Review

Performance Training Guidelines for the 1.5 and 2-Mile Runs

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Very little peer-reviewed information is available to aid military personnel in selecting training programs to enhance performance on fitness tests and direct fitness-related military policy.

Objective: This review provides recommendations on training programs for enhancing performance on 1.5-mile and 2-mile runs based on the available relevant literature.

Design: Short review article.

Methods: Collected relevant research articles by using search terms such as aerobic power, military physical fitness test, strength training, resistance training, endurance training, high intensity interval training, running economy, 3 km run, 5 km run, and 1.5/2-mile run.

Results: Evidence has shown running performance can improve with a combination of traditional strength training, high intensity interval training, and distance training.

Conclusion: A combination of traditional strength training, high intensity interval training, and distance training should be used to enhance running performance on the 1.5 and 2-mile run tests used by the military.

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Key words: Military fitness test ■ exercise program

INTRODUCTION

For several decades, most branches of the US military have used middle distance run tests (most commonly 1.5 or 2-mile) on a bi-annual or annual basis to evaluate the health and fitness of service members.[1-5] Despite widespread use of these tests, little research has directly focused on developing comprehensive optimal training methods of performance improvement for these middle distance runs. Military policy manuals typically provide the current American College of Sports Medicine or similar broad guidelines for health or fitness improvement, however these guidelines fall short of adequately prescribing a thorough range of research-based workloads, exercises, and practices that will produce optimal performance results. The U.S. Army FM 7-22[2] provides an a-la-carte assortment of run programming options; however, it falls short of showing the soldier (in sufficient detail) how to implement research-supported training programs with specifically recommended and practically reproducible intensity ranges for all exercise modes; studies assessing Army training programs have generally included many training methods with little evidence supporting effectiveness (as observed in Harman et al., 2008[6]). Such an approach may allow for ineffective exercise programming to be integrated into policy.

In our laboratory we have observed considerable 2-mile run performance improvement by ROTC cadets following 10-12 week programs using evidence-based interval training and traditional strength training methods combined with 1-2 distance runs per week, twice-monthly ruck marches, and selective use of short-sided games (unpublished data). Evidence-based programming and periodization may lead to superior fitness results with less risk of injury. Personal experience with the military population shows that the concept of periodization (strategically organizing training into phases) is often poorly implemented in typical military physical training programs. Periodization strategies were developed as a strategy for fatigue management throughout the training process; non-periodized training programs may increase exposure to risk of overuse injury.[7,8]

This review outlines available empirical training methods that may improve performance on the 1.5 and 2-mile runs, including studies from a wide range of populations (see Appendix). The purpose of this review is to aid military personnel to meet the minimum fitness testing run performance requirements and also maximize performance to a level that occupational demands will allow.

Physiological Variables for the 1.5 and 2-Mile Runs

Multiple physiological variables are responsible for performance in running. For our purposes in this paper we will discuss the energy systems used and their relative contributions, lactate threshold (LT), strength, and running economy (RE).

Energy Systems

The energy systems used during middle distance running have been investigated in some detail. High intensity, short-duration exercise may exceed the energy-producing capacity

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of the aerobic system.[9] When this occurs a considerable proportion of energy is provided by anaerobic glycolysis. Comparatively, energy consumption during a sprint would be derived primarily from the phosphagen system.[8] In his review, Brandon[10] noted that energy system contributions may vary between runners of different fitness levels, however energy used during these runs is sourced primarily from aerobic metabolism and anaerobic glycolysis.

Energy System Contributions to Power Output

Aerobic Power

Aerobic power has been studied in detail in Western literature for decades, and is defined as the rate of maximal oxygen uptake (VO_{2max}).[11] There is clearly a strong relationship between aerobic power and performance in longer middle distance run performance, particularly among heterogenous populations. Mello et al.[12] studied the relationship between VO_{2max} and performance on the 2-mile run in recreational joggers (44 males aged 20-51, VO_{2max} 50.4 ± 7.7, 17 females aged 20-37, VO_{2max} 40.2 ± 6.6). Correlations between VO_{2max} and performance were strong (-0.91 for males and -0.89 for females). As this was a heterogenous group, individuals with a higher VO_{2max} were likely to run faster. Performance factors of homogenous groups of runners have shown smaller relationships between VO_{2max} and run performance, indicating that anaerobic factors may also be very important to performance in longer middle distance runs.[13,14] However, the aerobic energy system contributions for 3,000 m race performances in trained track athletes may be as high as 93% in males and 94% in females.[15]

Anaerobic Power

Scientists have struggled to directly measure the anaerobic contributions to middle distance runs.[10] The most commonly implemented tests have been short in duration compared to middle distance runs, and seldom tests of relevant running ability (e.g. Margaria stair test, Wingate 30 s anaerobic cycle test, etc.). Due to the collaborative nature of energy production between the energy systems, some difficulty has been encountered in developing a test that solely measures anaerobic work capacity. For instance, up to 27% of energy production in the Wingate 30 s anaerobic cycle test may be derived from the aerobic system,[16] and 32% of the maximal anaerobic run test (MART) may be derived from the aerobic system.[17] We refer the reader to Brandon's[10] work for a thorough summary of the issues of practical measurement of anaerobic power. As a result of these issues, indirect measurements have been performed to estimate the anaerobic contributions to middle distance runs.

Total work rates observed in middle distance runs may require considerable support from anaerobic metabolism. Brandon[10] indicated that middle distance runners often perform at 110% of VO_{2max} for 10-11 minutes; such intensities clearly require energy from anaerobic metabolism. Duffield[15] used accumulated oxygen debt (AOD) and lactate-phosphocreatine (La-PCr) regression methods to estimate anaerobic contributions during a 3,000 m (1.86 mi) race by competitive middle distance athletes (N = ten 3,000 m athletes). Anaerobic contributions were estimated at 14 ± 7% (AOD) and 7 ± 1% (La-PCr) for males and 6 ± 2% (AOD) and 8 ± 2% (La-PCr) for females.

Practical Training Implications of Energy Systems Information

The basis for a high level of performance at 1.5 and 2-mile runs clearly involves aerobic power to a large degree, however the exact role of the other factors involved in run performance is unclear—it is evident that there is more to performance in middle distance runs than just aerobic power, anaerobic mechanisms provide a notable percentage of energy demands. Training programs designed to elicit improvements in other factors (lactate threshold, anaerobic power and strength, for instance) may combine to provide considerable improvements in middle distance performance.

