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Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Operators

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Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Operators

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Investigation performed at Warrior Human Performance Laboratory, Fort Bragg, North Carolina, USA

Background: Musculoskeletal injuries are a significant burden to United States Army Special Operations Forces. The advanced tactical skill level and physical training required of Army Special Operators highlights the need to optimize musculoskeletal characteristics to reduce the likelihood of suffering a recurrent injury.

Purpose: To identify the residual impact of previous injury on musculoskeletal characteristics.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Isokinetic strength of the knee, shoulder, and back and flexibility of the shoulder and hamstrings were assessed as part of a comprehensive human performance protocol, and self-reported musculoskeletal injury history was obtained. Subjects were stratified based on previous history of low back, knee, or shoulder injury, and within-group and between-group comparisons were made for musculoskeletal variables.

Results: Knee injury analysis showed no significant strength or flexibility differences. Shoulder injury analysis found internal rotation strength of the healthy subjects (H) was significantly higher compared with injured (I) and uninjured (U) limbs of the injured group (H, 60.8 ± 11.5 percent body weight [%BW]; I, 54.5 ± 10.5 %BW; U, 55.5 ± 11.3 %BW) ($P = .014$ [H vs I] and $P = .05$ [H vs U]). The external rotation/internal rotation strength ratio was significantly lower in the healthy subjects compared with injured and uninjured limbs of the injured group (H, 0.653 ± 0.122; I, 0.724 ± 0.121; U, 0.724 ± 0.124) ($P = .026$ [H vs I] and $P = .018$ [H vs U]). Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (I, 111.6° ± 9.4°; U, 114.4° ± 9.3°; $P = .008$). The back injury analysis found no significant strength differences between the healthy and injured groups.

Conclusion: Few physical differences existed between operators with prior knee or back injury. However, operators with a previous history of shoulder injury demonstrated significantly less shoulder strength than uninjured operators as well as decreased shoulder flexibility on the injured side. All operators, regardless of prior injury, must perform the same tasks; therefore, a targeted injury rehabilitation/human performance training specifically focused on internal rotation strength and tightness of the posterior capsule may help reduce the risk for recurrence of injury. Operators presenting with musculoskeletal asymmetries and/or insufficient strength ratios may be predisposed to musculoskeletal injury.

Clinical Relevance: Specific fitness programs to compensate for deficiencies in strength and flexibility need to be designed that may reduce the risk of injuries in Special Forces Operators.

Keywords: muscle injury; residual; performance; injury prevention; military

Musculoskeletal injuries are a significant burden in the United States Army Special Operations Forces (ARSOF).[18,25,26] Previous work from our laboratory found that the shoulder, knee, and low back were a significant problem, with a high rate of injury in ARSOF.[1] Due to the high physical demand of ARSOF operators training and operations, acute and overuse musculoskeletal injuries are the most common reason for medical clinic visits and missed duty days.[26] However, there are limited published data describing musculoskeletal characteristics of ARSOF operators who have suffered prior injury. Deficits in strength and flexibility after injury may impede tactical readiness, reduce physical performance, and increase risk of suffering a subsequent injury.[18,26] The advanced tactical skill level and physical training required to be an ARSOF operator highlights the need to improve suboptimal musculoskeletal characteristics, regardless of injury history, to reduce

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the likelihood of suffering a future injury as well as to maximize tactical performance.

It is understood that deficits in musculoskeletal characteristics are risk factors for musculoskeletal injury. A study in professional soccer players took a subset of subjects who presented with preseason strength imbalances and put them through a strengthening protocol to correct the strength imbalance.[9] Once corrected, there was no difference in injury rates between the corrected strength imbalance group and the group who showed no muscular imbalance in the preseason.[9] After a musculoskeletal injury in an athletic population, it is recommended that an athlete not return to full sport participation until the injured musculature is at least 90% the strength of the contralateral uninjured musculature.[10]

Another variable found to influence performance among both athletic and military populations is flexibility. Several studies have found that posterior shoulder tightness is related to shoulder impingement, rotator cuff injury, and labral tears.[6,15,20,24,44] Manske et el[28] also found that posterior shoulder tightness was a limiting factor in shoulder internal rotation flexibility. A study in military basic trainees found that increased hamstring flexibility decreased the overall number of lower extremity overuse injuries.[17]

