BLOCK-PERIODIZED TRAINING IMPROVES PHYSIOLOGICAL AND TACTICALLY RELEVANT PERFORMANCE IN NAVAL SPECIAL WARFARE OPERATORS

JOHN P. ABT,[1] JONATHAN M. OLIVER,[2] TAKASHI NAGAI,[3] TIMOTHY C. SELL,[3] MITA T. LOVALEKAR,[3] KIM BEALS,[3] DALLAS E. WOOD,[4] AND SCOTT M. LEPHART[5]

[1]College of Health Sciences, University of Kentucky, Lexington, Kentucky; [2]Department of Kinesiology, Texas Christian University, Fort Worth, Texas; [3]Neuromuscular Research Laboratory, Warrior Human Performance Research Center, Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, Pennsylvania; [4]Department of the Navy, Naval Special Warfare, Virginia Beach, Virginia; and [5]College of Health Sciences, University of Kentucky, Lexington, Kentucky

ABSTRACT

Abt, JP, Oliver, JM, Nagai, T, Sell, TC, Lovalekar, MT, Beals, K, Wood, DE, and Lephart, SM. Block-periodized training improves physiological and tactically relevant performance in Naval Special Warfare Operators. *J Strength Cond Res* 30(1): 39–52, 2016—Human performance training and prevention strategies are necessary to promote physical readiness and mitigate musculoskeletal injuries of the Naval Special Warfare (NSW) Operator. The purpose of this study was to measure the effectiveness of 2 training programs when performed during a training evolution of Operators. A total of 85 Operators (experimental: $n = 46$, age: 29.4 ± 5.5 years, height: 176.7 ± 6.4 cm, mass: 86.7 ± 11.6 kg; control: $n = 39$, age: 29.0 ± 6.0 years, height: 177.1 ± 6.3 cm, mass: 85.7 ± 12.5 kg) participated in a trial to measure the effectiveness of these programs to improve physical, physiological, and performance characteristics. Operators in the experimental group performed a 12-week block-periodized program, whereas those in the control group performed a nonlinear periodized program. Pretesting/posttesting was performed to assess body composition, aerobic capacity/lactate threshold, muscular strength, flexibility, landing biomechanics, postural stability, and tactically relevant performance. The experimental group demonstrated a significant loss in body fat, fat mass, and body mass compared with the control group, whereas aerobic capacity increased for the both groups. The experimental group demonstrated a significant increase in posterior shoulder flexibility and ankle dorsiflexion, whereas the control group had a significant reduction in shoulder, knee, and ankle flexibility. The experimental group also improved landing strategies and balance. Both groups improved upper and lower muscular power and upper-body muscular endurance, whereas only the experimental group demonstrated significant improvements in agility and total body muscular strength. Implementation of a population-specific training program provides structured and progressive training effectively and promotes physical readiness concurrently with tactical training without overload.

KEY WORDS human performance, injury risk, physical readiness

INTRODUCTION

Significant financial resources have been allocated to technological advancements of weaponry and tactical systems for Naval Special Warfare (NSW). Yet, the Operators remain NSW's most important weapon in military conflicts as they provide intelligence and direct action during missions. The NSW Operators (SEALS) are an elite and highly trained group whose military readiness and long-term retention are vastly compromised as a result of musculoskeletal injury (25). Musculoskeletal injuries have been previously reported as 0.32 injuries per subject during a 1-year period (1,3,22,23,37) with the majority of medical chart documented or self-reported injuries occurring to the lower extremity and upper extremity (1,3,22,23,37). Recreational activities/sports accounted for 8.6% of medical chart documented injuries and 20.8% self-reported injuries (1,3,22,23,37).

Physical readiness, performance optimization, and injury prevention are critical to the Special Operations Forces (SOF) community and specifically to the individual Operator. The responsive nature and frequency of tactical missions require a critical balance between systems development and recovery. Also, because of the physical demands, varied locations, and environmental conditions associated with

---

Address correspondence to Takashi Nagai, tnagai@pitt.edu.

30(1)/39–52

Journal of Strength and Conditioning Research

NSW operational training, human performance programs must be flexible in design to elicit improvements or maintenance (depending on phase of workup) in physical readiness while concomitantly reducing the risk of musculoskeletal injuries.

Comprehensive laboratory testing has created a biomechanical, musculoskeletal, and physiological profile of NSW Operators. Examination of the data has identified several physical readiness differences between SEAL Qualification Training Students and experienced Operators that may be related to the demands of training, exposure to stressful environments, and multiple deployment cycles. These findings suggest the need to focus on human performance training that limits age/experience-related physical readiness loss (1). In addition, Operators with a previous history of low back pain have exhibited suboptimal characteristics in balance when compared with the Operators without a previous history (37), and injury has been associated with various suboptimal musculoskeletal and physiological characteristics (3). Based on these findings, implementation of a comprehensive training program is necessary to match performance needs and injury prevention/mitigation requirements.

The fast tempo and ever-changing environments of operational training and deployment limit the ability to adhere to a long-term structured training program, making it difficult for Operators to maintain or improve physical fitness over the course of their career. Recently, a block-periodization model has been suggested for individuals in military while managing multiple operational training schedules (18). The benefits of the block-periodization model are in the medium- or short-sized cycles (mesocycles), allowing concentration of training on specific trainable characteristics and flexibility in program design (18). Despite the demonstrated benefits in a civilian athletic environment, to the authors' knowledge, this model has not been previously tested in the SOF community.

Although there is most likely not a single training program that can meet all the needs of SOF, it is clear that a combination approach is required to ensure the Operators are meeting optimal physical, physiological, and performance goals. Complementing traditional resistance and conditioning exercise, multidirectional agility, plyometrics with proper landing technique, joint-specific flexibility, strengthening, and postural stability have been shown to be effective in reducing a proportion of soldiers with musculoskeletal injuries (36).

The purpose of this investigation was to measure the effectiveness of 2 training interventions (block periodized, nonlinear periodized) by NSW's Tactical Athlete Program (TAP) when implemented during a training evolution of Operators. The programs were designed to improve biomechanical, musculoskeletal, physiological, and tactically relevant characteristics. It was hypothesized that both programs would result in improved physical and physiological characteristics, yet larger gains would result from performing the block-periodized program. Specifically, this program would result in greater tactically relevant field performance while improving laboratory-based characteristics in the areas of body composition, aerobic capacity, joint-specific flexibility/strength, landing characteristics, and static/dynamic postural stability.

METHODS

Experimental Approach to the Problem

A block-periodization model was developed to focus training on areas deemed to be suboptimal based on findings relative to biomechanical, musculoskeletal, physiological, and injury data (1,3,22,23,37). Additional corrective exercises and activities were incorporated into those performing the block-periodization model because this model of training was developed in an effort to combat deficiencies identified during the previous analyses (1,3,22,23,37). The experimental group performed the block-periodization model training, whereas the control group would continue performing the current training program that was based on a nonlinear periodization model in an effort to account for differing operational training and deployment scheduling. The total duration of the current study was 13 weeks, with 2 days of testing performed over 1 week before initiation of training and in the final week of training. This duration was selected based on availability of Operators during their training evolution.

Subjects

This study was reviewed and approved by the Institutional Review Board of the University and Human Research Protection Office at the Office of Naval Research. All subjects provided written informed consent prior to participation. Subjects were recruited from 2 SEAL teams and block assigned to an experimental or control group (experimental: $n = 46$, age: 29.4 ± 5.5 years, height: 176.7 ± 6.4 cm, mass: 86.7 ± 11.6 kg; control: $n = 39$, age: 29.0 ± 6.0 years, height: 177.1 ± 6.3 cm, mass: 85.7 ± 12.5 kg). The Operators were considered mission ready during their operational schedules. This enabled concurrent training physical programs to be implemented with tactical training and supervised with oversight by the investigators. All Operators were instructed to restrict performance of physical training beyond that which was prescribed for this project. All participants were active-duty and team-assigned NSW Operators aged 18–55 years, not diagnosed with any musculoskeletal injuries within 3 months before testing, and fully operational (deployable). The Operators were fully explained the potential risks of the investigation and given the opportunity to sign an institutionally approved informed consent in accordance with the human subject's guidelines.

