UNDELLATION TRAINING FOR DEVELOPMENT OF HIERARCHICAL FITNESS AND IMPROVED FIREFIGHTER JOB PERFORMANCE

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ABSTRACT

Peterson, MD, Dodd, DJ, Alvar, BA, Rhea, MR, and Favre, M. Undulation training for development of hierarchical fitness and improved firefighter job performance. J Strength Cond Res 22(5): 1683–1695, 2008—Firefighters routinely encounter physical demands that contribute to countless musculoskeletal injuries. Seemingly, a progressive prescription for fitness would offer superior protection against intrinsic job risks. The purpose of this study was to investigate the influence of two resistance training interventions on fitness adaptations among firefighters, and to assess the degree of transfer to job-specific tasks. Firefighter trainees were recruited for participation in this experimental study. Two distinct, periodized training models—undulation training (UT; n = 7) and standard training control (STCo; n = 7)—were used to determine the differential effects for muscular fitness and transference to firefighter performance batteries. Specific tests were administered to evaluate 1) upper- and lower-body muscular strength, 2) lower-body power output, 3) sprint speed and jumping ability, 4) anthropometry, and 5) firefighter Grinder performance (i.e., firefighter-specific job tests). The 9-week UT experimental treatment prescription was characterized by daily “nonlinear” fluctuations in training to preferentially elicit specific and distinct muscular fitness components, whereas the STCo treatment conformed to a traditional model, in which each fitness component was systematically targeted during a specified mesocycle. For both treatments, nearly all fitness and performance measures significantly increased from baseline (p < 0.05), with a trend in favor of UT. Further, the UT group experienced significantly greater improvements (p < 0.05) in Grinder performance over the STCo group. Calculation of effect sizes identified meaningful differences in the magnitude of changes in outcomes (effect size > 0.50) in favor of UT for measures of thigh circumference, vertical jump, 1RM squat, Grinder performance, and peak power output. These findings suggest a potentially greater stimulus for multidimensional muscular fitness development with UT, over a periodized STCo. This study effectively establishes that UT may offer a greater transference to performance for firefighter-specific job tasks.

KEY WORDS undulating periodization, fire service, muscular strength, occupation safety

INTRODUCTION

Emrgecy preparedness and response has become a global precedence and urgent governmental obligation (18,44). As a challenge to this agenda, firefighting is commonly recognized as one of the most physically demanding and dangerous nonathletic, civilian occupations (8,13,21). Extraordinary job risks and pronounced stressors contribute to countless yearly injuries and cardiovascular incidences within state and individual departments. Moreover, on an annual basis these hazardous occupational conditions claim the lives of many fire service personnel. Clearly, health and safety promotional endeavors for incumbent emergency workers must incorporate a balance between providing the appropriate resources and guidance to ensure facilitation of healthy behaviors and injury risk reduction. In particular, primary prevention of cardiovascular disease and musculoskeletal injuries necessitates that regular and progressive fitness strategies be adopted as a complementary, yet essential, protective measure to conventional fire-readiness systems.

Current recommendations and occupation health efforts for the fire service industry are based on broad epidemiological data (7,8,17,44). Such recommendations based exclusively on cross-sectional data (i.e., associations between risk factors and morbidity/mortality) are potentially erroneous because ample evidence has confirmed that the physiological stresses encountered during fire-suppression activities exceed those of most occupations (28,29). In fact, the incidence of work-related injury in the fire service has been estimated to
be nearly four times that for private industry (28). Innocuous models have been established to address health/safety disparities among all emergency workers, and these models offer practical, generalized specifications for large-scale administration. Unfortunately, much of these recommendations are nonspecific directives, reflect the same universal needs as those sanctioned for the general public, and are not necessarily appropriate for smaller-scale firefighter-specific exercise prescription. Local agencies and individual departments are responsible for organizing the efforts of health/fitness testing and programming at specific sites. However, many departments do not allocate adequate funding for the hiring and training, or even consultation, of consummate fitness professionals. Most notably, an estimated 80% of current fire departments neglect to maintain basic health and fitness programs (44).

Previous efforts to quantify normative fitness data for national fire service personnel have demonstrated mean operational levels vastly superior to those of most other occupations. Subsequent investigations have been conducted to distinguish the requisite functional capacity of physiological functioning for safe and successful employment as an incumbent firefighter, and these investigations have confirmed the need for advanced hierarchical health and fitness to effectively manage standard, job-specific duties (12,21,45). Substantial cardiovascular fitness (maximal VO2 and lactate threshold), high degrees of muscular development (muscular endurance, absolute and relative muscular strength, and muscular power), and sufficient functional movement capacity (overall joint range of motion, general flexibility, and movement coordination) are needed to safely embark on a productive career in the fire service industry. Cross-sectional research substantiates these findings, demonstrating that musculoskeletal injuries account for nearly 50% of all firefighter occupational injuries (44) and are largely attributable to overexertion and inferior physical preparedness (10,18,44,59).

With regard to musculoskeletal health and fitness, many contemporary training methods have been devised to preferentially optimize adaptation of muscular components through strategic periodization and exercise prescription. Such adaptations draw on synergistic physiological mechanisms that lead to increased force production, power output, and fatigue resistance, and include neuromuscular, metabolic, and hormonal-capacity modifications. Typically, progressive training techniques are reserved for advanced trainees and/or competitive athletes. However, because firefighters routinely encounter dangerous environmental fire-suppression tasks and rigorous physical stimuli, progressive strategies for muscular fitness and performance enhancement may offer superior protection against intrinsic hazards and improve the execution of job-specific duties.

