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Post-activation Potentiation for Firefighter Daily Preparedness

Nick Curtis
nicholas.curtis1516@gmail.com

CONCORDIA UNIVERSITY, ST. PAUL

ST. PAUL, MINNESOTA

DEPARTMENT OF KINESIOLOGY AND HEALTH SCIENCES

Post-activation Potentiation for Firefighter Daily Preparedness

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NICHOLAS CURTIS

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Abstract

Firefighters commonly face dangers that call upon numerous energy systems to achieve fireground objectives. If firefighters could be put in a state of greater physical activation, then it may be possible to achieve better outcomes regarding speed and safety of objective completion. Post-activation potentiation (PAP) is a possible mechanism for achieving this readiness state that translates to firefighter activity. This paper is going to investigate whether a low volume, but high-power exercise routine will reduce time to completion of fireground simulating tasks such as a stair climb, charged hose line advance, and victim drag. Pre-intervention data will be collected before the firefighters are randomly divided into control and experimental group. Pre and post scores data will be analyzed. If PAP is successful at potentiating the firefighter's neuromuscular readiness, then time to completion times should improve in the experimental group. This could have great benefits to improving firefighter performance and safety on the fireground, and future studies should examine the length of lasting effect with different PAP protocols.

Chapter 1: Introduction

Firefighting is a physically demanding job which calls upon numerous energy systems to effectively achieve objectives (Abel et al., 2015). A study by Le et al. (2020) consisting of 914 firefighters identified that 54.1% of non-fatal injuries were due to overexertion or "bodily reaction," such as sprains and strains. This is similar to past studies that found musculoskeletal injury rates of 31% in data from firefighters across the country (Campbell & Evarts, 2021). During the most dangerous aspects of the job, strength and power output by firefighters is especially called upon to perform the movements needed to escape from escalating conditions or successfully complete tasks (Abel et al., 2015). Examples of critical lifesaving movements include dragging a person from a burning building, forcible entry, and hose line advance (Abel et al., 2015). Further, firefighters are tasked with performing in a high force and power capacity at a moment's notice and sometimes multiple times a shift (Abel et al., 2015). A state of neurological readiness would be advantageous for a firefighter to help transfer them from a rested physical and psychological state to intense and active states. Post-activation potentiation (PAP) could be one potential facilitator that helps firefighters achieve maximal strength and power performance on the job.

PAP has been defined by Robbins (2005) as a phenomenon by which the force exerted by a muscle is increased due to its previous contraction. Typically, PAP protocols consist of completing exercises close to a one rep max (1RM) or completing many reps at lower weight but at high velocity (Garbisu-Hualde & Santos-Concejero, 2021). The use of PAP is well documented in the literature including both meta-analysis and systemic reviews that have demonstrated its effectiveness at creating benefits for explosive performance in quick succession, five-30 minutes, to facilitate the primary activity (Dobbs et al., 2019; Gouvea et al., 2013;

Krzysztofik et al., 2020). Though less voluminous, literature has also begun to show benefits of PAP for greater periods of time following the potentiating activity, in the range of six to 48 hours later (Chen et al., 2011; Chiu et al., 2003; Cook et al., 2014; Ekstrand et al., 2013; Tsoukos et al., 2018). The mechanisms of this phenomenon have been hypothesized, but there is still not a clear cause for the effects of PAP for either short-term or long-term benefits. Potential mechanisms may include changes to Musculo-tendinous stiffness, the release of hormones like testosterone, velocity specificity principles, and other neurological stimulation effects (Chiu et al., 2004; Cook et al., 2014; Elkstrand et al., 2013; Tsoukos et al., 2015).

Research has demonstrated that PAP can be effective at eliciting benefits in activities such as the drop jump (DJ), countermovement jump (CMJ), back squat, vertical jump, and sprinting (Chiu et al., 2004; Cook et al., 2014; Elkstrand et al., 2013; Tsoukos et al., 2015). These activities are commonly selected since they are examples of strength or power measurements. Similarly, firefighting requires the ability to produce not only great force but often great force at high velocity (Abel et al., 2015). Abel et al. (2015) demonstrated the association of firefighter tasks and the energy system they use. Examples of tasks requiring force production (phosphagen system) include hose line advances, forcible entry, and ladder raises, while strength and power is needed for victim drags and equipment carries (Abel et al., 2015). An increase in firefighters' readiness for high intensity work at any moment will likely reduce the risk of injury and death not only for the firefighters but the civilians they are tasked with helping (Schmit & Debeliso, 2019). It may also improve outcomes for firefighters and the public, such as improved response time, improved water on fire time, and improved primary search complete time. (Schmit & Debeliso, 2019).