Interventions

The training programs were 12 weeks in duration. This duration was dictated based on availability of the Operators during their training evolution. All Operators were well trained and familiar with all exercises performed throughout the training cycle. Physical training was supervised by

National Strength and Conditioning Association Certified Strength and Conditioning Specialists when Operators were stationed locally. Although assigned to remote training locations, detailed forms were provided to outline the training for the week. These forms were completed by the Operators and evaluated weekly for compliance. Physical training was limited to the prescribed training program and respective operational training. Operators performed only the assigned training programs with their respective operational training. Postworkout supplementation (20 g of protein, 45 g of carbohydrates, 3.5 g of fat) was provided on training days (Muscle Milk Collegiate; Cytosport, Benicia, CA, USA) for all Operators despite location of training as a part of routine postworkout regimen for all Operators. Those enrolled agreed to perform only the prescribed training and not to consume any nutritional or ergogenic supplements excluding protein supplementation and a daily vitamin for the duration of the training period.

Resistance training was performed 4 days per week immediately followed by conditioning. Additional conditioning was performed on 2 other days to allow a greater volume for the development of cardiorespiratory fitness. This was consistent between groups. A summary of the experimental group and control group workouts was described previously (29).

Experimental Group

Three training blocks each lasting 4 weeks were performed. Each block targeted a specific performance characteristic with an unload week scheduled the fourth week of each block to allow for recovery before initiation of the next block of training. The design of the block-periodization model training program was based on the biomechanical, musculoskeletal, and physiological characteristics of 302 NSW Operators previously tested (1,3,22,23,37). Based on these data, the block-periodization model training program included activities to improve on those areas deemed suboptimal. These activities were performed before exercise on those days in which resistance training was performed (4 days per week).

The first block was devoted to the development of basic abilities, including cardiorespiratory endurance, muscular strength, and basic coordination. On Monday and Thursday of block 1, participants performed multi-joint compound pulling exercises of the upper- and lower-body musculature. Pushing exercises of the upper and lower musculature were performed on Tuesday and Friday. All exercises were performed at an intensity of 8–12 one repetition maximum (1RM) with rest of 2–3 minutes between sets. Cardiorespiratory conditioning consisted of intervals performed on Monday and Thursday and tempo endurance training on Tuesday and Friday lasting ≤25 minutes. A longer (30–60 minutes) slower endurance exercise session was performed on Wednesday and Saturday. Strength training was always performed before conditioning.

The second block focused on the development of power and strength endurance. Olympic lifts were performed at an intensity of 4–6 1RM with 2–3 minutes rest between sets on Monday and Thursday. On Tuesday and Friday, participants performed a metabolic circuit, in which exercises were performed at an intensity of 10–15 1RM every 60 seconds. Conditioning during block 2 was only performed on Monday and Thursday and consisted of high-intensity intervals lasting ≤15 minutes following performance of resistance training. A longer (30–60 minutes) slower endurance exercise session was performed on Wednesday and Saturday.

The third and final block was specific in nature to focus on power, strength, and tactical drills performed at a high intensity and short rest. Participants performed Olympic lifts and multi-joint compound strength exercises at an intensity of 3–5 1RM explosively with rest of 2–3 minutes on Monday and Thursday. On Tuesday, participants performed maximal multi-joint compound effort lifts with 3–5RM with 2–3 minutes rest. High-intensity interval strength training performed on Friday lasted ≤25 minutes. Agility drills were performed following power training on Monday and Thursday, with interval training preceded by strength training on Tuesday. A longer (30–60 minutes) slower endurance exercise session was performed on Wednesday and Saturday.

The fourth week in each block (weeks 4, 8, 12) was designated as an unloading week. After a warm-up, participants performed resistance exercises using a suspension sling for 4 sets of 10 repetitions on Monday (for upper body) and Tuesday (for lower body), respectively. On Thursday, participants performed a routine physical fitness testing (not a part of the current study or dataset). A longer (30–60 minutes) slower endurance exercise session was performed on Monday, Tuesday, and Friday.

Control Group

Operators in the control group performed a nonlinear periodized program. However, changes were also varied in the program in 2-week increments, which repeated over the course of the 12-week training period. This had been the approach initially implemented by TAP to combat multiple operational schedules among NSW Operators. Each day of the 12-week block focused on the development of trainable characteristics congruent with the blocks of the experimental group. Congruent with the resistance training in block 1 of the experimental group, the control group performed a whole-body resistance training session on Tuesday focusing on the major muscle groups of the upper- and lower-body musculature at an intensity of 4–8 1RM with rest of 2–3 minutes between sets. No additional conditioning was performed on Tuesday. Similar to blocks 2 and 3 of the experimental group, participants in the control group performed Olympic lifts and multi-joint strength exercises at an intensity of 3–5 1RM explosively on Monday and Thursday. Rest interval for both days was established at 2–3 minutes between sets. Conditioning on these days mirrored that performed in block 2 of the experimental group, in that high-intensity intervals were performed for ≤15 minutes following performance of resistance training. To incorporate additional activities similar to block 3 of the experimental group, high-intensity interval strength training was performed on Friday and lasted ≤25 minutes. A longer (30–60 minutes) slower endurance exercise session was performed on Wednesday and Saturday.

The second block of 2 weeks was devoted to conditioning and high-intensity interval cross training. On Mondays and Thursday, a variety of tactically specific conditioning was performed (i.e., obstacle course, sand dune run), whereas on Tuesday and Friday, high-intensity interval cross training was performed similar to that which was performed in the experimental group. A longer (30–60 minutes) slower endurance exercise session was performed on Saturday. In contrast to the experimental group, warm-up activities were at the discretion of the participant chosen from a menu derived by the TAP strength and conditioning coaches.

Procedures

Testing took place over 2 days separated by at least 24 hours. Baseline testing occurred 1 week before training program initiation and posttesting occurred in the final week of training (week 12). On the first day of testing, Operators reported to the laboratory for determination of body composition, aerobic capacity, flexibility, muscular strength, biomechanical characteristics, static balance, and dynamic postural stability. On the second day of testing, Operators reported to the outside field for a series of tactically relevant performance tests routinely performed to evaluate upper- and lower-body power, agility, upper-body endurance, total body strength, and anaerobic capacity.

Body Composition

Height and body mass were recorded to the nearest 0.1 cm and 0.02 kg, respectively, using a stadiometer (Seca, Hanover, MD, USA) and digital scale (BOD POD; Cosmed, Chicago, IL, USA) calibrated according to the manufacturer's guidelines with Operators in socks or bare feet. Body composition was then determined using air displacement plethysmography (BOD POD; Cosmed) calibrated according to the manufacturer's guidelines with participants in appropriate attire (spandex and swim cap) to reduce air displacement and performed by a trained technician. Previous studies indicate air displacement plethysmography to be an accurate and reliable means (Intraclass Correlation Coefficient [ICC] = 0.98) to assess changes in body composition (8). Body mass (in kilograms), percent body fat (in percentage), fat-free mass (in percentage), and fat mass (in kilograms) were used for statistical analyses.