In particular, occupation readiness for the fire service industry requires a balanced approach to physical functioning and reinforces the need for simultaneous development and/or maintenance of each muscular fitness component. “Emergency preparedness” is not only the ability to complete a required job task; it is also the capacity to repeatedly do so without experiencing excessive, undue stress. Thus, combined with an adequate degree of cardiovascular fitness and uninhibited joint range of motion, the acquisition of optimized muscular endurance, muscular strength, and muscular power are equally vital to facilitate comprehensive firefighter readiness (14,49). At the very least, a diminished degree of muscular fitness may decrease the physical potential to effectively fulfill necessary occupational requirements. More importantly, however, this debilitated condition could substantially amplify the overall relative strain to the human body and lead to an exaggerated likelihood of sustaining a musculoskeletal injury or cardiovascular incident. Clearly, it must become a primary objective to not only encourage progressive training prescriptions but to promote simultaneous development of hierarchical fitness capacities.

Such an objective is inconsistent with traditional progressive models of strength and conditioning in which resistance exercise is systematically carried out to enhance fundamental fitness variables through training in a designated succession and during specified mesocycles. Such models may serve as an appropriate arrangement of training to elicit “peak” performance of a distinct fitness variable (e.g., rate of force production or peak power [PP]). However, for populations that require synchronized development of multiple fitness and performance objectives, such traditional prescription models may be particularly disadvantageous because of gradational shifts of training emphases over extended periods of time. A more appropriate system of periodization may include diverse training stimuli to induce multidimensional fitness parameters concurrently. Theoretically, an undulation training (UT) model that is characterized by frequent “nonlinear” fluctuations in prescription variables may be integrated to elicit a specific array of physiological fitness components. Previous research has demonstrated greater potential for enhancements of singular fitness components (i.e., muscular strength and local muscular endurance) through daily undulating periodization (50,52). In brief, daily alterations in training dosages seem to allow for superior gains in fitness over a standard progressive training control with equated training volume, intensity, and frequency.

Ostensibly, if this model is extrapolated to accommodate multidimensional fitness adaptations and performance enhancement, careful manipulation of the variables may allow for simultaneous improvement in various capacities (41). A training model that operates on such a schedule is potentially superior for firefighter populations and may serve as a practical solution and suitable stimulus over alternative, nonundulating training models for the development of hierarchical physical fitness and as a safeguard for overall health maintenance. The purpose of this study was therefore...
to investigate and compare the influence of UT vs. a standard training control (STCo) on muscular fitness adaptations of firefighter trainees, and to assess the degree of transfer of training to job-specific testing batteries. It was hypothesized that UT would yield a positive, yet nonsignificant, enhancement of muscle strength and power compared with the STCo group after 9 weeks of resistance training. It was further hypothesized, however, that the UT group would demonstrate a superior transfer response for performance enhancement in firefighter-specific job tasks. Clearly, identifying the potential fitness and performance implications of progressive training modalities for firefighter populations could offer insight into the contribution of hierarchical fitness acquisition for augmentation of fire-suppression duties. These data may also elucidate the degree to which a UT model may generate fitness and performance enhancements among moderately to highly fit individuals requiring concurrent development of multiple training objectives.

**METHODS**

**Experimental Approach to the Problem**

A longitudinal research design using two different periodized resistance training models was used to examine differential training adaptations for muscular fitness (i.e., strength and power development) of the upper- and lower-body musculature, as well as transference to firefighter-specific performance batteries. Before study commencement, subjects were assigned to one of two treatment groups, UT (n = 7) or STCo (n = 7). Because this training was a vital element of the firefighter academy and was meant to serve as preparation for the national fire service Candidate Physical Ability Test, it was not practical or acceptable to assign any attendees to a nontraining control. Instead, the protocol for this investigation used a comparison between an experimental, “nonlinear” training model (UT) and one that is commonly used and proven effective (35,56,61,65) for progressive sport performance (STCo). To ensure uniformity and control, and to eliminate the possible effect of confounding factors, subjects were randomly stratified into treatment groups based on preliminary body-mass–adjusted muscular strength capacity. This was critical to the study design because differences in relative lower-body muscular strength capacity have been proposed to be very influential in the performance of powerful, speed-related activities (46).

To determine the extent of physiological development generated by involvement in the treatments, as well as to examine the degree of transfer to job-specific assessments, each individual went through a rigorous agenda of physical fitness testing and firefighter-specific batteries. Throughout the subsequent training interventions, subjects were expected to meet three times per week, for approximately 1.0–1.5 hours per session. Collectively, testing plus training required that each subject attend for 12 weeks, or a total of 36 sessions. Both the UT and the STCo groups comprised seven subjects, each of whom committed to adhering to the respective training protocol for the duration of the study, and refraining from performing alternative or supplemental workouts. Compliance to training was monitored by the research group and sport conditioning staff responsible for training prescriptions. Whereas subjects in both groups missed training sessions, exclusion criteria for analyses was set at anything in excess of two missed workouts during the entire 9-week training intervention.

**Subjects**

Fourteen well-trained firefighter academy attendees were recruited for participation in this 12-week experimental study. Subjects’ mean (± SD) characteristics for age, height, and weight were 21.9 ± 1.8 years, 180.9 ± 5.7 cm, and 85.6 ± 9.9 kg, respectively. Subjects were limited to Fire Academy attendees in good standing, each of whom volunteered for participation with full awareness of the project plan and projected consequences. Inclusion criteria for participation in this study were 1) no pending medical problems that could be affected/exacerbated by progressive physical testing and training; 2) no pending medical problems that could influence testing outcomes, and/or 3) no ankle, knee, or back pathology within the preceding 4 months. All subjects were in good physical condition during the time of testing and training (i.e., taking part in fire service physical fitness procedures for at least 6 h·wk⁻¹) and were cleared by a medical physician to participate in progressive physical fitness conditioning. Furthermore, each subject signed informed consent documents allowing the use of pertinent testing data for research and publication purposes. All procedures were approved by an institutional review board for research with human subjects.

