WHITE PAPER

FIREFIGHTER STRESS & RECOVERY

How HRV Reflects Call Volume, Sleep, Fitness, and PTSD

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Human and Sport Performance

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Executive Summary

Firefighters are routinely exposed to physical, psychological, and operational stressors during 24-hour shifts, yet much of this stress is difficult to observe or quantify in real time. While stress is often discussed in subjective terms, fewer studies have examined how firefighter stress manifests physiologically across a shift and how it relates to workload, sleep disruption, physical fitness, and mental health in real-world fire service settings.

This white paper summarizes findings from a doctoral research study involving career firefighters working 24-hour shifts. Heart rate variability was assessed before and after a shift as an objective marker of autonomic nervous system stress and recovery. The study further examined how post-shift heart rate variability related to emergency call volume, sleep duration, aerobic fitness (VO_2max), and PTSD symptom severity.

Key Findings

- Heart rate variability significantly declined following a 24-hour shift, indicating acute physiological stress and reduced autonomic recovery across the sample.
- Higher emergency call volume was associated with lower post-shift heart rate variability, suggesting greater physiological strain with increasing workload.
- Greater PTSD symptom severity was inversely associated with post-shift heart rate variability, linking mental health symptoms with impaired physiological recovery.
- Higher aerobic fitness (VO_2max) was positively associated with post-shift heart rate variability, indicating that fitter firefighters demonstrated better stress resilience and recovery capacity.
- Sleep duration showed limited association with post-shift heart rate variability, suggesting that factors beyond sleep alone contribute to autonomic stress responses in firefighters.

Practical Implications for Firefighters

- Physiological stress accumulates across a 24-hour shift and can be objectively measured, even when subjective fatigue may be underestimated.
- Higher workload and greater psychological stress are associated with poorer autonomic recovery following a shift.
- Aerobic fitness may play a critical role in buffering physiological stress and supporting recovery in firefighters.
- Heart rate variability may offer a useful tool for understanding individual differences in stress tolerance and recovery capacity over time.

Conclusion

These findings demonstrate that firefighter stress is not solely psychological but is reflected in measurable physiological changes across a 24-hour shift. Workload, mental health symptoms, and fitness capacity all influence how well firefighters recover from occupational stress. Together, the data supports a broader approach to firefighter wellness that emphasizes physical fitness, stress management, and recovery as key components of long-term health.

1. Why Firefighter Stress Is Hard to See

Firefighting is widely recognized as a physically demanding and psychologically stressful occupation, yet much of the stress experienced by firefighters is not easily observed during or immediately after a shift. Firefighters are trained to perform under pressure, suppress discomfort, and maintain operational readiness regardless of fatigue or strain. As a result, stress is often normalized within the fire service and evaluated primarily through subjective experiences such as feeling tired, irritable, or mentally drained.

While these perceptions are important, they do not fully capture the physiological toll of repeated exposure to emergency response, disrupted sleep, high cognitive demand, and emotional stress. Firefighters may complete a shift feeling functional or even energized, despite underlying physiological strain that has accumulated over time. This disconnect between perceived readiness and physiological recovery makes firefighter stress particularly difficult to identify and address.

Traditionally, discussions of firefighter stress have focused on external workload indicators such as call volume, staffing levels, or shift intensity. Although these factors are relevant, they do not fully explain why some firefighters recover effectively after a shift while others experience persistent fatigue, declining performance, or worsening health over the course of a career. Two firefighters working the same station and responding to the same calls may show very different responses to the same occupational demands.

Emerging evidence suggests that firefighter stress should be understood not only as a psychological experience but also as a physiological process involving the autonomic nervous system. This system plays a central role in regulating heart rate, recovery, and the body's response to physical and emotional stress. When occupational stress outpaces recovery, physiological strain can accumulate even in the absence of obvious symptoms.

Heart rate variability has gained attention as a potential tool for understanding this process. By reflecting the balance between stress activation and recovery within the nervous system, heart rate variability provides insight into how the body responds to and recovers from occupational demands. In firefighters, this may help explain why workload, sleep disruption, fitness level, and mental health symptoms interact in complex ways that are not captured by call volume alone.

