Operational Stressors on Physical Performance in Special Operators and Countermeasures to Improve Performance: A Review of the Literature

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ABSTRACT

Objective: Military training in elite warfighters (e.g., U.S. Army Rangers, Navy SEALs, and U.S. Air Force Battlefield Airmen) is challenging and requires mental and physical capabilities that are akin to that of professional athletes. However, unlike professional athletes, the competitive arena is the battlefield, with winning and losing replaced by either life or death. The rigors of both physical training and prolonged deployments without adequate rest and food intake can compromise physical performance. Therefore, the primary purpose of this effort was to identify occupational stressors on the physical performance of Special Operators during training and while on missions. The secondary purpose was to suggest specific countermeasures to reduce or prevent significant decrements in physical performance and reduce musculoskeletal injuries. **Methods:** A search of the literature for 2000–2012 was performed using the Air Force Institute of Technology search engines (i.e., PubMed and ProQuest). There were 29 articles located and selected that specifically addressed the primary and secondary purposes of this literature review. The remaining 32 of 61 referenced articles were reviewed after initial review of the primary literature. **Conclusions:** This review indicates that operational stress (e.g., negative energy balance, high-energy expenditure, sleep deprivation, environmental extremes, heavy load carriage, etc.) associated with rigorous training and sustained operations negatively affects hormonal levels, lean muscle mass, and physical performance of Special Operators. The number of musculoskeletal injuries also increases as a result of these stressors. Commanders may use simple field tests to assess physical decrements before and during deployment to effectively plan for missions. Specific countermeasures for these known decrements are lacking in the scientific literature. Therefore, future researchers should focus on studying specific physical training programs, equipment, and other methods to minimize the effects of operational stress and reduce recovery time. These countermeasures could prevent mission mishaps and may save the lives of Special Operators during severe operational stress.

KEYWORDS: *Special Forces, Operators, physical training, military, injury prevention, human performance*

Introduction

Special Operators are an elite group, physically and mentally trained to overcome the worst possible conditions and battlefield scenarios and continuously redefining the body's limits. The physical prowess of Special Operations (SO) personnel has been compared with that of elite athletes. However, while elite athletes generally excel in one category of athletic ability, SO personnel must have an all-encompassing level of fitness that includes high aerobic capacity, muscular strength and endurance, and power.[1] For example, the mean maximal aerobic capacity (VO_2max) of a U.S. Navy SEAL in basic underwater demolition/SEAL training (BUD/S) is approximately 62mL/kg/min,[2] compared with 42mL/kg/min for the average man aged 20–29.[3] Additionally, it is imperative that Special Operators achieve high levels of overall fitness. A weak link in any level of the Operator's chain of fitness or strength could mean the difference between life and death and/or mission failure. A high operational tempo in Iraq and Afghanistan, characterized by longer and more frequent deployments,[4] has led to an increase in the number and duration of SOF missions.[5] Special Operators must train extensively and rigorously to prepare for missions and rapid deployments, which may include special reconnaissance, counterterrorism operations, direct action, and counterproliferation.[1]

U.S. Army Rangers and Navy SEALs are examples of Special Operators who undergo extensive and rigorous training before they qualify for a Ranger tab or Navy SEAL trident. The intention of SO high-stress training is to effectively prepare Special Operators for any combat situation. For example, the 21st Command Sergeant Major of the U.S. Army Ranger Training Brigade stated, "If a Soldier returns from his first major firefight and tells you that the training leading up to combat was much harder than the actual combat, then you know you have conditioned a Soldier correctly through tough and realistic training."[6] However, due to the nature and location of some SO missions and deployments, these Special Operators may endure several days to weeks of operational stressors such as sleep deprivation, caloric deficit, high-energy expenditure, and extreme environmental conditions ranging from tropical climates to the subarctic/arctic regions and varying terrain (e.g., snow, mud, sand) and altitudes.[7–9]

According to Kim and Diamond, stress is a condition in which a person (i.e., Special Operator) experiences a heightened excitable response due to an aversive situation. The magnitude of the stress response will be greater if the stressor is perceived as uncontrollable.[10] Decrements in physical performance and increased risk of injury may result due to operational and physiological stressors, thereby compromising mission effectiveness and the lives of Special Operators. Therefore, commanders may assess certain physical stressors by administering simple field tests. Suggested specific countermeasures may then be used to better assess Operators' risk of musculoskeletal injuries and enhance physical performance. A 2011 review by Henning and colleagues highlighted the current literature of physiological decrements during sustained military operational stress.[7] Henning et al. reviewed the effects of this stress on physical and military performance, endocrine status, skeletal muscle, and bone injuries. They suggested countermeasures to be used by commanders to plan missions accordingly. This group of investigators aims to expand on the review of this topic and suggest additional countermeasures that may reduce injury rates, reduce recovery time between missions, and improve overall human performance.

Nutrient intake, personal fitness, environmental conditions, and equipment worn and carried by Operators during training and critical missions are all important factors for commanders or team leaders to consider. A key concern during military operations is the ergonomic constraints posed by personal protective equipment (PPE) that may limit a Special Operator's range of motion and induce heat stress. This may result in a reduction in physical performance. Ideally, PPE should provide adequate protection to operational threats while not inhibiting an individual's ability to perform required tasks. Aside from the PPE worn by Special Operators, their missions often require them to carry heavy loads.[1] Carrying heavy loads during missions in adverse environments increases the amount of energy required to successfully complete any physical task, thus resulting in overall decrements in physical performance.

Operational Stressors on Endogenous Hormones, Body Composition, and Sleep

The physical and cognitive ability of Special Operators to endure stressful combat situations rely heavily on their intense physical training, which typically mirrors a multitude of very similar scenarios they will encounter on the battlefield. Sustained military operations (SUSOPS) can negatively affect Special Operators due to (1) physical and cognitive fatigue, (2) sleep deprivation, (3) high caloric expenditures, (4) diminished appetites, (5) energy deficits, (6) heavy combat loads (sometimes exceeding 50kg), and (7) environmental extremes.[7,9] As a result of Special Operators enduring these operational stressors for sustained and frequent periods of time, levels of circulating anabolic hormones decrease, while catabolic hormones increase. Additionally, skeletal muscle atrophy and bone loss have been reported, as well as an increase in musculoskeletal injuries (e.g., lower extremity stress fractures, ankle sprains, anterior knee pain, iliotibial band syndrome) and a decrease in physical/military performance, all of which may compromise mission success and the lives of Operators.[7,11–15] Whether training to become a Special Operator or deployed for SUSOPS missions, Special Operators must be able to endure multiple operational stressors (e.g., negative energy balance, sleep deprivation, environmental extremes) in addition to physiological stressors (e.g., endocrine changes, muscle atrophy, weight loss) related to intense training or missions.