**Testing Procedures**

**Anthropometry and Fitness Testing.** A variety of tests were incorporated in an attempt to evaluate physical and skill-related fitness. To address the essential needs of firefighter-specific testing and job-related physiological functioning, it was necessary to identify the defining metabolic, movement, and musculoskeletal requirements specific to the occupation. As previously mentioned, a thorough literature review facilitated the detection of epidemiological injury prevalence and classification (7,8,9,18,44) as well as recommendations to prevent implicit future on-the-job morbidity and mortality (17). Before and after the 9-week training interventions, specific fitness tests were administered to assess each of the following: (1) absolute and relative muscular strength, (2) lower-body PP and rate of force development (RFD), (3) jumping and sprinting ability, and (4) body anthropometry. A separate battery of tests was administered to assess firefighter-specific physical capacity/performance.

Standing height was measured using a stadiometer fixed to the wall and was recorded to the nearest 0.1 cm. Body mass was noted after an overnight fast and immediately after voiding, with subjects wearing light indoor clothing and no
shoes, and was recorded to the nearest 100 g. Upper-arm, chest, and upper-leg circumferences were measured to assess body segmental hypertrophic changes, and were recorded to the nearest 0.1 cm.

Lower- and upper-body dynamic muscular strength were measured via the one-repetition maximum (1RM) barbell back squat and barbell bench press exercises, respectively, according to the National Strength and Conditioning Association guidelines for strength testing (23). Before testing muscular strength, each subject underwent a familiarization training session to address the procedures of the test. Subjects were required to perform a nonspecific warm-up of jogging and dynamic stretching before executing approximately 10 submaximal repetitions with light resistance. The resistance was then progressively increased to amounts estimated to be less than the subject’s 1RM, for several subsequent warm-up sets. Finally, for the 1RM test, the resistance was increased in incremental loads after each successful 1RM attempt, until failure. All 1RM values were determined within three to five attempts, to ensure reliability. An inclusion criterion for squat failure. All 1RM values were determined within three to five sets. Finally, for the 1RM test, the resistance was increased in incremental loads after each successful 1RM attempt, until failure. All 1RM values were determined within three to five attempts, to ensure reliability. An inclusion criterion for squat depth was to complete the 1RM attempts at a 90° knee angle. For each respective subject, this measurement standard was set using a standard handheld goniometer (Jamar EZ-Read, Clifton, NJ) before warm-up sets. If this depth of squat was not sufficiently met, the test was not counted. Trained sport conditioning specialists and investigators oversaw the testing process to ensure proper technique and safety. Body masses were taken to enable a standardized evaluation of maximal lower-body relative strength.

Jumping ability was assessed using a countermovement vertical jump (VJ) and horizontal standing broad jump (SBH). For vertical jump testing, standing reach and vertical jump height were tested using the Vertec apparatus (Sports Imports, Columbus, Ohio). Each athlete was allowed three to five trials to achieve maximal jump performance. Horizontal standing broad jumps were performed with the use of a plastic measuring tape, which was fixed to the floor. Subjects began this testing with their toes behind the 0-cm mark of the tape. The distance from the rearmost heel strike to the starting line was used for measurement. Similar to the vertical jump test, each subject was allowed three to five trials to achieve maximal jump performance. Subjects were required to complete a nonspecific warm-up of running and dynamic stretching, as well as a specific, submaximal jump warm-up protocol, before all jump testing.

A commonly used measure of skill-related physical fitness capacity is sprint speed (43.62) for 40 yd (36.58 m). Likewise, this test was deemed specific to firefighter testing modalities and job performance. Time (seconds) was recorded for each subject using an infrared electric timing system (Speed Trap II Timer) while performing maximal running speed for 40 yd. Light stretching and submaximal sprint/agility trials preceded the respective tests, to serve as a warm-up. All tests were executed three times, with adequate rest in between trials, and the fastest trials were recorded.

Rate of muscular force development and power output were assessed at various relative intensities of the predetermined muscular squat strength values and were measured with a calibrated position transducer. The TENDO FiTROdyne Powerlizer (Tendo Sport Machines, Trencin, Slovak Republic) measures distance and time with a linear transducer and an internal timing mechanism. To effectively test movement velocity and power output during this test, the TENDO unit cord was attached to one end of the barbell. This arrangement allowed for the base of the TENDO FiTROdyne unit to be positioned on the floor next to the squat rack, in such a way that valid readings were obtained without impeding squat technique and/or performance. Subjects were weighed in immediately before performing each maximal, speed-strength test. To calculate power output in watts, each subject’s body mass plus the mass of the load lifted (i.e., 30% and 60% 1RM) was imported into the FiTROdyne microcomputer. Each subject had multiple opportunities to lift 30 and 60% of 1RM as fast as possible during the concentric phase of the barbell back squat exercise. These standardized relative intensities were chosen because they represent the continuum of proposed intensities in which PP may be expressed during explosive, lower-body, closed-kinetic-chain movements (4,32,37,57). This arrangement allowed for a computation of PP, according to the RFD (m·s\(^{-2}\)) in the concentric phase of the speed squat test, for each respective total load lifted. Certified strength and conditioning specialists and investigators oversaw all testing to ensure proper technique and safety.

