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*Original Research*

# Comparable Acute Metabolic Responses when Walking with Blood Flow Restriction and Walking with Load Carriage: Implication for Tactical Professionals

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ABSTRACT

***International Journal of Exercise Science 16(2): 304-314, 2023.*** The current study aimed to investigate exercise with blood flow restriction (BFR) as a low-intensity conditioning strategy in tactical professionals with load carriage. During the low-intensity exercise, researchers examined the acute metabolic responses from low-intensity BFR walking, walking with load carriage, and walking with BFR and load carriage. Twelve healthy adult males (age = 21.8 ± 1.5 yrs, height = 181.3 ± 7.2 cm, body mass = 84.4 ± 11.1 kg and BMI = 25.6 ± 2.6 kg·m$^2$) completed five bouts of 3-min treadmill walking at 4.8 km·h$^{-1}$ with 1-min rest interval under three different conditions: 1) blood flow restriction (BFR), 2) loaded with 15% of body mass (LOAD) and 3) loaded with 15% of body mass with blood flow restriction (BFR-LOAD). Oxygen consumption ($\dot{V}O_2$), heart rate, and local muscle oxygen saturation was measured during the exercise bouts. $\dot{V}O_2$ increased by 7% during the BFR- LOAD ($p$ = 0.001) compared with BFR or LOAD alone. There were no differences in $\dot{V}O_2$ between BFR and LOAD ($p$ = 0.202). BFR-LOAD showed significantly lower (-9%) muscle oxygen saturation ($p$ = 0.044) and deoxygenated hemoglobin ($p$ = 0.047) compared to LOAD. Low-intensity walking with the addition of BFR shares acute metabolic characteristics similar to walking with a load. These characteristics suggest there is potential for the use of BFR to increase exercise intensity for individuals training with load carriage.

KEY WORDS: Oxygen consumption, muscle oxygen saturation, KAATSU, exercise

## INTRODUCTION

One critical problem within the tactical professionals' (i.e., military, firefighters, law enforcement) specialized environment is the challenging complexities of load carriage. Load carriage takes the form of duty gear, equipment, weapons, body armor, and protective gear (15, 19, 31) and can range from 7 - 60 kg depending on specific occupations and operations conducted (8, 25). For instance, military operations in remote combat locations often burden service members with an average load of 30 kg on the modern battlefield (25). Similarly, law enforcement and firefighters work with fatiguing ranges of load carriage from 7 - 25 kg while performing various physically demanding occupational tasks (9, 16, 31).

Although the additional load is required for protection and combat-related activities, the added mass also has consequences. Musculoskeletal injuries account for 31% of medical evacuations and treatment for military non-battle-related injuries on deployments (25) and result in over 1.3 million medical visits in active duty soldiers each year (26). Similarly, there is a higher risk of injury when deployed soldiers and police officers wear load carriage for four hours or longer (8, 32). The load carriage endured by these professionals has also been found to alter biomechanical functionality (15, 19), and injuries similar to those experienced in athletics can adversely affect tactical professionals' mobility, readiness, and effectiveness in the unit (25, 27, 28). More importantly, recruits into a tactical population with lower levels of physical fitness are at an increased risk for injuries during initial training (23, 38).

The combination of the accumulated duration of wear, distance traveled, and increased weight carried leads to increased injury risk, as observed with higher training loads with tactical professionals (34). Injuries to the lower back and lower limbs pose significant issues during load carriage. Research suggests that more specific, individualized, and tailored physical training for each tactical professional is needed (28). Specific and tailored physical training programs that include load could improve aerobic fitness, muscular strength, and endurance (3, 14, 28). Thus, using low-intensity training methods to accustom individuals to additional load carriage requirements and physical conditioning in a progressive manner may be beneficial.

Recently, blood flow restriction (BFR) has become a novel accessory for various exercise training modes (13, 20, 35). Blood flow restriction is performed by applying pressurized cuffs to the proximal portion of the extremity to maintain arterial inflow while reducing venous return (2). For aerobic training exercises with BFR, such as cycling, rowing, and walking, the intensity is similar to the lighter workloads (using 20-40% of $\dot{V}O_{2max}$) (2, 7, 20, 29). BFR conducted with low-intensity aerobic exercise training (e.g., walking, cycling) has shown a significant increase in cardiac performance, metabolism, and muscular strength (1, 2, 7, 29). In a BFR training study with collegiate male basketball players, the athletes performed a two-week walking low-intensity interval training program (two sessions/day, six days/week; in total, 24 sessions), and investigators found an increase in $\dot{V}O_{2max}$ by 11.6% (29). These data show empirical support as a plausible training method for tactical professionals, especially with the addition of load carriage, while gaining strength, hypertrophy, and program optimization (5, 6, 21). Therefore, the purpose of this study was to compare metabolic responses of load carriage while walking with and without BFR.