For example, the U.S. Army Ranger School is a leadership course for elite Soldiers who upon graduating can become part of Special Operations (i.e., 75th Ranger Regiment) or return to their units to lead Soldiers in combat. Soldiers must endure a grueling 61-day course, which demands physical and mental toughness in heavily wooded areas, desert (eliminated in 1995, replaced with urban combat training), mountainous terrain, and swamp-like conditions. Nindl et al. studied the physiological consequences of Ranger School (a 1992 class) on strength, power, body composition, and somatotrophic hormones.[16] Ranger School is designed to be high stress. Along with the challenge of adapting to environmental extremes, Ranger students experience caloric deficits ranging from 1,000 to 4,000 kilocalories (kcals)/day during 7–10 days of underfeeding per phase, sleep an average of 3.6 h/day, and expend more energy than consumed for the majority of the 8-week course.[16]

These conditions are analogous with reports from other military Special Operators (i.e., U.S. Army Rangers, Special Forces, etc.) in which caloric deficits have ranged from 2,500 to 4,500kcal/day during operational situations.[16] As a result of 61 days of exposure to these stressors, circulating concentrations of total testosterone decreased 83%, which is within the range of a hypogonadal male.[16,17] Circulating concentrations of insulin-like growth factor 1 (IGF-1) decreased 55%, whereas cortisol increased 32%. Additionally, body mass (BM) decreased 12.6%, fat-free mass (FFM) decreased 6%, and fat mass (FM) decreased 50%. Absolute changes in FFM were significantly (although weakly) correlated with changes in IGF-1 (r = 0.42) and cortisol (r = –0.33), but not testosterone (r = 0.22). Similarly, absolute changes in FM were significantly (although weakly) correlated with changes in IGF-1 (r = –0.30) and cortisol (r = 0.40), but not testosterone (r = –0.20). These results suggest that changes in IGF-1 and cortisol are better indicators of severe weight loss correlating with tissue loss during operational stress rather than reductions in testosterone.[16] Monitoring circulating levels of endogenous hormones in Special Operators during training or during missions may not be practical.

Nonetheless, Nindl et al. found that after several months of high operational stress there were significant negative physiological changes that occurred.[16] Friedl et al. also studied the effects of "chronic energy deficit" on endogenous hormone levels throughout the 8-week Ranger course.[18] Analogous to the findings of Nindl et al,[16] after 8 weeks of high-stress training, testosterone decreased 86.5% and IGF-1 decreased 57.1%.[18] Cortisol increased 60.1%. Friedl et al. reported that energy deficit was associated with the significant declines in testosterone, not exercise.[18] For example, testosterone levels returned to normal during re-feeding despite high-energy expenditures during the training course, which averaged 6,000kcal/day. Friedl et al. suggested that artificial restoration of hormone levels within the normal range may be beneficial physiologically and psychologically for Ranger students.[18]

Despite the lack of correlation between FFM and testosterone reported by Nindl et al,[16] testosterone and FFM are known to be positively correlated with muscular strength.[19] Thus, Nindl et al. suggest the research and development of a novel therapeutic agent as a countermeasure, which would allow circulating concentrations of endogenous growth and anabolic hormones to be maintained, thus possibly attenuating losses in FFM.[16] Another recommended countermeasure would be the prescription of amino acid supplements. For example, Opstad and Aakvaag found that during a 5-day Ranger training course of operational stress, testosterone levels did not recover after cadets consumed additional calories primarily from carbohydrates.[20] This suggests that caloric deficiency is not a contributing factor toward lowered testosterone levels and that changes in testosterone and IGF-1 may be related to an insufficient intake of amino acids.[7,20,21]

Sustained operations, ranging from 3-day missions to 8 weeks of training, are consistently described in the scientific literature as (1) high-energy expenditure, (2) underfeeding, and (3) sleep deprivation. The combination of these operational stressors can lead to deleterious effects on physical and cognitive performance of Special Operators (Table 1). Body fat composition undergoes significant changes following SUSOPS, and the longer the SUSOPS, the greater is the effect on percent body fat composition. For example, BM has been reported to decrease 3.1% after 72 hours of SUSOPS,[22] 4.1% after 8 days of SUSOPS,[23] and 12.6% after 8 weeks of Ranger School.[16] Fat-free mass has been reported to decrease 2.3% after 72 hours of SUSOPS, with losses of FFM in the arms and trunk only (4–5%).[22] A similar 2.4% decrease in FFM was reported after 8 days of SUSOPS,[23] and Ranger students lost 6% of initial FFM after 8 weeks of training.[16] Significant decrements in FFM were reported in only the arms (12%) and legs (9%) after Ranger School, differing from the regional losses in FFM after 72 hours of operational stress.[16,22] Furthermore, overall FFM decreased 5% after 8 days of special support and reconnaissance (SSR), and the lower extremities lost 6% of muscle mass.[5] A 5% decrease in FFM after 8 days of SSR and a 6% decrease in FFM after 8 weeks of Ranger training depict the effects of mission duration and differences in types of operational stress imposed on the human body.

Whereas SSR units experience immobilization and muscle atrophy due to lack of muscular loading, high-intensity, long-duration training leads to muscle atrophy most likely attributed to nutritional deficiency, overexertion, and changes in hormonal levels. Because little can be done to change the reality of SUSOPS, an appropriate nutritional countermeasure may be beneficial in mitigating or preventing the losses of BM and FFM during missions. The First Strike Ration® is a suggested countermeasure for SUSOPS and is designed for use during repetitive 3- to 7-day missions that also include a recommended recovery period of approximately 1 to 3 days between missions.[24] This ration should be approximately 2,400kcal/day and should include the following macronutrients: 100 to 120g of protein, 350g of carbohydrate, and an estimated 58 to 67g of fat.