Aerobic Capacity

Maximal aerobic capacity was evaluated during a test of maximal oxygen consumption ($\dot{V}O_2$max) test performed on a treadmill (Life Fitness 95T; Life Fitness, Schiller Park, IL, USA) using a continuous incremental ramp protocol (8). Treadmill speed was based on subject's physical readiness test time (PRT). The protocol began with a 5-minute warm-up at 60% PRT speed followed by an initial 3-minute stage at 85% PRT speed at 0% grade. Incline was subsequently increased 2% every 3 minutes until volitional fatigue. Speed was maintained throughout at 85% PRT. The same speed was used pretesting and posttesting. Heart rate was obtained with a heart rate monitor (Polar, Lake Success, NY, USA) and recorded every 15 seconds. Oxygen uptake ($\dot{V}O_2$) was measured continuously using a gas analyzer (Parvo Medics True One 2400; Parvo Medics, Sandy, UT, USA). Blood was sampled by finger prick and immediately analyzed before, during the last 30 seconds of each stage, and at the conclusion of the test for determination of blood lactate using handheld lactate analyzer (Arkray; Kyoto, Japan). $\dot{V}O_2$max was calculated as the average of the 3 consecutive highest values obtained. Lactate threshold (LT) was defined as the point at which an increase was observed in blood lactate of $\geq 1 \text{ mmol}\cdot\text{L}^{-1}$. A valid determination of $\dot{V}O_2$max was verified by achievement of 2 of the following 3 criteria: (a) blood lactate $\geq 8.0 \text{ mmol}\cdot\text{L}^{-1}$ immediate postexercise; (b) peak RER of ≥1.08; (c) within ±10 beats of age-predicted heart rate maximum (220 − age). $\dot{V}O_2$max ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), $\dot{V}O_2$ at LT ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), and percentage of $\dot{V}O_2$max at LT were used for statistical analyses.

Flexibility

A digital inclinometer or goniometer was used for all flexibility/range of motion. Upper extremity flexibility (passive range of motion) was measured bilaterally for shoulder internal rotation, external rotation, and posterior shoulder tightness. For the lower extremity, only the dominant side was used to assess active knee extension (hamstring tightness), passive hip extension, and active ankle dorsiflexion (calf tightness). Alignment of the inclinometer and goniometer was described previously (35). The reliability was established previously {Sell, 2007 #4207}. All measurements were taken by the same certified athletic trainer. The average of 3 measurements was used for statistical analyses. All flexibility measures are in degrees.

Isokinetic Muscular Strength

Isokinetic muscular strength was assessed using the Biodex System 4 Pro Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). Operators were tested for muscular strength in the shoulder (internal/external rotation), knee (flexion/extension), and trunk (flexion/extension). The dominant arm and leg was used for the shoulder and knee testing, respectively. Three warm-up trials were performed at 50% maximum effort followed by 3 warm-up trials at 100% maximum effort. The participants rested for 5 minutes before the recorded 5 maximum test trials. The protocol consisted of 5 concentric/concentric repetitions at $60^\circ\cdot\text{s}^{-1}$. The reliability was established previously {Sell, 2007 #4207}. The average peak torque (in newton meter) was normalized for body weight and used for data analysis (percentage body weight [%BW]).

Biomechanical Characteristics

Raw coordinate data were collected during the lower extremity functional testing using the Vicon 3D Infrared Optical Capture System (Vicon, Centennial, CO, USA). Lower extremity joint kinematics and vertical ground reaction forces were collected during dominant leg single-legged drop-landing (SLDL) task. Reflective markers were attached to Operators at the hips (anterior supra iliac spine and posterior supra iliac spine), lateral mid-thigh, lateral epicondyle of the knee, mid-fibular shaft, lateral malleolus, over the head of the second metatarsal, and at the calcaneal tuberosity bilaterally. During the SLDL, Operators stood on the edge of a raised box platform (45.7 cm) that was aligned at the edge of a single force plate. Operators stood on the edge of the raised box platform with their forefoot hanging over the end and were instructed to raise the nondominant leg and drop off the box onto the force plate. A trial was considered unsuccessful if the Operator touched down with the nondominant leg, touched legs together, or could not maintain their balance on the force plate. Three to 5 practice trials were provided for familiarization of each test condition. Three successful trials were collected for the SLDL task.

Data reduction and calculation of biomechanical data were described in detail in our previous article (34). Biomechanical variables on the dominant leg were used for statistical analyses during the SLDL. Specifically, hip abduction/flexion angle and knee valgus/flexion angle (in degrees) at initial contact (defined as the point at which the vertical ground reaction forces pass above the 5% of their body weight), peak vertical ground reaction forces normalized to body weight (%BW), and maximal knee flexion angles were used for the analyses (in degrees).

Postural Stability

Determination of postural stability was assessed using the NeuroCom Smart Balance Master System (NeuroCom International, Inc., Clackamas, OR, USA) Sensory Organization Test (SOT). A full description of the administration, interpretation, and calculation of the SOT has been previously published (32). The test is designed to measure balance while simultaneously altering the input from the visual, vestibular, and somatosensory systems. A composite score represented overall postural stability performance. The validity of this test is supported in previous studies demonstrating correlations between balance impairments as measured by the SOT and other methods of balance determination (12,32).

Dynamic Postural Stability

Dynamic postural stability was examined using the same force plates used for biomechanical testing. A starting mark, measuring 40% of the Operator's height, was placed from the edge of the force plate. A 12-inch hurdle was placed halfway between the force plate and the starting mark. Operators were instructed to jump, with 2 feet, over the hurdle, landing on only the dominant foot on the force plate and maintain balance for 10 seconds. A minimum of 3 practice trials were provided and then 3 successful trials were collected. A trial was considered unsuccessful if they kicked the hurdle, touch down with nondominant leg, if the entire foot did not land on the force plate, or if the Operator hopped after initial landing (34). Data reduction, calculation, and reliability of dynamic postural stability were described in details in our previous manuscript (34). Dynamic postural stability index (DPSI) in the anterior-posterior, medial-lateral, vertical, and composite scores will be used for statistical analyses. The DPSI values are quite small; therefore, all DPSI values are reported with 4 decimal points.

Tactically Relevant Performance

All performance tests were conducted on the same day and separated by at least 24 hours following the laboratory

Table 1. Physiological variables.*

	Control			Experimental			Group Comp *p*
	PRE	POST	*p*	PRE	POST	*p*	
Body mass (kg)	86.96 ± 11.29	86.66 ± 11.69	0.267	88.01 ± 12.82	87.31 ± 12.96	0.037†	0.256
% Body fat	16.27 ± 7.24	16.44 ± 6.91	0.378	16.56 ± 7.06	15.20 ± 6.70	0.009†	0.029‡
Fat-free mass (kg)	72.21 ± 5.68	71.80 ± 5.98	0.039†	73.02 ± 9.05	73.63 ± 9.20	0.060	0.013‡
Fat mass (kg)	14.76 ± 8.73	14.83 ± 8.58	0.442	14.99 ± 8.08	13.68 ± 7.61	0.010†	0.039‡
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	49.42 ± 6.87	52.43 ± 7.10	0.001†	48.44 ± 6.17	50.43 ± 6.38	0.006†	0.184
$\dot{V}O_2$ @ LT	37.59 ± 4.18	39.43 ± 4.50	0.049†	38.18 ± 5.02	38.91 ± 5.92	0.201	0.212
%$\dot{V}O_2$max @ LT	77.60 ± 8.02	76.46 ± 9.10	0.300	79.06 ± 6.85	77.08 ± 7.13	0.126	0.379

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).

assessments. Operators were familiar with the field testing because this battery of tests is routinely performed. Operators were provided a visual demonstration of the tests and allowed to practice before performance. The order of tests was such that the effect of the previous test would not affect performance of subsequent tests. Unless otherwise noted, tests were separated by a standardized 5 minutes of rest. Before testing, a general dynamic warm-up was performed lasting approximately 5–10 minutes.