Lactate Threshold

As exercise intensity progressively increases, a larger proportion of energy is provided by anaerobic mechanisms.[8] Onset of a higher rate of glycolysis is reflected in the lactate threshold (LT), defined as the intensity at which lactate accumulation abruptly increases above baseline in the bloodstream (e.g. 4 mM lactate).[8] Brandon & Boileau[18] indicated that anaerobic factors appear to have a direct influence on performance at 1,500 m and 3,000 m, so including a moderate training emphasis on anaerobic factors may yield performance benefits, particularly because the training intensity is higher than typical long, slow distance (LSD) running. Billat[19] noted that [sustained] running speed is influenced by a relationship between running economy—steady state VO_2 at a given submaximal speed[20]—and LT, which determine the percentage of VO_{2max} used in runs beyond 10 minutes in duration. LT may be altered considerably with appropriate training. In untrained subjects LT occurs at about 50-60% of VO_{2max}, while highly trained runners may experience LT at intensities of 60-85% VO_{2max}.[21] Raising the LT may allow a greater proportion of energy to be produced from aerobic metabolism at a given running pace, along with an improved tolerance to metabolic acid production that occurs at higher exercise intensities.[8] In his review Brandon[10] indicated that runners with a high LT perform at a higher percentage of VO_{2max} than those with a lower LT. Indeed higher LTs demonstrated in middle distance athletes have been connected with better running performances. In a sample of national-level French middle distance runners, Lacour et al.[14] found a higher correlation (0.66) between LT and mean 3,000 m velocity than VO_{2max} and mean 3,000 m velocity (0.51). Because anaerobic factors play a greater role in middle distances than longer runs, increasing LT is likely to improve performance in 1.5 and 2-mile runs. Alterations in LT likely require training at or above LT.[22,23]

Strength

A stronger runner may indeed be a faster runner due to less relative effort being required by the movement and greater mechanical efficiency at a given pace.[24] Increasing strength may also allow a runner to maintain mechanics for longer during intense running.[25] A variety of strength training programs using heavy loads and lighter loads in explosive strength training have been shown to improve running performance in middle distances and laboratory runs within our target timeframes with subjects from a variety of populations.[26-28] No studies were available that evaluated chronic strength training programs (beyond 28 weeks) in distance runners. However, evidence indicates that strength training can improve run performance.[24,29] Therefore, chronic strength training may provide further performance benefits for runners.

Running Economy

If two runners ran at a constant speed, the runner with a lower VO_2 is assumed to have better running economy.[29] Conley and Krahenbuhl[30] found that running economy accounted for 65.4% of the variation in finish times among well-trained competitive runners in a 10 km race (mean finish time 32.1 mins). Strength also has a role in running economy (RE), and may play a considerable role in neuromuscular efficiency improvements in running gait.[31,32] Adaptations in musculotendinous stiffness from running mechanics drills and plyometric exercises may also greatly improve running economy.[28] Evidence suggests that running economy improves with a variety of resistance training and sport-specific methods.[10,24,29]

Acute Practical Strategies

Many practical strategies may be influential on acute performance in 1.5 and 2-mile runs. Nutritional interventions and hydration are beyond the scope of this article, however we will discuss warm-up and pacing strategies as potential factors that may have measurable effects on acute performance.

Warm-up

Conventional running wisdom holds that a runner should perform a warm-up of some kind to promote optimal performance. Interrupting resting physiological homeostasis by increasing muscle temperature (T_m) and aerobic metabolism, promoting increased joint range of motion by active stretching, practicing stride, and employing mental preparation strategies have been suggested by multiple sources with a sound theoretical base.[9,33,34] Priming metabolism to a level near that which is experienced during training or competition may reduce the severity of stress encountered in the early part of the run. Bishop[34] suggested that a warm up of ≈ 40-60% VO_{2max} followed by a brief rest period (≤ 5 minutes) may be physiologically optimal for aerobic events. He added that care should be taken to avoid excessively intense warm-up activities that may lead to fatigue and affect later effort. Warm up strategies may potentially be limited to 10 minutes in duration to effectively increase T_m and reduce risk of decreasing stored glycogen reserves that will be required for optimal performance in the event. A rest period of less than 5 minutes between the warm up and performance may allow some recovery without allowing VO_2 to drop considerably.

Research showing explicit performance benefits of warming up for a middle distance run is scant. Only one article that included a method that documented improved performance was found. Ingham et al.[35] showed that a warm up session including six 50 m race-pace strides separated by a walking recovery (45-60 s) and one race-pace 200 m run elicited superior performance over a 10-minute jog warm-up in 11 well-trained 800 m athletes. The runners exhibited higher lactate levels and higher VO_2 during the 800 m run as a result of the shorter warm up method, indicating that the metabolic machinery was functioning at an appropriate rate to support exercise intensity. Caution should be used in transferring use of this specific warm up method to the 1.5 or 2-mile runs until more research is conducted. However, the take-home point from this study was that the athletes primed metabolism using brief bouts of intermittent exercise at race pace, thus enhancing performance during the event.

Wittekind & Beneke[36] evaluated the effects of three warmup protocols on time to exhaustion (TTE) at 105% vVO_{2max} (test designed to elicit exhaustion in ≈ 5 mins) in club level runners. No warmup, a 10-minute jog warmup at 60% vVO_{2max}, and a 60% vVO_{2max} jog warmup then six 15 s strides at 105% vVO_{2max} separated by 1 min standing rest were evaluated. Total work was equated between the two warmup methods. After warm-up runners showed higher VO_2 during the run, yet improvements in performance (mean TTE at 105% vVO_{2max} increased 34 s following jog and 26 s after jog + strides) did not reach statistical significance (possibly due to small sample size). We estimated an effect size of 7.98 (Cohen's d based on r value provided) for the combined warm up condition compared to control, indicating that a considerable effect did occur.[37] Ingjer & Stromme[38] also found that an active warm-up provided higher oxygen uptake, lower lactate and higher blood pH levels during a 4-minute treadmill run at 100% VO_{2max} compared to passive warm-up or no warm-up. There appears to be physiological evidence that a warm-up may potentially aid performance, however no studies exist that provide direct evidence that warm-up improves performance on a middle distance maximal run in the 8-20 minute range. It is likely that warm-up activities aid performance in the 1.5 mile and 2-mile runs, however further research needs to be conducted on the topic; it is possible that any metabolic priming advantages may be lost over the course of a longer run, potentially negating the benefits of a warm up in poorly trained individuals through factors such as pacing errors.