Furthermore, it is recommended that a high-carbohydrate supplement (~400kcal or 100g) be added to the First Strike Ration for Operators who require higher energy needs.[24] By using this ration, body weight loss during SUSOPS could be attenuated, and it is recommended that weight loss be measured after 1 month of using this ration. Erdman et al. recommend that if an Operator's weight loss is greater than 10%, he should not be sent on assault missions until weight stabilizes within 5% of

Table 1 *Physiological Changes During Special Operations Training.*

Training Duration	Changes in BM (%)	Changes in Total FFM (%)	Changes in Total FM (%)	Changes in Lower Body Power Output (%)	Changes in Maximal Jump Height (%)	Changes in Maximal Lifting Strength (%)	Changes in MVC (%)	Changes in RFD (%)
72 hours SUSOPS (Nindl et al, 2002)	↓ 3.1	↓ 2.3	↓ 7.3	↓ 9	↓ 15 (total work for squat jumps)			
8 days SUSOPS (Welsh et al.)	↓ 4.1	↓ 2.4	↓ 12.7	↓ 8.9	↓ 4.9			
8 days SSR (Christensen et al.)	↓ 4	↓ 5.1			↓ 8.2		↓ 9.2	↓ 15–30
8 days SSR (Thorlund et al.)	↓ 3.2	↓ 5.0	No change		↓ 9.9		↓ 10.9	↓ 17–22
8 weeks Ranger training (Nindl et al, 2007)	↓ 12.6	↓ 6.1	↓ 48	↓ 21	↓ 16	↓ 20 (simulated power clean)		

his initial weight.[24] This recommendation is similar to Friedl's recommendations that BM losses of at least 5% and possibly 10% are necessary before any significant decrements in Soldier physical performance occur.[25]

Along with nutritional deficiency, Special Operators sleep very little during SUSOPS. Tharion et al. studied the effects of Hell Week and caffeine during BUD/S training on Navy SEAL trainees' marksmanship.[26] SEAL trainees endure sleep deprivation, fatigue, psychological stress, and cold-wet environmental conditions during Hell Week, likely the toughest training they will ever experience during their military career. Tharion et al. suggested 200mg of caffeine as an optimal dose for an acute effect on marksmanship in sleep-deprived individuals (e.g., after 72 hours of Hell Week) and 300mg of caffeine as a performance enhancer for up to 8 hours. The intake of 200mg of caffeine helped decrease sighting time to target, but not accuracy in SEAL trainees after 72 hours of Hell Week.[26]

Therefore, caffeine intake in appropriate doses may be beneficial for marksmanship of Special Operators during missions in which sleep deprivation and other operational stressors may negatively impact mission success. Moreover, Flanagan et al. suggest that Soldiers conducting dangerous combat missions at night should routinely nap during the afternoon to increase evening alertness and performance.[6] For example, a 26-minute afternoon nap improved National Aeronautics and Space Administration pilots' cognitive performance on aviator tasks by 34%.[27] Flanagan et al. support the incorporation of naps during Ranger School, with the idea that routine naps in training will become standard procedure in forward-deployed locations.[6] Commanders may consider naps as a simple countermeasure to improve alertness and cognitive performance when Special Operators are sleep deprived and must coordinate nighttime missions.

Effects of Operational Stressors on Human Performance

The multiple stressors in a combat environment endured by Special Operators yield an overall stress burden with similar consequences of athletic "overtraining."[28] Additionally, Nindl et al. hypothesized that physical overexertion (independent of sleep and energy restriction) may be the attributing factor of compromised physical performance for Soldiers in the field.[22] Furthermore, physical overexertion alongside energy deficit may together lead to greater losses in physical performance.[22] For example, significant physical performance decrements including losses in lower body power output, jump height, and maximal lifting strength were identified after 8 weeks of Ranger School. A 21% decline in lower body power output, measured by a maximal (1–RM) vertical jump test, was significantly correlated (r = 0.30) with changes in FFM.[16] Lower body power output in U.S. Marines decreased 8.9% after 8 days of SUSOPS, also measured by a maximal unloaded vertical jump test.[23] A 9% decrease in power output and 15% decrease in total work performed in Soldiers were observed following 72 hours of SUSOPS, measured by squat jumps (30 repetitions of 30% of 1–RM).[22]

Concomitantly, maximal jump height decreased 16% after Ranger School,[16] 4.9% after 8 days of SUSOPS,[23] and 8.2% and 9.9% after SSR missions where Soldiers were required to remain in the lying face down (i.e., prone) position for 8 days.[5,29] Significant declines in lower body power output can result in as little as 72 hours (9% decrease) of rigorous training and greater losses in as little as 8 weeks of training (21% decrease). Therefore, it may be important for Special Operators' lower body power output to be assessed before and during deployments. The assessment of lower body power output could be critical because explosive lower body power is highly pertinent to battlefield activities that require bouts of both high-intensity and short-duration activity.[30] Additionally, decrements in lower body power output were associated with losses in FFM following 8 weeks of Ranger School ($r = 0.30$).[16] Commanders should also be aware of potential losses in muscle mass and power output in Special Operators who are on long missions (i.e., at least 8 weeks) in which caloric deficit, sleep deprivation, and high-energy expenditure are expected; thus, specific countermeasures and adequate recovery time after mission completion could be considered to attenuate Operators' muscle atrophy and loss of lower body power output.

Considering the significant association between lower body power and military tasks, commanders could also track changes in Special Operators' lower body power output to maintain operational proficiency in the field. For example, a simple field test such as the maximal vertical jump (countermovement) test could be utilized by commanders to assess lower body power output performance decrements.[5,16,23,30] This test requires minimal equipment, practice, and time.[16] The test may be valuable in the field, since it can be administered using chalk-marked fingers and a blackboard or wall.[16,30] Nindl et al. provide a description of this test.[16] Welsh et al. also found a maximal vertical jump test to be sufficient in detecting changes in lower body power output after 8 days of SUSOPS.[23] However, a loaded jump test may be relevant for Soldiers because of the substantial loads carried during military operations, which may be more representative of changes in strength and lower body power.[22,23] The vertical jump test to assess lower body power decrements during operational stress may be a important consideration for commanders due to its face validity and content validity in measuring brief, powerful lower body exertions similar to many battlefield activities.[30]

Special Operators engage in a variety of missions, some of which may require high-energy expenditure and result in overexertion, while others may be opposite in nature, described by immobilization. For example, Christensen et al. and Thorlund et al. reported a significant 10% and 11% decline in knee extensor maximal voluntary contraction (MVC), respectively, following 8 days of a simulated SSR mission, in which Danish National Guard SSR unit Soldiers were required to remain in a face down lying position the entire mission.[5,29] Furthermore, the rate of force development (RFD) diminished 17%–22% and 18%–26% after the 8-day mission, and following a 3-hour recovery from the initial post-mission measurement, late-phase RFD (0–200 ms) remained suppressed.[5,29] Reduced RFD is an important outcome measure because the ability to quickly generate muscle force is necessary during swift exfiltration from an SSR mission.[5]