## METHODS

*Participants*

An *a priori* power analysis using statistical software (G*power VA 3.1.9.7) determines an adequate sample size. Based on previous work using $\dot{V}O_2$ as a dependent variable between conditions with and without BFR over five intervals resulted in $\eta^2 = 0.2$. To obtain a minimal sample size number, the following parameters were used: Repeated measures analysis of variance, $f = 0.50$, $\alpha = 0.05$, $1\text{-}\beta = 0.95$. The power analysis resulted in a sample size of 12 for adequate power. The researchers compared sample size based on previous studies that noted a significant difference between conditions between using BFR and no BFR (6, 22, 30, 36). In agreement with previous literature, a sample of 12 healthy males (age = 21.8 ± 1.5 yrs, height = 181.3 ± 7.2 cm, mass 84.4 ± 11.1 kg and BMI 25.6 ± 2.6 $kg{\cdot}m^2$) were recruited and completed this study. The participants were recreationally active as defined by completing both aerobic (3-5 days a week) and resistance training (one to two days a week) for at least the past six months, meeting ACSM physical activity guidelines (17). Participants self-reported their current level of physical fitness over the previous six months on a 0-15 physical activity rating (PA-R) scale (10).

Additionally, the participants were familiar with or had experience with load carriage through duty gear, body armor, or backpack wear. The North Dakota State University Institutional Review Board # HE18106 approved all the procedures in the study. Participants were informed of the benefits and risks of the study before signing the informed consent document. This research was carried out following the ethical standards of the International Journal of Exercise Science (24).

This investigation was a randomized crossover design with all participants completing all conditions. Participants came to the lab for two separate visits and were instructed to: (1) not exercise for 24 h before each testing visit; (2) not consume caffeine within 8 h of the testing visit; and (3) not to consume food within 2 h of each testing visit. During the first visit, participants completed paperwork to determine exclusion criteria.

Participants were excluded from the study if: 1) they did not meet the required physical activity criteria; 2) they had any previous injuries in their neck, back or legs; 3) they were taking any medications for high blood pressure/hypertension; 4) if determined they had any known or major signs of cardiovascular, pulmonary, metabolic diseases or have two or more major coronary risk factors, or other reasons needing a medical clearance from the Health History Questionnaire. Participants had their risk for deep venous thrombosis (DVT) assessed using the DVT Risk Assessment tool (4), excluding those above low risk.

*Protocol*

The first session included walking with BFR familiarization (BFR). Researchers conducted BFR through compression cuffs controlled by the Kaatsu device (Kaatsu Nano, Sato Sports Plaza, Tokyo, Japan). Before the Kaatsu walk training, researchers placed the specially designed cuffs (50 mm wide) around the most proximal portion of each leg. During the first visit, researchers familiarized participants with the Kaatsu leg cuffs by conducting a Kaatsu (pressure) cycle with the device. The Kaatsu cycle involved eight rounds of cuff inflation for 20 seconds, followed by five seconds of deflation.

The optimal pressure for exercise was determined by measuring the individual's capillary refill time (CRT), or the time in seconds taken for the color to return to an external capillary bed. CRT was checked by applying pressure to the quadriceps above the knee to cause blanching during cuff inflation. A CRT of approximately three seconds indicated optimal pressure for exercise. As a safety measure, our laboratory used 1.3 times the resting systolic blood pressure as an upper limit to the cuff pressure (11, 12). For both experimental trials, the final training pressure (156.3 ± 4.9 Standard Kaatsu Units) was individualized based on capillary refill per the Kaatsu user manual or the safety measure of 1.3 times systolic. All participants could utilize the upper limit cuff pressure given resting systolic blood pressure (119.5 ± 4.2 mmHg). Restriction of leg muscle blood flow lasted for the entire exercise session, including one-minute rest periods (19 min), and was released immediately upon completion of the session.