Upper-Body Muscular Power

Following the general warm-up, upper-body muscular power was assessed by performance of the kneeling medicine ball toss. Operators were given several practice throws to confirm familiarity with the procedure. Operators began kneeling behind a marked line corresponding to the 0-cm mark of a measuring tape affixed to the floor. Using a chest pass with no lower-body movement, participants threw a 9-kg medicine ball forward. The distance from the 0-cm mark to the center of the medicine ball was measured. Three trials were performed and recorded (in meters) and averaged for statistical analysis.

Lower-Body Muscular Power

Determination of lower-body muscular power was assessed by the standing broad jump (SBJ), which is correlated with other explosive movements. Operators began with their toes on a marked line corresponding to the 0-cm mark of a measuring tape affixed to the floor. In an explosive movement with an arm swing, Operators propelled forward landing alongside the measuring tape. After performance of the SBJ, the distance from the 0-cm mark and the rearmost heel strike was measured. If participants fell backward, the trial was repeated. Three trials were performed separated by 2-minute rest with average distance recorded (in meters) for statistical analysis.

Agility

Agility was evaluated by performance of the pro-agility shuttle run (PASR). Three chalk lines were drawn at 5-yd intervals. Operators began by straddling the center line facing the timer. On movement of the subject, the timer began recording. Operator sprinted to the chalk line on the right, touching the line with their right hand. Operators then immediately turned around and sprinted 10 yd to the farthest line touching the line with their left hand. Again, Operators turned around and sprinted through the center line. Timing stopped upon crossing the midline. Operators performed 2 trials each to the right and left sides. Trials were separated by 2 minutes and averaged (in seconds) by direction for statistical analysis.

Upper-Body Muscular Endurance

Upper-body muscular endurance was evaluated by the performance of maximum number of weighted pull-ups (WPU) and maximum repetitions of body mass bench press (BMBP). Operators were required to complete the

Table 2. Flexibility.*

	Control			Experimental			
	PRE	POST	*p*	PRE	POST	*p*	Grp comp *p*
Right shoulder internal rotation (°)	60.04 ± 5.18	56.02 ± 5.48	0.002†	55.06 ± 6.59	54.13 ± 5.74	0.169	0.024‡
Left shoulder internal rotation (°)	62.75 ± 6.05	59.98 ± 4.31	0.010†	58.43 ± 6.30	57.49 ± 5.61	0.130	0.089
Right shoulder external rotation (°)	103.23 ± 4.59	98.58 ± 5.50	<0.001†	102.56 ± 6.42	102.58 ± 6.14	0.489	<0.001‡
Left shoulder external rotation (°)	97.61 ± 3.16	93.12 ± 3.23	<0.001†	97.79 ± 6.01	97.04 ± 5.67	0.189	0.003‡
Right posterior shoulder tightness (°)	97.38 ± 4.71	98.42 ± 2.90	0.172	95.82 ± 3.64	97.49 ± 2.48	0.010†	0.299
Left posterior shoulder tightness (°)	98.42 ± 3.94	98.17 ± 2.54	0.385	98.17 ± 3.62	98.06 ± 2.86	0.446	0.452
Active knee extension (°)	23.79 ± 7.93	28.03 ± 9.83	0.012†	24.25 ± 7.97	23.18 ± 9.08	0.149	0.004‡
Hip extension (°)	19.91 ± 3.39	19.86 ± 2.18	0.465	20.21 ± 2.34	20.12 ± 2.84	0.425	0.477
Ankle dorsiflexion (°)	12.03 ± 4.39	10.17 ± 4.91	0.029†	9.45 ± 4.35	12.21 ± 4.70	<0.001†	<0.001‡

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).

maximum number of pull-ups with an 11.34-kg weight secured to their waist. For the WPU, Operators began with secured to a high bar with a pronated grip with arms at full extension. Repetitions were counted when the Operator pulled the whole body up until the chin passed the bar then lowering the body down until the arms were fully extended. Repetitions were not counted unless proper form was followed. Following a 5-minute rest, Operators performed maximum repetitions of BMBP using previously determined body mass. Operators were allowed to perform a self-selected warm-up before testing. For a repetition to be counted, the bar had to touch the chest and then be fully extended during the concentric phase of the lift.

Total Body Strength

Determination of maximal strength was assessed by 1RM deadlift exercise. Briefly, Operators were allowed to warm-up with loads less than their estimated 1RM. The warm-up included approximately 2 × 5 repetitions at 40–60% 1RM separated by 2–3 minutes rest, followed by 2 × 3 repetitions at 60–80% separated by 3-minute rest. Operators then began testing for their 1RM deadlift. A maximum of 3 progressive lifts were allowed with the maximum amount (in kilograms) lifted being used as their 1RM. A 3-minute rest was used between successive attempts.

Anaerobic Capacity

Anaerobic capacity was determined by performance of the 300-yd shuttle (300 YS). On a flat surface, 2 chalk lines were drawn 25 yd apart. Operators began with their feet behind one of the chalk lines identified as the start line. On the "Go" command, the Operator ran to the opposite 25-yd chalk line touching the line with his foot before turning and running back to the start. Six cycles were performed for a total of 300 yd. Researchers provided verbal cues to assist participants in determination of end of test. On approach during the final run, participants ran through the start line and the time was stopped. The times were recorded to the nearest 0.01 of a second. Two trials were performed separated by 3 minutes. The average of the 2 trials was used for further analysis.

Statistical Analyses

Statistical significance was set at $p \leq 0.05$ (1-sided) a priori. Normality was assessed using Shapiro-Wilk tests. Descriptive statistics were calculated for all variables. Change within group was calculated as post − pre values for each variable. Change within group was analyzed using paired *t*-tests and Wilcoxon signed ranks tests. The change over time (post − pre) was compared between groups using independent samples *t*-tests and Wilcoxon rank sum tests.

For almost all variables, the results of the parametric test agreed with the results of the nonparametric test, as far as statistical significance of the results was concerned. For convenience, mean values, *SD*s, and the results from parametric tests were included in the manuscript. For a few variables, the results of the parametric and nonparametric tests

TABLE 3. Isokinetic muscular strength.*

	Control			Experimental			
	PRE	POST	*p*	PRE	POST	*p*	Grp comp *p*
Shoulder internal rotation (%BM)	72.20 ± 13.44	68.30 ± 12.71	0.035†	72.70 ± 14.92	71.31 ± 14.01	0.188	0.163
Shoulder external rotation (%BM)	46.04 ± 8.03	42.93 ± 8.02	0.010†	45.90 ± 7.19	42.34 ± 6.41	<0.001†	0.380
Shoulder external rotation to internal rotation ratio	0.65 ± 0.11	0.63 ± 0.08	0.231	0.64 ± 0.11	0.61 ± 0.11	0.006†	0.149
Knee flexion (%BM)	141.88 ± 19.43	130.92 ± 27.43	0.004†	138.62 ± 18.92	132.73 ± 23.89	0.027†§	0.136
Knee extension (%BW)	277.89 ± 35.21	254.81 ± 48.45	0.003†	263.71 ± 37.36	253.05 ± 38.18	0.009†	0.074
Knee flexion to extension ratio	0.51 ± 0.05	0.52 ± 0.06	0.381	0.53 ± 0.06	0.53 ± 0.06	0.393	0.343
Trunk flexion (%BM)	228.44 ± 28.21	228.05 ± 35.11	0.481	239.29 ± 42.74	225.69 ± 36.92	0.014†	0.089
Trunk extension (%BM)	367.39 ± 59.99	374.20 ± 70.26	0.320	374.83 ± 70.60	356.32 ± 67.10	0.065	0.090
Trunk extension to flexion ratio	1.62 ± 0.26	1.66 ± 0.29	0.276	1.59 ± 0.29	1.61 ± 0.37	0.371	0.392

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).
§*p*-value from nonparametric test.