The literature has already demonstrated the need for improved physical fitness in the firefighting industry (Le et al., 2020; Poston et al., 2011). Peate et al. (2007) also identified that when a fitness program was designed specifically around strengthening the pelvis, trunk, and spine in firefighters, the injury risk decreased 42% and the time lost to injury was decreased 62%. Further, the need for improving firefighter fitness is highlighted by the development of fireground simulating exercise and testing of firefighter preparedness (Pawlak et al., 2015; Schmit & Debeliso, 2019). These fireground simulating gauntlets have been validated for their ability to simulate true fireground conditions and the physiologic demand a firefighter experiences while working on a structure fire (Gledhill & Jamnik, 1992). A recent study by Schmit & Debeliso (2019) used a simulated firefighting tasks and demands battery with the tasks validated by Gledhill & Jamnik's (1992) original work. These tasks were specifically selected since they are common fireground tasks and provide testing of both the aerobic and anaerobic systems (Schmit & Debeliso, 2019). These tasks included weighted stair climb with a high-rise pack, charged hose advance, and victim drag (Gledhill & Jamnik, 1992; Schmit & Debeliso, 2019). Considering these activities have been validated to represent the physiologic demand of the fireground, it is these tasks that should be used to demonstrate the effectiveness of PAP on firefighter performance.

The purpose of this study is to assess the efficacy of a pre-shift exercise routine to induce PAP and therefore enhance the performance of firefighters during fireground operations. PAP introduced by specific pre-shift exercise should create enhanced short-term and long-term performance of fireground tasks compared to non-potentiated firefighters. This should therefore result in reduced time to completion of the stair climb (SC), charged hose advance (CHA), and

victim drag (VD) to provide overall better outcomes such as reduced injury, quicker task completion and property protection, and less line of duty deaths.

Chapter 2: Methodology

Participants

The participants for this study will be firefighters selected from the Bloomington municipality which includes six fire stations. The firefighters will be either volunteer firefighters qualified as interior firefighters or career firefighters and must have been working for one of the fire departments in the municipality for at least one year. In either case, the firefighters will be required to have a physical on file that they have passed, including the typical required annual physical to assess fitness for duty. Volunteer firefighters become qualified for interior firefighting by taking and passing the Firefighter-One and Firefighter-Two courses (Department of Public Safety, 2017). These qualifications ensure the firefighter is licensed to enter burning structures and will be performing the tasks that are being highlighted in this study. The age range includes firefighters between 20 and 50 years old. According to data released on the ages of firefighters in the United States, this age range will include 71% of all firefighters by age and excludes age ranges from 16-19 and 51-60 (Fahy, 2021). This will include about one standard deviation (68%) worth of firefighters by age that are currently involved in firefighting and more likely to be actively fighting fires (National Fire Protection Agency, 2021). Exclusion criteria include firefighters who have recently suffered any injuries that limit their ability to perform firefighting tasks, resistance training tasks, or creates pain to perform these activities. Also, exclusion will include any firefighters who have already done or do PAP type activity before shift work. Recruitment will take place through emails sent out from each station's Chief that describes the purpose and procedures of the study.

Training history, weight, height, and gender will be assessed verbally, while BMI will be calculated with the equation: Kg/m^2 (kilograms of body weight divided by firefighter body surface area in meters squared) (Schmit & DeBelso, 2019). Training history will be divided into beginner/untrained if the firefighter has not been training more than two times a week for the past two months (Baechle, 1989). If the firefighter has been training for the last two-six months at a rate of greater than or equal to two times a week, they will be considered in the trained category (Baechle, 1989). Training history is important since it has been demonstrated to influence PAP effectiveness in both short-term and long-term studies (Garbisu & Santos, 2021; Gouvêa et al., 2013; Lagrange et al., 2020). By including training history in the randomization process, it will help reduce skewed results that become possible if one group consists of more trained firefighters than the other.

