International Journal of EXERCISE SCIENCE

Original Research

The Impact of External Loads Carried by Police Officers on Vertical Jump Performance

AMY WILEY†[1], AARON JOSEPH†[1], ROBIN ORR‡[1,2], BEN SCHRAM‡[1,2], CHARLES L. KORNHAUSER‡[3], RYAN J. HOLMES‡[3], AND J. JAY DAWES‡[4]

[1] Bond Institute of Health and Sport, Bond University Gold Coast QLD 4229, AUSTRALIA; [2] Tactical Research Unit, Bond University, Gold Coast QLD 4229, AUSTRALIA; [3] Colorado State Patrol Training Academy, Golden, CO, USA; [4] Oklahoma State University, Oklahoma, UNITED STATES

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(6): 1179-1189, 2020. The purpose of this study was to examine the impact that external loads have on vertical jump height and peak anaerobic power output (PAPw) of police officers during a vertical jump (VJ) test. Retrospective data of 47 (mean age 38.79 ± 7.97 years) police officers from a US Law Enforcement Agency (LEA) were used for analysis. VJ heights and body mass were used in the Sayers Peak Power Equation to calculate PAPw. Power-to-weight (P:W) ratios were then calculated by dividing PAPw by the officer's body mass. VJ height significantly ($p < .001$) decreased with load (unloaded = 49.49 ± 8.46 cm: loaded = 43.62 ± 7.68 cm). A Pearson's correlation showed a significant ($p < .01$) low-moderate ($r = .387$) relationship between absolute load (9.57 ± .94 kg) and change in PAPw, and a significant ($p < .01$) strong ($r = .794$) correlation between relative load and changes in P:W. This study supports previous research that suggests that occupational load carriage has a negative impact on VJ performance in police officers and may influence job performance, and that training programs may mitigate these negative effects.

KEY WORDS: Tactical; law enforcement; police recruit; power; body armor

INTRODUCTION

Police officers have a sworn duty to serve and protect the citizens of their community (34). To accomplish this duty, officers are trained to quickly engage in mentally and physically demanding activities often in response to a critical threat (34). These activities may include pursuing fleeing suspects, arresting non-cooperative suspects, breaking up fights, making entries during search warrants, and lifting objects of substantial weight (7, 33). In order to successfully complete such tasks and limit the risk of injury, officers require adequate leg power (26, 37).

Research has also shown that power is a critical component in allowing tactical personnel to perform the short-duration, high-intensity tasks that are essential to their profession (27, 33). A study by Dawes et al (7) demonstrated a correlation between vertical jump (VJ) performance (a surrogate measure of power (18, 26)) and an officer's ability to sprint short distances. These findings were supported by the previous works of Marques who observed significant, moderate to strong correlations between VJ Scores and 5m and 30m sprint times (22, 23). Apart from performance impacts, a recent study by Orr et al (26) looked at leg power as an indicator of a police recruit's risk of injury or illness during recruit training. Their findings showed that lower VJ scores were associated with decreased overall fitness, greater levels of fatigue, and an increased risk of injury and/or illness (26). When fatigue increases, as a result of repeated physical activities throughout the day, officers are placed at an even greater risk (28). Consequently, the VJ has been suggested as a screening tool for police recruits, with the expectation of limiting the number of injured or sick recruits during basic training (26). In essence, it is imperative that police officers have the ability to generate power, whether it be to potentially reduce their risk of injury (26) or to sprint and seek cover in high risk situations (10). Considering this requirement, a notable occupational factor that may have a negative impact on the ability of police officers to generate power is the equipment they are required to wear (5).

The equipment carried by police officers when on duty is required to help protect themselves and the community (5, 35). This equipment includes, but is not limited to, a ballistics vest, duty belt, handcuffs, Taser, baton, radio, flashlight, tactical boots, extra magazines, and a department issued side arm. The weight of this equipment for general police officers can be up to 10kg with specialist units carrying loads of more than 20kg (1, 2). The weight of this equipment is believed to negatively impact the ability to pursue and apprehend a suspect (2, 35) significantly reduce the performance of break contact, fire and movement, combat-rush simulations (16, 36), and VJ (11, 14, 36) and increase times of both short distance sprints (17, 36) and the agility run (9, 24).

