicable state and federal laws

Contact the IRB office if you have any further questions. Thank you for your cooperation and best wishes for a successful project.

Re: IRB Notification: Request for Status of IRB Approved Study 22.158-UWM

LC Leah Callan Stoiber
To Kyle T Ebersole; Rudi Alexis Marciniak

Reply | Reply All | Forward | ...

Wed 1/18/2023 1:19 PM

If there are problems with how this message is displayed, click here to view it in a web browser.

Good afternoon,

Thanks for responding to the status request. Your study approval has been extended for another year. The new expiration date for your study is February 8, 2024.

As a reminder, please submit an Amendment if any changes are needed to your study, or a Reportable Event form if any unexpected problems or protocol deviations occur.

You'll continue to receive annual status requests about your study until it is completed and closed.

Best,

Leah

Leah Stoiber, M.S.
IRB Administrator
University of Wisconsin-Milwaukee
IRB Office: (414) 662-3544
Direct: (414) 977-7593
Engelmann 270
Pronouns: she/her/hers

Appendix C: Recruitment Script

Script for In-Person or Email Recruitment

Hello. My name is Rudi Marciniak and I am a doctoral student at the University of Wisconsin-Milwaukee and member of the Human Performance & Sport Physiology Laboratory working under Dr. Kyle Ebersole. The Human Performance & Sport Physiology Laboratory at UWM is currently seeking volunteers to participate in a study to quantify the on-duty workload experienced by active-duty firefighters and identify how fitness impacts the workload of job duties.

Eligible firefighters include:

- Firefighters who are currently a non-probationary firefighter at a rank of captain, lieutenant, heavy equipment operator, and/or firefighter and cleared for full active-duty work
- Individuals who:
  - Have not had a doctor or department official tell you not to participate in exercise
  - Do not have any diagnosed and unmanaged cardiovascular (e.g., high blood pressure, etc.) or metabolic (e.g., diabetes, etc.) conditions

Participants that meet the eligibility requirements and are interested in participating will be enrolled into the study.

The study will involve participants performing a series of activities off-duty at a single session. This session will include a brief questionnaire on demographics, exercise history, lifestyle behaviors, and medications, as well as anthropometric measures (i.e., body mass, 3-site skinfold, hip and waist circumference) and the completion common fitness tests for strength, power, balance, movement quality, and running on a treadmill. The testing session will take approximately 90 minutes, but can vary by person. Following this session, we will work with you to select a total of 4 shifts within 2-weeks where you will complete a series of questionnaires and wear a heart rate strap while completing your already assigned work shifts. Upon completion of the 4th shift data collection, participants will be compensated with $50 cash and an executive summary of their individual fitness and shiftwork outcomes.

Participants from this study will benefit from gaining a greater knowledge of their individual fitness levels and will, therefore be able to improve or adapt their fitness to meet the demands of their tasks. This study will also help further the knowledge pertaining to specific methods of quantifying on-duty workload and identifying how fitness influences on-duty workload demands. In doing so, preparation and recovery strategies may be improved and reduce controllable risks for musculoskeletal injury and sudden cardiac death in the fire service.

If you are interested in volunteering in this study, please see me after this meeting or contact me directly at (rudim@uwm.edu).

Appendix D: Criteria for Inclusion Questionnaire

Human Performance & Sport Physiology Laboratory
Dept of Rehabilitation Sciences & Technology
College of Health Sciences
University of Wisconsin-Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy & Athletic Training, Room 365
Milwaukee, WI 53211-2956

ID#: ____________________

Date: ___________________

Criteria for Inclusion Questionnaire

Study Title: *Quantifying On-Duty Workload in Active-Duty Firefighters*

The following questions will help determine if you meet the eligibility criteria for this study. It is important that you accurately answer each question.

Please answer the following questions with a YES or NO response	YES	NO
1. Are you a non-probationary, active-duty firefighter at a rank of captain, lieutenant, heavy equipment operator, and/or firefighter with the City of Milwaukee Fire Department and currently cleared for full duty?		
2. Have you been diagnosed by your physician with a cardiovascular (e.g., high blood pressure, etc.) or metabolic (e.g., diabetes) condition that is currently not being managed with medication?		
3. Do you know of any reason why you should not engage in submaximal or maximal exercise or physical activity or participate in this study?		

Eligible to Participate in Study:

YES NO

Follow-Up Confirmation of Eligibility at the start of the Shift-Work Phase:

Eligible: YES NO

Appendix E: General Information Questionnaire

Study Title: *Quantifying On-Duty Workload in Active-Duty Firefighters*

ID Code: IRB Protocol #: **22.158**

Date: Approval Date: 02/10/2022

Please indicate your responses to the following items.

1. **Are you allergic to latex: YES NO**
2. **Gender: __________**
3. **Age: _____ yrs ______ months**
4. **Ethnicity (cultural background): _________________**
5. **Firefighting experience: _______yrs_______months**
6. **Current rank (firefighter, lieutenant, captain, HEO, chief, other): __________________**
7. **Do you currently work a second job on your days off from firefighting?**
    - **a.** YES or NO
    - **b.** If yes, is your second job physical/labor intensive? YES or NO
8. **Do you currently take any medications that:**

	YES	**NO**
Change heart rate (i.e., beta blocker)		
Change blood pressure		
Change mood (i.e., depression, anxiety, sleep)		
Manage breathing conditions (i.e., asthma)		
Manage diabetes		
Other medication(s) that you believe could influence your performance in this study (i.e., over the counter medications for pain, inflammation, cold, or similar)		

9. **Select the following that apply to your current lifestyle.**

	YES	**NO**
Would you describe your diet as favoring anti-inflammatory foods? For example, tart cherry juice, curcumin or turmeric, berries, fish, avocados.		
Do you consume any nutritional supplements that are considered stimulants? If so, list type and approximate amount.		
Do you regularly consume spicy foods? If so, list type and approximate amount.		
Do you regularly consume caffeine (coffee, energy drinks, etc.)? If so, list type and approximately amount.		
Do you believe you adequately hydrate on a regular basis?		
Do you currently smoke or use tobacco products?		
Are you currently experiencing more stress than is typical for you?		

10. For the general exercise described in each row, check the column that best reflects your participation in the last 12 months.

I have participated in this type of exercise within the past…	3 months	6 months	12 months	I do not participate in this activity.
<100 min of moderate intensity activity/week (40-60% heart rate max)				
>150 min of moderate intensity activity/week (40-60% Heart Rate max)				
>75 min of vigorous activity/week (60-85% heart rate max)				
≥ 2 sessions of resistance-training/strengthening activities/week				

11. Select any common fitness activities that you participate in.

	YES	NO
Walking		
Swimming		
Biking		
Running		
Elliptical or Similar		
Resistance Training		
CrossFit or Circuit Training		
Yoga or Meditation		
MFD FIT Camps		
Other (briefly describe)		

12. Do the types of exercise selected above in question #11 represent a typical pattern for you (i.e., established exercise habits)? If no, please describe.

____

____