The sample sizes were calculated to include 29 firefighters in each group based off a power of 0.80 and an effect size derived from Ekstrand et al. (2013), calculated at 0.664 for backwards overhead shot-put throws six hours after a training regime. The Ekstrand et al. (2013) study was used since it looked at PAP effectiveness for both upper body and lower body potentiation as this study will be doing. In this study, 30 firefighters will set as the goal sample size for each study group, for a total of 60 participants.

IRB approval will be needed before initiation of the study and firefighter recruitment. Informed consent will need to be provided by all firefighters after an in-person group presentation to the firefighters that allows time for individual questions and conversation. No financial compensation is offered, and all participation will be voluntary.

Instruments

Firefighter Personnel Protection Equipment (PPE). Firefighter PPE consists of boots, gloves, hoods, turnout jackets, helmets, and pack with air tank weighing approximately 22.7kg (Schmit & DeBelso, 2019). Firefighters should wear the equipment issued to them by their fire department. By equipping the firefighters in full turnout gear during testing, the conditions are set to mimic true firefighting operations.

Stair climb (SC). A stopwatch is needed for timing of the stair climb, victim drag, and charged fire hose advance. A recommended stopwatch is the ACCUSPLIT Pro Survivor-A601X (Accusplit Inc., Pleasanton, California, USA). Following the study done by Schmit & DeBelso (2019), the high-rise pack for the stair climb will consist of two lengths of fire hose (2.5-inch diameter) weighing approximately 18.1 kg, along with full firefighter PPE. Access to at least one flight of stairs is needed. The firefighters will ascend six flights of stairs either all at once or accumulatively. The firefighters will descend the same number of flights. Instructions will be to ascend and descend six flights of stairs (72 steps) as quickly as possible. When the firefighters have finished the time will be noted, starting when the firefighter takes his first step with the equipment on their shoulder and ending when the firefighter places both feet on the ground after the last step (Schmit & Debelso, 2019). This activity mimics common fireground work and assesses the oxidative system. (Abel et al., 2015; Schmit & DeBelso, 2019). The SC test is used to assess the effect of PAP on the oxidative system.

Charged Hose Advance (CHA). Two links of 50ft, $1^{3}/_{4}$-inch diameter fire hose is needed with access to a hydrant and enough space to stretch 30m of charged hose. The firefighter will be wearing full PPE while picking up the hose and stretching it 30m. The time will start when firefighter takes his first step with the nozzle over his shoulder and end when the firefighter has

both feet over the 30m line (Schmit & DeBelso, 2019). This exercise works to mimic another common fireground task and assesses capability of the firefighters phosphagen system (Abel et al., 2015; Schmit & DeBelso, 2019). This activity is used to assess the ability of PAP to potentiate the phosphagen system.

Victim Drag (VD). A designated dummy is needed with recommendation of the "Rescue Randy" weighing 84kg. The firefighters need access to 30m of space to drag the dummy while wearing full PPE and is timed. The firefighters will be instructed to drag the dummy as fast as they can. Instructions are given to lift the dummy off the ground and wrap under the arms and around it's torso. The time starts when the firefighter takes their first step backwards with the dummy raised and ends when they place both feet past the 30m mark (Schmit & DeBelso, 2019). This activity mimics common fireground tasks and assesses the glycolytic capability of the firefighters (Abel et al., 2015; Schmit & DeBelso, 2019). This activity is used in the study to assess PAP in potentiating the glycolytic system.

PAP Routine and Testing. The 1RM back squat and bench press will need power racks, benches, weight plates and barbells. A recommendation is Hammer Strength (Life Fitness, Franklin Park, IL, USA) equipment as used by Schmit & DeBelso (2019). Since the firefighters have a mixed training history, the Brzycki method of calculating the 1RM will be used to limit chances of injury (Brzycki, 1993). The Brzycki equation is as follows:

$$\text{Predicted 1RM} = \text{Weight Lifted} / 1.0278(0.0278x),$$

where x= reps completed (Brzycki, 1993). The Brzycki method has been shown to be reasonably accurate at calculating 1RM bench press in untrained and trained athletes compared to other methods (Mayhew et al., 1995). The PAP routine will also be utilizing the same power racks, benches, barbells, and weights.