The aforementioned batteries of fitness and performance tests are well-known, accepted indices within the strength and conditioning profession (23). Furthermore, all tests were deemed to be fundamental competencies for firefighter testing modalities (see Job Specific Testing Battery: “The Grinder”) and requisite to fire scene preparedness. Because this investigation incorporated numerous fitness tests, the battery of performance measures were administered over the duration of 1.5 weeks, to ensure adequate recovery between each test. Before and after the 9-week intervention (i.e., for a total of 12 weeks), testing procedure and order were identically matched for each subject. To further ensure reliable testing outcome measures, subjects were familiarized before the investigation, which included practice sessions of the exact testing procedure. Test-retest reliabilities for all experimental tests done in this same order demonstrated intraclass correlations (ICC) of $R \geq 0.90$.

Job-Specific Testing Battery: “The Grinder.” Six separate job performance tasks were performed in sequence, each as quickly as possible and timed for total performance score. The Grinder tasks included an equipment hoist, a hose pull, a Keiser sled and sledgehammer test, a stair climb while carrying a high-rise hose pack, an attic crawl, and a simulated civilian carry/drag. These tasks were judged to be representative of tasks performed at an actual fire scene, by fire
department administrators and previous researchers (21). Furthermore, exercises in this battery of tasks have been demonstrated to be highly contingent on general physical fitness and, thus, may serve as a valuable baseline measuring tool to assess job readiness (49) and emergency preparedness. Each subject performed the Grinder test in the same sequence, to avoid any confounding influences of fatigue or strategy. All tests were performed in specified firefighter turnout clothing, including boots, pants, coat, and helmet. A standard self-contained breathing apparatus (i.e., 25-kg SCBA tank) was worn throughout the duration of the test. Each subject had previously performed these tests numerous times in conjunction with the standard fire service training curriculum, for purposes of monitoring physical fitness and skill. Hence, each subject had been well familiarized with the procedures of the test. As mentioned, each test was performed in sequence, with no rest/recovery between them. Grinder tests were completed in the following order, under strict inspection by the academy fire chief for proper technique and execution.

**Equipment Hoist.** Secured to a rope was a 30-kg iron pipe, which was to be hoisted by rope and pulley up two stories of the training tower (12.1 m). The clock started at the command of the timer, and the hoist test was completed when the pipe was lifted, hand over hand, for two full repetitions to the second floor, and back to the ground. To successfully complete the test, subjects had to securely lift and lower the pipe without losing control of the rope.

**Hose Pull.** A 5-cm, uncharged (i.e., dry) fire hose was pulled as quickly as possible to a length of 65.6 m, as previously described (49). Specifically, the hose was laid out in 5-m segments, imulating the withdrawal of hose from a fire engine. Firefighters wrapped a maximum of 2 m around their trunk or shoulders, grasping the nozzle with both hands and extending it in front of the body. Subjects were instructed to run as fast as possible with the hose in tow, from the start through the finish line. Time for the test was continued from the completion of the equipment-hoist test.

**Keiser Sled and Sledgehammer.** This test was completed to simulate fire-scene hammering and axe chopping. Using a sledgehammer, the objective was to drive a 150-lb steel beam 5 ft. Subjects’ feet were required to be on the sled runners, located on each side of the 150-lb weight. Using the 3.5-kg “dead-blow” sledgehammer (i.e., 2.6-in diameter head, 26-in handle, fully rubber covered) subjects were to move the 3-ft-long, 150-lb steel weight a distance of 5 ft by striking the sledge to the forward face of the weight. Time for the test was continued from the completion of the hose-pull test.

**Stair climb.** A 10-kg high-rise hose pack was carried over each shoulder while ascending and descending five flights of stairs of the fire training tower. Firefighters were required to touch each step while ascending and descending the tower. Time for the test was continued from the completion of the Keiser sled and sledgehammer test.

**Attic Crawl.** This test was completed to simulate a housefire attic crawl. Each subject was required to crawl on hands and knees, as quickly as possible, through a 15-m-long, 3 x 3-in crawl space (i.e., with two right-angle turns). All subjects were required to maneuver this dark crawl space wearing full firefighter turnouts, with no lighting assistance. Time for the test was continued from the completion of the stair-climb test.

**Simulated Civilian Carry/Drag.** Firefighters were instructed to securely drag two 25-kg high-rise hose packs backwards as quickly as possible. The test was started with the hose packs being secured on each forearm, and it commenced with each subject dragging the packs 20 m across the finish line. Time for the test was continued from the completion of the attic-crawl test. The clock was stopped for the Grinder test when the feet of the subject crossed the finish line of this simulated civilian-carry/drag test.

**Training Protocol**

Both resistance training programs were adapted from concepts and principles considered to be accepted approaches of progressive training for athletic populations (63). For both treatment groups, each exercise training session included a general cardiovascular preparatory warm-up, which lasted 10–15 minutes, followed by a movement-specific “dynamic warm-up” to address adequate joint mobility, neuromuscular compliance, and functional range-of-motion capacities. After these warm-ups, individuals were divided into the respective treatment groups to perform individualized strength, power, endurance, speed, and functional movement training modalities. Both groups trained three times per week, for approximately 1.0–1.5 hours per session, and were instructed to refrain from performing alternative or supplemental workouts. The 9 week of training (i.e., 27 total sessions) were subdivided into three mesocycles, each lasting 3 weeks in duration. At the end of each 3-week period, the training programs were altered to compensate for improvements in fitness and to modify the training exercises and movements. Throughout every week of the study, three distinct training sessions were prescribed to target the musculature of the entire body. Training took place on Monday, Wednesday, and Friday, allowing a minimum of 1 day between each session. This agenda was chosen because it coincided with the firefighters’ subsequent weekly academy obligations.