Additionally, Christensen et al. reported a 4% decrease in BM and a 5% decrease in total FFM, while the muscle mass of the lower extremities decreased 6%.[5] The loss of lower extremity muscle mass was attributed to knee extensor atrophy. Reduction of MVC will also reduce the ability of Special Operators to jump and sprint, since these movements depend on RFD.[5] These findings are in accordance with the 8.2% and 9.9% decline in maximal jump height following the 8-day SSR mission.[5,29] A vertical jump test may also then be used to assess the strength of the knee extensors. Christensen et al. concluded that the effects of long-term covert SSR missions (i.e., weight loss, muscle atrophy, reduction of muscle contraction dynamics) are similar to those of microgravity and bed rest.[5] Christensen et al. and Thorlund et al. recommended the following countermeasures be considered for future research: (1) resistance training programs for cramped spaces, (2) electrical muscle stimulation,[31] and (3) amino acid supplementation to attenuate or prevent muscle atrophy.[32] Fitts et al. studied the effects of 28 days of bed rest on human skeletal muscle fibers.[32] With the aim of counteracting muscle atrophy and loss of power, these researchers assigned one group of subjects three daily supplements, each containing 16.5g of essential amino acids and 30g of sucrose. The supplementation prevented type I fiber force decline in the soleus muscle (located in the deep portion of lower leg behind the calf muscle) and prevented the decline in peak power of the vastus lateralis type II muscle fibers.

Additionally, Fitts et al. suggested that a supplement that stimulates muscle protein synthesis be tested as a countermeasure for astronauts on the International Space Station.[32] Christensen et al. and Thorlund et al. therefore proposed that the effectiveness of this supplementation be tested on Special Operators immobilized for days on SSR missions.[5,29] Moreover, Thorlund et al. noted that researchers should be mindful of the highly restricted space for equipment and supplies during SSR missions and suggested that a reconditioning period be considered between deployments in which Special Operators may be conducting highly immobile missions.[29]

The fitness requirements of Special Operators are necessitated by the types of occupational tasks they must perform. Some of these physical tasks may require (1) carrying very heavy loads for long periods of time, (2) short bursts of high-intensity physical activity, (3) lifting heavy loads, and (4) climbing while wearing PPE.[1] For example, during the different phases of training, Ranger students are required to perform various types of physical tasks that require high levels of muscular strength, power, and endurance. Some trainees arrive to the 3-day Ranger Assessment Phase (RAP) not prepared for the initial Ranger Physical Fitness Test (RPFT). The RPFT consists of sit-ups, chin-ups, push-ups, and a 5-mile run. The remainder of events during RAP week includes combat water survival, land navigation (day and night), and a 12-mile loaded foot march. Hence, 60% of all Ranger School failures occur in the first 3 days of the course (RAP, with 25% of all RAP week failures occurring during the RPFT).[33] Of these failures, most occur during the push-up event, where Soldiers are required to complete a minimum of 49 push-ups in 2 minutes.[33] Following 8 weeks of Ranger School, Soldiers' maximal lifting strength was measured by having them perform a simulated power clean using a weight stack machine. Researchers reported that there was a 20% decline in maximal lifting strength.[16] However, following 9 weeks of Croatian Armed Forces Special Operations Battalion (SOB) training, only a 6.5% decrease in maximal lifting strength was observed.[34]

In contrast, this same group of researchers (Sporiš et al.) measured a 24.7% decline in strength when measured by a bench thrust of 70% of body weight. Regardless, 8 weeks or more of military training under operational stress resulted in significant declines in muscular strength. Sporiš et al. reported an 18.9% decrease in number of pull-ups after 9 weeks of Croatian Armed Forces SOB training.[34] Burke and Dyer also reported a significantly reduced number of pull-ups. For example, prior to training, 167 men were able to perform 10 pull-ups; after 8 weeks of Ranger training, they could only perform 8.6 pull-ups.[35] This is in opposition to the increased number of push-ups observed after training and may be attributed to the lack of performing pull-ups versus push-ups during training. Prusaczyk et al. stated that 9 of 20 Navy SEAL missions involved a substantial amount of lifting, pulling, carrying, and climbing.[36] According to Hyde et al, the maximum number of pull-ups is a highly relevant occupational task associated with special operations.[37] The research of Sporiš et al. suggests that the maximum number of pull-ups be used as a field test to assess losses in upper body strength.[34] If access to weights is available, Nindl et al. suggest a power clean (this study used a weight stack machine), which had a test-retest reliability of $r = 0.91$, to test for maximal lifting strength.[16] This test has been shown to correlate with a Soldier's ability to successfully perform load carriage and field artillery ammunition loading (Nindl et al., 2007; see Nindl et al, 1997).[38] Pull-ups and power cleans are examples of physical tests that could be used by commanders to assess any decrements in muscular strength prior to SUSOPS and any changes in muscular strength after SUSOPS.

Specific countermeasures to prevent decrements in lower body power output and strength are lacking in the scientific literature. Specific training programs have not been adequately researched and implemented for Special Operators who are preparing for training or missions in which operational stressors may cause physical performance decrements. Additionally, subsequent evaluation of the effectiveness of a specific training program to mitigate performance decrements during periods of high operational stress will be necessary to this effort. General recommendations in the scientific literature include optimizing nutrition and physical training programs to enhance performance before Operators are exposed to sustained physical stressors[7,16] and to focus on muscular strength and power for urban operations while decreasing aerobic endurance training.[34] However, in the development of a pre-selection physical fitness training program for Canadian Special Operations Regiment (CSOR) applicants, the results of a physical movement task analysis identified lifting, lowering, and carrying equipment as the most frequently utilized tasks in the Assessment Center (AC) phase of the CSOR selection process.[1]

Carlson and Jaenen concluded that it is essential to train the following skeletal muscles in Special Operator applicants: lower body muscles that are responsible for hip extension and knee flexion (both concentrically and eccentrically), core muscles that are recruited to stabilize the spine, skeletal muscles responsible for movement of the body in the transverse plane, and upper body musculature responsible for gripping and holding objects.[1] Carlson and Jaenen incorporated four muscular strength and endurance training circuits into their proposed fitness training program that targeted the primary skeletal muscles identified as most used in the AC. Each of the four circuits incorporates the following: (1) a full body exercise, (2) three to four lower body exercises, and (3) three to four upper body exercises that emphasize the ability to grip and hold on to items.[1] All exercises target the muscles most used in the AC. Because weight-loaded marching is a critical task of SOF Soldiers,[39] circuit training may be more optimal than strictly resistance training because circuits have been shown to produce a greater transfer of training effect for weight-loaded marching.[40]