Pacing Strategy

Practical experience with military testing shows that often pace at the beginning of a military fitness test run is too fast, and the individual fails to maintain the chosen pace after a short time and struggles to maintain speed through the middle of the run. Much of this may be due to psychological factors related to the high-stakes career impacts of military fitness testing. For this reason it may be advantageous for military personnel to strive to maintain a pace close to average race pace for the initial phase of the run during a test to mitigate any deleterious effects of a super-fast start.

Tucker et al.[39] evaluated pacing strategies for multiple men's world record performances in several race distances. Splits for the 5,000 m record runs were available in 1 km increments. Because the current world record for the 5,000 m is just over 12.5 minutes, elite runners competing at this distance may hold some useful hints for lesser athletes competing in the 1.5 and 2-mile runs. Many elite 5,000 m athletes slow their pace (1-3 seconds per km) from 1-4 km until the last 1 km of the race, when they increase the pace and exhaust their reserves to finish.[39] Gosztyla et al.[40] evaluated 5,000 m pacing strategies in moderately trained female runners (collegiate cross country runners) and found that a start pace 6% faster than average race pace held during the first 1.63 km (1 mile) resulted in the fastest run times (best time for 8 of 11 runners) compared to a 3% faster (best time for 3 of 11 runners) or race pace start. The 6% faster condition group showed considerably slower speeds throughout the 1.63 km splits (6:25 ± 8, 6:41 ± 9, 6:51 ± 10) with a strong burst to finish.

Using a computer model, Fukuba and Whipp[41] suggested that if pace slows considerably from the theoretical threshold of fatigue (as would be seen as the runner attempts to recover from a too-fast start), the runner may not be able to regain the lost time by sprinting at the end of a race. For novice runners, the pace changes employed by elite athletes may be difficult to replicate. To ensure a successful run test, a dramatic slowing of pace may not be advisable for less-fit military personnel. Strategies may vary considerably according to training status, however caution should be taken in applying pacing strategies used by elite or moderately trained athletes to military populations until pacing strategies have been investigated within this population. Until these studies have been performed, we advise military personnel to closely monitor pacing to acquire insight on individual trends in run speed during practice tests to ensure consistency in official fitness tests.

High Intensity Interval Training (HIIT) Studies

The use of HIIT has become common due to numerous publications showing improvements in VO_{2max} and performance in tests to exhaustion.[42,43] Interval training is used to develop the ability to perform at higher intensities than during continuous running. To optimally improve performance, all exercises and intensities should be specifically prescribed for each individual according to training status.

HIIT is an effective technique that stresses both anaerobic and aerobic metabolism.[44] Because the high intensities of short distance interval training are beyond what can be maintained during steady-state exercise, rapid adaptations in aerobic metabolism have been observed within the muscles. Burgomaster et al.[45] observed increased levels of mitochondrial enzymes (citrate synthase and cytochrome oxidase) after just two weeks (six sessions) of HIIT.

A useful variable for controlling the intensity of training is vVO_{2max}.[46] Training at intensities of or near vVO_{2max} may elicit improvements in power output.[22] Caution should be taken when extrapolating vVO_{2max} from laboratory-based treadmill tests to vVO_{2max} in a track and field environment, as conditions are different.

Training at intensities near vVO_{2max} allow the total training load to be reduced from typical volumes found in military training. This may reduce incidence of injury without compromising improvements in aerobic fitness. [47,48] Denadai et al.[42] showed in well-trained runners, that training at 100% of vVO_{2max} twice a week for 8 weeks leads to an increase in vVO_{2max} without significant changes in VO_{2max}. Because of the improvements in 1500 m, 3000 m and 5000 m trials,[23,28,29] it is reasonable to infer that training with this method may also improve 1.5 and 2-mile test performance. Billat et al.[46] found that performing only one interval training session per week at vVO_{2max} (along with several runs at onset of blood lactate accumulation) was sufficient to increase vVO_{2max} and running economy after four weeks of training. The HIIT session consisted of five 1,000 m work bouts with 500 m rest; subjects performed these sessions on one or three days per week. The remaining sessions consisted of easy runs (4 or 2 per week respectively). The group performing three HIIT sessions per week did not present signs of overtraining or decrease performance (both groups achieved 85 km total training volume). Subjects all showed lower heart rate at 14 km/h. This study[46] indicates that a relatively high training volume of HIIT can be performed up to three times a week for up to 4 weeks without risk of overtraining.

The training state of runners has been observed to play a role in how long they can sustain vVO_{2max}. Billat et al.[19,49] studied maximal time (T_{lim}) at vVO_{2max} during incremental tests and found that T_{lim} ranged from 3-12 minutes. Hill & Rowell[50] found that in a group of highly trained middle-distance runners 60% of the T_{lim} is sufficient to reach VO_{2max}. The amount of time at VO_{2max} may be an important factor in aerobic fitness improvement.[44] Several review papers have supported the idea that 50-70% of T_{lim} may be an ideal interval work period for aerobic performance improvement.[22,44] Smith et al.[51] found that performing two HIIT sessions per week at vVO_{2max} for 60-75% of T_{lim} with 2:1 work to rest interval, subjects improved by 17 seconds in a 3000 m all-out trial (616.6 to 599.6 seconds).

The majority of training studies investigating vVO_{2max} and T_{lim} were performed with subjects who were moderately aerobically trained and relatively young; these studies did not always include subjects similar in age or training history to military personnel. Billat et al.[43] showed in an older population (mean 52 years old), that using a very short training interval (15 seconds) at 85% of VO_{2max}, the subjects were able to maintain vVO_{2max} for up to 14 minutes during a single session. Future research may elucidate proper training parameters for groups that have difficulty in maintaining high intensities for periods longer than one or two minutes.