During the entire 9 weeks, resistance training exercises were identical between treatments, as were the mean training dosages (i.e., equated intensity, volume, frequency, and rest). This was critical to the study design because differences in training modalities and overall dosages have been proposed to influence performance and muscular adaptation (47). Each training session consisted of a specific exercise prescription (e.g., mesocycle 1: day 1), and was expected to be completed a total of three times during the respective 3-week period. The two primary core exercises used for the lower and upper
body were the barbell back squat and bench press, respectively. Numerous subsequent core strength exercises and alternative movements were also used to supplement. Additionally, sessions strategically included ballistic movements (e.g., countermovement vertical jumps, weighted box jumps, barbell loaded squat jumps, medicine ball tosses, split squat jumps, sprints of various distances, plyometric depth jumps, etc.) and were prescribed according to particular day/mesocycle of training.

The UT experimental treatment prescription was characterized by daily fluctuations in training to preferentially elicit one of the following primary components of muscular fitness: 1) muscular endurance and hypertrophy, 2) basic and functional muscular strength capacity, and 3) RFD and PP output. Each of these primary fitness objectives was individually emphasized through distinctive training dosage prescriptions (i.e., volume, intensity, rest break, mode, etc.). To provide a unique and adequate training stimulus to elicit the desired response within a specific session, the program variables were manipulated to comply with currently recommended practices (63). Furthermore, to reduce the likelihood of overtraining, excessive fatigue, or training staleness/boredom, it was deemed necessary to further offset the prescription objectives by staggering the upper- and lower-body training assignments. As the model in Figure 1A indicates, day 1 was designated to target upper-body endurance/hypertrophy and lower-body muscular strength; day 2, to target upper-body muscular strength and lower-body speed/power; and day 3, to target upper-body speed/power and lower-body endurance/hypertrophy. Figure 2 represents the 9-week training module used for the UT group and illustrates the systematic manipulation of the pertinent dosages to preferentially promote each respective training objective. As may be seen, there is also a fundamental expanded dosage assignment over time, to ensure progressive overload.

In contrast, the STCo group conformed to a traditional model of periodization, in which each of the aforementioned fitness parameters was systematically targeted through specific training in a designated order and during a specified mesocycle (i.e., mesocycle 1, weeks 1–3: muscular endurance and hypertrophy; mesocycle 2, weeks 4–6: basic and functional strength capacity; and mesocycle 3, weeks 7–9: RFD and PP output). The specific STCo program model may be seen in Figure 1B.

**Statistical Analyses**

Statistical analyses were accomplished using analysis of variance with repeated measures. If needed, Tukey post hoc analysis was used to determine pairwise differences between data distribution. Alpha was set at 0.05 to determine statistical significance. Effect size data were computed using an equation proposed by Hedges and Olkin (24) in which the changes in performance between groups is divided by a pooled standard deviation. The average statistical power for the analyses was 0.47.

**RESULTS**

Descriptive statistics and pre-post test result for fitness and performance variables may be seen in Table 1. Numerous measures of fitness and performance increased significantly in both treatment groups from baseline (*p*, 0.05), including 1RM bench press, 1RM squat, power output, and Grinder time. Furthermore, the UT group experienced significantly greater improvements (*p*, 0.05) in Grinder performance than the STCo group. UT demonstrated greater general improvements in many of the administered tests, including upper-body muscular strength, lower-body muscular strength, PP output at 30% 1RM, average and PP output at 60% 1RM, and vertical jumping ability. The majority of changes in body anthropometry were both statistically and

![Figure 1](image-url)

*Figure 1.* (A) Undulation training (UT) model for weeks 1–9. (B) Standard training control (STCo) model for weeks 1–9. Each mesocycle represents a 3-week block of time.
clinically nonsignificant. Percent improvements for all performance measures are offered in Figure 3.

**DISCUSSION**

The present study reveals a greater potential training effect for simultaneous multidimensional muscular fitness development of firefighter trainees with UT over a periodized STCo. In particular, the findings for muscular strength are in accordance with previous work, verifying a superior outcome for maximal strength using a daily-undulating periodization model (50). Effect size data allowed for the statistical calculation and observance of the magnitude of difference between training effects, which is of particular importance in the absence of a large sample population. As with the current investigation, the consequence of diminished statistical power is often unavoidable when small sample sizes are employed, making it difficult to identify significant differences between treatments, regardless of treatment outcome.

**Figure 2.** Sample 9-week undulation training model for moderately trained firefighters. As weeks progress, it is recommended to increase the dosage of training, per specific training objective, across each mesocycle.