The purpose of this white paper is to examine how firefighter stress shows up physiologically across a 24-hour shift and how heart rate variability relates to call volume, sleep duration, aerobic fitness, and PTSD symptom severity. By focusing on objective measures alongside real-world operational conditions, this work aims to provide firefighters with a clearer understanding of how stress and recovery operate within the body and why individual responses to the job can differ so widely.

2. What Heart Rate Variability Is and Why Firefighters Should Care

Heart rate variability refers to the natural variation in time between consecutive heartbeats. Rather than beating at a perfectly steady rhythm, a healthy heart continually adjusts

its timing in response to physical demands, emotional stress, and recovery processes. These small variations are regulated by the autonomic nervous system, which governs the balance between stress activation and recovery within the body.

The autonomic nervous system has two primary components that work together to maintain physiological balance. The sympathetic branch supports alertness and action during physical or psychological stress, while the parasympathetic branch supports recovery, restoration, and physiological calmness. Heart rate variability reflects how effectively these systems interact. Higher heart rate variability generally indicates greater parasympathetic influence and a stronger capacity to recover from stress. Lower heart rate variability suggests reduced recovery capacity and greater physiological strain.

Firefighting requires repeated transitions between rest and high-intensity physical and cognitive demands, often with little warning. Emergency responses, disrupted sleep, emotional stress, and physical exertion all activate the sympathetic nervous system. When recovery is insufficient, parasympathetic activity may remain suppressed, leading to persistently lower heart rate variability over time.

Unlike traditional health metrics that capture long-term outcomes such as body composition or aerobic fitness, heart rate variability provides insight into how the body is responding to stress in the short term. It reflects not only physical workload but also psychological stress, sleep disruption, and overall recovery status. This makes it useful for understanding why two firefighters with similar assignments and fitness levels may experience the job very differently.

Importantly, heart rate variability is not a measure of toughness, motivation, or mental strength. Instead, heart rate variability reflects how the nervous system is adapting to accumulated demands. In the context of firefighting, it can help explain why chronic fatigue, irritability, poor sleep, or declining performance may occur even when firefighters continue to meet operational expectations.

By examining heart rate variability before and after a 24-hour shift, this white paper uses an objective physiological signal to better understand how stress accumulates and how recovery capacity differs among firefighters. When considered alongside call volume, sleep duration, aerobic fitness, and PTSD symptom severity, heart rate variability offers a clearer picture of how occupational stress affects the body and why resilience varies across individuals working in the same environment.

3. Key Findings: What Happens to Stress and Recovery Across a 24-Hour Shift

This study examined how heart rate variability changed from before to after a 24-hour shift and how post-shift heart rate variability related to emergency call volume, sleep duration, aerobic fitness, and PTSD symptom severity. Together, the findings provide insight into how physiological stress accumulates during a shift and why recovery capacity differs among firefighters exposed to similar operational demands.

3.1 HRV After One 24-Hour Shift

Across the sample of 53 male firefighters, heart rate variability significantly declined from pre-shift to post-shift measurements. This decrease indicates an acute reduction in autonomic recovery capacity following a 24-hour tour of duty and suggests that the physiological demands of the shift place measurable strain on the nervous system. Importantly, this decline occurred even when firefighters remained operationally functional, reinforcing the idea that physiological stress can accumulate beneath the surface without obvious outward signs.