HIIT should ideally be prescribed according to individual needs, relative to each subject's vVO_{2max} and T_{lim}. These two variables may vary widely between groups of differing aerobic fitness levels, however training intensities around 100% vVO_{2max} appear to elicit fitness improvements in all populations. For individuals who do not have access to laboratory testing equipment, Daniels suggested an estimate vVO_{2max} may be obtained by finding the pace used during a 10-12 minute race run.[33] Another option is the 5 minute test proposed by Berthon et al.[52], that showed high correlations between vVO_{2max} observed during incremental tests on a laboratory treadmill and incremental and steady-state tests on a 400 m track. The authors later demonstrated the test's reliability with various populations.[53] Because Billat et al.[19,49] found that the T_{lim} usually ranges from 3-12 minutes, we propose that it may be appropriate to initially implement run programming with healthy military populations based on Berthon's 5-minute estimate of vVO_{2max}.[52] Daniels' 10-12 minute method may be more appropriate for testing in well trained runners.[33]

Distance Training Studies

Many studies have been performed that examine the effects of endurance running training, however most of the studies within our search parameters include a combination of aerobic training methods or provide minimal details of intensities prescribed. As a result, detailed analysis of individual training methods included in these studies is impossible.[48,54,55]

Kraemer et al.[56] implemented a comprehensive 4-day per week training program with soldiers. Two best-effort 40-minute long distance runs per week were included, along with two workouts including 400-800 m intervals at 90-100% VO_{2max}. All participants that performed the run program improved their 2-mile run times, while the strength training-only group did not. Despite the fact that a variety of run training methods were used, it appears that the best-effort distance training included in this study may be a legitimate method as part of a comprehensive approach to improve performance. Harman et al.[6] compared the results of an 8-week weight training based group (WTBG) and an Army Standardized Physical Training (ASPT) group in active healthy civilian males between 18-35 years old. WTBG performed best-effort 2-mile runs after weight training two days per week, along with a variety of training methods, including agility training and foot marches. ASPT performed runs according to the IET Standardized Physical Training Guide[57], which allowed for slightly different paces and volumes of distance running based on the subjects' 1-mile run time. Mean 2-mile improvements were similar between training programs (13% ASPT and 12% WTBG). Although the training groups included a different variety of training methods, both groups improved 2-mile performance.

Other modes of training (commonly referred to as cross training) may be intelligently substituted for running training to manage impact stress and account for poor running mechanics when needed.[58] Because the military employs individuals with a wide variety of fitness levels and body types, management of impact is necessary for allowing recovery and preventing overuse injuries. Cross-training using modes such as cycling and aqua-running may be employed to maintain chronic exposure to exercise. White et al.[59] used a cycling program to maintain offseason running fitness in female collegiate cross country runners. A cycling workout at 75-80% of maximum heart rate on alternate days equivalent to the caloric expenditure of a running workout was found to maintain aerobic fitness. The authors noted no statistically significant change in subjects' 3,000 m run times over the course of the study. Aqua-running is another form of aerobic exercise that has been shown to increase cardiorespiratory fitness.[60] This may include deep water running with flotation devices or shallow water running with or without a treadmill. Michaud et al.[60] recruited sedentary individuals to participate in three aqua-running workouts per week at 63-82% of their age-predicted maximum heart rate for 16-36 min. The authors suggested that athletes may improve or maintain cardiorespiratory fitness with aqua-running and observed a small training effect that may carry over to treadmill running.

The relevant literature shows that as little as 2-3 days of endurance exercise per week may play a role in the improvement of run performance in the 1.5 mile or 2-mile run tests, however the role of this mode of training in performance improvement is unclear—the inclusion of distance run training may not be necessary to ensure adequate performance on fitness tests if interval training is performed.[51] Prescription of distance running in the relevant literature ranges from 12-40 minutes at about 60-80% of maximum heart rate (HR_{max}). For individuals who have caloric deficit goals or need a lower impact exercise due to injury, non-impact modes such as cycling or aqua-running appear to be appropriate alternatives since aerobic fitness may be maintained or increased with these methods.

Strength Training Studies

There exists considerable evidence that strength training may improve running speed, economy, and performance, however we were unable to find any well-controlled studies that included traditional methods in strength/power training and specifically observed run performance in longer middle distance events. Two studies are available that included the 2-mile run as part of a test battery used to evaluate strength and conditioning programs for collegiate athletes. Fry et al.[26] evaluated a 12-week offseason volleyball training program that included strength training, plyometrics, on-court play, and 30 minutes of steady-state endurance running four times per week at approximately 80% of HR_{max}. Mean 2-mile run times were improved by 33 seconds in starters and 18 seconds in non-starters. Hoffman et al.[61] recruited collegiate football players for strength training (2-6 days/week) and football conditioning (2 days/week) as part of a 10-week offseason conditioning program. Mean improvement on the 2-mile run from football training among all groups was 116 seconds. As this notable improvement in the 2-mile run time was achieved with only strength training and sprint work, it is important to note that just resistance and sprint training has been shown to improve 2-mile run times in non-endurance trained athletes.[61]

Conventional training programs for athletes competing in longer middle or long distance running events have seldom included typical strength training. It is assumed that runners irrationally fear a performance-reducing gain in muscle mass associated with strength gains or that time spent on strength training has an unfavorable cost-benefit. In fact, distance running and strength training have contradictory physiological responses. The mTOR pathway, which has a role in muscle growth, can be inhibited by aerobic activity.[62] It is highly unlikely that a distance runner could have large chronic gains in muscle mass as a result of chronic resistance training—this has been observed in at least one short term study with distance runners training with heavy loads compared to a run-only control.[63] It is likely that the initial adaptations from strength training are primarily neural.[64] Genetic factors may also have a major role in a lack of hypertrophy in distance athletes. Van Etten et al.[65] found slender males (ectomorphs) did not gain fat-free mass after undertaking a 12-week weight-training regimen while subjects with a larger build (mesomorphs) showed gains in fat-free mass (1.6 kg). The authors noted that the mesomorphs tended to be stronger at the beginning of the study and that body build may influence the rate of fat free mass that an individual gains as a result of training. We were not able to find any training studies that included subjects who were well-trained in both strength and running that met our specific limitations, so any belief that chronic strength training is not effective for runners or deleterious to performance is not supported by research.