Effects of Equipment on Physical Performance

In 2011, a review article by Larsen et al. highlighted the literature investigating the impact of body armor on physical performance. Additionally, the effect of body armor on thermal stress and physical exertion was discussed.[42] From the review by Larsen and colleagues, a few studies investigating the impact of body armor on physical performance and exertion were identified. Riccardi et al. reported a decrement in performance on pull-ups (by 61%), hang time (by 63%), and stair stepping (by 16%), but no effect was seen on grip strength.[43] An additional finding of interest is the significant increase in VO_2 consumption in the trials with body armor.[43] Influence of protective vests on physical performance was studied by Hasselquist and colleagues and DeMaio and colleagues. Hasselquist et al. studied the impact on physical performance and exertion for four test conditions: wearing a 8.7kg tactical vest and three upper extremity armor configurations of similar weight, but varying surface area coverage.[44] Gait adaptations, decreased performance (increased completion time for sprints and obstacle courses and reduced number of box lifts), and increased Vo_2 consumption were all associated with the three extremity armor configurations for the maximal effort tasks analyzed.[44]

DeMaio et al. investigated the effect of a protective vest on physical performance during cardiopulmonary exercise, balancing tasks, field tests, and upper extremity climbing tasks. Performance during the treadmill assessment (duration of time doing the task) was significantly reduced in the trial run with the protective vest. Also reported for the treadmill task was a significant decrease in Vo_2 consumption. While this may seem to be contrary to what is expected, this finding was attributed by the authors to a potential restriction of chest wall motion by the protective vest.[45] Additionally, as noted by Larsen et al, this finding may have been due to the shortened time of the treadmill test with the protective vest.[42] During the field assessments, a significant reduction in shuttle runs resulted from wearing the protective vest. However, no significant difference was detected in the box agility test and upper extremity climbing task.[45]

To fully understand the impact of body armor on performance, the external loads carried by military personnel should also be considered when evaluating the influence of PPE on physical performance and exertion and heat stress.[42,46,47] Sell et al. found an increase in maximum knee flexion angle and maximum ground reaction forces during two-legged drop landings while carrying approximately 15kg of equipment (both combat and protective).[46] Recommended countermeasures to reduce the risk of injury include eccentric strengthening of lower extremity muscles and training on proper landing techniques. Additionally, training protocols should include the management of external weight representative of actual missions to ensure accurate preparation for operational scenarios.[46]

Other studies have focused on the kinematic changes resulting from operational material handling tasks.[48,49] Seay et at. investigated the impact of carrying a rifle during operational tasks on upper body kinematics and gait. During the running task, sagittal plane trunk range of motion decreased and trunk transverse range of motion increased when carrying a rifle. During the walking task, carrying the rifle decreased sagittal plane range of motion. No significant effects were detected on pelvis range of motion for the rifle condition in either the running or walking test.[48] Since military personnel can carry loads upwards of 68kg, a study by Rodriguez-Soto and colleagues used magnetic resonance images to investigate the changes in lumbar spine kinematics resulting from carrying heavy loads. Significant differences were detected in the "loaded" test conditions, with varying responses of the superior and inferior levels of the lumbar spine evident under the heavy load. These responses resulted in an overall reduced lordosis of the lumbar spine.[49] While much of the impact of these kinematic changes on risk of injury is unknown, additional work is needed to understand how design changes within both PPE and combat equipment can minimize the kinematic adaptations of the human body under loads, thus minimizing the effect of the load on risk of injury and physical performance.

Effects of Operational Stressors on Musculoskeletal Injuries

Special Operators are well-rounded athletes, attaining high levels of strength, power, and aerobic fitness in preparation for training and later missions. Strength, power, and quick movements such as jumping and sprinting have been shown to be important indices of fitness in combat, especially in urban operations. Aerobic endurance has also been shown to be an important fitness component for U.S. Army Rangers and Navy SEALs.[36,41] Special Operators include some of the most aerobically fit warfighters in the Armed Forces, with Vo_2max levels of (1) 57.7mL/kg/min for U.S. Navy SEALs, (2) 62.4mL/kg/min for BUD/S trainees, (3) 55mL/kg/min for U.S. Army Special Forces, and (4) 58.5mL/kg/min for British parachutists.[1,2] High aerobic fitness is necessary for the Special Operator, since SUSOPS is characterized mostly by extended endurance movements.[24] Special Operators are prepared for possible near-continuous daily physical activity by their extensive training. For example, Navy SEALs may conduct continuous combat operations in the field for longer than 24 hours.[26] Rigorous training while wearing heavy back pack loads may be necessary to prepare Special Operators for combat and solidify the warrior ethos, but extended durations of load carriage are commonly associated with stress fractures.[50] Henning et al. postulated that the significantly lower levels of IGF-1 during 8 weeks of Ranger training and caloric restriction[16] may be an important mediator of bone loss, since IGF-1 may be vital in stimulating osteogenesis.[7,51] The operational environment of training in addition to the constant backpack load could lead to a reduction in physical performance and increased injury risk.[34]

Furthermore, Special Operators can be required to carry heavy rucksacks for long distances and over challenging terrain.[1] For example, paratroopers within the 82nd Airborne Division in Afghanistan in 2003 carried an average 46kg approach load and 60kg emergency approach load.[47] Increased combat load is associated with increased heart rate and respiratory rate, muscle fatigue, reduced marksmanship, knee pain, low back injuries, stress fractures, and foot blisters.[50,52] In extreme cases, heavy rucksack carriage can lead to nerve damage of the upper body musculature, possibly resulting in rucksack palsy.[53] Orr et al. recommended that load carriage conditioning be conducted two to four times per month at a volume sufficient to provide a training stimulus but as to not cause a rapid overload prior to deployment.[54]

Aharony et al. studied the effects of 14 weeks of Navy SEAL preparatory training on overuse and irreversible injury to trainees' lumbar sacral spine and right knee as indicated by magnetic resonance imaging.[55] Preparatory SEAL training has been described as "super physiological" in nature, and SEAL candidates train wearing ceramic vests weighing 7kg, carry 4- to 5.5kg rifles, and carry up to 40% of their body weight while running and marching for up to 90km.[55] After the 14-week training period, the volunteer trainees' backs did not show any signs of overuse injury. These findings are remarkable considering that trainees in this study far exceeded the U.S. National Institute for Occupational Safety and Health recommendations for loading limits in magnitude and duration: the maximum acceptable lifting weight for industrial workers is 23kg under the most favorable conditions.[56] Adams et al. stated that frequent lifting of heavy loads is a major risk factor for disc prolapse,[57] while Videman et al. concluded that maximal weight lifting was associated with greater degeneration throughout the entire lumbar spine.[58] Although the findings of Aharoney et al. suggest that healthy trainees can safely participate in rigorous SEAL training with no acute evidence of damage to their lumbar sacral spines,[55] future research should examine the long-term effects of such training in the decades following a Navy SEAL's career. Despite no evidence for acute back damage, the trainees' knees showed signs of overuse injury.[55]