Considering the importance of power for police safety and performance and the negative impact imparted by the loads they must carry, there is limited known research specifically investigating the impact of a police officer's load on their ability to generate power. As such, the aim of this study was to identify the impact that external loads have on the leg power of police officers using a VJ Test.

METHODS

Participants

Retrospective data representing the results of 53 (male n = 44: female n = 9) officers from a US Law Enforcement Agency (LEA) were provided. Healthy (or 'full duty status') law enforcement officers who were currently serving within the LEA were randomly selected to participate using a random number generator. Data for five of the 44 male officers and one of the nine female officers were incomplete or contained inaccurate data and were consequently excluded from analysis. The data for 47 officers (male n = 39; female n = 8), were analysed for this study (Table 1). All data were made non-identifiable prior to the researchers receiving it. The University of Colorado–Colorado Springs Institutional Review Board (IRB 15-074) and the Bond University Human Research Ethics Committee approved this archival data study (RO1927). This study and subsequent manuscript met the standards on ethical issues relating to scientific discovery in exercise science (25).

Table 1. Descriptive characteristics of participants by cohort and by sex.

	Cohort Mean ± SD (Range)	Male Mean ± SD (Range)	Female Mean ± SD (Range)
Age (years)	38.79 ± 7.97 (22 – 66)	38.36 ± 8.06 (22-66)	40.88 ± 7.68 (25-50)
Height (cm)	177.45 ± 8.36 (156.21 – 195.58)	179.53 ± 6.95 (165.10 – 195.58)	167.32 ± 7.49 (156.21 – 177.80)
Weight (kg)	88.61 ± 19.44 (51.71 – 154.59)	91.35 ± 18.20 (66.04 – 154.58)	75.22 ± 20.95 (51.71 – 118.16)
Absolute load (kg)	9.57 ± .94 (7.08 – 12.02)	9.61 ± .97 (7.08 – 12.02)	9.34 ± .81 (8.26 – 10.70)
Relative load (% body weight)	11.19 ± 2.14 (5.93 – 17.02)	10.82 ± 1.87 (5.93 – 14.56)	13.00 ± 2.56 (8.41 – 17.02)

Protocol

During the unloaded condition, participants wore daily training athletic wear, including footwear. For the loaded condition, each participant wore all of the equipment they would routinely wear whilst on duty, which included uniform, belt, boots, weapon, handcuffs, and Personal Protective Equipment (PPE) (10). Results were recorded in pounds before being converted to kg. Relative load was then calculated for each participant.

Participant lower-body muscular power was determined using a VJ test. The VJ is both a valid and reliable measure commonly used to determine leg power (18, 26) and features in many testing batteries as a way to indirectly measure the leg power of police personnel (3, 4, 8). The test took place in a standard indoor gym facility with wood flooring. Scores were measured using a Just Jump (ProBotics Inc, Huntsville, AL) electrical contact operated system. The Just Jump is a 27-in x 27-in mat and it calculates jump height by measuring vertical displacement time, or the amount of time a subject's feet are not in contact with the mat. Before commencing testing, all participants performed a 3-5-minute self-selected warm-up. No familiarization tests were conducted for this assessment as all participants had conducted this test previously as part of their yearly fitness assessment or academy entrance standard. Each participant was instructed to step onto the mat, and when ready execute a squat jump with an arm-swing and jump as high as possible (Figure 1). All participants were allowed no less than 10 sec. and up to 30 sec. rest between each jump. Participants were given three attempts and the highest jump height was utilized for the purposes of this study. The highest jump height was used as this represented the maximum ability of the officer during the assessment. This result was then converted to cm. This was done in both the unloaded and loaded condition with the unloaded condition conducted first. The unloaded VJ was performed first to limit the number of uniform changes due to time restraints and out of convenience for the officers.

Figure 1. Officer performing the vertical jump.

