LEE BROWN, MSC, CSCS, CSPS, TSAC-F, RSCC,
AND SCOTT CAULFIELD, MA, CSCS,*D, TSAC-F,*D, RSCC*E

POTENTIAL FOR USING THE REACTIVE STRENGTH INDEX (RSI) TO DECREASE INJURY RISK AND IMPROVE OPERATIONAL PERFORMANCE IN UK FIREFIGHTERS

INTRODUCTION

Much like police officers, paramedics, and military personnel, programming strength and conditioning training for fire service personnel requires physical and tactical training to enhance operational performance (6,7). Pre-operational work specific training in their rest times while at work awaiting emergency callouts prepares firefighters for the physical and psychological demands of their work. To be effective, fire service personnel must have muscular strength, power, and endurance to complete endurance work on operational duties and maneuver in close quarters while carrying external loads (3). Although tactical training programs aim for positive long-term adaptations, overtraining or chronic exhaustion can lead to decreased operational performance. Therefore, a measure of monitoring neuromuscular performance capabilities and central neuromuscular fatigue could provide deeper insights into the level of ability when carrying out actions such as stair ascending and descending while carrying heavy equipment under duress (5,7).

INJURY ACTIVITY IN THE FIRE SERVICE

Firefighters are trained for extremely hazardous work in harsh, chaotic, and unpredictable environments, with heated temperatures that cause deleterious effects on the firefigther (10). Firefighters face numerous hazards on the job, including toxic vapors, hazardous combustion products, high radiant heat loads, and a hectic work environment (9). In addition to the hazards experienced at the fire scene, firefighters execute rescues, extrication, and emergency medical system calls and respond to natural disasters and hazardous material spills. Descending stairs while fatigued, carrying heavy equipment, wearing personal protective equipment (PPE) under duress, and carrying victims can be the leading cause of lower limb injury (6). Additionally, firefighter may experience lower back pain when pivoting stairwells with ladders and victims (6).

CURRENT CHALLENGES IN THE FIRE SERVICE

The standard fitness test for the London Fire Brigade is split into six work-related tasks and must be passed with competence prior to qualifying as a firefighter. At present this is only required when leaving the academy and as of January 2024, the Chester treadmill test was introduced (4). Until recently, the fire service did not implement an annual fitness assessment for current personnel and fitness testing was not compulsory; however, now the Chester treadmill test must be completed to ensure cardiovascular standard ability for all current serving firefighters (10). The annual fitness assessment using the Chester treadmill test is in the pilot year (2024/2025). Strength and stamina assessments such as reactive strength index (RSI) testing will be brought into effect at some point following the outcome from the initial first year period.

- Aerobic Chester treadmill test: a progressive 12-min walk/run test, set at a speed of 6.2 km/hr on a treadmill, with a 3% gradient increase every two minutes beginning at 0%, wearing sports attire such as shorts and t-shirt (not wearing protective kit).
- Ladder climb: climb a 13.5-m (45-ft) ladder to a specific point, two thirds of the full working height, take a leg lock, remove the hands from the ladder, look down to the assessor below where they will be asked to identify a symbol.
- Ladder lift: raise the bar of a ladder lift simulator weighing 30 kg (4 stone) to a height of 190 cm (6 ft 3 in).
- Casualty drag: drag a 55-kg (8-stone) dummy backwards around a 30-m (100-ft) course around four cones within a set time.
- Enclosed space: wearing a breathing apparatus face mask, negotiate a crawl and walkway with clear vision. Halfway through the route, vision will be obscured, and the task is to retrace your steps to the start/finish point.
- Equipment assembly: assemble and then disassemble a portable pump while wearing fire gear.
- Equipment carry: carrying the equipment over a 25-m course around two cones within 5 min and 47 s. The equipment is made up of one 30-m (100-ft) hose reel tubing on a drum, three coiled 70 mm soft suction hoses, one 100 mm hard suction hose and suction strainer in a basket and one 33-kg (5-stone) barbell.

These tests are designed to identify the readiness of the recruits for entry into a working environment that may require them to perform all these tasks, with repeated bouts and continued exertion throughout an emergency situation that could last up to several hours. Firefighters routinely execute jobs in uncomfortable and injury-prone positions, increasing their risk of developing an occupational musculoskeletal injury. There is evidence that having appropriate core muscular strength can aid and assist in avoiding injury (3).