Strength gains have been shown to be muted by endurance training in a number of studies that investigated the interaction between exercise methods.[66-68] Studies that have demonstrated this effect have compared the effects of strength and endurance training (S+E) performed in one or more groups to the effects of the same endurance training program performed by another group. It is possible that the total training volume was too severe in the S+E group in these studies, and desirable adaptations were reduced as a result. It is also possible that a longer time period may be necessary to see similar gains when comparing endurance training to concurrent training in a group of soldiers.[68]

Concurrent strength and endurance training has been used with sedentary subjects and not shown interference.[70] It is possible that after the initial neural adaptations have occurred, strength adaptations of resistance training may be muted by endurance training. It is also possible that by the time muscle remodeling occurs as a result of chronic strength training, a continually high concurrent training load becomes too taxing to recover from. The research has not yet conclusively elucidated the timeframe of this effect, however it is likely to occur within 6 weeks of training.[68] Kraemer et al.[67] observed that concurrent strength and endurance training may decrease muscle fiber size while improving strength. This may be evidence of several specific adaptations to conflicting stimuli.

Instead of adding a strength training program to a run program, Paavolainen et al.[29] substituted some run volume for strength training as they investigated the use of 9 weeks of explosive strength training and run-specific power development exercises in a group of elite cross-country runners. Subjects improved significantly in 5,000 m time trial, decreased ground contact time during running, and demonstrated improved running economy (RE) after the strength training program. The authors concluded that neuromuscular efficiency may be developed concurrently with endurance training in elite runners. Part of this performance improvement may lie in improved ability to maintain running mechanics under fatigue. Esteve-Lanao[25] found stride length loss during interval training sessions at race pace was attenuated following an 8-week strength training program. Runners in the strength training group showed less reduction of stride length (less fatigue) than the strength training-only group and the running-only control group.

Longer duration training studies using a variety of methods with marathon runners have shown clear benefits of heavier loading and periodization. Taipale et al.[71] led untrained (strength) recreational marathon runners through a 28-week periodized training program that included heavy strength, power, and circuit training groups. The preparatory phase of strength training was undertaken by all groups and included 2-3 sets of 10-15 repetitions at 50-70% 1RM for a combination of free weights, machines, and countermovement jumps. The three groups then split up and performed programs focused on strength or power development or circuit training. Strength training volume was reduced and endurance volume was increased for the final 14-week phase of training. The max strength and power groups increased speed at vVO_{2max} and RE throughout the training period despite minimal changes in VO_{2max}. The circuit training group only increased VO_{2max}. A small increase in body mass was observed in the max strength training group (1.4%), accompanied by an increase in thigh muscle girth—which did not lead to performance decrements. After strength training volume was reduced, the maximal strength group continued to increase speed at vVO_{2max}. This demonstrates the importance of planned overreaching and tapering to enhance performance.[8,72] Over the course of the training program the authors noted that the neuromuscular and strength improvements that led to faster vVO_{2max} and improved RE appeared to have a larger effect on run performance than improvements in VO_{2max}.

Further demonstrating benefits of a diverse program, Greico et al.[73] put female collegiate soccer players through a 10-week training program, consisting of total body resistance training (2d/week), run mechanics, plyometrics, agility drills (2d/week), and soccer play (2d/week; volume & intensity not stated). The players improved time to exhaustion at vVO_{2max} over the course of the study (13.86 ± 2.5 to 14.82 ± 2.0 mins)—within the desired timeframe of our focus population. Sporis et al.[74] found that a 12-week strength-training program improved aerobic power (4.3%) and anaerobic power (2.7%) in well-trained female soccer players (half were national level players; mean VO_{2max} 49.24 ± 4.32 ml/kg). Evidence indicates that it is possible that a well-rounded physical development program is optimal to improve running performance.

Many short-term training studies have shown improvements in RE at faster paces following various methods of strength training and plyometric training.[32] Predictably, greater loading patterns tend to elicit greater improvements in RE.[31,63] Bodyweight circuit training, however, has not shown much promise for the improvement of RE. Taipale et al.[75] found no improvements in RE in recreational marathon runners who performed a 6-week initial strength training regimen (1-2 sessions/week), then an 8-week body-weight circuit and run program. Strength training of various types showed increases in peak speed and running speed at respiratory compensation threshold in this study, indicating that strength training may indeed be of benefit to distance runners.

A muscular endurance-enhancing approach (such as body weight circuit-training or calisthenics) is often favored by coaches and athletes in conventional run training programs and military physical training settings.[33,76] Current philosophy within many military populations holds that a combination of aerobic training and muscular endurance exercises such as calisthenics will elicit 1.5/2-mile running improvements in military servicemembers, however there is a paucity of literature regarding effective long-term calisthenic or circuit training program integration.[6] When considering resistance training programming choices, coaches, athletes, and military personnel must realize that the neurological demands of light/body weight circuit training may be insufficient to produce significant demands on the neuromuscular system, so a relatively small strength training effect is likely.[76] Both Yamamoto's[77] and Jung's[78] reviews confirm that no evidence exists suggesting that circuit training improves distance running performance in trained runners. Gettman et al.[79] noted that traditional strength training methods that incorporate heavy weight and fewer repetitions are more effective at developing strength than circuit training or super circuit (circuit training with aerobic activity in-between sets) programs. The authors also commented that circuit training has been found to enhance work capacity better than heavy weight training programs, however these programs should be used specifically as a tool to enhance work capacity as part of a yearly plan—the implementation of periodization strategies may be considerably useful leading up to a fitness test for military personnel.

Summary

Very little research has been conducted to determine the most effective training programs to enhance performance in the 1.5 and 2-mile runs. According to the studies available, performance benefits including improved power output, LT, strength, and RE may result from 1-3 HIIT sessions up to 60% T_{lim} in duration performed around vVO_{2max} and 0-4 distance runs of 12-40 minutes at 60-80% HR_{max}, along with 2-5 strength training sessions per week including 2-10 exercises, ≥ 3 sets of multiple joint exercises at intensities up to 95%1RM (see Table 1). With consideration of the demands of common military occupational tasks, strength training sessions are appropriate to develop a strength base that will improve performance on run tests and enable success in occupational tasks.[76] It is important to consider occupational demands and adapt the training program accordingly, particularly due to the wide range of work settings and demands of each military career field. Further research should focus on training methods specifically designed to enhance performance on military fitness tests and occupational tasks, to include periodization and training variation strategies for specific career fields. It is likely that increasing strength over the course of several months with typical strength training, then decreasing emphasis on strength training and gradually increasing emphasis on test events (such as push ups, 2-mile pace work, etc.) for several weeks leading up to a fitness test will be an effective strategy to prepare for military fitness tests .[71]