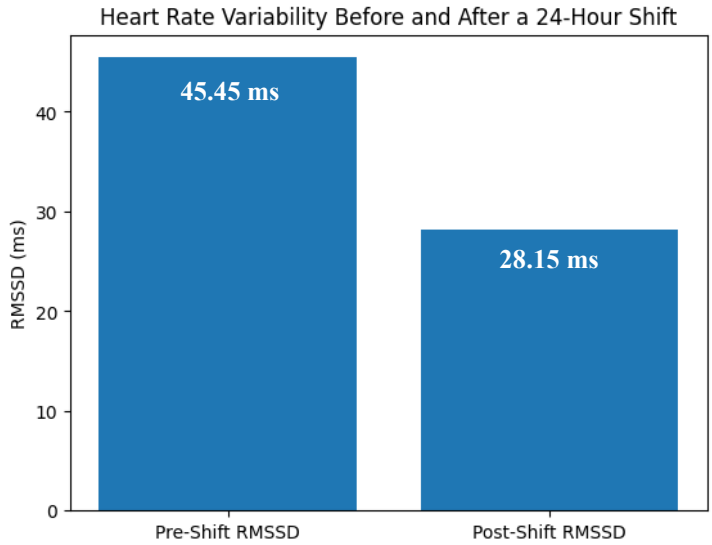

Figure 1. Average heart rate variability measured before and after a 24-hour shift in career firefighters. Heart rate variability declined following the shift, indicating reduced autonomic recovery capacity.

3.2 HRV Decline in Relation to Call Volume

Post-shift heart rate variability was inversely associated with emergency call volume. Firefighters who responded to a higher number of calls during the shift tended to demonstrate lower heart rate variability afterward, reflecting greater physiological strain. This finding supports the expectation that increasing workload places added stress on recovery systems, though it also highlights that call volume represents only one component of the overall stress response rather than a complete explanation.

3.3 How Mental Health impacted HRV Decline

PTSD symptom severity was also inversely related to post-shift heart rate variability. Firefighters reporting greater symptom burden demonstrated lower recovery capacity following a shift, indicating that psychological stress is closely linked to physiological stress regulation. This relationship highlights how mental health symptoms can influence autonomic function and recovery, even in the absence of acute psychological distress during a given shift.

3.4 Aerobic Fitness Protects HRV Decline Post-Shift

In contrast, aerobic fitness showed a positive association with post-shift heart rate variability. Firefighters with higher VO_2max values tended to maintain greater autonomic recovery capacity following a 24-hour shift. This finding suggests that aerobic fitness may serve as a protective factor, buffering the physiological impact of occupational stress and supporting more effective recovery.

3.5 Sleep Has Little Influence on Autonomic Recovery Post-Shift

Sleep duration showed limited association with post-shift heart rate variability in this study. While sleep disruption is widely recognized as a critical stressor in the fire service, these findings suggest that recovery following a shift may be influenced by a broader set of factors, including chronic stress exposure, fitness capacity, and psychological health, rather than sleep duration alone.

All together, these findings indicate that firefighter stress is a measurable physiological process that intensifies across a 24-hour shift and is shaped by both workload and individual characteristics. Call volume and psychological stress contribute to reduced recovery capacity, while aerobic fitness appears to support resilience. These patterns help explain why firefighters exposed to similar operational demands may experience very different levels of fatigue, recovery, and long-term health risk.

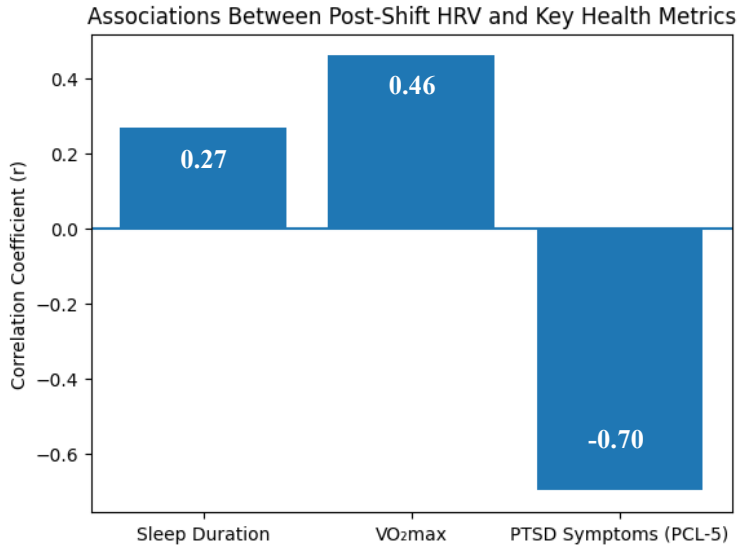

Figure 2. Associations between post-shift heart rate variability and key health metrics in career firefighters. The correlation coefficient (r) reflects the strength and direction of each relationship with sleep duration showing a weak positive association (r = 0.27), aerobic fitness showing a moderate positive association (VO_2max: r = 0.46), , and PTSD symptom severity showing a strong negative association (r = −0.70) with post-shift recovery capacity.