Procedures

The firefighters will be randomly selected for groups by assigning random numbers between zero and one to each firefighter using excel (Microsoft Corporation, Redmond, WA, USA). The numbers can then be ranked in order from largest to smallest. The smaller value half of ranked firefighters will be placed into the experimental group and the greater value half of ranked firefighters will be placed in the control group. The firefighters will be pair-matched by age, gender, and training history.

To gather baseline measurements, all the firefighters will gather to complete a standardized warmup. The warmup will follow that of Schmit & DeBelso (2019) which focused on preparing the firefighters for the same movements being done in the present investigation. The warmup will consist of inch worm to upward and downward dog, single leg hip hinge, walking forward lunge with overhead reach, leg swings, walking knee hugs, dynamic quad pull, bodyweight squats, and side to side lunges with each movement being done for five repetitions on each side (if applicable) before moving to the next (Schmit & DeBelso, 2019). Next, the firefighters will complete the firefighter specific tasks for baseline measurements. The order of the tasks will be SC, CHA, and VD for standardization and reproducibility with ten minutes rest in-between tasks. This same sequence and timing will be done for post-test measurements. The time for each firefighter will be recorded.

Three days later (at least 72 hours), the firefighters will complete their 1RM testing for the back squat and bench press. The same standardized warmup that was used before testing the back squat 1RM in each firefighter. The firefighters will then work up to a weight that brings them to exhaustion at the point of completing 5 reps (Brzycki, 1993). The Brzycki equation will then be applicated to estimate a 1RM for the back squat. Next, the firefighters will rest for a

three-minute interval before moving to the bench press and beginning working up to a weight that they felt could bring them to exhaustion before reaching 10 reps. After completing as many reps as possible with the weight, the Brzycki equation will be applied to calculate the 1RM for the bench press.

The firefighters will wait one full week before returning, now randomized, to do post-tests. The firefighters are instructed to not train 48 hours before testing, which mimics the instructions given by Lagrange et al. (2020). The control group and experimental group will complete the same standardized warmup. The experimental group will then complete a PAP protocol while the control group waits eight minutes to begin the retesting of SC, CHA, and VD. The firefighters in the experimental group will start by doing a PAP specific warm up of back squats for one set at 40% of the calculated 1RM with a tempo of 2-2-2 (2 seconds eccentric, 2 seconds isometric at the bottom, and 2 seconds concentric). Then, one will be completed at 60% 1RM for four reps without the tempo. The last warm up set is done at 80% for two reps and no tempo. The firefighters will then complete jump squats (JS) for three sets of four reps at 40% of their standard back squat 1RM. The emphasis is placed on the speed of the lift and height of the jump. Three minutes rest will be given between sets. The same format will be used for bench press. The bench press will be done with emphasis on speed and explosiveness in the concentric muscle action phase for three sets of four reps at 40% of their standard bench press 1RM. The choice for low volume but high-power resistance training is due to the work by Tsoukos et al. (2018) that demonstrated better recovery and improved force production compared to heavy PAP protocols. After completing the PAP protocol, the experimental group will wait eight minutes before completing the fireground simulating tasks. Eight minutes was chosen based off Gilbert & Lees (2006) work identifying that potentiation may peak after eight minutes.

Design and Statistical Analysis

The study design is a pre-post design with an intervention of a PAP protocol. The participating firefighters will be volunteers and stratified by age, gender, and training history. The analysis for the main question will use a factorial ANOVA to determine if differences existed between groups and within groups at the pre and posttests. Alpha is set at .05 and will be calculated for both groups pre and post-test. A post-hoc test can be done on any significant findings. The dependent variable is time to completion of the firefighter tasks (SC, CHA, and VD) and the independent variable is the implementation of the PAP protocol.

Ethical Considerations

The firefighters in this study will be asked to complete demanding physical tasks that are designed to mimic the intensity of a fireground. For this reason, there is inherent risk of over-exertion and cardiovascular injury, heat related illnesses, and musculoskeletal injury such as sprains and strains. Although these risks are real, there is less risk than a true fireground considering there is no direct danger from fire or visual impairment. Therefore, the study design does not ask the firefighters to do anything more than is required of their profession on duty and in training.