Statistical Analysis

The retrospective non-identifiable data were provided in a Microsoft Excel datasheet (Microsoft Excel version 15.41). Prior to transferring the data into the IBM Statistical Package for the Social Sciences, absolute and relative loads were determined. In this study absolute loads were defined as being the total amount of load the officer was carrying irrespective of personal body weight, and relative load was defined as the amount of load the officer was carrying in relation to their body weight (32). Absolute loads were determined by subtracting the officer's fully loaded weight from their unloaded weight. Relative loads were determined by dividing the absolute load carried by the officer's unloaded weight and multiplying the result by 100 to give a percentage value. To calculate the peak power output of each participant the Sayers Peak Power Equation (31) ($Peak\ power\ (Watts) = 60.7 \bullet jump\ height(cm) + 45.3 \bullet body\ mass(kg) - 2055$) was used. When calculating peak power for a VJ, the Sayers equation has been found more valid than the protocols described by Harman and more accurate than those of Lewis (5). Peak power output and body mass were then used to find power-weight ratios for each participant.

Descriptive analysis (means and standard deviations) of the data as a cohort and by sex were performed followed by paired sample t-tests, which were used to determine if there was a significant difference in VJ performance between the load conditions. Independent t-tests were conducted to see if there were differences in the impact of load between males and females. Differences in VJ performance (loaded VJ – unloaded VJ) were then compared to both absolute (loaded – unloaded weight) and relative ([loaded – unloaded weight]/unloaded weight *100) loads using Pearson's Correlations, done by cohort and by sex. Alpha levels were set at 0.05 a priori.

RESULTS

Participants jumped higher in the unloaded condition compared to the loaded condition, with a statistically significant (t(46) = 14.635, $p \leq .001$) mean difference of 5.87 (± 2.75) cm. This significance was found when accounting for sex (male mean difference = 6.07 ± 2.98 cm, $p \leq .001$: female mean difference = 4.92 ± .62 cm, $p \leq .001$) (Table 2). Peak anaerobic power output (PAPw) was significantly (t(46) = -2.945, $p = .005$) lower during the unloaded condition as compared to the loaded condition (mean difference of -76.80 ± 178.82 W). This significance was found when accounting for sex (male mean difference = -67.06 ± 193.72 W, $p = .037$: female mean difference -124.31 ± 57.50 W, $p \leq .001$). Power to weight ratios (P:W) were higher for the unloaded condition compared to the loaded condition, with a statistically significant (t(46) = 14.42, $p \leq .001$) mean difference of 5.02 (± 2.39 W/kg). Significant differences between load conditions were also found when accounting for sex (male mean difference = 5.12 ± 2.51 W/kg, $p \leq .001$: female mean difference = 4.52 ± 1.67 W/kg, $p \leq .001$).

Table 2. Mean data ± SD for the unloaded and loaded VJ, PAPw and P:W.

	Unloaded	Loaded
VJ (cm):		
Cohort	49.49 ± 8.46	43.62 ± 7.68†
Male	51.39 ± 7.50	45.32 ± 6.78†
Female	40.22 ± 6.79	35.31 ± 6.54†
PAPw (W):		
Cohort	4963.02 ± 879.17	5039.83 ± 913.92**
Male	5202.74 ± 708.75	5269.80 ± 773.37*
Female	3794.38 ± 686.64	3918.69 ± 714.72†
P:W (W/kg):		
Cohort	56.67 ± 6.41	51.66 ± 4.93†
Male	57.72 ± 6.12	52.60 ± 4.58†
Female	51.56 ± 5.52	47.03 ± 4.04†

Note. Indicates statistically significant difference between unloaded and loaded condition, *$p \leq .05$, **$p \leq .01$, †$p \leq .001$.

The change found in VJ height between the unloaded and loaded conditions was greater in males than in females, with a statistically significant (t(45) = -1.077, $p = .005$) mean difference of -1.15 (± 1.07) cm. (Table 3). The change found in PAPw between the unloaded and loaded conditions was less in males compared to females, with a statistically significant (t(45) = -.822, $p = .026$) mean difference of -57.25 (± 37.09 W). There were no significant differences ($p = .73$) found between males and females for absolute load or relative load and changes in P:W.

Table 3. Mean data ± SD of the difference between unloaded and loaded conditions by sex.