If affected musculature is not properly rehabilitated after injury, the residual flexibility and strength deficits are thought to be a risk factor for future reinjury and early onset osteoarthritis[38]; therefore, impaired musculoskeletal characteristics as a result of past injury may be detrimental to the short-term physical readiness of ARSOF operators and overall career longevity. While identifying characteristics associated with increased risk of musculoskeletal injury within the ARSOF community would be ideal to understand the mechanisms that produce injury, this is not always feasible. Little is known about the physical differences of operators who have a previous history of musculoskeletal injury and those who have not suffered a previous injury. The purpose of this study was to identify the residual impact of previous injury on current musculoskeletal characteristics.

METHODS

Operators were recruited through the Special Forces community via posted flyers, platoon briefings, and word of mouth. Operators who volunteered for testing participated in a standard protocol that included the measures defined below. Prior to testing, all operators read and signed the approved informed consent form in accordance with civilian and military institutional review boards. Demographic data were collected from operators for age, race, and years of active duty experience. Also, a self-report history was performed for musculoskeletal injuries sustained from time of active duty status to study enrollment. A musculoskeletal injury was defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc) that resulted in alteration in tactical activities, tactical training, or physical training for a minimum of 1 day, regardless of whether medical attention was sought. All injuries were recorded by a certified athletic trainer who had extensive training and experience in the field of sports medicine.

Participants

All operators were recruited from the United States Army Special Operations Command. To meet inclusion criteria, all operators must have been between 18 and 55 years of age; been cleared for full active duty; not sustained any musculoskeletal injuries in the 3 months before the study; not sustained a traumatic brain injury or balance disorder in the past 3 months; had no cardiac, pulmonary, or metabolic disorder; and not have exercised in the 12 hours before the assessment.

Injury Operational Definitions

Subjects were grouped as injured (shoulder/knee/lower back) or healthy. Injured subjects were defined at the time of this study as those that had any chart-documented history of injury to the specified anatomic location for which medical advice was sought. For shoulder and knee injuries, we observed unilateral injury only; this was defined as past injury to only 1 side, and designated the "injured side". The opposite side was designated the "uninjured side". Subjects with bilateral injury were excluded from analysis; this was defined as a chart-documented history of past injury to both sides of the body, even if at different time points. Healthy subjects were defined at the time of this study as those without any chart-documented history of injury to a specified anatomic location (shoulder/knee/lower back).

All injury types had standardized designations that were discussed and defined by experienced clinicians and researchers in our group to ensure validity and consistency of data. Shoulder injuries included all those that could be clinically localized to the shoulder region (eg, impingement syndrome, acromioclavicular joint sprain), knee injuries included all those that could be clinically localized to the knee region

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(eg, ligament sprain, patellofemoral pain), and lower back injuries included all those that could be clinically localized to the lumbosacral region (eg, facet joint syndrome, muscle strain). Healthy subjects were defined at the time of this study as those without any chart-documented history of past injury to the specified anatomic locations.

Laboratory Data

Body Composition. Body composition was measured using the Bod Pod (COSMED USA). The Bod Pod is an air displacement plethysmograph that uses whole-body densitometry to determine body composition. The Bod Pod was calibrated, and testing was performed in accordance with the manufacturer's instructions. Briefly, subjects were tested while wearing only tight-fitting clothing (eg, compression shorts) and an acrylic swim cap. Thoracic gas volume was estimated for all operators using a predictive equation integral to the Bod Pod software, and body density was calculated internally using the appropriate density equation. Air displacement plethysmography has been found to be a reliable and valid method for measuring body composition in multiple populations.[2,13,27,32]

Muscular Strength. Muscular strength was assessed by using the Biodex System 4 Pro Isokinetic Dynamometer (Biodex Medical Systems Inc), and operators were stabilized according to the manufacturer's instructions. Operators were tested for muscular strength in the shoulder (bilateral internal/external rotation), knee (bilateral flexion/extension), and trunk (flexion/extension). All practice and test trials were reciprocal concentric-concentric contractions performed at 60 deg/s. Three warm-up trials were given at 50% of self-perceived maximum exertion and then 3 warm-up trials were given at 100% self-perceived maximum effort. The subject rested for 1 minute prior to performing 5 maximum test trials. The average peak torque (N·m) was normalized for body weight and used for data analysis. Muscular strength measured by isokinetic dynamometry has been found to be a reliable and valid method[11,29,43] for measuring strength and has been used previously in our laboratory.[31,41]