**Table 1.** Pre- and posttest descriptive statistics (mean ± SD) for the undulation training and standard training control groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pretraining</th>
<th>Posttraining</th>
<th>Pretraining</th>
<th>Posttraining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>21.6</td>
<td>21.6</td>
<td>22.1</td>
<td>22.1</td>
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<tr>
<td>Body mass (Kg)</td>
<td>84.68 ± 11.1</td>
<td>84.39 ± 13.77</td>
<td>86.56 ± 9.3</td>
<td>88.25 ± 10.4</td>
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<tr>
<td>Chest circumference (cm)</td>
<td>102.57 ± 8.96</td>
<td>102.29 ± 9.59</td>
<td>101.64 ± 8.07</td>
<td>103.93 ± 5.79</td>
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<tr>
<td>Biceps circumference (cm)</td>
<td>35.38 ± 4.14</td>
<td>35.57 ± 3.77</td>
<td>34.07 ± 3.9</td>
<td>36.36 ± 3.19</td>
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<tr>
<td>Thigh circumference (cm)</td>
<td>55.36 ± 5.78</td>
<td>53.64 ± 3.47</td>
<td>56.57 ± 5.75</td>
<td>55.93 ± 2.73</td>
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<tr>
<td>1RM bench (kg)</td>
<td>99.46 ± 23.44</td>
<td>102.29 ± 23.20</td>
<td>102.38 ± 27.85</td>
<td>119.55 ± 24.52</td>
</tr>
<tr>
<td>1RM squat (kg)</td>
<td>119.07 ± 15.56</td>
<td>129.1 ± 11.71</td>
<td>135.76 ± 31.19</td>
<td>163.62 ± 32.52</td>
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<td>VJ (cm)</td>
<td>59.16 ± 7.79</td>
<td>62.05 ± 8.37</td>
<td>60.6 ± 8.25</td>
<td>66.22 ± 6.93</td>
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<tr>
<td>SBJ (cm)</td>
<td>225.14 ± 21.84</td>
<td>240.46 ± 19.39</td>
<td>234 ± 17.82</td>
<td>243.66 ± 22.00</td>
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<tr>
<td>PP 30% 1RM (W)</td>
<td>2486 ± 379.79</td>
<td>2688 ± 310.66</td>
<td>2811 ± 377.63</td>
<td>2998.71 ± 450.90</td>
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<tr>
<td>RFD 30% 1RM (m-s⁻¹)</td>
<td>2.15 ± 0.28</td>
<td>2.23 ± 0.25</td>
<td>2.16 ± 0.16</td>
<td>2.23 ± 0.19</td>
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<tr>
<td>PP 60% 1RM (W)</td>
<td>2518.33 ± 360.43</td>
<td>2691.8 ± 377.81</td>
<td>2675 ± 440.66</td>
<td>3103.57 ± 425.43</td>
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<td>RFD 60% 1RM (m-s⁻¹)</td>
<td>1.67 ± 0.15</td>
<td>1.66 ± 0.21</td>
<td>1.64 ± 0.11</td>
<td>1.71 ± 0.10</td>
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<tr>
<td>40-yd dash (s)</td>
<td>5.61 ± 0.21</td>
<td>5.37 ± 0.35</td>
<td>5.42 ± 0.13</td>
<td>5.24 ± 0.16</td>
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<tr>
<td>Grinder performance (s)</td>
<td>304.43 ± 47.79</td>
<td>239.43 ± 26.25</td>
<td>297 ± 51.70</td>
<td>211 ± 21.54</td>
</tr>
</tbody>
</table>

1RM = one-repetition maximum; VJ = countermovement vertical jump; SBJ = standing broad jump; PP = peak power output; RFD = rate of force production.
Furthermore, with regard to the actual effectiveness of the given treatment(s), no information is gained from knowing the $p$ value. In such situations, there is an explicit need for the inclusion of an effect size calculation, because this value may offer an improved quantification over the $p$ value to identify practical significance (48). According to these findings, the current analyses have revealed a distinct advantage for muscular fitness adaptation among firefighter trainees who were engaged in UT, such that daily fluctuations in training may be a superior model among populations that require advanced and sustained concurrent adaptation in an array of physiological fitness parameters and performance objectives.

These data counter the preliminary postulate, which conjectured that nonundulating training would elicit similarly favorable development of muscular fitness capacities. Relatively few research investigations have been conducted to evaluate the impact of UT for multiple fitness and performance objectives (41). In theory, this type of training may offer a superior stimulus for adaptation and greater training effect attributable to frequent changes in neuromuscular stimulation. Proponents of undulating models suggest that the fluctuation in training variables allows for sufficient and greater recovery between similar sessions while preventing detraining. This type of manipulation may also diminish the risk of overtraining by decreasing the frequency of corresponding neurological stimulation. The UT model incorporated in the current study was designed to target each specific muscular fitness component and training objective once per week (see Figure 1A) compared with the STCo group, which employed a thrice-weekly agenda of comparable dosages for individual muscular parameters. Seemingly, the greater lapse in time between like training dosages may have provided improved recovery during subsequent training sessions of different neuromuscular stimuli.

The concept of integrating concurrent training for multiple fitness objectives is not necessarily novel. In fact, a widespread topic of debate among professionals and researchers is that which addresses the compatibility of distinctive training prescriptions to preferentially elicit adaptation in dissimilar fitness components (e.g., power, strength, speed, cardiovascular endurance, etc.). It has been proposed that, for individuals seeking maximal improvement in a single fitness objective, simultaneous training (i.e., in the same basic time frame) for other fitness parameters should not be performed, because of a potential noncompatibility of the training stimuli (5,51,53). Many professionals believe that, in such situations, the extent of adaptation to one or more fitness attributes could be diminished. Most research on this topic of training stimulus "compatibility" has proven to be inconsistent, exhibiting the most deleterious affects occurring between simultaneous training for extremely dissimilar fitness components (e.g., aerobic capacity and neuromuscular PP) (25,34,40,51). It has been recently suggested that this interference of strength development during concurrent training may be a result of differential and antagonistic intracellular signaling mechanisms (39). However, it is likely that these divergent adaptation mechanisms are morphological interferences, such that endurance training may attenuate the metabolic hypertrophic responses of muscle cell proliferation and architecture. However, adaptation to very intense anaerobic exercise is largely influenced by neurological adaptations, such that an increased "neural drive" to the muscles contributes to significant increases in 

![Figure 3. Percent improvement for fitness and firefighter performance variables. *Peak power improvements represent performance at 60% 1RM squat. Measures of fitness and performance increased significantly in both treatment groups from baseline ($p < 0.05$), including 1RM bench press, 1RM squat, power output, vertical jump, and Grinder time. †The undulation training group experienced significantly greater improvements ($p < 0.05$) in firefighter Grinder performance than the STCo group.](image-url)
maximal contractile force and RFD, even in the absence of changes in muscle size (1,2). Thus, neurological innervation is an exceedingly important determinant of maximal contractile functionality. Although the effect of resistance training on muscle morphology has received considerable examination, less is known about the specific neural mechanisms responsible for the training-induced increase in maximal muscle strength and power. Furthermore, it is unknown whether changes in adaptive protein synthesis through muscular endurance training will similarly and/or negatively impact neuromuscular adaptation to strength/power training. For the most part, there does not seem to be a physiological synergistic benefit to combining dissimilar training stimuli. However, for an occupation such as firefighting, which requires constant maintenance of multiple hierarchical components of fitness, such a training model may be indispensable.