	Males	Females
Δ VJ (cm)	-6.07 ± 2.98	-4.92 ± .62**
Δ PAPw (W)	67.06 ± 193.72	124.31 ± 57.50*
Δ P:W (W/kg)	-5.12 ± 2.51	-4.53 ± 1.67

Note. Indicates statistically significant difference between males and females, *$p \leq .05$, **$p \leq .01$.

A weak positive but not significant correlation (r = .159, p = .285) was found between absolute load and changes in VJ; however, a moderate negative and significant correlation (r = -.341, p = .034) was found between relative load and changes in VJ for males only. There was a moderate positive and significant correlation (r = .387, p = .007) found between absolute load and changes in PAPw. A similar correlation was found for males (r = .400, p = .012) and for females (r = .766, p = .027) (Table 4). A strong positive correlation (r = .794, $p \leq .001$) was found between relative load and changes in P:W, with this trend also found for males (r = .748, $p \leq .001$) and for females (r = .857, p = .007) when viewed by sex independently (Table 4).

Table 4. Correlations of power performance and load condition.

	Absolute Load	Relative Load
Δ VJ:		
Cohort	.159	-.211
Male	.186	-.341*
Female	.195	-.128
Δ PAPw:		
Cohort	.387**	-.164
Male	.400*	-.243
Female	.766*	-.361
Δ P:W:		
Cohort	-.210	.794**
Male	-.093	.748**
Female	-.763*	.857**

Note. Indicates a statistically significant correlation, *$p \leq .05$, **$p \leq .01$.

DISCUSSION

The purpose of this study was to identify the impact that external loads have on the leg power of police officers, using a VJ Test. VJ height, PAWw, and P:W were all significantly affected in the loaded condition. Males showed a greater change in VJ, PAPw, and P:W (W/kg) than females. However, only females had a statistically significant change in VJ and PAPw between the unloaded and loaded conditions. A weak negative correlation was found between absolute load and changes in VJ, a moderate negative correlation between absolute load and changes in PAPw, and a strong positive correlation between relative load and changes in P:W.

The VJ height of the cohort when unloaded was 49.49 (± 8.46) cm, which was comparable to the findings of research in other tactical populations, most notably law enforcement (Dawes et al (5) (55.40 ± 6.7 cm), Dempsey et al (11) (46.94 ± 7.6 cm), Lewinski et al (17) (54.0 ± 1.0 cm), Crawley et al (4) (57.1 ± 12.1 cm), Cocke et al (3) (55.32 ± 10.68 cm)), and military populations (Hunt et al (15) (55.6 ± 6.8 cm)). Dawes et al (5), Dempsey et al (11), Lewinski et al (17), and Hunt et al (15) tested males exclusively, which may have resulted in the higher average jump means. Cocke et al (3) analyzed data from 70 males and 20 females; however, jump means were reported as a whole cohort and not separated by sex. Crawley et al (4) found a higher average jump height for 61 males participants (59.1 ± 11.1 cm), but similar jump height for 7 females (39.9 ± 4.5 cm). Given the similarity of the unloaded jump heights in the law enforcement population reported in this study, the transferability of findings to other law enforcement populations is encouraging.

VJ height was reduced on average by 12% when wearing 9.57 (± .94) kg of additional load. These results were consistent with the findings of Dempsey et al (11) who reported a 13% decrease in jump performance with a load of 7.65 kg and Holewijn and Lotens (14) who found a 27% loss of performance when wearing a 16 kg vest. Lewinski et al (17), who reported unloaded and loaded jump scores for descriptive purposes only, found a 17% decrease in jump performance with a load of 9.07 kg. Taylor et al (36) compared four tiers of loaded conditions (tier-one 21.6 kg, tier-two 25.0 kg, tier-three 26.0 kg, tier-four 29.2 kg) and found no significant decrease in jump performance between each of the four tiers; however, a significant decrease was observed between each tier and the control group (19.1 kg), with no comparison to an unloaded condition reported. Regardless of different loads and different populations, even the relatively light loads carried by police (when compared to the military from which most research is drawn) can have a negative impact on VJ performance.