The second session had two testing conditions: loaded walking without BFR (LOAD) and loaded walking with BFR (BFR-LOAD). The subjects' second visit consisted of 1) walking protocol with load carriage followed by a 20-min recovery, performed Kaatsu cycle, ended with the walking protocol with load carriage and BFR; or 2) Kaatsu cycle, walking protocol with load carriage and BFR followed by a 20-min recovery, ended with a walking protocol with load carriage. Load carriage consisted of an adjustable vest (V-Max Weight Vest, Rexburg, ID) with 15% of the participant's body mass (12.7 ± 1.6 kg). Researchers selected 15% of relative load carriage based on previous literature, the effects on metabolic parameters (1, 12), and the ability to use the vest to adjust loads quickly for progressive exercise prescriptions.

The two sessions were 24 h apart, and the LOAD and BFR-LOAD conditions were counterbalanced to avoid an order effect. The participant conducted a walking session with the Kaatsu device while breathing into a two-way non-rebreathing valve connected to the metabolic analyzer (Parvo Medics, Logan, UT) was used to measure $O_2$ consumption ($\dot{V}O_2$) and wore a telemetry heart rate monitor (Polar Electro Inc., Lake Success, NY). All data were evaluated using 15-second averaging. Researchers performed filter replacement and calibration between tests according to the manufacturer's guidelines.

Modified from previously established walking protocol duration in the literature (2, 31) included five sets of three-minute walking at 4.8 km·h-1 with zero percent grade and a 1-minute rest where the researcher stopped the treadmill. Once they completed the walking protocol, the research assistant familiarized the participant with the weight vest and the muscle oxygen sensor for the subsequent session. Muscle oxygen was measured using a non-invasive near-infrared spectroscopy monitor (MOXY, Hutchinson, MN). The monitor's placement was on the left leg's vastus lateralis. The sensor continuously monitored muscle oxygen saturation ($SmO_2$), total hemoglobin (THb), oxygenated hemoglobin (OxyHb) and deoxygenated hemoglobin (DeoxyHb) during both sessions (LOAD and BFR-LOAD).

*Statistical Analysis*
All statistical analyses were performed using SPSS version 28 (IBM, Armonk, NY, USA). In the event of missing data, researchers used pairwise deletion. Descriptive statistics are reported as mean ± standard deviation (SD). Separate repeated-measures analysis of variance (ANOVA) (exercise × time) was used to analyze $\dot{V}O_2$ and heart rate between the LOAD, BFR-LOAD, and BFR-only conditions. The one-minute average measurement of $\dot{V}O_2$ and HR occurred through all exercise sets during, recovery, and rest periods. The average muscle oxygen saturation data was collected across all exercise sets and rest periods during the trials. A separate (exercise × time) repeated measures ANOVA was conducted comparing $SmO_2$, THb, OxyHB, and DeOxyHb between LOAD and BFR-LOAD at exercise and during rest. Statistical significance was determined by $p < 0.05$. When a significant $F$ statistic was found, post hoc testing using Bonferroni corrections was performed.

## RESULTS

There was no significant exercise condition × time effect, F (8, 88) = 1.569, $p = 0.146$, $\eta^2 = .125$ or time effect for $\dot{V}O_2$ F(4, 44) = 0.526, $p = 0.717$, $\eta^2 = .046$. However, there was a significant exercise condition effect for $\dot{V}O_2$, F(2, 22) = 21.683, $p < 0.001$, $\eta^2 = .663$. Bonferroni corrected pairwise comparisons indicated significantly greater $\dot{V}O_2$ in the BFR-LOAD versus LOAD ($p < 0.01$), but no differences between BFR and LOAD ($p = 0.202$) (Figure 1). There were no significant exercise condition × time effects for HR, F(8, 88) = .238, $p = 0.983$, $\eta^2 = .021$ condition effects (Table 1).