Despite the intense physical demands of firefighting, unknowingly, some firefighters may not maintain the necessary levels of conditioning for peak work performance. The United Kingdom fire

service has recently identified minimal cardiorespiratory fitness standards (42.3 ml·kg^{-1}·min^{-1}) for firefighters using the Chester step test (10); with the six task-related assessments to pass academy are passed or failed on set timings and the ability to carry out the tasks with competence. However, there is still uncertainty about the necessary strength and muscular endurance for safe and effective firefighting operations (8). Firefighters have extensive periods of stress-free activities, but during an emergency there is an abrupt increase in energy demand. If they have proper physical fitness conditioning, their ability to conduct a rescue mission and increase recovery from firefighting in hazardous situations encountered such as climbing over debris and entering burning buildings, and reduced the risk of injury. If firefighters exhibit low physical conditioning, this could jeopardize safety when performing fire suppression responsibilities, which may occur with deconditioning due to the lack of continued testing that is seen at present, but due to change in June 2024.

Despite varying physical demands and vocational needs, monitoring muscular strength and power is essential for all tactical populations, specifically for firefighters that are often ascending and descending stairwells (London is becoming increasingly populated with high rise buildings), as well as carrying heavy equipment and/or victims (5,6,7,10). Human performance monitoring involves evaluating program efficiency and efficacy at the macro level, ensuring that training prescriptions and adaptations sought are met (7). A specific performance entity that can be measured that identifies the efficiency of the lower limbs within the kinetic chain while performing work is RSI. RSI measures the limb's ability to exert force from the eccentric to the concentric phases of muscle contraction, as explained extensively by Wilson and Flanagan (11).

A positive link is seen with higher RSI scores that attain superior endurance performance through a lower energy cost or a more significant overall distance traveled (7,11). Another critical performance factor for high scores of RSI is the increased ability to create safer change of direction (COD). High COD ability is essential when having to negotiate through buildings that may be littered with debris and uneven surfaces while filled with smoke and wearing heavy PPE. High RSI demonstrates the ability to facilitate energy preservation using elastic energy storage with the use of plyometrics (stretch-shortening cycle [SSC]). Without sacrificing strength gains, plyometric training is superior to resistance training in terms of enhancing power, jump, and stair climbing performance. While this type of training appears doable, it can carry a higher risk of injury that should be considered when creating programs for older and less experienced firefighters and physiological monitoring is required to ensure safe and effective application is ensured (12).

Merrigan et al. identified the effects of Newton's laws of motion on military personnel and their importance on performance and injury risk reduction (7). Such as improving leg strength and maintaining body mass, which can aid a person in accelerating and decelerating from ground reaction forces (GRFs). By observing Newton's Third Law of Motion, which asserts that "every action has a corresponding and opposing reaction," depicting the interaction between the body's muscle forces and opposing external forces (7). An example is during a drop jump protocol (Figure 1), a high-intensity plyometric exercise where the legs push back against the GRF when contact is made, propelling the body up.

RSI

All the performance factors affected by RSI scores can be attributed to the tasks involved in firefighter duties, from exiting the fire engine in an emergency (known as appliances or pumps in the UK) onto hard and uneven surfaces to rushing to secure equipment. High RSI thresholds would increase the physiological effectiveness of the firefighter when operating in highly hazardous environments, decreasing fatigue and injury risk. When ascending and descending stairwells while wearing heavy equipment, carrying hoses, lifting victims to safety, or breaking through obstacles, a high RSI threshold would potentially decrease muscular fatigue to counteract the eccentric forces met when stepping down (12).

In other athletic populations, female collegiate volleyball players who demonstrated lower RSI scores are linked to an increased likelihood of a non-contact lower limb injury; however, this outcome was not shared by the male volleyball players in the study by Brumitt et al (1). The outcome also suggested that further studies are necessary to confirm this preliminary result and assess RSI's suitability as a screening tool for sport and tactical populations.