Even though jump performance decreased, the ability to generate lower leg power during a VJ, calculated using the Sayers equation, increased significantly from the unloaded to the loaded condition ($p \leq .005$). This could potentially be due to an acute neuromuscular potentiation effect in response to the additional load placed on the musculoskeletal system of the officers. A study by Weber et al (38) found acute potentiation of muscle power in the lower limbs of participants after performing a heavy-load back squat. While post activation potentiation (PAP) typically refers to the enhanced neuromuscular state that is observed directly after a bout of heavy resistance exercise that may increase acute gains in muscular power during an explosive power exercise (38), the simple addition of additional load to the body may have increased potentiation. This premise is supported, for example, by the actions of Pacinian corpuscles which respond to compression and pressure within joints and increase action potentials when stimulated (21). The same hypothesis may be used to explain why PAPw was greater during the loaded VJ than the unloaded VJ. Since females were carrying a greater relative load than males, the significant increase in PAPw seen in females compared to males may also be caused by this potentiation.

The negative impact that load has on measures of power is important to understand when discussing the ability of police officers to run and seek cover. Studies by Hunt et al (16), Taylor et al (36), and Hasselquist et al (13) reported a significant decrease in 30 m sprint performance when loaded, and supports that police officers require more time to reach safety when carrying occupational loads. The relationship between jump performance and sprint performance has also been supported by the works of Dawes et al (5), Marques et al (22, 23), and Wisløff et al (39). In 2004, Wisløff et al (39) found a moderate to strong correlation between VJ and 10 m (r = .72, $p \leq .01$) and 30 m sprint time (r =.60, $p \leq .01$). Later in 2011, Marques et al (22) who found a significant moderate to strong relationship between VJ performance and 5 m sprint (r = -.664 to -.801, $p \leq .01$), and in 2014 (23) found a significant moderate relationship between VJ concentric peak power and 30 m sprint time (r =-.688 , $p \leq 0.05$). These findings are further supported by Dawes et al (5) who found a significant moderate to strong relationship between jump performance and forward linear speed over 5 m (r = -.572, $p \leq .001$), 10 m (r = -.608, $p \leq .001$), and

20 m (r = -.602, $p \leq .001$). This relationship is important because training and conditioning programs that focus on increasing lower limb power, through jump performance, may play a huge role in the enhancing an officer's ability to move quickly over short distances to seek cover (5).

It has been reported that police officers suffer the greatest number of injuries to the upper limb, compared to other tactical populations, like the military, who suffer more injuries to the lower limb (20). With police officers now becoming more paramilitary and beginning to wear body armour more frequently (10), police uniforms may start to resemble that of military personnel more closely than in the past, and as a result officers could suffer a higher number of lower limb injuries. Lower VJ scores have also been associated with a greater risk of injury (26). Rodacki et al (30) found the decreases in VJ performance were directly linked with knee extensor muscle fatigue, and Fallowfield et al (12) used a VJ test pre- and post a load carriage march and found that lower limb power was significantly less after completing the march. These findings are supported by Pope (28) who reported that risk of injury increases as a result of repeated exposure to physical activities. To reduce the risk of injury, it has been suggested that the VJ test be used as a screening tool for police recruits (26). Furthermore, the authors suggest that officers aim to increase lower-body power to counteract the deleterious effects associated with increased load carriage.

Females were more affected by absolute loads in the VJ, PAPw, and P:W than males. Lyons et al (19) and Ricciardi et al (29) both found that subjects with a higher body fat percentage had reduced aerobic capacity and load carriage task performance ability (p = .01). Studies by Dawes et al (6, 8) reported a significant negative correlation between VJ height and body fat percentage (r = -.566, $p \leq .001$) and fat mass (r = -.369, $p \leq .001$), and a significant positive correlation between VJ height and lean mass (r = .391, $p \leq .001$). This could be because a VJ requires strength as well the ability to lift one's entire body mass off of the ground, and the increased lean mass appeared to generate an adequate increase in leg power to overcome the additional mass (8). Ricciardi et al (29) also reported that when participants were wearing relatively light loads of 10 kg, the amount of body fat of males (17 %) and females (26 %) negatively correlated (r = −0.88; $p \leq .001$) with the physical task performance. Due to females generally having a significantly higher body fat percentage than males, it has been argued that lean body mass should be used instead of overall body mass when calculating 'relative loads' since lean mass is directly responsible for force generation (32).