As with most performance-enhancement endeavors, it is vital to determine suitable training models to render the most effective preparedness and to reduce the likelihood of overtraining. Strength and conditioning models for competitive athletes typically take place over many months and follow a systematic pattern in which fundamental fitness variables are targeted through specific training in a designated order (63). These models have been used and modified to correspond with nearly every athletic venture, and they are suitable to ensure progression and peak physical preparedness specific to the nature of a given sport. Conversely, as referenced, firefighting requires a balanced operation of physiological fitness, reinforcing a requisite need for simultaneous development and/or maintenance of each muscular fitness component, to safely and effectively engage in the occupation. It was hypothesized that although potentially inferior for absolute muscular fitness development, a “nonlinear” undulation model of resistance training for concurrent adaptation in hierarchical fitness would contribute to improved operational capacity. Notwithstanding significant improvements among both treatment groups, this is the first study to date to establish that UT may, in fact, offer greater transference to performance in firefighter-specific job tasks.

On the basis of these findings, a greater emphasis should be placed on separating fitness adaptation requirements by prescribing specific dosages to elicit those objectives. UT program variables should, therefore, be manipulated to comply with currently recommended guidelines (63) to support maximal adaptation in muscular endurance, basic and functional strength capacity, and RFD and PP output. Specific training for improvement in local muscular endurance may decrease the obligatory rest between repeated bouts of physical exertion and/or increase the capacity to preserve posture-related isometric contractions. The acquisition of superior muscular endurance is a fundamental fitness parameter and training objective for firefighters. Jobs may last hours and require numerous bouts of emergency responses in which firefighters are expected to repeatedly engage in strenuous physical exertion. A breakdown in muscular endurance could compromise the ability to perform repeated technical firefighting tasks or lead to an increased risk of muscular failure, injury, or death while engaged in emergency situations.

Although somewhat associated with force generation and strength capacity, the adaptations that lead to muscular endurance and hypertrophy are, in fact, only partially responsible for muscular strength development (26). The ability of the nervous system to adapt to and become more efficient while performing a new stimulus/stressor may be considered the foundation of firefighter performance enhancement. Specifically, for fire service personnel, absolute muscular strength (i.e., maximal strength index, quantified by a 1RM) is essential because it provides the force production necessary to lift, hoist, and carry/drag heavy loads. Equally important, the enhancement of relative strength capacities (i.e., body mass adjusted, or “pound-for-pound” strength) is fundamental for improvement in movement efficiency, muscular power, and speed and to reduce perceived physical exertion when encountering moderate to heavy resistances (3,11,46,64). Finally, greater muscular strength is necessary for optimal joint health and integrity and to decrease the risk of accident-related injuries (55,59).

For all occupations or endeavors in which emergency-related physical preparedness is fundamental, muscular power may also be considered a necessary parameter of fitness for superior functional ability. Greater neural drive and power output may enable a firefighter to produce the same amount of work in less time, or a greater magnitude of work in the same time. Given that PP is related both to force generation and movement velocity, muscular PP capacity should be viewed as an exceedingly important testing procedure and training objective for firefighter-specific conditioning programs. Therefore, as an adjunct to high-resistance, slow-velocity training for improvement in muscular strength capacity, it is recommended that various training approaches be deployed to elicit subsequent adaptation of the neuromuscular system to improve RFD and PP output. Fundamental explosive lifts, such as the Olympic lifts, as well as alternative movements, such as speed squatting, sprint training, and resisted plyometric jump training, may be incorporated safely and effectively.

Evidence from this study would suggest a greater potential for simultaneous multidimensional muscular fitness development, as well as transference to firefighter-specific performance, with UT over a traditional model of periodization. This conjecture is supported by similar training recommendations and previous research that has verified a greater training effect for maximal strength using mixed-methods training or daily-undulation periodization (50). Though tedious, combining distinctly different training dosages within a given regimen may be an optimal approach to support the improvement in a variety of performance
variables related to maximum muscular endurance, strength, and/or power (41). More importantly, however, failure to optimize each of the basic force-producing characteristics of the neuromuscular and morphological systems may diminish the developmental potential of muscular adaptation and expression across a continuum of variable forces and variable movement speeds. For that reason, the combination of diverse training modalities and dosages to elicit maximal transference in muscular development to occupation-specific requirements is critical for fire service personnel. Of particular importance to the continued advancement in health, fitness, and job performance, progression in the specialized stimuli must accompany increased training experience and physiological adaptation (33,47).

Progressive UT may also be vital in diminishing the impact of age-related decrements in physiological performance among veteran firefighters. Decreases in muscular fitness capacities can manifest gradually, often without marked declines in perceived functionality. However, reductions in functional capacity are well documented and are often considered an unavoidable consequence of the aging process. Sarcopenic decrements in the morphological and operational characteristics of the neuromuscular system may be considered the primary causal elements of disability among aging adults (19). Specifically, deterioration in muscular strength and power may explain the majority of this decline (38,58) because denervation and atrophy of fast fibers occurs more rapidly and to a greater extent than slow fibers (16,36). Seemingly, the etiology of these processes in physiological functioning may be explained by the collective interactions of aging and diminished physical activity volumes and intensities. Whereas the acquisition of superior muscular strength and power capacities has been associated with improvement in numerous tasks of functionality, a reduction of these fitness parameters has been shown to have profound detrimental effects on the maintenance of functionality (16,19,38,58).