The most common types of injuries among military personnel are musculoskeletal overuse injuries, in which the majority occur at or below the knee.[11] For example, Kaufman et al. reported that musculoskeletal injury rates can range from 30 to 35 per 100 Navy special warfare candidates, and among 449 trainees, the most common injuries were stress fractures, iliotibial band syndrome, patellofemoral syndrome, Achilles tendinitis, and periostitis.[11] These findings are analogous to a study of overuse injuries at BUD/S, with sprains, strains, and blisters as additional common overuse injuries.[14] In assessing SEAL recruits' physical activity 6 months prior to BUD/S, Shwayhat et al. found that recruits who ran slower than an 8 min/mile pace and on softer surfaces (e.g., sand, grass, dirt, artificial track) and recruits with lower weekly running mileage and for shorter durations were at greater risk for an overuse injury.[14] Shwayhat et al. suggest that recruits prepare for BUD/S by running on both hard (e.g., concrete and asphalt) and soft surfaces as a countermeasure to possibly reduce the incidence of overuse injuries.

Additionally, the same group of researchers suggests gradual increases in speed, duration, and weekly mileage as a preventive countermeasure.[14] However, this research was published in 1994, and a thorough, detailed training program with gradual increases in training intensity for both running and swimming, as well as an injury prevention guide, is available for SEAL recruits on the official website.[59] A further countermeasure includes the development of a durable, shock-absorbing orthotic insert for military boots that also provides effective support for minimizing ankle sprains.[11]

Anterior knee pain syndrome (AKPS) is reportedly a common injury during strenuous military physical training due to temporary overexertion.[15] A dynamic patellofemoral brace has been suggested as a preemptive countermeasure to the development of anterior knee pain during strenuous physical training. In a study by Van Tiggelen et al, military recruits were split into a brace group (n = 54) and control group (n = 113) before basic military training (BMT).[15] The brace group wore two dynamic patellofemoral braces (as instructed by an experienced physical therapist) during all physical activities at BMT. After 6 weeks of BMT, 18.5% of the brace group developed anterior knee pain, compared to 37% of the control group, indicating that a significantly lesser number of recruits developed anterior knee pain while wearing the braces than with no brace ($p = .020$). Therefore, although the exact mechanism of action remains unknown, these researchers suggest that a patellofemoral brace is an effective preemptive countermeasure to AKPS during strenuous physical training.[15] However, this research did not mention any negative effects of wearing the braces (e.g., performance decrements, cumbersome mobility, perceived comfort, etc.), so it may be necessary for additional research to be conducted. Furthermore, because the mental fortitude of Special Operators is quite different than the general population, the acceptance of preemptive knee braces in this population should be studied.

Special Operators infiltrate target areas in a variety of ways, such as nighttime airborne parachute operations. The insertion itself poses a significant stressor in addition to the considerable operational stressors leading up to the jump. For example, over 25% of U.S. Army Rangers from the 2/75th Ranger Battalion during Operation Just Cause did not sleep at least 24 hours prior to the jump (December 1989) and only slept an average of 3 hr/day during the first 72 hours of combat.[13] In addition to sleep deprivation, Rangers reported not eating an average of 17 hours prior to the jump. Their reports resulted in a 35% casualty rate, and most of the injuries were musculoskeletal (sprains) and nonsurgical, with 90% occurring during the nighttime parachute insertion. The ankle was the most frequently injured area (19.6%), in which sprains constituted over 80% of these injuries.[13] Of the Rangers sustaining ankle injuries, 38% were physically unable to carry on with the mission, and 27% experienced limited mobility during the mission.[13] However, despite little sleep and insufficient nourishment during the first few days of combat, as well as the tropical climate (i.e., Panama), Rangers suffered no heat strokes.

Also, the majority reported they had more energy than expected during battle, which may be attributed to their high fitness levels and youth.[13] Whether environmental variables, inadequate sleep, negative energy balance, equipment stressors, or all concurrently were to blame for 90% of injuries occurring during the insertion, preventative countermeasures could be implemented to reduce the number of injured Operators prior to combat. Furthermore, Kotwal et al. evaluated static-line parachute (T10C parachute) injuries sustained by the 75th Ranger Regiment during four nighttime combat airborne missions: two conducted in Afghanistan in 2001 and two conducted in Iraq in 2003.[12] Although the recommended safety threshold for the T10C parachute is 360 pounds, the average total weight of the jumper plus equipment load ranged from 323 to 380 pounds across the four missions. The risk of parachute injury is associated with equipment and weight: the heavier the parachutist (jumper plus equipment), the faster the rate of descent, and the greater the force on impact.[12] In total, 83 injuries were sustained by 76 of 634 Rangers. Lower extremity injuries accounted for 68.7% of the injuries, and the foot was the most frequently injured (3.2%) followed by the ankle (3.0%). The ankle is usually the most frequently injured anatomical region in parachuting,[60] but Rangers in this study wore parachute ankle braces (PABs) mandated as part of their uniform, which may have accounted for the lower than predicted ankle injury rates.[12]

Although this is the first published study of PAB use in combat, the PAB ankle injury rate (3.0%) was significantly lower (p <.001) than the combat non-PAB ankle injury rate (10.8%) reported for Army Rangers in Panama during Operation Just Cause.[12,] The use of PABs as a preventative ankle injury countermeasure requires additional study, as the PABs could either be beneficial for preventing ankle injuries or causative in the higher rate of foot injuries seen in the study by Kotwal et al.[12] Regardless, the use of preemptive ankle braces during an airborne insertion may be beneficial in reducing the number of injured Operators prior to combat.

Conclusions and Future Recommendations

Special Operators are an elite military group both physically and mentally. They must endure extensive training for the toughest, often intricately detailed operations. Therefore, Special Operators often seek any opportunity to employ their skills against real enemy combatants.[6] This fearless mindset is necessary for Special Operations and is further developed through rigorous training, in which stressful combat scenarios are simulated to prepare Operators for real combat scenarios. Special Operators must learn how to overcome many operational stressors in training, which will further develop their skills for similarly stressful missions. As expected, high-energy expenditure, underfeeding, sleep deprivation, heavy equipment loads, and environmental factors during SUSOPS can lead to changes in body composition and physical performance decrements, which may result in musculoskeletal injuries and mission mishaps. For example, as a result of operational stressors, loss of lean tissue and decrements in lower body power output has been reported for SUSOPS lasting as little as 72 hours.