The findings of this study highlight the need for strength and conditioning programs that concentrate on increasing the lower limb power of police officers. When wearing external loads for an extended amount of time (during work shifts), greater fatigue may ensue. As such, increasing lower-body power capacity is important due to the unpredictable nature of when officers must perform lower-body power activities and the cost of wearing PPE may cause significant fatigue (e.g., a foot pursuit at the end of a shift). Subsequently, improving VJ and lower-body power-capacity is important to create a larger lower-body power reserve.

ACKNOWLEDGEMENTS

The authors would like to thank the officers that participated in this study.

REFERENCES

1. Baran K, Dulla J, Orr R, Dawes J, Pope R. Duty loads carried by the LA sheriff's department deputies. Journal of Australian Strength and Conditioning 26(5): 34-38, 2018.

2. Carlton SD, Orr R, Stierli M, Carbone PD. The impact of load carriage on mobility and marksmanship of the tactical response officer. Journal of Australian Strength and Conditioning 22(1): 23-27, 2013.

3. Cocke C, Dawes J, Orr RM. The use of 2 conditioning programs and the fitness characteristics of police academy cadets. J Athl Train 51(11): 887-896, 2016.

4. Crawley AA, Sherman RA, Crawley WR, Cosio-Lima LM. Physical fitness of police academy cadets: baseline characteristics and changes during a 16-week academy. J Strength Cond Res 30(5): 1416-1424, 2016.

5. Dawes JJ, Orr R, Elder C, Krall K, Stierli M, Schilling B. Relationship between selected measures of power and strength and linear running speed amongst special weapons and tactics police officers. Journal of Australian Strength and Conditioning 23(3): 23-28, 2015.

6. Dawes JJ, Orr R, Elder C, Rockwell C. Association between body fatness and measures of muscular endurance among part-time SWAT officers. Journal of Australian Strength and Conditioning 22(4): 33-37, 2014.

7. Dawes JJ, Orr R, Flores RR, Lockie RG, Kornhauser C, Holmes R. A physical fitness profile of state highway patrol officers by gender and age. Ann Occup Environ Med 29(1): 16-26, 2017.

8. Dawes JJ, Orr RM, Siekaniec CL, Vanderwoude AA, Pope R. Associations between anthropometric characteristics and physical performance in male law enforcement officers: a retrospective cohort study. Ann Occup Environ Med 28: 26-32, 2016.

9. De Maio M, Onate J, Swain D, Morrison S, Ringleb S, Naiak D. Physical performance decrements in military personnel wearing personal protective equipment (PPE). Naval Medical Center. Virginia, VA, USA 2009.

10. Dempsey PC, Handcock PJ, Rehrer NJ. Impact of police body armour and equipment on mobility. Appl Ergon 44(6): 957-961, 2013.

11. Dempsey PC, Handcock PJ, Rehrer NJ. Body armour: the effect of load, exercise and distraction on landing forces. J Sports Sci 32(4): 301-306, 2014.

12. Fallowfield JL, Blacker SD, Willems ME, Davey T, Layden J. Neuromuscular and cardiovascular responses of Royal Marine recruits to load carriage in the field. Appl Ergon 43(6): 1131-1137, 2012.

13. Hasselquist L, Bensel CK, Corner B, Gregorczyk KN, Schiffman JM. Understanding the physiological, biomechanical, and performance effects of body armor Use. Army Natick Soldier Research Development and Engineering Centre, MA, USA. 2008.

14. Holewun M, Lotens WA. The influence of backpack design on physical performance. Appl Ergon 35(2): 149-157, 1993.

15. Hunt AP, Orr RM, Billing DC. Developing physical capability standards that are predictive of success on Special Forces selection courses. Mil Med 178(6): 619-624, 2013.

16. Hunt AP, Tofari PJ, Billing DC, Silk AJ. Tactical combat movements: inter-individual variation in performance due to the effects of load carriage. Ergon 59(9): 1232-1241, 2016.