Chapter 3: Discussion (Conclusion and Practical Application)

Outcomes

There are two potential outcomes for this research paper. If the PAP protocol proves effective, then experimental group firefighters would show improved time to completion of the stair climb, charged hose advance, and victim drag compared to their baseline testing and the control group. Research has indicated improved power and performance output in both short-term and long-term time frames, ranging from 4 minutes to 48 hours post protocol (Gouvêa et al., 2013; Tsoukos et al., 2018). If the statistical analysis indicates improvements in performance for the experimental group, then we have identified that firefighting tasks can be potentiated by weight room exercises in the short term. Further research should focus on identifying the best PAP protocol for eliciting potentiation in firefighters. Also, further research could focus on testing long term effectiveness of PAP over time periods like that of a firefighters shift length, 12-24 hours. If the results show no improvement between baseline and PAP tests or detrimental effects in the PAP group, then we cannot conclude that firefighter tasks can be potentiated by weight room exercises in the short term. Research that has shown inconsistent findings in the effectiveness of PAP highlights the balance between fatigue from the PAP protocol and the recovery period as an important contributing factor (Tillin & Bishop, 2009). Further research would need to focus on justifying and applying other PAP protocols and recovery periods for testing.

Limitations

This study has limitations that prevent it from being of immediate use to firefighters. First, the time effects of PAP are being studied in short term succession to completion of the

PAP protocol. The reason for this is to see if the principles of PAP can be applied to dynamic, real-life activities found on firegrounds. To the authors knowledge, previous studies have not been done to explore the use of PAP to enhance performance of firefighter specific activities. In reality, firefighters are typically on shift for 24 hours at a time and this study does not measure the effects of PAP over this length of time (U.S. Bureau of Labor Statistics, 2022).

A second limitation is due to the study design. Neither the groups nor the data collectors were blinded to the group pairs. This limitation leads to potential placebo effects if the experimental group un-consciously begins performing with more effort after the intervention compared to baseline. Also, the control group could be left unmotivated to give the same effort as they did at the baseline considering that they have not been given the same treatment or attention as the experimental group.

Last, this study includes mixed training histories, ages, and genders. This is representative of the general firefighter population, but there may be some fire stations that have highly trained firefighters of largely median age, or some firehouses may be all volunteer with minimal to no exercise training and largely consisting of older members (Fahy et al., 2021). Studies have documented that training history plays a role in response to PAP, which may limit the usefulness of this study to only fire departments who are well mixed in training history or have a majority of firefighters that can be considered “trained” (Jo et al., 2010).

Recommendations for Further Research

In the future, research should continue experimenting with different PAP protocols to determine a routine that works best for firefighting tasks. In this study, a low volume, power type exercise protocol was proposed that focused on high velocity movements. Seitz & Haff (2016) have described differences in performance benefits from different intensities and exercise types.

It may be useful for future research to use this information to create a different PAP protocol to test on firefighters. If this study identifies that the PAP protocol is effective, future studies may want to use this model for long duration testing as well. This PAP model has displayed efficacy proved efficacy in delayed improvements to explosive performance by Tsoukos et al (2018) and cold be an ideal fit. Research has demonstrated that potentiating out to the 24-hour mark, and even 48-hour mark is possible (Chen et al., 2011; Chiu et al., 2003; Cook et al., 2014; Ekstrand et al., 2013; Tsoukos et al., 2018). It will be important for future researchers to be cognizant of the short-term detriments that can occur with PAP protocols if the intensities or volumes are too great (González, 2016). A middle ground may need to be achieved to get PAP lasting to 24 hours without creating significant detriment in the earlier hours of the shift.

Conclusion

The aim of this study is to determine if PAP can be effectively used to enhance performance of fireground tasks. If positive results are found with this study and future research, it could have a profound effect on the role of the firefighter. By establishing effectiveness of PAP on firefighting tasks and the ability of PAP to endure for the duration of a firefighter's shift, protocols can then be taught to firefighters across the country that can potentially reduce injuries and help the firefighter be better prepared to protect themselves and the communities they serve.

References

Abel, M. G. , Palmer, T. G. & Trubee, N. (2015). Exercise program design for structural firefighters. *Strength and Conditioning Journal, 37*(4), 8-19. https://doi.org/10.1519/ssc.0000000000000123

Baechle, T. (1989). *Essentials of strength training and conditioning* (4th ed.). Human Kinetics.