TABLE 4. Biomechanical characteristics.*

	Control			Experimental			Grp comp *p*
	PRE	POST	*p*	PRE	POST	*p*	
Hip flexion angle at initial contact during single-legged drop-landing (°)	18.18 ± 6.95	18.19 ± 4.86	0.498	15.84 ± 5.91	18.49 ± 5.56	0.009†	0.076
Hip abduction (−) angle at initial contact during single-legged drop-landing (°)	−5.45 ± 9.53	−8.59 ± 3.27	0.069	−11.88 ± 3.21	−9.24 ± 3.68	<0.001†	0.007‡
Knee flexion angle at initial contact during single-legged drop-landing (°)	23.95 ± 15.64	10.22 ± 4.97	<0.001†	11.47 ± 3.83	11.55 ± 4.82	0.454	<0.001‡
Knee valgus (−) angle at initial contact during single-legged drop-landing (°)	−1.33 ± 7.00	2.30 ± 2.31	0.031†	0.57 ± 2.39	1.62 ± 3.82	0.012†§	0.097
Maximal knee flexion angle during single-legged drop-landing (°)	61.05 ± 10.11	60.18 ± 10.32	0.341	57.82 ± 9.12	63.60 ± 10.42	0.003†	0.014‡
Vertical ground reaction forces normalized to body weight during single-legged drop-landing (%BW)	443.02 ± 56.02	444.24 ± 70.35	0.426	456.91 ± 55.00	446.34 ± 59.10	0.055	0.114

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).
§*p*-value from nonparametric test.

did not agree, and data were not normally distributed. For these few variables, the nonparametric test *p* value was reported. Statistical analysis was conducted using IBM SPSS Statistics, Version 21 (IBM Corp., Armonk, NY, USA).

RESULTS

The 12-week trial comprised 66 training sessions both onsite and at remote training sites to correspond with the Operators' tactical training cycle. A minimum adherence of 80.0% was required for retention in the study. Of the 86 Operators originally enrolled, attrition occurred in 40.4% of subjects in the experimental group and 51.3% of subjects in the control group. Of those who achieved the minimum standard for retention, the average attendance for the experimental group was 96.8% with a range of 89.4–100.0%, whereas the average attendance for the control group was 92.2% with a range of 83.3–100.0%. No significant differences were observed in baseline demographics between the 2 groups.

Physiological data are presented in Table 1. The majority of results partially supported our hypotheses. The experimental group demonstrated a significant loss in % body fat (experimental: −1.36 ± 2.85% [mean ± *SD*], control: 0.16 ± 2.26%) and fat mass (experimental: −1.31 ± 2.78 kg, control: 0.08 ± 2.26 kg), and gain in fat-free mass (experimental: 0.61 ± 2.03 kg; control: −0.41 ± 0.94 kg) compared with the control group. The experimental group demonstrated a loss in total body mass (experimental: −0.70 ± 1.98 kg) and increase in $\dot{V}O_2$ (experimental: 1.99 ± 3.89 $ml\cdot kg^{-1}\cdot min^{-1}$) following the intervention. The control group demonstrated a loss in fat-free mass (control: −0.41 ± 0.94 kg) and gain in LT (control: 1.84 ± 4.30 %$\dot{V}O_2$ max).

Flexibility data are presented in Table 2. The majority of flexibility results did not meet the expected hypotheses for either between- or within-group changes. For the experimental group, significant improvements were demonstrated for right shoulder posterior tightness (experimental: 1.68 ± 3.50°) and ankle dorsiflexion (experimental: 2.76 ± 3.29°). For the control group, no significant improvements were identified, whereas significant losses were demonstrated for shoulder internal rotation (control: right side: −4.02 ± 5.25°, left side: −2.77 ± 4.72°) and external rotation (control: right side: −4.65 ± 5.04°, left side: −4.49 ± 4.15°), hamstring flexibility (control: 4.24 ± 7.51°), and ankle dorsiflexion (control: −1.86 ± 3.99°). The improvement in ankle dorsiflexion was significantly greater in the experimental group compared with the control group (experimental: 2.76 ± 3.29°, control: −1.86 ± 3.99°).

Strength data are presented in Table 3. None of the results were consistent with the expected hypotheses for between- or within-group changes. For the experimental group, significant losses in strength were demonstrated for shoulder external rotation (experimental: −3.56 ± 4.51 %BW), shoulder external/internal rotation ratio (experimental: −0.04 ± 0.07), knee flexion (experimental: −5.89 ± 14.90 %BW) and

TABLE 5. Postural stability variables.*

	Control			Experimental			Group comp *p*
	PRE	POST	*p*	PRE	POST	*p*	
Sensory Organization Test composite score	81.88 ± 3.87	84.29 ± 3.39	0.001†	82.14 ± 4.76	83.90 ± 4.08	0.033†	0.309
Dynamic postural stability index medial-lateral direction	0.0263 ± 0.0063	0.0260 ± 0.0046	0.434	0.0297 ± 0.0052	0.0290 ± 0.0055	0.272	0.417
Dynamic postural stability index anterior-posterior direction	0.1298 ± 0.0134	0.1336 ± 0.0097	0.031†	0.1375 ± 0.0098	0.1350 ± 0.0089	0.050†	0.006‡
Dynamic postural stability index vertical direction	0.3045 ± 0.0388	0.3061 ± 0.0318	0.400	0.3224 ± 0.0363	0.3139 ± 0.0385	0.037†	0.095
Dynamic postural stability index	0.3327 ± 0.0371	0.3355 ± 0.0300	0.329	0.3522 ± 0.0347	0.3435 ± 0.0358	0.026†	0.061

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).

Table 6. Tactical-relevant performance variable.*

	Control			Experimental			
	PRE	POST	*p*	PRE	POST	*p*	Grp comp *p*
Medicine ball throw (m)	3.63 ± 0.34	3.82 ± 0.20	0.007†	3.90 ± 0.41	4.01 ± 0.35	0.005†	0.128
Standing broad jump (m)	2.33 ± 0.15	2.40 ± 0.16	0.003†	2.38 ± 0.25	2.45 ± 0.27	<0.001†	0.433
Pro-agility shuttle run–right (ss:ms)	5.02 ± 0.26	5.00 ± 0.33	0.314	5.10 ± 0.38	4.95 ± 0.34	<0.001†	0.010‡
Pro-agility shuttle run–left (ss:ms)	5.02 ± 0.27	4.98 ± 0.31	0.628	5.09 ± 0.4	4.93 ± 0.32	<0.001†	0.020‡
Maximum pull-ups (repetitions)	16.64 ± 5.57	18.50 ± 7.27	0.037†	13.39 ± 5.05	17.48 ± 4.86	<0.001†	0.014‡
Body mass bench press (repetitions)	13.40 ± 6.25	13.60 ± 5.97	0.315	14.73 ± 6.78	14.91 ± 5.58	0.367	0.490
1RM deadlift (kg)	173.48 ± 23.04	177.12 ± 22.65	0.098	174.79 ± 27.22	181.71 ± 23.50	0.036†	0.256
300-yd shuttle run (ss:ms)	64.48 ± 4.68	64.06 ± 4.51	0.057	63.24 ± 6.57	63.14 ± 6.08	0.395	0.266

*Data are represented as mean ± *SD*.
†Significant difference from PRE to POST within the group ($p \leq 0.05$).
‡Significant difference in change from PRE to POST between the groups ($p \leq 0.05$).

extension (experimental: −10.66 ± 22.11 %BW), and trunk flexion (experimental: −13.60 ± 30.93 %BW). For the control group, significant losses in strength were identified for shoulder internal (control: −3.90 ± 8.82 %BW) and external rotation (control: −3.11 ± 5.31 %BW), knee flexion (control: −10.96 ± 15.86 %BW) and extension (control: −23.08 ± 31.51 %BW).