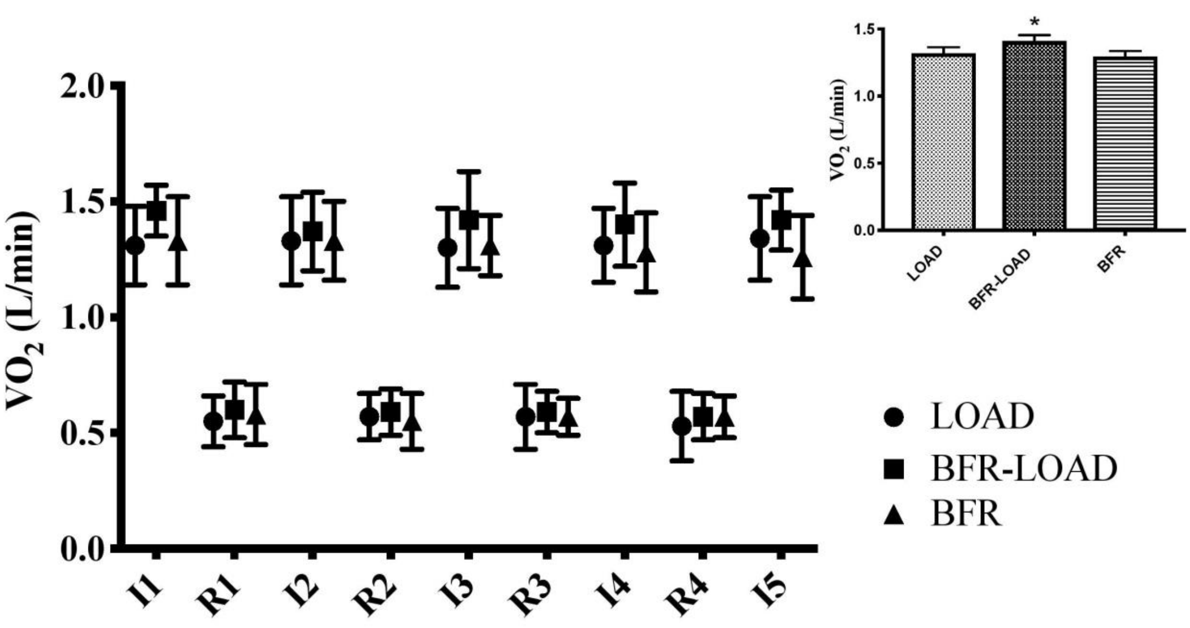


**Figure 1.** Oxygen uptake ($\dot{V}O_2$) during Walking and Rest Intervals. The exercise consisted of walking at 4.82 km·h$^{-1}$ for five 3-min bouts (from Interval (I) 1 to 5) with a 1-min rest (R) between bouts between three conditions: LOAD, BFR-LOAD, and BFR. Significant differences with the BFR-LOAD condition: * $p < 0.05$.

**Table 1.** Heart rate (bts · min$^{-1}$) during walking intervals between conditions.

| Condition | Interval 1 | Interval 2 | Interval 3 | Interval 4 | Interval 5 |
|---|---|---|---|---|---|
| LOAD | 99.7 ± 10.9 | 99.1 ± 11.2 | 99.8 ± 11.6 | 100.3 ± 10.7 | 99.6 ± 12.7 |
| BFR-LOAD | 101.7 ± 8.4 | 100.3 ± 10.2 | 101.2 ± 10.7 | 101.9 ± 11.2 | 102.0 ± 10.9 |
| BFR | 99.2 ± 11.0 | 97.8 ± 11.5 | 98.3 ± 10.3 | 99.5 ± 11.1 | 98.8 ± 10.1 |

Conditions: loaded with 15% of their body mass (LOAD) and loaded walking with blood flow restriction (BFR-LOAD) and with blood flow restriction walking (BFR), heart rate response in beats per minute (BPM) (Mean ± SD).