Brzycki, M. (1993). Strength testing-predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88-90 https://doi.org/10.1080/07303084.1993.10606684

Campbell, R. & Evarts, S. (2021). United States firefighter injuries. National Firefighter Protection Agency. https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Emergency-responders/osffinjuries.pdf

Chen, J., Yeh, D., Lee, J., Chen, C., Huang, C., Lee, S., Chen, C., Kuo, T. B. J., Kao, C., & Kuo, C. (2011). Parasympathetic nervous activity mirrors recovery status in weightlifting performance after training. *Journal of Strength and Conditioning Research, 25*(6), 1546-1552. https://doi.org/10.1519/JSC.0b013e3181da7858

Chiu, L. Z., F., Fry, A. C., Schilling, B. K., Johnson, E. J., & Weiss, L. W. (2004). Neuromuscular fatigue and potentiation following two successive high intensity resistance exercise sessions. *European Journal of Applied Physiology, 92*(4-5), 385-392. https://doi.org/10.1007/s00421-004-1144-z

Cook, C. J., Kilduff, L. P., Crewther, B. T., Beaven, M., & West, D. J. (2014). Morning based strength training improves afternoon physical performance in rugby union players. *Journal of Science and Medicine in Sport, 17*(3), 317-321. https://doi.org/10.1016/j.jsams.2013.04.016

Department of Public Safety - State Fire Marshal Division. (2017). *Firefighter training in Minnesota*. Minnesota Management and Budget. https://www.mbfte.org/Forms/WebsiteMenu/FTR2017.pdf

Dobbs, W., Tolusso, D., Fedewa, M., & Esco, M. (2019). Effect of postactivation potentiation on explosive vertical jump: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research, 33*(7), 2009-2018. https://doi.org/10.1519/jsc.0000000000002750

Durand, G., Tsismenakis, A. J., Jahnke, S. A., Baur, D. M., Christophi, C. A., & Kales, S. N. (2011). Firefighters' physical activity. *Medicine & Science in Sports & Exercise, 4* (9), 1752-1759. https://doi.org/10.1249/mss.0b013e318215cf25

Ekstrand, L. G., Battaglini, C. L., McMurray, R. G., & Shields, E. W. (2013). Assessing explosive power production using the backward overhead shot throw and the effects of morning resistance exercise on afternoon performance. *Journal of Strength and Conditioning Research, 27*(1), 101-106. https://doi.org/10.1519/jsc.0b013e3182510886

Fahy, R., Evarts, B., & Stein, G. P. (2021). *US fire department profile*. National Fire Protection Association. https://www.nfpa.org/News-and-Research/Data-research-and-tools/Emergency-Responders/US-fire-department-profile

Garbisu-Hualde, A., & Santos-Concejero, J. (2021). Post-activation potentiation in strength training: A systematic review of the scientific literature. *Journal of Human Kinetics*, *78*(1), 141–150. https://doi.org/10.2478/hukin-2021-0034

Gilbert G, & Lees A. (2006). Changes in the force development characteristics of muscle following repeated maximum force and power exercise. *Journal of Sports Sciences*, *24*(6), 635–636. https://doi.org/10.1080/00140130500101163

Gledhill, N., & Jamnik, V. K. (1992). Characterization of the physical demands of firefighting. *Canadian Journal of Sports Science*, *17*(3), 207-213. https://doi.org/10.1249/00005768-198004001-00032

González-Badillo, J. J., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas, J., López-López, C., Mora-Custodio, R., Yañez-García, J. M., & Pareja-Blanco, F. (2016). Short-term recovery following resistance exercise leading or not to failure. *International Journal of Sports Medicine*, *37*(4), 295–304. https://doi.org/10.1055/s-0035-1564254

Gouvêa, A. L., Fernandes, I. A., César, E. P., Silva, W. A., & Gomes, P. S. (2013). The effects of rest intervals on jumping performance: A meta-analysis on post-activation potentiation studies. *Journal of Sports Sciences*, *31*(5), 459–467. https://doi.org/10.1080/02640414.2012.738924