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Table 1. Training Recommendations

HIIT 1-3 sessions per week; interval durations up to 60%T_{lim}, total of ≈ 10 mins close to vVO_{2max} ; use no-impact modes for additional training volume for overweight individuals [41,45,50,57]
Distance Training 0-4 sessions per week; 12-40 mins in duration, 60-80% HR_{max} [29,55,68]
Plyometrics/Mechanics Drills 2 sessions per week: 5-10 sprints of 20-100m, 30-200 foot contacts, 5-20 repetitions per set, loads 0-40% 1RM [29,72]
Strength Training 2-10 exercises; 2-5 sessions per week; ≥3 sets of multiple joint exercises at intensities from 12RM to 3RM (≈ 70-95% 1RM); periodized program; [27,28,32,62,70,72,73]

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Appendix. Training Studies

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Billat et al. (1999)	N = 8 Endurance Trained male athletes		Normal Training – 1x/wk, 5 x 50% of T_{lim} at vVO_{2max} (3min at vVO_{2max}). Overload Training – 3x/wk, 5 x 50% of T_{lim} at vVO_{2max} (3min at vVO_{2max}).	Baseline Training – 6x/wk (easy) from 45 - 90min all ≤ 70% vVO_{2max} Normal Training – 4x/wk (easy) from 45 - 60min all ≤ 70% vVO_{2max} - 1x/wk, 2 x 20min at OBLA (85% vVO_{2max}). Overload Training – 2x/wk (easy) from 45 - 60min all ≤ 70% vVO_{2max} -1x/wk, 2 x 20min at OBLA (85%vVO_{2max})		vVO_{2max} -improved in all training blocks Running Economy - improved in all training blocks OBLA and Heart Rate - improved in all training blocks when running at 14km/h
Denadai et al. (2006)	N = 17 Well-trained male mid and long-distance runners		2x/wk for 4 wks at 95% or 100% vVO_{2max}	4 sessions/wk for 4 wks -1x/wk at OBLA velocity, 3x/wk at 60-70% vVO_{2max}	Improved 1500 m and 5000 m time trial; 95% of group improved in run TTE at 95% & 100% vVO_{2max}	No change in VO_{2max} Improved vVO_{2max} Improved vOBLA in both groups RE improved in submax test
Esfarjani & Laursen (2007)	N = 17 Moderately trained male runners		Group 1 – 2x/wk for 10 wks – 8 bouts at vVO_{2max} for 60% T_{lim} (1:1 work to rest ratio) Group 2 – 2x/wk for 10 wks – 12 bouts at 130% vVO_{2max} for 30 sec and 4.5 min rest	Groups 1 and 2 – 2x/wk for 10 wks, 60 min run at 75% vVO_{2max} Control – 4x/wk for 10 wks, 60min run at 75% vVO_{2max}	Improved 3km run time in groups 1 & 2	VO_{2max}, vVO_{2max}, T_{lim} (increased for Groups 1 and 2), Velocity at Lactate Threshold (improved in Group 1 only).

Appendix. continued.

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Esteve-Lanao et al. (2008)	N = 18 male, well trained/ subelite middle distance runners (divided evenly into 3 groups – periodized strength [PS], non-periodized strength [NPS] and endurance only control [C])	4 wk preparatory period – 9 sessions total (PS and NPS)– 3 isometric session, 2 body weight session, and 4 resistance training sessions 8 wks intervention period containing 3 mesocycles – PS weight training wks 1-2, circuit training wks 1-5, plyometrics wks 4-5; NPS weight training wks 1-2,4-5,7-8, circuit training wks 1,3,5,7, plyometrics wks 2,4,6 4 wk competition period – no specific strength training; sporadic, light maintenance sessions	8 wks intervention period containing 3 mesocycles – PS hill intervals wks 4-5, weighted belt intervals 6-8; NPS hill intervals wks 1,3,5,7, weighted belt intervals wks 2,4,6 4 wk competition period – short run reps at competition pace	4 wk preparatory period (all groups)– 4-5 runs/wk of 40-60 min at 70%HR_{max}, 2x/ wk at 90% HR_{max} (9x3min, 7x4min, 6x5min) 8 wks intervention period containing 3 mesocycles (all groups) – fartlek training, long reps at maximal lactate steady state		PS – no loss in stride length NPS and C – loss in stride length
Fry et al. (1991)	N = 14 NCAA D-I women's volleyball players	Traditional strength training 4X/week for 12 weeks Plyos – 2x/wk for 12 wks (various types of jumps)		4x/wk for 12 wks 30 min run at 80% of HR_{max}	Improved 2 mile run time	Improved strength on multiple lifts, improved strength in sport-specific isometric tests, improved performance on 30s vertical jump, agility, increased isokinetic leg extension torque, increased lean mass,

Appendix. continued.

Study	**Subjects**	**Strength training**	**HIIT**	**Endurance training**	**Run Performance**	**Physiological variables**
Greico et al. (2012)	N = 15 DI female soccer players	Strength – 2x/wk for 10 wks – 3 x 6-12 Wks 1, 2, 5, 6, 9, 10 - 1d DB single arm power clean, BB power jerk, BB front lunge, SLDL, Back squat, BB bent-over row, Dips (assisted), Medicine ball side tosses, Basket hangs, Planks -1d BB hang clean, DB single arm jerk, Box jumps, Russian hamstring extension, Front squat, Pull-ups (assisted), DB incline chest press, Roman chair hyperextension, Roman chair sit-ups Wks 3, 4, 7, 8 -1d DB single arm power clean, BB power jerk, BB front lunge, SLDL, Back squat, Inverted row, MB push-ups, Cable chops, Around the world, Planks – 1d BB hang clean, DB single arm jerk, Box jumps, Russian hamstring extension, Overhead squat, Pull-ups (assisted), Plyo clapping push-ups, Roman chair hyperextension, Roman chair sit-ups Plyos – 2x/wk for 10 wks with dynamic warmup – 1d fast feet, falling accelerations, get-up starts, ins and outs, flying 40s, wall drills – 1d tuck jumps, star jumps, 1 step crossover, 3 line drill, agility ladders, Proagility, T drill, NFL 3-cone drill				Increase in VO_{2peak} Increase in TTE No change in RE

Appendix. continued.