17. Lewinski WJ, Dysterheft JL, Dicks ND, Pettitt RW. The influence of officer equipment and protection on short sprinting performance. Appl Ergon 47: 65-71, 2015.

18. Lockie RG, Murphy A, Knight T, de Jonge X. Factors that differentiate acceleration ability in field sport athletes. J Strength Cond Res 25(10): 2704-2714, 2011.

19. Lyons J, Allsopp A, Bilzon J. Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. Occup Med 55(5): 380-384, 2005.

20. Lyons K, Radburn C, Orr R, Pope R. A profile of injuries sustained by law enforcement officers: A critical review. Int J Environ Res Public Health 14: 142, 2017. doi:10.3390/ijerph14020142.

21. Marieb EN, Hoehn K. Human anatomy & physiology 7th Edition. Pearson Education; 2007.

22. Marques MC, Gil H, Ramos RJ, Costa AM, Marinho DA. Relationships between vertical jump strength metrics and 5 meters sprint time. J Hum Kinet 29(1): 115-122, 2011.

23. Marques MC, Izquierdo M, Ferraz R, Carneiro AL, González-Badillo JJ. Force plate vertical jump measurements and 30 m sprint performance in trained athletes: A short report. Int J Sports Med 15(1): 77-83, 2014.

24. Martin PE, Nelson RC. The effect of carried loads on the combative movement performance of men and women. Mil Med 150(7): 357-362, 1985.

25. Navalta JW, Stone WJ, Lyons S. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

26. Orr R, Pope R, Peterson S, Hinton B, Stierli M. Leg power as an indicator of risk of injury or illness in police recruits. Int J Environ Res Public Health 13: 237, 2016. doi:10.3390/ijerph13020237

27. Peterson MD, Dodd DJ, Alvar BA, Rhea MR, Favre M. Undulation training for development of hierarchical fitness and improved firefighter job performance. J Strength Cond Res 22(5): 1683-1695, 2008.

28. Pope R. Prediction and prevention of lower limb injuries and attrition in army recruits. Doctoral Thesis, Charles Sturt University; 2002.

29. Ricciardi R, Deuster PA, Talbot LA. Effects of gender and body adiposity on physiological responses to physical work while wearing body armor. Mil Med 172(7): 743-748, 2007.

30. Rodacki ALF, Fowler NE, Bennett SJ. Vertical jump coordination: Fatigue effects. Med Sci Sports Exerc 34(1): 105-116, 2002.

31. Sayers S, Harackiewicz DV, Harman E, Frykman P, Rosenstein M. Cross-validation of three jump power equations. Med Sci Sports Exerc 31(4): 572-577, 1999.

32. Scott PA, Ramabhai L. Comparison of male and female responses to carrying absolute and relative loads while on a three-hour military march. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 44(17): 161-164, 2000.

33. Shephard R, Bonneau J. Assuring gender equity in recruitment standards for police officers. Can J Appl Physiol 27: 263-295, 2002.

34. Sorensen L, Smolander J, Louhevaara V, Korhonen O, Oja P. Physical activity, fitness and body composition of Finnish police officers: a 15-year follow-up study. Occup Med 50(1): 3-10, 2000.

35. Stubbs D, David G, Woods V, Beards S. Problems associated with police equipment carriage with body armour, including driving. In Contemporary Ergonomics 2008: Proceedings of the International Conference on Contemporary Ergonomics (CE2008), 1-3 April 2008, Nottingham, UK (p. 23). CRC Press.

36. Taylor NA, Burdon CA, van den Heuvel AM, Fogarty AL, Notley SR, Hunt AP, Billing DC, Drain JR, Silk AJ, Patterson MJ, Peoples GE. Balancing ballistic protection against physiological strain: evidence from laboratory and field trials. Applied physiology, nutrition, and metabolism 41(2): 117-124, 2016.

37. Warfe PG, Jones DD, Prigg SK. Developing injury prevention strategies for the Australian Defence Force. J Mil Veterans Health 19(3): 45-49, 2011.

38. Weber KR, Brown LE, Coburn JW, Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. J Strength Cond Res 22(3): 726-730, 2008.

39. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 38(3): 285-288, 2004.