There is strong evidence to suggest that sarcopenia is a reversible cause of disability and that aging persons with early sarcopenia are perhaps the most likely to benefit from exercise training interventions (15,20,22,27). Clearly, for firefighters experiencing such age-related declines in fitness and function, progressive resistance training may serve as a superior modality over other forms of physical activity to minimize further diminution. Mixed-methods resistance training programs are particularly advantageous because of an ability to preferentially elicit hypertrophic, strength, and muscular power adaptations as well as improved functionality among aging adults (22,41). Newton and colleagues determined that, despite inevitable age-related reductions in muscle strength and power, older men exhibit similar improvements in these variables to younger populations, with appropriate periodized resistance-training programming (41).

Ample cross-sectional research exists to confirm the elevated rates of morbidity and mortality among veteran firefighters. These data verify a deficit in functional capacity to perform necessary job-specific strenuous tasks, which typically worsens with advancing chronological age (6,54,60). Although the rate of decline is largely an individual phenomenon (31), further decrement may be attenuated with systematic screening and thorough exercise training (30). Although the current investigation examined only young, moderately to highly conditioned firefighter trainees, evidence would seemingly suggest an even greater potential relevance for veteran emergency workers (41). More research is certainly needed to confirm the efficacy of this type of training among diverse populations as well as across various age spans. Furthermore, because this is the first published study to confirm superior fitness adaptation for UT among moderately to highly fit individuals, subsequent research should examine the morphological and neuromuscular mechanisms of adaptation between the differential training stimuli when implemented in an undulating model.

Regardless of age or demographic stratification, epidemiological data have identified musculoskeletal injuries to be the perennial causes of all occupational injuries (~50%) and to cost millions of dollars per year (44). Moreover, these statistics have identified the cause of this injury prevalence to be highly correlated to overexertion and inadequate physical preparedness (10,18,44,59). The financial burden that is inherent in the insurance and administration of first responders is a considerable hardship for government agencies. UT may provide the necessary training stimulus to ensure hierarchical development of muscular fitness and functionality, protection against intrinsic job risks, improvement in firefighter-specific job tasks, and safeguards for overall health maintenance.

**Practical Applications**

In August 2000, the National Fire Protection Association released NFPA 1583: Standards on Health-Related Fitness Programs for Firefighters (42). The purpose of this document was to provide minimum requirements for a health-related fitness program for fire department members who are involved in rescue, fire suppression, emergency medical services, hazardous materials operations, and related activities (42). Implementation of this document was intended to encourage the ability of participating fire service personnel to perform occupational activities with “vigor” and to demonstrate the “traits and capacities normally associated with a low risk of premature development of injury, morbidity, and mortality” (42). In response, the American Council on Exercise joined with the International Association of Fire Fighters (IAFF) in an effort to establish a minimum standard for individuals seeking to pursue careers in the fire service industry as peer fitness professionals. The “objective” of this effort was to encourage the incidence of appropriate exercise prescription for firefighters and other emergency workers by setting standards of practice for prospective fire service personal trainers. Specifically, as Fire Service Peer Fitness
Trainers, certified candidates are expected to help the IAFF/IAFC Task Force to accomplish two of its fundamental missions 1) improving firefighter health, wellness, fitness, safety, and performance and 2) improving the effectiveness of fire fighters and every fire department to meet the needs of the community. Ultimately, this notion was initiated and is funded for the purpose of reducing the prevalence of, and incurred costs associated with, cardiovascular and musculoskeletal afflictions, as well as to promote widespread acceptance of physical fitness programming among individual departments. Although this provides an acceptable minimum standard to mandate general exercise recommendations, this criterion is less than optimal with regard to promotion of specific and progressive fitness programming to address the intricate health, fitness, and occupational needs for fire service personnel. The establishment of a higher level of qualification is needed to ensure proficient assessment of the precise occupation functions and the design and implementation of individualized exercise prescriptions.

Accordingly, to facilitate a sufficient training system for hierarchical fitness adaptation among firefighter populations, program variables should be manipulated to correspond with currently recommended guidelines by the National Strength and Conditioning Association (63). Compliant with the principles of specificity, adaptation to exercise is unique and entirely dependent on the specific mode of training. As with traditional models, manipulation of the training variables for UT must occur to allow for intensity of training to be inversely related to training volume, to yield progress without excessive physiological stress. If done so gradually and indirectly, it is possible to concurrently increase both volume and intensity of training, without overtraining, and to experience superior progression of muscular fitness. Various modifications to this model may be compulsory and logical, depending on the training status of the firefighter(s).

The training dosages provided in the reported model are prescribed for moderately to highly trained fire service populations. When necessary, these dosages may be modified on the basis of individual requirements. Furthermore, depending on the degree of sustained overload and on subsequent delayed onset of muscular soreness, there may be a need to allow greater recovery between training sessions. Rather than persistently operating on an agenda of three sessions per week, the schedule can be manipulated to allow 1–3 days of rest between sessions at any point in time, if necessary. Conversely, if more recovery is desired between upper-body and lower-body divisions within a given full-body workout (i.e., to reduce excessive fatigue if/when training takes place during a job shift), training sessions could be divided into two sessions per day (e.g., upper body in the morning and lower body in the afternoon/evening) or split to occur on separate days (e.g., Monday: upper-body hypertrophy/endurance; Tuesday: lower-body strength, etc.). Essentially, it is important to regard each unique block of training as specific to a particular fitness component and as a fundamental piece of the cumulative firefighter health-fitness-performance objective.

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Undulation Training for Development of Hierarchical Fitness


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