Biomechanical data are presented in Table 4. For the experimental group, significant improvements were demonstrated for hip flexion at initial contact (experimental: 2.65 ± 5.40°), hip abduction at initial contact (experimental: 2.64 ± 3.73°), knee valgus at initial contact (experimental: 1.05 ± 3.43°), and maximum knee flexion ankle (experimental: 5.78 ± 9.76°). For the control group, a significant improvement in knee valgus was identified (control: 3.63 ± 7.42°). Significant group differences were demonstrated for hip abduction at initial contact (experimental: 2.64 ± 3.73°, control: −3.14 ± 8.28°) and maximum knee flexion (experimental: 5.78 ± 9.76°, control: −0.87 ± 8.60°).

Postural stability data are presented in Table 5. For the experimental group, significant improvements were demonstrated in dynamic postural stability in the vertical direction (experimental: −0.0085 ± 0.0238 N) and composite stability index (experimental: −0.0088 ± 0.0223), and for SOT composite score (experimental: 1.76 ± 4.95). For the control group, a significant improvement was identified in the SOT composite score (control: 2.41 ± 2.65). No significant group differences existed.

Tactically relevant performance data are presented in Table 6. The experimental group performed significantly better than the control group for the pro-agility run (right: experimental: −0.13 ± 0.17 seconds, control: 0.00 ± 0.18 seconds; left: experimental: −0.16 ± 0.16 seconds, control: −0.04 ± 0.17 seconds) and maximum pull-ups (experimental: 4.09 ± 2.35 reps, control: 1.86 ± 3.57 reps). For the experimental group, significant improvements were demonstrated for the medicine ball throw (experimental: 0.11 ± 0.18 m), SBJ (experimental: 0.07 ± 0.09 m), PASR (experimental: right: −0.13 ± 0.17 seconds, left: −0.16 ± 0.16 seconds), WPU (experimental: 4.09 ± 2.35 reps), and 1RM deadlift (experimental: 6.92 ± 17.16 kg). For the control group, significant improvements were identified for the medicine ball throw (control: 0.19 ± 0.26 m), SBJ (control: 0.08 ± 0.09 m), and WPU (control: 1.86 ± 3.57 reps).

Discussion

The objective of the current study was to measure the effectiveness of 2 training interventions when implemented in a training evolution of Operators. The programs were refined following 2 years of scientific data collection. A block periodization model was compared with a nonlinear model currently used in NSW Operators. Both programs were examined over the course of an operational training evolution. The main findings of the current study suggest that both training models were effective at improving certain physiological and performance variables while the new training program may have advantages on body composition, agility, and upper-body muscular endurance. Based on the current results, the hypotheses were partially supported. It is clinically important to continue refining the implemented training programs to address all components of physical performance and readiness as critical components of injury prevention and optimal performance.

The experimental group was successful in reducing body mass, body fat percentage, and body fat mass, which has important implications for both performance and injury prevention. Individuals with increased body fat have repeatedly been shown to have decreased physical fitness (8); yet, the optimal body composition in the SOF community remains unknown. Crawford et al. (8) determined that the U.S. Army Soldiers with higher levels of body fat, based on the Department of Defense standards, had lesser overall strength, aerobic capacity, and anaerobic capacity than soldiers with less body fat. A study of Finnish soldiers showed decreased performance in a 12-minute run for distance and maximum effort calisthenics in those carrying more body fat (24). Furthermore, previous research has indicated higher body mass index as a risk factor among the U.S. Army Soldiers (31). Among NSW Operators, our previous research has revealed a positive correlation between the percent body fat and injury count and determined 15% body fat as a threshold for injury count (3). When compared with this threshold, the current NSW Operators were just above the threshold. This implies that Operators training based on a block-periodization model may be more effective at reducing body fat below the 15% threshold. Maintaining a leaner body composition is important to optimize physical performance and decrease injury risk.

Both groups were successful in improving aerobic capacity, as measured by $\dot{V}O_2max$, which play an important role in the foundation of tactical performance. The improvements reported in the current study in those performing the block-periodized training are slightly less than previously reported in studies investigating the effects of block-periodization in other athletic populations (33). However, in those studies, the athletes were not performing any resistance training. In a group of U.S. Army Soldiers, Kraemer et al. (17) reported a 7.69% gain in $\dot{V}O_2max$ following 12 weeks of concurrent training using traditional periodiziation, and this did not differ from those performing only endurance training. Although greater gains were observed in military personnel in the study by the authors, subjects in that study were housed, fed, and trained on the campus of a research laboratory. The physiological demands of operational training likely attenuated the response of the current programs.

Aerobic capacity also plays an important role in injury prevention. Reynolds et al. (30) reported a reduction in aerobic capacity, as measured in 2-mile run test, was a risk factor for low back and lower extremity musculoskeletal injuries among infantry soldiers. Improved aerobic capacity in both original and refined TAPs confirmed sufficient volume of aerobic conditioning.

Overall, the experimental group in the current investigation had significant changes in posterior shoulder and ankle dorsiflexion flexibility, whereas the shoulder, hamstring, and ankle flexibility worsened in the control group. This is an important finding because of a role of flexibility and its association with musculoskeletal injuries. For example, reduced shoulder internal rotation, external rotation, and posterior shoulder tightness are associated with individuals with chronic shoulder injury (27). Hamstring flexibility is associated with individuals with a muscle injury in the lower extremity (40). The ankle dorsiflexion flexibility is associated with individuals with an overuse injury (16). Although the experimental group was better than the control group on flexibility, flexibility values among Operators are lower when compared with the 101st Division Soldiers and triathletes (35). Therefore, a continued effort to improve flexibility is warranted.

Contrary to the hypotheses, the experimental group did not improve shoulder, knee, and trunk isokinetic muscular strength. It is somewhat surprising, given that tactical-relevant performance variables were increased. It is likely related to the specificity of training focusing more on tactical-relevant performance variables than local muscular strength. Specific local musculature plays an essential role in injury prevention. For example, shoulder external rotators play an important role in stabilizing the shoulder against the anterior translation of the humeral head (20). In fact, a reduction in shoulder external rotation strength was found in individuals with shoulder impingement (39). Specific exercises to improve the shoulder external rotators should be considered.

Similarly, knee flexion and extension strength was decreased in both groups. Hamstring weakness is associated with hamstring injuries and anterior cruciate ligament (ACL) injuries (26,42). Our previous intervention study with the 101st Airborne Division (Air Assault) successfully resulted in increased knee flexion and extension strength (2). Despite the difference between the conventional forces' and SOF, a strategy to minimize reduction in knee strength should be carefully examined. As the Operators in the experimental group had decreased shoulder, knee, and trunk strength, the current exercise selection (specificity) and/or training intensity, frequency, and volume should be examined. Elite athletes (Operators) who engage in concurrent training will need to determine strategies to reduce the interference and improve/maintain their muscular strength (10).

Hip flexion angle at initial contact and maximal knee flexion angle increased in the experimental group, whereas knee flexion angle at initial contact decreased in the control group. This is an important finding because landing in a more extended position increases the risk of injury to the ACL and menisci of the knee joint (5). Boden et al. (6) demonstrated previously using video analysis that landing with less knee and hip flexion places an individual at increased risk of tearing an ACL. The experimental group also had favorable adaptation in the frontal plane hip and knee landing kinematics. Subjects landed with narrower hip abduction angles and with less valgus collapse at the knee. When combined with greater hip and knee flexion angles, proper landing technique resulted in a reduction in vertical ground reaction forces in the experimental group.