Jo, E., Judelson, D. A., Brown, L. E., Coburn, J. W., & Dabbs, N. C. (2010). Influence of recovery duration after a potentiating stimulus on muscular power in recreationally trained individuals. *Journal of Strength & Conditioning Research*, *24*(2), 343–347. https://doi.org/10.1519/jsc.0b013e3181cc22a4

Krzysztofik, M., Wilk, M., Stastny, P., & Golas, A. (2020). Post-activation performance enhancement in the bench press throw: A systematic review and meta-analysis. *Frontiers in Physiology*, *11*, 598628. https://doi.org/10.3389/fphys.2020.598628

Lagrange, S., Ferland, P. M., Leone, M., & Comtois, A. S. (2020). Contrast training generates post-activation potentiation and improves repeated sprint ability in elite ice hockey players. *International Journal of Exercise Science*, *13*(6), 183–196.

Le, A., McNulty, A., Dyal, A., DeJoy, M., & Smith, D. (2020). Firefighter overexertion: A continuing problem found in an analysis of non-fatal injury among career

firefighters. *International Journal of Environmental Research and Public Health*, *17*(21), 7906. https://doi.org/10.3390/ijerph17217906

Linnamo, V., Hakkinen, K., & Komi, P. (1998). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading (Fatigue neuromusculaire et recuperation suite a des charges de forces explosives par rapport a des forces maximales). *European Journal of Applied Physiology*, *77*(1–2), 176–181. https://doi.org/10.1007/s004210050317

Mayhew, J. L., Prinster, J. L., Ware, J. S., Zimmer, D. L., Arabas, J. R., & Bemben, M. G. (1995). Muscular endurance repetitions to predict bench press strength in men of different training levels. *Journal of Sports Medicine and Physical Fitness*, *35*(2), 108–113. https://doi.org/10.1519/1533-4287(1995)009<0099:mertpb>2.3.co;2

Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2015). Considerations for determining the time course of post-activation potentiation. *Applied Physiology, Nutrition & Metabolism*, *40*(11), 1163–1170. https://doi.org/10.1139/apnm-2015-0175

Pawlak, R., Clasey, J. L., Palmer, T., Symons, T. B., & Abel, M. G. (2015). The effect of a novel tactical training program on physical fitness and occupational performance in firefighters. *Journal of Strength and Conditioning Research*, *29*(3), 578-588. https://doi.org/10.1519/jsc.0000000000000663

Peate, W. F., Bates, G., Lunda, K., Francis, S., & Bellamy, K. (2007). Core strength: A new model for injury prediction and prevention. *Journal of Occupational Medicine and Toxicology (London, England)*, *2*, 3. https://doi.org/10.1186/1745-6673-2-3

Poston, W. S., Haddock, C. K., Jahnke, S. A., Jitnarin, N., Tuley, B. C., & Kales, S. N. (2011). The prevalence of overweight, obesity, and substandard fitness in a population-based

firefighter cohort. *Journal of Occupational and Environmental Medicine*, *53*(3), 266–273. https://doi.org/10.1097/JOM.0b013e31820af362

Robbins, D. W. (2005). Postactivation potentiation and its practical applicability: A brief review. *Journal of Strength and Conditioning Research, 19*(2), 453-458. https://doi.org/10.1519/R-14653.1

Schmit, M., & Debeliso, M. (2019). The relationship between firefighters' physical performance characteristics and simulated firefighting demands. *Turkish Journal of Kinesiology, 5*(2), 63-75. https://doi.org/10.31459/turkjkin.560623

Seitz, L., & Haff, G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Medicine*, *46*(2), 231–240. https://doi.org/10.1007/s40279-015-0415-7

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports medicine (Auckland, N.Z.), 39*(2), 147–166. https://doi.org/10.2165/00007256-200939020-00004

Tsoukos, A., Veligekas, P., Brown, L., Terzis, G., & Bogdanis, G. (2018). Delayed effects of a low-volume, power-type resistance exercise session on explosive performance. *Journal of Strength and Conditioning Research, 32*(3), 643-650. https://doi.org/10.1519/jsc.0000000000001812

U.S. Bureau of Labor Statistics. (2022, April 18). *Firefighters: Occupational outlook handbook*. https://www.bls.gov/ooh/protective-service/firefighters.htm#:%7E:text=Work%20Schedules,or%2072%20hours%20off%20duty.