Flexibility. A digital inclinometer or standard plastic goniometer was used for all range of motion measures. Range of motion was measured in both shoulders for passive internal rotation, external rotation, and posterior shoulder tightness. For lower extremity range of motion, active knee extension (hamstring tightness) and active ankle dorsiflexion (calf tightness) were measured bilaterally. Alignment of the inclinometer and goniometer was performed based on previous research, which has been shown to have good intrarater reliability (intraclass correlation coefficient $\geq$0.85).[4,22,30] Briefly, for internal and external rotation, the fulcrum of the goniometer was aligned with the axis of rotation for that joint, while the stationary and movement arms were aligned parallel to proximal and distal bony segments, respectively. Supine posterior shoulder tightness was assessed with the participant supine on a treatment table. One tester was positioned beside the shoulder being tested, while the participant was asked to maximally retract his scapula. The tester then placed 1 hand under the scapula, pressing the thenar eminence against the lateral border of the scapula, stabilizing the scapula in the maximally retracted position. The tester then used the other hand to passively move the participant's arm into horizontal adduction while maintaining neutral humeral rotation. At the end range of horizontal adduction, the second tester recorded the angle formed between the humerus and the horizontal plane from the superior aspect of the shoulder. The fulcrum of the goniometer was placed over the estimated glenohumeral joint center, and the movement arm was aligned with the humerus. The stationary arm was kept parallel to the floor guided by a bubble level attached to the arm.[30] A full description of our methods can be found in a previous article.[39]

Data Analysis

Descriptive statistics were calculated for demographic, body composition, strength, and flexibility variables. Data reduction procedures were performed before statistical analyses. Average peak torque values were normalized to bodyweight (%BW).[40] Shoulder external/internal rotation ratios were calculated by dividing external rotation values by internal rotation values. Knee flexion/extension ratios were calculated by dividing knee flexion values by knee extension values.[14] Torso extension/flexion ratios were calculated by dividing trunk extension values by trunk flexion values. Prior to statistical significance testing, normality of data was assessed with the Shapiro-Wilk test. For within-group side-to-side comparisons, paired *t* tests were used for normally distributed data and Wilcoxon signed rank tests for nonnormally distributed data. For between-group comparisons, unpaired *t* tests were used for normal distributions and Mann-Whitney tests for nonnormal distributions. Statistical analyses were performed using SPSS version 21 (SPSS Inc). Significance levels were set a priori ($\alpha = .05$).

Clinical significance of data was also assessed. Based on previous work, threshold values were identified for reciprocal muscle group ratios: 0.7 for shoulder external/internal rotation,[3,4,12] 0.6 for knee flexion/extension,[14] and 1.3 for torso extension/flexion.[19,42] Ratios below these thresholds were considered clinically significant. Limb symmetry indices (LSIs) were computed similar to calculations used by other authors: *LSI* (%) = (*right side/left side*) × *100*.[9,14] In line with previous work, a side-to-side difference <10% was considered normal[14,37]; an LSI <90% or >110% (ie, >10% side-to-side difference) was therefore defined as abnormal and considered clinically significant. Frequency counts were made of participants with reciprocal muscle group ratios below the previously identified threshold values along with participants with side-to-side differences >10% and proportions (prevalence) calculated. For the reciprocal muscle group ratio proportions, numerators were the total number of participants with subthreshold values and denominators were the total number of participants in each anatomic region sample: *prevalence* (%) = (*number of participants with subthreshold ratio/number of participants in the sample*) × *100*.[36] For LSI proportions, numerators were the total number

TABLE 1
Demographic Data[a]