Due to equipment malfunction, one participant's muscle oxygenation data was excluded resulting in n= 11 for $SmO_2$, THb, OxyHb, and DeoxyHb. There was a significant exercise condition × time effect with $SmO_2$, F(1, 10) = 5.294, $p = 0.044$, $\eta^2 = 0.346$ (Figure 2). Post hoc analysis revealed $SmO_2$ was significantly lower during exercise and rest with BFR-LOAD compared to LOAD, $t(10) = -4.433$, $p < 0.001$ and $t(10) = -5.438$, $p < 0.001$, respectively. Both conditions revealed a time effect with BFR-LOAD, $t(10) = 6.083$, $p < 0.001$ and LOAD, $t(10) = 4.205$, $p = 0.002$. Additionally, there was a significant exercise condition × time interaction with DeOxyHb, F(1, 10) = 5.138 $p = 0.047$, $\eta^2 = 0.339$. Post hoc analysis revealed DeOxyHb was significantly higher during exercise and rest with BFR-LOAD compared to LOAD, $t(10) = 4.425$, $p < 0.001$ and $t(10) = 5.572$, $p < .001$, respectively. Both conditions revealed a time effect with BFR-LOAD, $t(10) = -6.522$, $p < 0.001$ and LOAD, $t(10) = -4.265$, $p = 0.002$. There was no significant condition × time effect for OxyHb, F(1, 10) = 3.852, $p = 0.078$. However, there was a significant exercise condition effect for OxyHb, F(1, 10) = 26.577, $p < 0.001$, $\eta^2 = .727$ and separate time effect, F(1, 10) = 24.388, $p < 0.001$, $\eta^2 = .709$. There was no significant condition × time effect for THb, F(1, 10) = 0.238, $p = 0.636$. But there was a significant separate time effect F(1,10) = 5.641, $p = 0.039$, $\eta^2 = 0.361$ (Table 2).

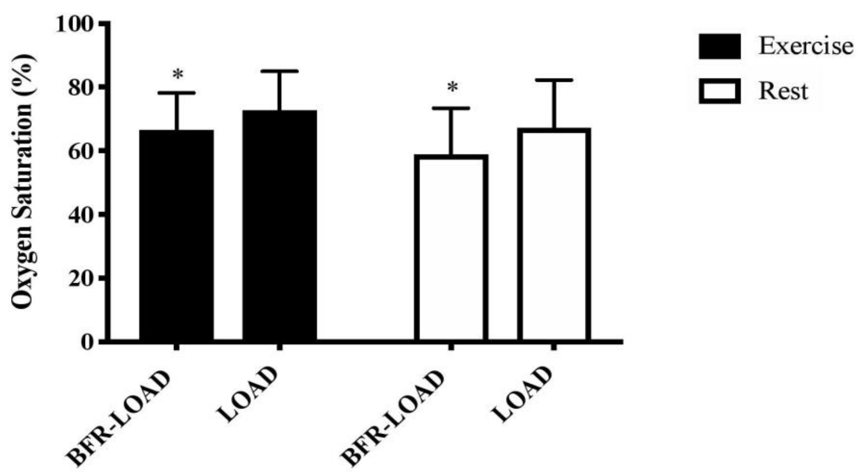


**Figure 2.** Vastus lateralis $SmO_2$ Levels (%) During Exercise and Rest with LOAD and BFR-LOAD. Significantly lower differences from the BFR-LOAD to LOAD conditions: * $p < 0.001$.

**Table 2.** Hemoglobin values during exercise and rest for BFR-LOAD and LOAD

| | BFR- LOAD Exercise | BFR- LOAD Rest | LOAD Exercise | LOAD Rest |
|---|---|---|---|---|
| THb (g ·dL$^{-1}$) | 12.22 ± 0.35 | 12.30 ± 0.40† | 12.27 ± 0.32 | 12.33 ± 0.32* |
| OxyHb (g ·dL$^{-1}$) | 8.10 ± 1.27* | 7.22 ± 1.68 | 8.89 ± 1.35† | 8.24 ± 1.71 |
| DeoxyHb (g ·dL$^{-1}$) | 4.12 ± 1.52‡ | 5.08 ± 1.86‡ | 3.38 ± 1.58 | 4.08 ± 1.94 |

THb = total hemoglobin, OxyHb = oxygenated hemoglobin, DeoxyHb = deoxygenated, (Mean ± SD). * denotes a significant difference from LOAD Exercise. † denotes a significant difference from BFR- LOAD exercise. ‡ denotes a significant difference between LOAD Exercise and LOAD Rest (main effect of exercise type). Significant difference at $p < 0.05$.

## DISCUSSION

This investigation aimed to compare the metabolic responses with load carriage walking with and without BFR. The main findings of this study are as follows: (1) BFR-LOAD elicited increased $\dot{V}O_2$ consumption during exercise and decreased muscle $O_2$ saturation during exercise and rest; (2) there was no difference in heart rate response between the conditions; interestingly, there were similar metabolic responses between BFR and LOAD. These acute perturbations provide some further implications for conditioning strategies for load carriage.