The experimental group engaged in plyometric exercises. Our previous intervention study has indicated that plyometric exercises have advantages on improving landing technique, resulting in higher hip and knee flexion angles and less vertical ground reaction forces during landing when incorporated with resistance training (21). Another study has indicated the effectiveness of plyometric and balance exercise program for preventing knee injuries (15). If Operators continue improving landing biomechanics, it will result in a reduction in landing-related injuries.

The results demonstrated that both groups had a significant increase in the SOT scores representing an improvement in postural stability as measured by the SOT. When comparing the SOT scores with a previous civilian study, the current SOT scores by the Operators were superior (7). One possible reason for improved SOT scores by the Operator is that their tactical/mission training require high level of postural stability because of environmental and equipment considerations. The SOT comprised 6 different testing components that replicate various conditions by altering the visual environment and moving the base of support. Because the Operators often maneuver on rugged terrain at night with or without visual aids (i.e., night vision goggles), training that would replicate these conditions may be necessary. Future studies should explore each component of the SOT scores and identify if there is association with the Operators with current or a history of musculoskeletal injuries. For those Operators who score lower SOT scores, it may be beneficial to continue working on balance exercises.

Despite the significant changes in the SOT composite scores in the control group, there were minimal changes (DPSI anterior-posterior direction got worse) within the control group after the intervention. This finding supports our previous study that indicated no relationship between dynamic postural stability and static postural stability (34). However, the experimental group had significantly better DPSI in the anterior-posterior, vertical, and composite score. This may support the use of corrective exercises, such as single-leg exercise, providing sufficient stimuli for favorable changes in the DPSI. When the current DPSI scores were compared with the previous DPSI scores from college-aged individuals, the NSW Operators possess similar or better dynamic postural stability (34). Potential reason was described above.

Both groups improved upper-body power. These results are similar to those reported by Hartmann et al. (13), in which the authors reported a 6.1 and 7.1% increase in upper-body power in block-periodized and nonlinear training, respectively, as measured during the bench press throw.

We also observed similar improvements in lower-body power in the current study. This would seem surprising given the lack of plyometric drills included in the nonlinear program. However, Tricoli et al. (38) observed significant improvements in static jump and countermovement jump height following 8 weeks of power training with weightlifting exercises. Given that both groups used weightlifting exercises throughout the 12-week training program, this likely attributed to the similar gains in lower-body power output. The improvement in upper- and lower-body power output is likely attributable to increased motor unit recruitment and/or increased rate of firing (19) as a result of the training program implemented.

The experimental group had significantly better agility on both directions. In the current study, only those in the experimental group performed agility training. As expected, improvements in agility were only observed in this group. Furthermore, agility training has been shown to improve neuromuscular control of the quadriceps and hamstrings musculature after an anterior tibial translation force is applied to the knee, whereas strength training alone did not improve muscular reaction time (41). Given that anterior tibial translation forces are a primary factor in potential ACL ruptures, enhanced neuromuscular control of the knee joint alone would make agility training a worthwhile investment for Operators not currently using this method (14).

Upper-body endurance as measured by maximum pull-ups improved in both groups. The greater upper-body muscular endurance following training in the WPU is similar to that observed in world-class kayakers performing block-periodized training (9), although method of determination differed. It is likely that the high-intensity interval training would have contributed to the increases in upper-body endurance as measured by the maximum pull-ups.

Improvement in strength was only observed in the experimental group. Strength as measured by the 1RM deadlift increased 5.0% over the 12-week period in the experimental group. The improvements observed in the current study were likely attributable to the underlying physiological and neuromuscular adaptations. Alterations in fiber types contribute to altered muscle mechanics. Kraemer et al. (17) reported an increase in type IIa with a concomitant decrease in type IIx muscle fibers following concurrent training, whereas strength training alone lead to an increase in type IIa and type I with reduced type IIx. Similar fiber-type adaptations have also been reported in other studies following concurrent training (4). An increase in myofibrillar ATPase activity has also been reported following concurrent training, and this increase was larger than those observed in strength training alone (4). Furthermore, the authors also reported an increase in capillary to fiber ratio following concurrent training. Similar adaptations are likely to have contributed to the increase in total body strength.

The lack of significant improvement in the experimental group is not necessarily surprising. A confounding aspect of the current study was the concurrent operational training, in which NSW Operators were also involved. Mission preparedness requires continued operational training on the part of the Operators. In an effort to mimic tactical requirements, operational training often exposes military personnel to extreme physiological stressors, including caloric deficit, with periods of high caloric expenditure, sleep deprivation, and exposure to extreme temperatures (11,28). Physiological effects of these stressors are evidenced by alterations in hormonal patterns (11,28). Furthermore, operational training often differs among Operators in the same team, making implementation of any type of periodization model difficult. However, we recently demonstrated a pattern and time course of salivary hormones consistent with training stimuli during the experimental group's training (29), suggesting that this periodization model may reduce the likelihood of overtraining.

Practical Applications

We recognize the concurrent operational training in which the Operators were also performing is a limitation of the current study. However, because of the physical demand of the profession and the need for continued mission preparedness, this is unavoidable in this population. The selection and assignment of subjects was purposely completed to minimize these extraneous variables. Furthermore, the nonlinear training program used currently in TAP in an effort to account for differing operational schedules resulted in a lower total volume load and less specificity of training, likely contributing to the divergent findings between these 2 training designs. However, the results presented herein suggest that the block-periodized training program used by the experimental group, and combined with a scientifically based injury prevention protocol, results in greater improvements in body composition, flexibility, landing biomechanics, dynamic balance, agility, and upper-body endurance when compared with a nonlinear program design. Given that the tests used in the current study were designed to test those skills identified as highest importance for mission preparedness and injury prevention in SOF Operators, these data suggest that from a practical standpoint, whenever it is possible, a block-periodized design is more appropriate than a nonlinear training design. Continued effort to refine the program is warranted.

Acknowledgments

This study was supported by the Office of Naval Research N00014-11-1-0929.

Opinions, interpretations, conclusions, and recommendations are those of the authors and not necessarily endorsed by the Department of Defense, US Navy, or Naval Special Warfare. The results of the present study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.