4. Interpretation: What These Findings Mean for Firefighters

The findings from this study suggest that firefighter stress should be understood as a physiological process that accumulates across a shift rather than as a feeling that is always consciously perceived. The observed decline in heart rate variability following a 24-hour shift indicates that even when firefighters feel capable of performing their duties, the nervous system may be experiencing reduced recovery capacity. This helps explain why fatigue, irritability, or difficulty recovering between shifts can occur even when a firefighter does not feel acutely stressed.

4.1 Workload Matters, but It Does Not Explain Everything

The inverse relationship between call volume and post-shift heart rate variability reinforces the idea that workload contributes to physiological strain, but it also highlights the limits of call volume as a standalone indicator of stress. While higher call volume was associated with poorer recovery, differences in heart rate variability were not explained by call volume alone. This suggests that two firefighters working the same shift may experience very different physiological responses depending on factors beyond workload, including fitness level and psychological stress.

4.2 Psychological Stress Influences Physical Recovery

The association between PTSD symptom severity and lower post-shift heart rate variability is particularly important for firefighters to understand. This finding does not imply that firefighters with higher symptom burden are less capable or less resilient. Rather, it indicates that psychological stress can influence the body's ability to regulate stress and recovery at a physiological level. Mental health symptoms and physical stress responses appear to be closely linked, even when psychological distress is not outwardly visible during a shift.

4.3 Fitness as a Buffer Against Occupational Stress

In contrast, the positive relationship between aerobic fitness and post-shift heart rate variability suggests that fitness may play a meaningful role in supporting physiological resilience. Firefighters with higher aerobic capacity demonstrated greater recovery capacity following a 24-hour shift, despite being exposed to the same occupational demands. This finding supports the idea that fitness does more than improve job performance. It may also help buffer the physiological impact of stress and support more effective recovery between shifts.

4.4 Why Sleep Alone Does Not Determine Recovery

The limited association between sleep duration and post-shift heart rate variability does not diminish the importance of sleep for firefighter health. Instead, it suggests that recovery is influenced by a complex interaction of factors that extend beyond sleep alone. Chronic stress exposure, psychological health, and fitness capacity may shape how the body responds to disrupted sleep, making recovery outcomes highly individual.

Overall, these findings emphasize that firefighter stress and recovery are not determined solely by assignment, workload, or willpower. They are influenced by an interaction of

operational demands and individual capacity. Understanding this interaction can help firefighters better interpret their own fatigue and recovery patterns and can shift conversations away from blame toward more realistic discussions of resilience, recovery, and long-term health.

5. What Firefighters Can Actually Do With This Information

The findings from this study are not intended to suggest that firefighter health outcomes are simply a matter of personal discipline or motivation. Instead, they point to a more realistic conclusion. Firefighter stress and recovery are shaped by an interaction between occupational demands and individual capacity. Understanding where influence exists and where it does not allows firefighters to respond to stress more effectively and without unnecessary self blame.

5.1 Recognize That Feeling Fine Does Not Always Mean Fully Recovered

One of the most important implications of this work is that physiological stress can accumulate even when firefighters feel operationally capable. A decline in heart rate variability following a 24-hour shift suggests reduced recovery capacity that may not be consciously perceived. Firefighters should understand that persistent fatigue, irritability, or difficulty bouncing back between shifts may reflect underlying physiological strain rather than a lack of toughness or commitment. Recognizing this disconnect can help normalize recovery needs and reduce the tendency to ignore early warning signs.

5.2 View Call Volume as Context

Higher call volume was associated with greater physiological strain, but workload alone did not explain recovery differences across firefighters. This means that assignment to a busy or slower station does not determine stress outcomes on its own. Firefighters should view call volume as one part of the stress landscape rather than a definitive predictor of health. This perspective can help shift conversations away from comparing stations and toward understanding how multiple stressors interact over time.