TESTING RSI AND PROGRAMMING

GRFs can be measured using relatively inexpensive jump mats with the height (m) divided by contact time (s) from a drop jump of varying heights to land and rebound (Figure 1). Although force plates are the preferred choice for sports scientists and researchers, due to the complexity of software and data extrapolation and high prices, jump mats are ideal for tactical facilitators as they are inexpensive and easy to use. Testing at differing heights of the step-off should be 10, 20, and 30 cm to determine the thresholds of reactive strength training (2,11). Step heights of fire engines in the UK are 20 cm apart and 30 cm from the lower step to the floor, and the step height in private buildings are generally between 15 – 22 cm.

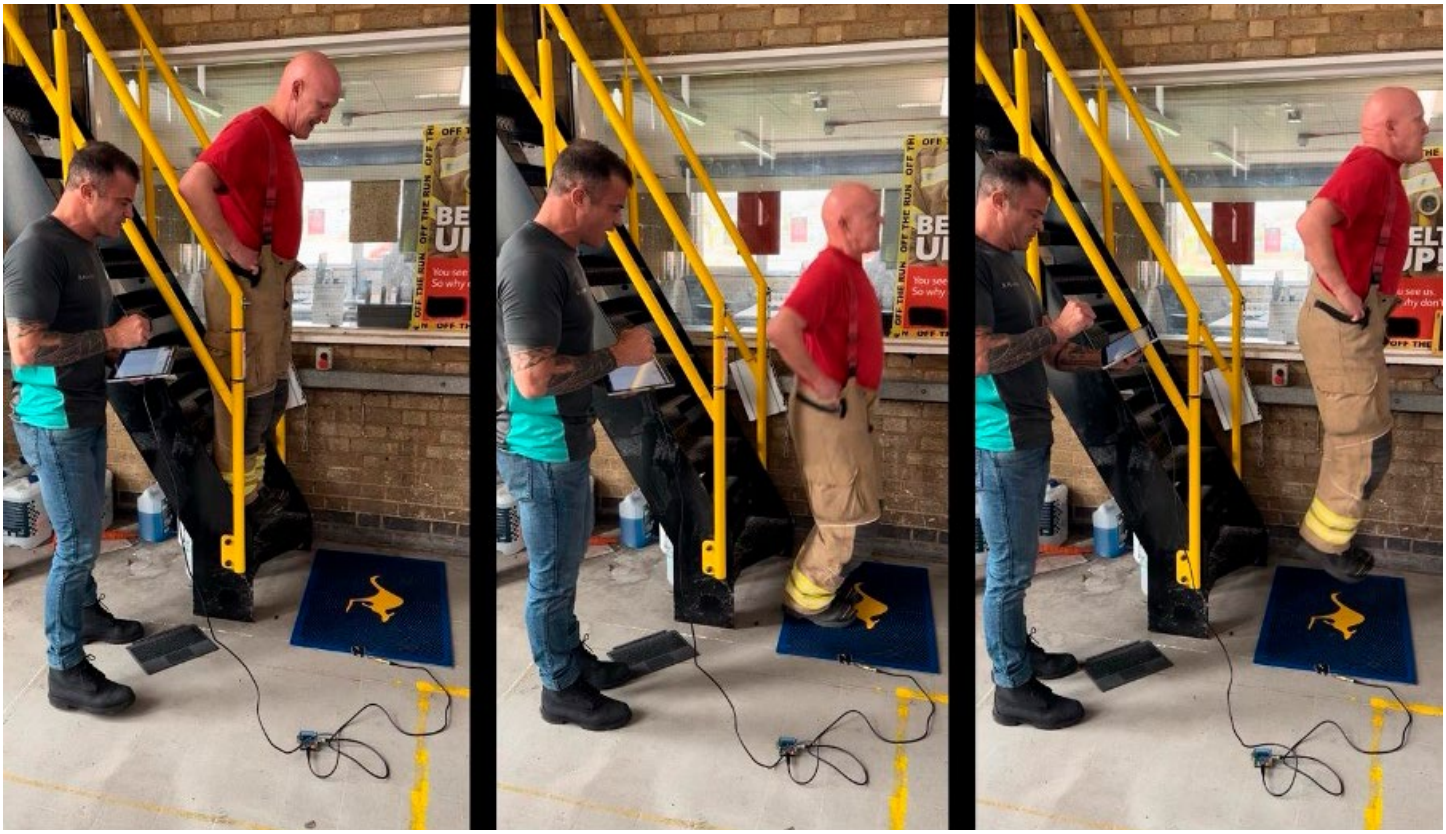

FIGURE 1. EXAMPLE OF DROP TEST PROTOCOL

The firefighter is performing the drop jump test protocol, stepping from 30 cm onto the jump mat (Chronojump, Spain), and rebounding on contact with hands placed on hips.