A simple field test such as the maximal vertical jump test can be used to measure changes in lower body power output in Special Operators. Because these changes may negatively impact mission success, it is suggested that commanders be aware of these declines when planning missions and consider implementing appropriate countermeasures to attenuate physical changes during high-tempo missions or SSR immobilization. A nutritional countermeasure, the First Strike Ration, has been suggested for repetitive 3- to 7-day missions. An additional 400 kcal of a high-carbohydrate supplement has been recommended for Operators requiring higher energy, although it is widely recommended that Special Operators optimize their nutrition, muscular strength, and power prior to missions. However, to these researchers' knowledge, no specific training program has been recommended and/or implemented as a countermeasure to attenuate decrements in lower body power output. Nonetheless, Carlson and Jaenen have recommended circuit training of specific targeted musculature from a task movement analysis conducted by the Canadian Special Operations Regiment Assessment Center.[1]

Research documenting the effectiveness of circuit training to prepare for the rigorous AC as a training countermeasure for physical detriments during SUSOPS has not been investigated. These investigators found no specific physical training countermeasures designed to reduce expected losses of lower body power output, muscular strength, and lean tissue for Special Operations (SUSOPS and SSR). While several researchers[5-7,9,16,22,23,29,34] have reported the effects of military operational stress, future studies should investigate specific physical, nutritional, and therapeutic countermeasures to sustain physical performance and decrease the risk of musculoskeletal injuries during training and SUSOPS. Furthermore, future studies should also focus on improving equipment design to minimize the impact of PPE and external loads on the physical performance of the Operator.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy or position of the U.S. Air Force, Department of Defense, or U.S. Government.

Disclosures

The authors have nothing to disclose.

References

1. Carlson MJ, Jaenen SP. The development of a preselection physical fitness training program for Canadian Special Operations Regiment applicants. *J Strength Conditioning Res.* 2012;26(Suppl 2):S2–S14.
2. Beckett MB, Goforth HW, Hodgdon JA. Physical fitness of U.S. Navy Special Forces team members and trainees. San Diego, CA: Naval Health Research Center; 1989: report No. 89-29.
3. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription.* 8th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2010.
4. Deuster PA, O'Connor FG, Henry KA, et al. Human performance optimization: an evolving charge to the Department of Defense. *Mil Med.* 2007;172:1133–1137.
5. Christensen PA, Jacobson O, Thorlund JB, et al. Changes in maximum muscle strength and rapid muscle force characteristics after long-term special support and reconnaissance missions: a preliminary report. *Mil Med.* 2008;173:889–894.
6. Flanagan SC, Kotwal RS, Forsten RD. Preparing Soldiers for the stress of combat. *J Spec Oper Med.* 2012;12:33–41.
7. Henning PC, Park BS, Kim JS. Physiological decrements during sustained military operational stress. *Mil Med.* 2011;176:991–997.
8. Rintamäki H, Kyröläinen H, Santtila M, et al. From the subarctic to the tropics: effects of 4-month deployment on Soldiers' heat stress, heat strain, and physical performance. *J Strength Conditioning Res.* 2012;26(Suppl 2):S45–S52.
9. Montain SJ. Physiological demands of combat operations. In Committee on Optimization of Nutrient Composition for Military Rations for Short-Term, High-Stress Situations, et al. *Nutrient composition of rations for short-term, high-intensity combat operations.* Washington, DC: The National Academies Press; 2005:169–180.
10. Kim JJ, Diamond DM. The stressed hippocampus, synaptic plasticity and lost memories. *Nat Rev Neurosci.* 2002;3:453–462.
11. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med.* 2000;18(3 Suppl):54–63.
12. Kotwal RS, Meyer DE, O'Connor KC, et al. Army Ranger casualty, attrition, and surgery rates for airborne operations in Afghanistan and Iraq. *Aviat Space Environ Med.* 2004;75:833–840.
13. Miser WF, Doukas WC, Lillegard WA. Injuries and illnesses incurred by an Army Ranger unit during Operation Just Cause. *Mil Med.* 1995;160:373–380.
14. Shwayhat AF, Linenger JM, Hofherr LK, et al. Profiles of exercise history and overuse injuries among United States Navy Sea, Air, and Land (SEAL) recruits. *Am J Sports Med.* 1994;22:835–840.
15. Van Tiggelen D, Witvrouw E, Roget P, et al. Effect of bracing on the prevention of anterior knee pain—a prospective randomized study. *Knee Surg Sports Traumatol Arthrosc.* 2004;12:434–439.
16. Nindl BC, Barnes BR, Alemany JA, et al. Physiological consequences of U.S. Army Ranger training. *Med Sci in Sports Exerc.* 2007;39:1380–1387.
17. Harman SM, Metter EJ, Tobin JD, et al; Baltimore Longitudinal Study of Aging. Longitudinal effects of aging on serum total and free testosterone levels in healthy men. *J Clin Endocrinol Metab.* 2001;86:724–731.
18. Friedl KE, Moore RJ, Hoyt RW, et al. Endocrine markers of semistarvation in healthy lean men in a multistressor environment. *J Appl Physiol.* 2000;88:1820–1830.
19. Roy TA, Blackman MR, Harman SM, et al. Interrelationships of serum testosterone and free testosterone index with FFM and strength in aging men. *Am J Physiol Endocrinol Metab.* 2002;283:E284–E294.
20. Opstad PK, Aakvaag A. Decreased serum levels of oestradiol, testosterone and prolactin during prolonged physical strain and sleep deprivation, and the influence of a high calorie diet. *Eur J Appl Physiol Occup Physiol.* 1982;49:343–348.
21. Sánchez-Gómez M, Malmlöf K, Mejía W, et al. Insulin-like growth factor-I, but not growth hormone, is dependent on a high protein intake to increase nitrogen balance in the rat. *Br J Nutr.* 1999;81:145–152.
22. Nindl BC, Leone CD, Tharion WJ, et al. Physical performance responses during 72h of military operational stress. *Med Sci Sports Exerc.* 2002;34:1814–1822.
23. Welsh TT, Alemany JA, Montain SJ, et al. Effects of intensified military field training on jumping performance. *Int J Sports Med.* 2008;29:45–52.
24. Committee on Optimization of Nutrient Composition for Military Rations for Short-Term, High-Stress Situations, et al. *Nutrient composition of rations for short-term, high-intensity combat operations.* Washington, DC: The National Academies Press; 2005.
25. Friedl KE. When does energy deficit affect soldier physical performance? In Marriott BM, editor. *Not Eating enough: overcoming underconsumption of military operational rations.* Washington, DC: The National Academies Press; 1995:253–283.