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Harman et al. (2008)	N (total) = 32 civilian N (ASPT) = 17 N (weight-based) = 15	Weight-based - 2 sessions/wk for 8 weeks – 2-3 sets (each set lasted a total of 90s with rest) ASPT – 8 wks – body weight circuit 3x/wk – 5-10 exercises with 5-20 reps each	Weight based –1 session/wk for 8 weeks – 2-3 600-800m sprints, 8-10 100-200m sprints – agility drills 1x/week (75 min) ASPT – 300yd shuttle 1x/wk – military movement drills 5x/wk – sprint intervals 1x/wk – 30-60s sprints with 60-120s rest (number of sprints dependent on mile run time)	Weight based - 2 sessions/wk for 8 weeks, best effort 3.2 km run	Improved 2 mile run time in both groups	
Hennessy & Watson (1994)	N = 56 Rugby players (divided into 4 groups) E – 4d/wk S – 3d/wk SE – 5d/wk (2d running and resistance, 2d run only, 1d resistance only C- no training	S – 3d/wk for 8 wks – 2d/wk 2-3 x 10 at >70% 1RM for squat, bench press, hamstring curls, shoulder press, arm curls; 2-3 x 15-25 crunches – 1 d/wk 3 x 10RM lunge, upright row, DB flies, triceps press/ pushdown, calf raise, bent knee situp SE – 3d/wk for 8 wks –1d/wk moderate intensity weights –2d/wk high intensity weights		E – 4d/wk for 8wks – 2d/wk 20-60 min at 70% HRmax, 1d/wk 15-35 min fartlek run, 1d/wk 20-40 min at 85% HRmax SE – 4d/wk for 8 wks – same as above		SE - Attenuated strength gains E, SE – gains in estimated VO_{2max}
Hickson et al. (1988)	N (total) = 8 (participated in endurance training for a minimum of 2 months prior to adding strength training)	3 days/wk for 10 wks, 3-5 X 5 (at 80% 1RM) parallel squats, knee extensions/flexions; 3x25 toe raises; as strength increased additional weights were added		Normal training continued 3 days/wk		Short term max exercise performance increased 13% during treadmill running after S&E; 10km run performance was not significantly different after strength training

Appendix. continued.

Study	**Subjects**	**Strength training**	**HIIT**	**Endurance training**	**Run Performance**	**Physiological variables**
Hickson (1980)	N = 23 Active in recreational sports	S and SE Groups – 5d/wk for 10 wks: 3 days of 5x5 parallel squats, 3x5 knee flexion, and 3x5 knee extensions; 2 days of 3x5 leg press and 3x20 calf raises; all exercises at approx. 80% of max weight and weight was increased as strength improved (RM sessions) E group– no strength training.	E and SE Groups – 3d/wk for 10 wks: cycling on alternate days from running 6 x 5-min of cycling at a work rate near the subjects' VO_{2max}; 2 min rest between intervals. Work rate increased as power output increased	E and SE Groups – 3 d/wk for 10 wks: best effort run for 30 min/day during the 1st week, 35 min/day during the 2nd week, and 40 min/day thereafter.		Parallel Squat – Increased all weeks for the S group, increased up to week 7 for SE group then decreased, no differences for E group. Cycling and running VO_{2max} - same improvements for E and SE Group, and no significant changes for the S group.
Hoffman et al. (1990)	N (total) = 61 NCAA D-IAA Football team N (3 days/wk) = 12 N (4 days/wk) = 15 N (5 days/wk) = 23 N (6 days/wk) = 11	3, 4, 5, or 6 days/wk for 10 wks Wks 1-4 – 4x8 Wks 5-8 – 5x6 Wks 9-10 – 1x10, 1x8, 1x6, 1x4, 1x2		2 days/wk for 10 wks 8 minutes (1 mile)	Improved 2-mile run time	Improved strength
Johnston et al. (1997)	N (total) = 12 female distance runners N (Endurance + strength, ES) = 6 N (Endurance only, E) = 6	3 days/wk for 10 wks 2x20RM bent leg heel raise 2X12RM straight leg heel raise 2x15RM weighted sit-up Max rep abdominal curl 3x8RM knee flexion, knee extension, front and rear lat pull down, seated row 3x6RM parallel squat, seated press, hammer curl, lunge, bench press		4-5 days/wk for 10 wks 20-30 miles/wk		Increase in strength for ES 4% RE improvement for ES

Appendix. continued.

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Kraemer et al. (2004)	N = 35 active duty military divided into 4 groups (ET, RT, RT+ET, UB+ET)	4 days/wk for 12 weeks Varied within each week (strength – 5x5, 5x10 for trunk, Tues/Fri; hypertrophy – 3x10, 2x25 for trunk, Mon/Thurs)	Tues/Fri 100-400m (total distance 400-800m) at 90-100% VO_{2max}	Mon/Thurs Best effort 40 min run at 70-80% VO_{2max}	Improved 2-mile run for UB+ET, RT+ET, and ET	
Kraemer et al. (1995)	N (total) = 35 N (SE) = 9 N (UB+E) = 9 N (E) = 8 N (S) = 9	S, SE, and UB+E (only UB exercises) - 4 d/wk for 12 wks – 2d/wk 2-3 x 10RM bench press, flies, military press, upright row, lat pull down, seated row, arm curl, single knee extension, leg curl, calf raise, split squat; 2 x 25RM sit up – 2d/wk 4-5 x 5-6RM bench press, military press, arm curl, lat pull down, obliques, sit up, double knee extension, leg press, deadlift; 3 x 10RM calf raise		E, SE, and UB+E - 4 d/wk for 12 wks – 2d/wk best effort 40 min run – 2d/wk 200-800m intervals		SE, UB+E, E – increase in VO_{2max} SE, S – increase in strength
McCarthy et al. (2002)	N = 30 sedentary (divided evenly into 3 groups – S, E, and SE)	S and SE – 3d/wk for 10 wks – 1 warm up set, 3 x 6RM of 8 exercises		E and SE – 3d/wk for 10 wks – 50 min cycling at 70% HRR		SE – no impairment of strength development
Michaud et al. (1995)	N (total) = 23 healthy sedentary N (exercise) = 16 (14F, 2M) N (control) = 7 F			3 days/wk for 8 wks Deep water running using a flotation belt (no treadmill) Interval workout (at an RPE of 5 with 30s rest between intervals) for a total of 25-45 min		Increased VO_{2max}

Appendix. continued.