	Low Back		Knee		Shoulder	
	Injured (n = 20)	Healthy (n = 86)	Injured (n = 24)	Healthy (n = 51)	Injured (n = 29)	Healthy (n = 53)
Mean age, y	35.0 ± 6.38	32.60 ± 6.35	34.25 ± 6.42	33.51 ± 6.56	35.97 ± 7.26[b]	31.40 ± 5.79
Mean height, cm	180.87 ± 5.64	179.20 ± 5.63	180.67 ± 5.08	179.46 ± 5.17	178.83 ± 4.47	179.62 ± 5.56
Mean weight, kg	89.35 ± 9.53	86.03 ± 10.75	90.12 ± 11.14	85.59 ± 9.11	88.05 ± 9.81	85.51 ± 10.24
%BF	20.0 ± 5.75	17.73 ± 6.30	18.63 ± 5.68	17.37 ± 6.24	19.0 ± 7.03	17.55 ± 5.99
BMI, kg/m^2	27.30 ± 2.40	26.76 ± 2.83	27.59 ± 2.98	26.57 ± 2.55	27.52 ± 2.88	26.48 ± 2.63

[a]Values are reported as mean ± SD. %BF, percent body fat; BMI, body mass index.
[b]Significantly different between groups ($P < .05$).

of subjects with side-to-side differences >10%, and denominators were the total number of participants in each anatomic region sample: *abnormal LSI prevalence* (%) = (*number of participants with side-to-side differences >10%/number of participants in the sample*) × *100*.[36]

RESULTS

Demographic data for height, weight, percent body fat, and body mass index did not differ between injured and healthy operators. Injury data reflect any injury incurred during active duty status up to 3 months prior to testing. Healthy is defined as the operator not reporting any injuries during his active duty career. Age was significantly different between healthy and injured operators with a previous history of shoulder injury ($P = .003$); however, no differences were seen in any other group (Table 1).

Low Back

A total of 86 healthy and 20 injured (low back) operators were included in this analysis. No significant strength differences were demonstrated between groups for trunk strength. Insufficient extension/flexion ratios, operationally defined as differences greater than 1.3, were identified in 18.6% of healthy subjects and 30% of injured subjects (Table 2).

Knee

A total of 51 healthy and 24 injured (knee) operators were included in this analysis. Knee extension strength was significantly different between limbs of the healthy group (right, 231.59 ± 42.44 %BW; left, 224.73 ± 36.42 %BW; $P = .029$). No significant between-limb or between-group differences in strength were demonstrated within the injured group. Asymmetry differences for knee flexion strength were identified in 45.1% of healthy subjects and 25% of injured subjects. Individual bilateral differences for knee extension were identified in 43.1% of healthy subjects and 25% of injured subjects. Insufficient knee flexion/extension ratio (<0.60) was identified in 43.1% of healthy subjects and 66.6% of injured subjects. No significant differences were demonstrated between limbs (injured) or between groups. Bilateral hamstring flexibility was significantly different between limbs within the healthy group (right, 17.89° ± 9.23°; left, 20.54° ± 9.93°; $P < .001$) (Table 3).

TABLE 2
Low Back Data[a]

Strength, %BW	Injured	Healthy
Flexion	193.53 ± 40.31	191.39 ± 33.42
Extension	282.15 ± 60.97	300.85 ± 69.86
E/F ratio	1.48 ± 0.31	1.59 ± 0.35

[a]Values are reported as mean ± SD. %BW, percent body weight; E, extension; F, flexion.

Shoulder

A total of 53 healthy and 29 injured (shoulder) operators were included in this analysis. Internal rotation strength of the healthy subjects was significantly greater (60.57 ± 11.54 %BW) than injured (54.54 ± 10.45 %BW; $P = .05$) and uninjured (55.54 ± 11.27 %BW; $P = .014$) limbs of the injured group. The external rotation/internal rotation strength ratio was significantly lower in healthy subjects (0.65 ± 0.12) compared with the injured (0.72 ± 0.12; $P = .026$) and uninjured (0.72 ± 0.12; $P = .018$) limbs of the injured group. Individual bilateral differences for internal rotation strength were identified in 45.3% of healthy and 44.8% of injured subjects. Individual bilateral differences for external rotation strength were identified in 35.8% of healthy subjects and 34.5% of injured subjects. Insufficient bilateral external rotation/internal rotation strength ratios (<0.70) were identified in 35.8% of healthy subjects and 31.0% of injured subjects. Internal rotation flexibility was significantly different bilaterally within the healthy group (right, 58.35° ± 11.30°; left, 60.88° ± 9.83°; $P = .040$). Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (injured, 111.62° ± 9.44°; uninjured, 114.40° ± 9.34°; $P = .008$). However, no significant differences were seen between groups with regard to shoulder flexibility (Table 4).