26. Tharion WJ, Shukitt-Hale B, Lieberman HR. Caffeine effects on marksmanship during high-stress military training with 72 hour sleep deprivation. *Aviat Space Environ Med.* 2003;74:309–314.
27. Rosekind MR, Smith RM, Miller DL, et al. Alertness management: strategic naps in operational settings. *J Sleep Res.* 1995;4(S2):62–66.
28. Friedl KE, Mays MZ, Kramer TR, Shippee RL. Acute recovery of physiological and cognitive function in U.S. Army Ranger students in a multistressor field experiment. Paper presented at the RTO HFM Workshop on "The Effect of Prolonged Military Activities in Man. Physiological and Biochemical Changes. Possible Means of Rapid Recuperation," Oslo, Norway, 3–5 April 1995, RTO MP-042.
29. Thorlund JB, Jakobsen O, Madsen T, et al. Changes in muscle strength and morphology after muscle unloading in Special Forces missions. *Scand J Med Sci Sports.* 2011;21:e56–e63.
30. Harman EA, Gutekunst DJ, Frykman PN, et al. Prediction of simulated battlefield physical performance from field-expedient tests. *Mil Med.* 2008;173:36–41.
31. Parker MG, Bennett MJ, Hieb MA, et al. Strength response in human femoris muscle during 2 neuromuscular electrical stimulation programs. *J Orthop Sports Phys Ther.* 2003;33:719–726.
32. Fitts RH, Romatowski JG, Peters JR, et al. The deleterious effects of bed rest on human skeletal muscle fibers are exacerbated by hypercortisolemia and ameliorated by dietary supplementation. *Am J Physiol Cell Physiol.* 2007; 293:C313–C320.
33. U.S. Army Maneuver Center of Excellence. Ranger training brigade. https://www.benning.army.mil/infantry/rtb/.
34. Sporiš G, Harasin D, Bok D, et al. Effects of a training program for special operations battalion on Soldiers' fitness characteristics. *J Strength Conditioning Res.* 2012; 26:2872–2882.
35. Burke WP, Dyer FN. *Effects of Ranger training in selected measures of strength and cardiovascular fitness.* Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences; 1980:Research Report 1353.
36. Prusaczyk WK, Stuster JW, Goforth HW Jr, et al. *Physical demands of U.S. Navy Sea-Air-Land (SEAL) Operations.* San Diego, CA: Naval Health Research Center; 1995:Report No. 95-24.
37. Hyde D, Thomas JR, Schrot J, et al. *Quantification of Special Operations mission-related performance: operational evaluation of physical measures.* Bethesda, MD: Naval Medical Research and Development Command; 1997: Report NMRI 97-01.
38. Nindl BC, Friedl KE, Frykman PN, et al. Physical performance and metabolic recovery among lean, healthy men following a prolonged energy deficit. *Int J Sports Med.* 1997;18:317–324.
39. Knapik JJ, Harman EA, Steelman RA, et al. A systematic review of the effects of physical training on load carriage performance. *J Strength Conditioning Res.* 2012;26:585–597.
40. Williams AG, Rayson MP, Jones DA. Training diagnosis for a load carriage task. *J Strength Conditioning Res.* 2004;18:30–34.
41. Pemrick MD. *Physical fitness and the 75th Ranger Regiment: the components of physical fitness and the Ranger mission.* Master's thesis. Fort Leavenworth, KS: U.S. Army Command and General Staff College; 1999.
42. Larsen B, Netto K, Aisbett B. The effect of body armor on performance, thermal stress, and exertion: a critical review. *Mil Med.* 2011;176:1265–1273.
43. Ricciardi R, Deuster PA, Talbot LA. Metabolic demands of body armor on physical performance in simulated conditions. *Mil Med.* 2008;173:817–824.
44. Hasselquist L, Bensel CK, Corner B, et al. Understanding the physiological, biomechanical, and performance effects of body armor use. In Proceedings of the Army Science Conference (26th), Orlando, Florida, 1–4 December 2008.
45. DeMario M, Onate J, Swain D, et al. Physical performance decrements in military personnel wearing personal protective equipment (PPE).Paper presented at the RTO Human Factors and Medicine Panel (HFM) Symposium, Sofia, Bulgaria, 5–7 October 2009, RTO-MP-HFM-181.
46. Sell TC, Chu Y, Abt JP, et al. Minimal additional weight of combat equipment alters air assault soldier's landing biomechanics. *Mil Med.* 2010;175:41–47.
47. Task Force Devil Combined Arms Assessment Team (Devil CAAT). *The modern warrior's combat load: dismounted operations in Afghanistan.* Natick, MA: U.S. Army Center for Army Lessons Learned, U.S. Army Natick Soldier Center; 2004.
48. Seay JF, Hasselquist L, Bensel CK. Carrying a rifle with both hands affects upper body transverse plane kinematics and pelvis-trunk coordination. *Ergonomics.* 2011;54: 187–196.
49. Rodriguez-Soto AE, Jaworski R, Jensen A, et al. Effect of load carriage on lumbar spine kinematics. *Spine.* 2013; 38:E783–E791.
50. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med.* 2004;169:45–56.
51. Ballard TL, Clapper JA, Specker BL, et al. Effect of protein supplementation during a 6-mo strength and conditioning program on insulin-like growth factor 1and markers of bone turnover in young adults. *Am J Clin Nutr.* 2005;81:1442–1448.
52. Ricciardi R, Deuster PA, Talbot LA. Effects of gender and body adiposity on physiological responses to physical work while wearing body armor. *Mil Med.* 2007;172: 743–748.
53. Daube JR. Rucksack paralysis. *JAMA.* 1969;208:2447–2452.
54. Orr R, Pope R, Johnston V, Coyle J. Load carriage and its force impact. *Austral Defence Force J.* 2011;185(Jul–Aug):52–63.
55. Aharony S, Milgrom C, Wolf T, et al. Magnetic resonance imaging showed no signs of overuse or permanent injury to the lumbar sacral spine during a Special Forces training course. *Spine J.* 2008;8:578–583.
56. Waters TR, Putz-Anderson V, Garg A. *Applications manual for the revised NIOSH lifting equation.* Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and

Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH); 1994:115:Publication No. 94-110.
57. Adams MA, Freeman BJ, Morrison HP, et al. Mechanical initiation of intervertebral disc degeneration. *Spine*. 2000; 25:1625–1636.
58. Videman T, Sarna S, Battié MC, et al. The long-term effects of physical loading and exercise lifestyles on back-related symptoms, disability, and spinal pathology among men. *Spine*. 1995;20:699–709.
59. SEAL+SWCC: Official Naval Special Warfare Website. (n.d.). BUD/S training guides. http://www.sealswcc.com/seal-default.aspx#.
60. Bricknell MC, Craig SC. Military parachuting injuries: a literature review. *Occup Med*. 1999;49:17–26.

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