With BFR-LOAD, there was a significantly higher $\dot{V}O_2$ consumption (7% increase) versus LOAD. This overall increase in net $\dot{V}O_2$ is consistent with observed responses during walk training with BFR (22). Unexpectedly, no differences were observed between the LOAD and BFR sessions used as a familiarization session for the subjects. With similar metabolic responses, individuals may use BFR walking as a standard modality to experience similar localized metabolic effects in the lower body musculature without additional external weight that could put them at higher risk for injury. Further, walking with BFR combined with load carriage can provide further local metabolic stress without the additional high impact that may be observed with increased loads or speed of travel.

With BFR, venous return and stroke volume are typically reduced due to the vascular resistance from the inflation of the cuff (36). Due to this decrease in stroke volume, HR traditionally increases to maintain cardiac output (30). During this study, the increase in HR was not found to be statistically significant. The researchers suspect that there are several explanations for this lack of response. First, the participants were walking at 4.8 km•h$^{-1}$, which is a low intensity with this physically active sample, based on the reported PA-R level (8.1 ± 2.1), translating into 6-7 hours per week of vigorous activity. Presumably, if the intensity of the exercise were higher (e.g., increased speed, increased grade), there would have been a greater separation in HR between the two conditions. Secondly, the cuff's pressure (156.3 ± 4.9 mmHg) was lower than in other studies, ranging from 160-230 mmHg (7, 29, 30, 33). Since this was the first-time participants had used BFR, our laboratory used 1.3 times the resting systolic blood pressure as an upper limit to the pressure resulting in an average pressure of 156 ± 5 mmHg. Additionally, since participants were walking, a dynamic exercise, blood flow restriction can fluctuate during the activity. Presumably, with higher cuff pressure, the reduced levels of venous return would reduce stroke volume, thus, increasing HR.

Muscle $O_2$ saturation of the vastus lateralis of the left leg was significantly lower during both the exercise and rest during BFR-LOAD than in the LOAD condition (-9 % and -14%, respectively). DeOxyHb was considerably higher with BFR-LOAD during exercise and rest compared to the LOAD condition. These higher levels indicate local metabolic stress (i.e., low $O_2$, intercellular pH levels, high $CO_2$ levels) induced in the working muscles. Additionally, the BFR-LOAD condition was producing a hypoxic muscular environment. Earlier research supports that creating a hypoxic environment combined with low load resistance training can stimulate muscle protein synthesis via the Akt/mTOR, including muscular adaptation with subsequent muscular hypertrophy (18, 37). The use of BFR in concurrence with load carriage could produce favorable increases in muscle hypertrophy in addition to the aerobic benefits previously mentioned. However, since this was an acute study, we can only speculate on the adaptations from BFR during a load carriage training program.

This investigation utilized a novel model of acute BFR sessions as a mode of exercise implemented in combination with load carriage as a training method for military load carriage tasks. Limitations of the study included the recruitment of only fit young, healthy male participants as there were additional requirements for female participants (e.g., pregnancy testing and being unable to be on birth control) with the addition of BFR. The participants had higher fitness levels, which may have influenced the cardiovascular and metabolic responses at the lower intensities. Using a self-selected pace may have allowed for a higher level of intensity. Consequently, researchers suspect there was no time effect in $\dot{V}O_2$ consumption due to the low intensity of the exercise. Lastly, a relative load could be a limitation where the tactical population typically operates with absolute loads. Using a relative load would give the practitioner another variable to manipulate for their exercise prescription during the conditioning process. Despite these limitations, our study presents compelling data for future investigations using BFR and load carriage.

Our finding suggests further investigation of BFR as a method to condition tactical professionals for walking with load carriage is warranted. Blood flow restriction exercise can also be used by tactical professionals who may not be able to tolerate training with high loads for various reasons (i.e., lower levels of physical fitness). An example would be an individual walking at a self-selected pace with load carriage equivalent to 15% of their body mass with BFR to reproduce a metabolic response similar to walking with a higher percentage of load carriage. Progressive training models using BFR could prepare personnel for the rigors of load carriage required for their occupation. Along with training models, education on the logistical requirement of using BFR training and assurance that this training method does not negatively impact job performance would also be imperative. Besides, higher aerobic and muscular endurance levels protect against common injuries (34). Blood flow restriction sessions as a mode of low-intensity training exercise in combination with load carriage could be implemented as a conditioning training model for load carriage tasks. Aerobic and muscular endurance physical training programs may increase performance and the longevity and sustainability of these tactical professionals.

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