DISCUSSION

Despite the high rate of musculoskeletal injuries suffered among ARSOF operators, there is little published evidence

TABLE 3
Knee Data[a]

	Healthy		Injured	
	Right	Left	Injured	Uninjured
Strength, %BW				
Flexion	129.05 ± 20.48	126.44 ± 21.82	122.65 ± 21.72	125.71 ± 21.74
Extension	231.59 ± 42.44	224.73 ± 36.42[b]	233.67 ± 39.05	235.87 ± 33.15
F/E ratio	0.57 ± 0.08	0.56 ± 0.08	0.53 ± 0.08	0.54 ± 0.13
Flexibility, deg				
Hamstring (AKE)	17.89 ± 9.23	20.54 ± 9.93[b]	20.28 ± 9.93	19.63 ± 9.63

[a]Values are reported as mean ± SD. AKE, active knee extension; %BW, percent body weight; E, extension; F, flexion.
[b]Significantly different between limbs ($P < .05$).

TABLE 4
Shoulder Data[a]

	Healthy		Injured	
	Right	Left	Injured	Uninjured
Strength, %BW				
External rotation	38.84 ± 6.33	38.59 ± 7.05	39.10 ± 8.06	38.84 ± 8.01
Internal rotation	60.57 ± 11.54[b]	59.02 ± 11.86	54.54 ± 10.45	55.54 ± 11.27
ER/IR ratio	0.65 ± 0.12[b]	0.66 ± 0.12	0.72 ± 0.12	0.72 ± 0.12
Flexibility, deg				
External rotation	95.42 ± 8.48	95.10 ± 9.51	93.02 ± 11.07	94.90 ± 7.73
Internal rotation	58.35 ± 11.30[c]	60.88 ± 9.83	56.33 ± 13.25	58.67 ± 10.69
PST	111.67 ± 8.30	112.78 ± 7.54	111.62 ± 9.44[c]	114.40 ± 9.34

[a]Values are reported as mean ± SD. %BW, percent body weight; ER, external rotation; IR, internal rotation; PST, posterior shoulder tightness.
[b]Significantly different between right healthy and injured shoulder ($P < .05$).
[c]Significantly different between limbs ($P < .05$).

describing the musculoskeletal characteristics of operators with a history of musculoskeletal injury and those with no history of musculoskeletal injury.[1] The objective of this study was to determine the residual impact of previous injury on current musculoskeletal characteristics. A review of the data within both the prior musculoskeletal injury group and no prior injury group revealed a higher proportion of subjects demonstrating bilateral asymmetry >10%, regardless of whether they presented with a prior injury. This threshold has been found to be critical in previous knee research to reduce the risk of musculoskeletal injury and optimizing physical readiness.[14,35,37] The large number of subjects presenting with musculoskeletal asymmetries, specifically strength-related asymmetries, may predispose operators to additional injury. These scenarios may limit physical readiness at the individual and unit level.