5.3 Understand the Role of Psychological Stress in Physical Recovery

The inverse relationship between PTSD symptom severity and post-shift heart rate variability highlights the close connection between psychological stress and physiological recovery. This finding does not imply weakness or reduced capability. Instead, it reinforces that mental health symptoms influence how the nervous system regulates stress. Firefighters should recognize that addressing psychological stress is not separate from physical health but directly related to recovery capacity. Seeking support, whether formal or informal, should be viewed as part of maintaining readiness rather than as a personal shortcoming.

5.4 Prioritize Aerobic Fitness as a Resilience Tool

Among all variables examined, aerobic fitness showed one of the strongest relationships with post-shift recovery. Firefighters with higher VO_2max values demonstrated greater heart rate variability following a shift, suggesting improved physiological resilience. This supports the idea that aerobic fitness does more than improve task performance. It may also help buffer the body against occupational stress. While firefighters cannot control every aspect of their workload or

sleep, maintaining aerobic fitness represents a meaningful area of influence that can support recovery across repeated shifts.

5.5 Avoid Reducing Recovery to Sleep Alone

Although sleep is critical for health and performance, sleep duration alone showed limited association with post-shift heart rate variability in this study. This does not diminish the importance of sleep, but it does suggest that recovery is shaped by multiple interacting factors. Firefighters should avoid interpreting poor recovery as solely a sleep problem. Chronic stress exposure, psychological health, and fitness capacity likely influence how the body responds to disrupted sleep. A broader view of recovery can help firefighters adopt more realistic expectations and strategies.

5.6 Use Physiological Data to Inform

Heart rate variability should not be viewed as a scorecard of performance or worth. Instead, it can serve as an informational tool that reflects how the body is adapting to stress over time. For firefighters, this means using physiological signals to guide recovery decisions, training load, and self-awareness rather than as a basis for comparison with others. Interpreted appropriately, these measures can support more informed conversations about stress, resilience, and long-term health.

6. Conclusion

This white paper examined how firefighter stress and recovery manifest physiologically across a 24-hour shift using heart rate variability as an objective marker of autonomic nervous system function. The findings demonstrate that firefighter stress is not solely a subjective experience but is reflected in measurable changes in recovery capacity that occur even when firefighters remain operationally capable.

Heart rate variability declined following a 24-hour shift, indicating acute physiological strain, and was influenced by multiple factors beyond workload alone. Higher call volume and greater PTSD symptom severity were associated with poorer post-shift recovery, while higher aerobic fitness was linked to more favorable physiological responses. These patterns help explain why firefighters exposed to similar operational demands may experience markedly different recovery trajectories over time.

Importantly, the results suggest that firefighter stress should be understood as a systemic occupational exposure shaped by the interaction of workload, psychological stress, and individual capacity. Assignment, station tempo, or perceived toughness do not fully determine recovery outcomes. Instead, resilience appears to be influenced by longer-term factors such as fitness and stress regulation.

Together, these findings support a broader approach to firefighter wellness that extends beyond call volume or sleep alone. Strategies that emphasize aerobic fitness, psychological health, and recovery capacity may help mitigate the cumulative physiological impact of repeated 24-hour shifts and support long-term firefighter health and performance.

About the Author

Daniel Higuera, PhD is a professor of kinesiology whose work focuses on improving firefighter health, fitness, and career longevity. His research explores the applicability of wearable technology for firefighters and examines how occupational demands such as emergency call volume, sleep disruption, physical fitness, and chronic stress influence firefighter performance and long-term health outcomes.

Dr. Higuera has worked closely with over 25 fire departments through health and wellness programs, fitness assessments, and applied research initiatives, allowing him to study firefighters in real operational environments rather than laboratory-only settings. His work emphasizes translating scientific evidence into practical insights that firefighters and departments can use to better understand health risks embedded in the job. This white paper is based on doctoral research involving career firefighters working 24-hour shifts and reflects commitment to evidence-based, firefighter-centered approaches to health and performance.

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