TABLE 1. SUGGESTED PROGRAMMING FOR PROGRESSION TO SAFELY INCREASE RSI CAPABILITY (2)

RSI SCORE	Plyometric Type	Strength Type	a) Frequency b) Intensity c) Volume
RSI <1.5	Light bounding Skipping rope Half squat jump (>0.25 s contact time on rebound)	Developmental base strength: squats, lunges, and calf raises	a) 2 per week b) Light c) Moderate
RSI 1.5 – 2.0	Lateral hops Pogo jumps	Increase in strength development	a) 2 – 3 per week b) Moderate c) Low to moderate
RSI 2.0 – 2.5	Depth/drop jumps Pogo jumps	Extensive strength training and ability to increase height on drop jumps	a) 2 – 3 per week b) Moderate to heavy c) Low to moderate
RSI 2.5 – 3.0	Multiple depth jumps to box jump combination. Hurdle jumps: determine height based on contact time. If the contact time is longer than 0.25 s for the rebound, decrease height. Weighted rebound jumps.	The maintenance level of reactive strength attained the possibility of diminishing returns if the intensity is increased	a) 2 per week b) Moderate to heavy c) Moderate
RSI >3.0	Altitude drops Weighted drops and rebounded jumps	Exceptional athletic capability with minimal potential for improvement	a) 2 per week b) Heavy c) Low

Use <0.25 s on contact time for high-intensity exercises but prolonged contact time for low RSI (<1.5)

Thresholds identified to determine RSI ability found that those with scores <1.5 have low reactive strength ability and may be unprepared for high-intensity plyometrics while those with scores >3.0 are world-class athletes with slight potential for improvements in reactive strength training (2). The tactical facilitator should appropriately govern the intensity of the programming to the specificity of the needs and capability of the firefighter (Table 1). Low thresholds (<1.5) suggest the development of baseline strength is warranted. When the intensity of the jumps and explosive rebound activities are too high, with too little rest and too much volume, the outcome may cause musculoskeletal (MSK) injuries such as tendinopathies (2).

CONCLUSION

Although many other variables are attributed to a firefighter's physical readiness than RSI alone, such as core strength, endurance, and technical and tactical training, RSI can substantially determine readiness and injury risk reduction. RSI can be monitored by trained strength and conditioning coaches integrated into the fire service or consultants to design appropriate programs to aid and assist firefighting personnel readiness. The work of a firefighter is both arduous and hazardous. Firefighter safety is paramount to being an effective lifesaving service that works to save victims from danger. Operational duties can be lengthy, with exhaustion being the critical detriment to performance and precursor for increased injury risk. Therefore, strength should be placed in high importance when prescribing training programs. RSI levels should be observed and included in the needs analysis of program construction, where the musculotendinous units can be trained to save energy when performing tasks (1).

Like other tactical populations, firefighters often will not have the luxury of a warm-up prior to needing to move explosively. Still, high RSI capability may offset strains, sprains, and muscle tears, as well as increase firefighter readiness to deploy to more optimal operational standards. Increasing strength and power enhancement will decrease injury and improve performances, and more research is being published showing the positive effects of plyometrics to decrease falls and injury risk. However, as there is a dearth of research on RSI's ability to assess for injury prediction, researchers and practitioners should further develop a better understanding of how this tool could be used for such purposes to reduce injury risk.

REFERENCES

1. Brumitt, J, Dorociak, R, Dunn, S, Critchfield, C, Benner, J, and Cuddeford, T. Lower preseason reactive strength index scores are associated with injury in female collegiate volleyball players but not male collegiate basketball players. *Journal of Science and Medicine in Sport* 24(6): 549-554, 2021.