Isokinetic strength testing revealed a suboptimal strength ratio between agonist and antagonist muscle groups in the low back (<1.30), knee (<0.60), and shoulder (<0.70). Operators with prior injury to the low back demonstrated an extension/flexion ratio that is closer to ideal (1.3) than their healthy cohorts. Rehabilitation with low back pain typically focuses on increasing flexibility and strengthening the core.[23] This process of rehabilitation and the fear of reinjury could have led the injured group to more favorable habits within their physical training. Bilateral strength testing of the quadriceps and hamstring resulted in 66.6% of subjects in the injured group presenting with an insufficient knee flexion/extension ratio. A lower percentage of healthy subjects (43.1%) also presented with an insufficient knee flexion/extension ratio. These abnormal knee extension/flexion ratios are associated with lower extremity injuries in an athletic population.[21] Previous research using male participants found individuals with a >10% difference between sides were at increased risk for injury.[14,37] Operators with prior history of injury tended to have decreased shoulder internal rotation strength compared with their healthy cohorts. Achieving an optimal agonist:antagonist muscular strength ratio is critical to the prevention of musculoskeletal injury[7,34] as well as optimizing tactical readiness. Bilateral differences were not found in the shoulder; however, for knee flexion and knee extension strength, asymmetries were found in both healthy and injured subjects. The exact reason for the high proportion of bilateral asymmetries among operators is not entirely understood. We hypothesize that a high proportion of bilateral asymmetries may result from greater emphasis being placed on the operator's dominant side over a period of time. An operator can be part of an actively deploying Special Forces team for several years and complete repetitive mission-essential training on a regular basis during that time to consistently maintain or improve his level of tactical readiness. If the operator repeatedly places a greater amount of stress on the dominant limbs during tactical training (shooting, carrying loads, airborne operations, hand-to-hand combat training, etc) over the course of a long duration of time, it can be realistically proposed that natural adaptions, such as increased muscular strength, will occur due to increased demands.

The injured operator group showed bilateral asymmetries with posterior shoulder tightness. Several studies have indicated that posterior shoulder tightness can be a risk factor for future injury[20,24] and reinjury.[16] While posterior shoulder tightness was not measured prior to injury, and therefore it cannot be determined whether it was a reason for the previous injury, improper return to within normal limits (bilateral symmetry within 10%) can lead to future risk of reinjury. While no asymmetrical differences were seen bilaterally within the injured group, we did find significant bilateral differences with hamstring flexibility in our healthy group. Previous hamstring injury has been linked to deficits in proprioception, which is correlated with future risk of injury in both the hamstring and low back.[38,41] Previous research in the military setting has found that implementing a hamstring flexibility protocol has decreased the risk of overuse injuries.[17]

A strength of this study is the large cohort of both injured and uninjured operators. In addition, a within-person comparison was able to be performed on each individual. A limitation of this study is that it was not possible to track which operators performed physical therapy, how often, and whether they had been discharged from their previous injury. The injury history of operators was collected as a self-report, which may present with certain advantages as well as certain limitations. The injury history was collected by a certified athletic trainer with extensive sports medicine training and a clinical background in preventing, diagnosing, and treating musculoskeletal injuries. This allows for more accurate recording of specific anatomic injury location and understanding of injury mechanisms. By nature of a self-report injury history, an operator may have not recalled every injury he has suffered, thus omitting injuries during the self-report history.[8] However, past research has shown that individuals in overall good health, of younger age, and with higher education will more accurately report injuries.[4,43] In addition, operators do not always report injuries to medical personnel so that they can avoid being rolled from specialized schools, work-ups, and deployments, so a self-report may have allowed us to capture data that would not have been present in a medical chart review. Another limitation for this study is that operators were excluded if they presented with an injury in the previous 3 months. This may suggest that our group was tolerating their limitations without sustaining another injury.

Clinical Implications

This study agrees with other studies that a critical strength threshold >10% in both previously injured and uninjured operators exists bilaterally. This critical threshold places the operator at risk for musculoskeletal injury during physical training and tactical mission operations.[33,34] A large proportion of operators in this study with previous history of injury present with agonist:antagonist ratios that are considered suboptimal in the low back and knee. These suboptimal characteristics place the operator at greater risk for future injury. These potential injuries may then affect the mission at both an individual and unit level, potentially causing changes in personnel, as well as the need for medical care. Identifying factors that cause bilateral asymmetries and suboptimal agonist:antagonist ratios in operators will need to be examined, and better medical records on rehabilitation after injury will need to be tracked. While operators are trained to perform all duties (weaponry, tactical maneuvers, etc) bilaterally, a greater demand may be placed on the dominant side, which potentially may lead to these asymmetries.[45] We recommend a specialized comprehensive fitness program to compensate for these deficiencies, which will hopefully reduce the risk for injuries in Special Forces operators. Previous research also has found several other interventions that may be beneficial. These include education for preventing overtraining, agility-like training, and nutrient replacement education.[5]

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