References

1. Abt, JP, Sell, TC, Beals, K, Allison, KF, Nagai, T, Wood, DE, and Lephart, SM. Physical/physiological comparison between cohorts of naval special warfare SEAL operators and SEAL qualification training students. Paper presented at: American College of Sports Medicine Annual Meeting, May 27–31, 2014; Orlando, FL.
2. Abt, JP, Sell, TC, Crawford, K, Lovalekar, M, Nagai, T, Deluzio, JB, Smalley, BW, McGrail, MA, Rowe, RS, Cardin, S, and Lephart, SM. Warrior model for human performance and injury prevention: Eagle tactical athlete program (ETAP) Part II. *J Spec Oper Med* 10: 22–33, 2010.
3. Allison, KF, Abt, JP, Sell, TC, Beals, K, Wood, DE, and Lephart, SM. The relationship between body fat, injury, and musculoskeletal/physiological performance in Naval Special Warfare operators. Paper presented at: American College of Sports Medicine Annual Meeting, May 27–31, 2014; Orlando, FL.
4. Bell, GJ, Syrotuik, D, Martin, TP, Burnham, R, and Quinney, HA. Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. *Eur J Appl Physiol* 81: 418–427, 2000.
5. Blackburn, JT and Padua, DA. Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. *J Athl Train* 44: 174–179, 2009.
6. Boden, BP, Torg, JS, Knowles, SB, and Hewett, TE. Video analysis of anterior cruciate ligament injury: Abnormalities in hip and ankle kinematics. *Am J Sports Med* 37: 252–259, 2009.
7. Broglio, SP, Sosnoff, JJ, and Ferrara, MS. The relationship of athlete-reported concussion symptoms and objective measures of neurocognitive function and postural control. *Clin J Sport Med* 19: 377–382, 2009.
8. Crawford, K, Fleishman, K, Abt, JP, Sell, TC, Lovalekar, M, Nagai, T, Deluzio, J, Rowe, RS, McGrail, MA, and Lephart, SM. Less body fat improves physical and physiological performance in army soldiers. *Mil Med* 176: 35–43, 2011.
9. Garcia-Pallares, J, Garcia-Fernandez, M, Sanchez-Medina, L, and Izquierdo, M. Performance changes in world-class kayakers following two different training periodization models. *Eur J Appl Physiol* 110: 99–107, 2010.
10. Garcia-Pallares, J and Izquierdo, M. Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Med* 41: 329–343, 2011.
11. Gomez-Merino, D, Chennaoui, M, Burnat, P, Drogou, C, and Guezennec, CY. Immune and hormonal changes following intense military training. *Mil Med* 168: 1034–1038, 2003.
12. Hamid, MA, Hughes, GB, and Kinney, SE. Specificity and sensitivity of dynamic posturography. A retrospective analysis. *Acta Otolaryngol Suppl* 481: 596–600, 1991.
13. Hartmann, H, Bob, A, Wirth, K, and Schmidtbleicher, D. Effects of different periodization models on rate of force development and power ability of the upper extremity. *J Strength Cond Res* 23: 1921–1932, 2009.
14. Hewett, TE, Ford, KR, and Myer, GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med* 34: 490–498, 2006.
15. Hewett, TE, Lindenfeld, TN, Riccobene, JV, and Noyes, FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med* 27: 699–706, 1999.
16. Kaufman, KR, Brodine, SK, Shaffer, RA, Johnson, CW, and Cullison, TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med* 27: 585–593, 1999.
17. Kraemer, WJ, Patton, JF, Gordon, SE, Harman, EA, Deschenes, MR, Reynolds, K, Newton, RU, Triplett, NT, and Dziados, JE. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J Appl Physiol (1985)* 78: 976–989, 1995.

18. Kraemer, WJ and Szivak, TK. Strength training for the warfighter. *J Strength Cond Res* 26(Suppl 2): S107–S118, 2012.
19. Kyrolainen, H, Avela, J, McBride, JM, Koskinen, S, Andersen, JL, Sipila, S, Takala, TE, and Komi, PV. Effects of power training on muscle structure and neuromuscular performance. *Scand J Med Sci Sports* 15: 58–64, 2005.
20. Lee, SB, Kim, KJ, O'Driscoll, SW, Morrey, BF, and An, KN. Dynamic glenohumeral stability provided by the rotator cuff muscles in the mid-range and end-range of motion. A study in cadavera. *J Bone Joint Surg Am* 82: 849–857, 2000.
21. Lephart, SM, Abt, JP, Ferris, CM, Sell, TC, Nagai, T, Myers, JB, and Irrgang, JJ. Neuromuscular and biomechanical characteristic changes in high school athletes: A plyometric versus basic resistance program. *Br J Sports Med* 39: 932–938, 2005.
22. Lovalekar, M, Abt, JP, Sell, TC, Keenan, KA, Zimmer, A, and Lephart, SM. Descriptive epidemiology of musculoskeletal injuries in naval special warfare personnel. Paper presented at: American College of Sports Medicine Annual Meeting, May 29 to June 1, 2013; Indianapolis, IN.
23. Lovalekar, M, Abt, JP, Sell, TC, Zimmer, A, and Lephart, SM. Assessing self-reported recall of unintentional musculoskeletal injuries in Naval Special Warfare Operators. Papers presented at: Annual Meeting and Exposition of the American Public Health Association, November 2–6, 2013; Boston, MA.
24. Mattila, VM, Tallroth, K, Marttinen, M, and Pihlajamaki, H. Physical fitness and performance. Body composition by DEXA and its association with physical fitness in 140 conscripts. *Med Sci Sports Exerc* 39: 2242–2247, 2007.
25. Mercer, G and Strock, M. Introduction of functional physical training into special operations units. *J Spec Oper Med* 5: 54–59, 2005.
26. Myer, GD, Ford, KR, Barber Foss, KD, Liu, C, Nick, TG, and Hewett, TE. The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clin J Sport Med* 19: 3–8, 2009.
27. Myers, JB, Laudner, KG, Pasquale, MR, Bradley, JP, and Lephart, SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med* 34: 385–391, 2006.
28. Nindl, BC, Barnes, BR, Alemany, JA, Frykman, PN, Shippee, RL, and Friedl, KE. Physiological consequences of U.S. Army Ranger training. *Med Sci Sports Exerc* 39: 1380–1387, 2007.
29. Oliver, JM, Abt, JP, Sell, TC, Beals, K, Wood, D, and Lephart, SM. Salivary hormone response to 12-week block-periodized training in naval special warfare operators. *J Strength Cond Res* 29: 66–73, 2014.
30. Reynolds, J, Marsh, D, Koller, H, Zenenr, J, and Bannister, G. Cervical range of movement in relation to neck dimension. *Eur Spine J* 18: 863–868, 2009.
31. Reynolds, K, Cosio-Lima, L, Bovill, M, Tharion, W, Williams, J, and Hodges, T. A comparison of injuries, limited-duty days, and injury risk factors in infantry, artillery, construction engineers, and special forces soldiers. *Mil Med* 174: 702–708, 2009.
32. Riemann, BL and Guskiewicz, KM. Effects of mild head injury on postural stability as measured through clinical balance testing. *J Athl Train* 35: 19–25, 2000.
33. Ronnestad, BR, Hansen, EA, and Raastad, T. High volume of endurance training impairs adaptations to 12 weeks of strength training in well-trained endurance athletes. *Eur J Appl Physiol* 112: 1457–1466, 2012.
34. Sell, TC. An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Phys Ther Sport* 13: 80–86, 2012.
35. Sell, TC, Abt, JP, Crawford, K, Lovalekar, M, Nagai, T, Deluzio, JB, Smalley, BW, McGrail, MA, Rowe, RS, Cardin, S, and Lephart, SM. Warrior model for human performance and injury prevention: Eagle tactical athlete program (ETAP) Part I. *J Spec Oper Med* 10: 2–21, 2010.
36. Sell, TC, Abt, JP, Nagai, T, Deluzio, JB, Lovalekar, M, Wirt, MD, and Lephart, SM. The eagle tactical athlete program reduces musculoskeletal injuries in the 101st airborne division (Air assault). Paper presented at: American College of Sports Medicine Annual Meeting, May 28 to June 1, 2013; Indianapolis, IN.
37. Sell, TC, Clark, NC, Abt, JP, Lovalekar, M, and Lephart, SM. Single-leg balance impairments persist in fully operational Military Special Forces Operators with a previous history of low back pain. Paper presented at: American Orthopaedic Society Specialty Day, March 23, 2013; Chicago, IL.
38. Tricoli, V, Lamas, L, Carnevale, R, and Ugrinowitsch, C. Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. *J Strength Cond Res* 19: 433–437, 2005.
39. Warner, JJ, Micheli, LJ, Arslanian, LE, Kennedy, J, and Kennedy, R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med* 18: 366–375, 1990.
40. Witvrouw, E, Danneels, L, Asselman, P, D'Have, T, and Cambier, D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *Am J Sports Med* 31: 41–46, 2003.
41. Wojtys, EM, Huston, LJ, Taylor, PD, and Bastian, SD. Neuromuscular adaptations in isokinetic, isotonic, and agility training programs. *Am J Sports Med* 24: 187–192, 1996.
42. Yeung, SS, Suen, AM, and Yeung, EW. A prospective cohort study of hamstring injuries in competitive sprinters: Preseason muscle imbalance as a possible risk factor. *Br J Sports Med* 43: 589–594, 2009.