2. Flanagan, E. The reactive strength index was revisited. *Train With Push*. 2016.

3. Frost, DM, Beach, TA, Callaghan, JP, and McGill, SM. Exercise-based performance enhancement and injury prevention for firefighters: Contrasting the fitness-and movement-related adaptations to two training methodologies. *Journal of Strength and Conditioning Research* 29(9): 2441-2459, 2015.

4. Haynes, J. *Personal communication.* Utilization of the Chester treadmill test. May 24, 2024.

5. Kesler, RM, Horn, GP, Rosengren, KS, and Hsiao-Wecksler, ET. Analysis of foot clearance in firefighters during ascent and descent of stairs. *Applied Ergonomics* 52: 18-23, 2016.

6. Melton, BF, Ryan, G, Snarr, RL, Weeks, M, Langford, E, and Villafuerte, M. 2023. Fitness policies within the fire service: A pilot investigation of exercise adherence on fitness outcomes among rural firefighters. *American Journal of Lifestyle Medicine* 17(3): 437-442, 2023.

7. Merrigan, JJ, Stone, JD, Martin, JR, Hornsby, WG, Galster, SM, and Hagen, JA. Applying force plate technology to inform human performance programming in tactical populations. *Applied Sciences* 11(14): 6538, 2021.

8. Payne, N, and Kinman, G. Job demands, resources and work-related well-being in UK firefighters. *Occupational Medicine* 69(8-9): 604-609, 2019.

9. Rhea, MR, Alvar, BA, and Gray, R. Physical fitness and job performance of firefighters. *Journal of Strength and Conditioning Research* 18(2): 348-352, 2004.

10. Stevenson, RD, Siddall, AG, Turner, PF, and Bilzon, JL. Physical employment standards for UK firefighters: Minimum muscular strength and endurance requirements. *Journal of Occupational and Environmental Medicine* 59(1): 74-79, 2017.

11. Wilson, JM, and Flanagan, EP. The role of elastic energy in activities with high force and power requirements: A brief review. *Journal of Strength and Conditioning Research* 22(5): 1705-1715, 2008.

12. Van Roie, E, Walker, S, Van Driessche, S, Delabastita, T, Vanwanseele, B, and Delecluse, C. An age-adapted plyometric exercise program improves dynamic strength, jump performance and functional capacity in older men either similarly or more than traditional resistance training. *PloS One* 15(8): e0237921, 2020.

LEE BROWN, MSC, CSCS, CSPS, TSAC-F, RSCC,
AND SCOTT CAULFIELD, MA, CSCS,*D, TSAC-F,*D, RSCC*E

ABOUT THE AUTHORS

Lee Brown is currently working towards a PhD by publication of "Practical Application of Strength and Conditioning Preparation for Muay Thai Coaches and Athletes." He has experience with professional sports and tactical populations, such as the British Parachute Regiment and the London Fire Brigade. He holds the Certified Strength and Conditioning Specialist® (CSCS®) and Registered Strength and Conditioning Coach® (RSCC®) certifications through the National Strength and Conditioning Association (NSCA). Brown is also a Registered Clinical Physiologist (RCCP), Registered Clinical Exercise Physiologist and Chartered Scientist through the British Association of Sport and Exercise Sciences (BASES), and a senior lecturer at the University of East London in high performance sports. More recently, he has been working with Parkinson's United Kingdom on research that involves hypoxia and exercise. One of his roles is to oversee the working laboratory with clients and scholars at the human performance center. After recently opening a clinical physiology practice, Brown works mainly with neuro patients, as well as overseeing clients with cancer, metabolic, and cardiac conditions.

Scott Caufield oversees, develops, and manages strength and conditioning programs for 600+ student-athletes at Norwich University in 22 Division III varsity athletic programs. He guides Reserve Officers' training Corps (ROTC) leadership and cadets in best practices in strength and conditioning and manages the annual strength and conditioning plan for the Norwich Ranger Company. Caulfield is the National Strength and Conditioning Association Foundation (NSCAF) Vice President and the State Director for NSCA Vermont. He holds a Bachelor's degree in Physical Education from Castleton University and a Master of Arts degree in Sports Coaching from the University of Denver.