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Millet et al. (2002)	N (total) = 15 well trained subjects N (SE) = 7 N (E) = 8	SE – 2x/wk 3-5 x 3-5RM lower limb muscles only		SE and E – 20 hrs total endurance training per week for 14 weeks (run 44-48 km/wk; cycle 210-221 km/wk; swim 18.3-19.8 km/wk)		SE – increase in RE, increase in strength, no change in VO_2
Paavolainen et al. (1999)	N (total) = 22 elite male cross country runners N (experimental) = 12 (32% explosive strength training, the rest was endurance and circuits) N (control) = 10 (3% explosive strength training, the rest was endurance and circuits) Subjects were matched for VO_{2max} and 5km time	8-9 times/wk for 9 wks Explosive strength training – 15-90 min, sprints and jumps – sprints 5-10 (20-100m) – jumps with or without weight (alternative jumps, bilateral countermovement, drop and hurdle jumps, and 1 legged, 5 jump test) – leg press and knee extensor/flexor-low loads (0-40% of 1 RM) and high movement velocity (30-200 contractions/sessions; 5-20 reps/set) Circuit training – specific abdominal and leg exercises with dozens of reps at slow movement velocity-no added weight		Cross country or road running – 0.5-2h either above or below LT	Improved 5km run for experimental group	Improved RE for experimental group

Appendix. continued.

Study	Subjects	Strength training	HIIT	Endurance training	Run Performance	Physiological variables
Pichot et al. (2000)	N (total) = 15 N (control) = 8 healthy sedentary males N (experimental) = 7 national level male middle distance runners		4 wks (3 wks exhaustive, 1 wk light); Some sprint training – daily totals summed for the week	4 wks (3 wks exhaustive, 1 wk light); Some endurance training – weekly total summed		Progressive decrease in heart rate variability
Saunders et al. (2006)	N = 15 Highly trained distance runners	1x/wk for 9 wks: 1 - 5 sets – rep 6 – 20 of back extension, leg press, countermovement jumps, knee lifts, ankle jumps, hamstring curls; 1 - 6 sets from 5m - 30m of alternate leg-bounds, skip for height, single leg-ankle jumps, continuous hurdles jumps, scissor jumps for heights. Control group – No plyometrics	1x/wk for 9wks of 3 intense intervals for both groups	1 Long run/wk (60-150 min) for 9 wks 3 mid-range runs/wk (30-60min) for 9wks		Running economy at 18 km/h (improved in Plyometric group).
Smith et al., (1999)	N = 5 Middle-distance trained subjects		2x/wk for 4 wks – 6 intervals of 60-75% T_{lim} at vVO_{2max} (work to rest ratio 1:1)	1x/wk for 4 wks – 30min at 60% vVO_{2max}	3000 m time-trial (improved)	Improved VO_{2max} , vVO_{2max} , & T_{lim}
Sporis et al. (2011)	N = 24 female soccer players	3 d/wk for 12 wks 3 x 8 at 70% 1RM, 4 x 10 at 75% 1RM, 5 x 12 at 80% 1 RM		3 d/wk for 12 wks (1d “friendly” game for 45 min, 2d practice at 75% VO_{2max} 90-105 min)		Increase in aerobic power
Storen et al. (2008)	N (total) = 17 (9 M, 8 F) well trained runners N (intervention) = 8 (4 M, 4 F) N (control) = 9 (5 M, 4 F)	3 d/wk for 8 wks 4x4RM half squat (3 min rest between sets) – if subject could do 5 reps then 2.5kg was added for next set		Normal training for 8 wks – self reported intensity		Increased strength, Increased RE at 70% VO_{2max}

Appendix. continued.

Study	**Subjects**	**Strength training**	**HIIT**	**Endurance training**	**Run Performance**	**Physiological variables**
Taipale et al. (2013)	N = 37 Male recreational endurance runners	8 wks training for all groups (unclear how many days per week) Maximal Strength Group – Squat and Leg-press 3 sets, 4-6 reps 80-85% 1 RM, calf exercise 2 sets, 12-15 rep 50-60% 1RM, 2min rest Explosive power group – Squat and Leg-press 3 sets, 6 reps 30-40% 1 RM, Scissor Jumps 2-3 sets of 10 seconds, Maximal Squat Jumps unweighted and weighted – 2-3 set of 5 reps each – 2min rest. Mixed maximal strength + explosive power – weeks 0-4 Squat and Leg press 2 sets of 6 reps 6 RM (3min rest), Weeks 4-8 Squat and Leg press 3 sets of 4 reps 4 RM (3min rest); All 8 weeks Box and vertical jumps 2-3 sets of 8-10 reps (2-3min rest) Control Group – circuit training squats, push-ups, lunges, sit-ups, toe-raises, back-ups, planks and step-ups (work to rest ratio 45:15 then 50/10 seconds)		5:38 ± 0:56h weekly of training intensity below the lactate threshold (controlled by the heart rate) for all groups on non-strength training days.		vVO_{2max} and Velocity at respiratory compensation threshold (improved in all groups including control from week 0 to 8). 1 RM Leg Press (improved in all groups but control at week 4 and 8 compared to the beginning). CMJ (improved in max strength group at week 4 and all experimental groups at week 8 compared to the beginning).

Appendix. continued.

Study	**Subjects**	**Strength training**	**HIIT**	**Endurance training**	**Run Performance**	**Physiological variables**
Taipale et al. (2010)	N (total) = 28 recreational endurance runners N (S_{max}) = 11 N (S_{exp}) = 10 N (circuit) = 7	6 wk preparatory period – All groups – 2-3 x 10-15 at 50-70% 1RM squat, leg press, knee flexion, knee extension, lat pull down, bench press, calf exercises, CMJ 8 wk intervention period – 2x/wk S_{max} – 3 x 4-6 at 80-85% 1RM squats, leg press; 2 x 12-15 @ 50-60% 1RM calf exercise S_{exp} – 3 x 6 @ 30-40% 1RM explosive squats, leg press; 2-3 x 10s scissor jump with 20kg load; 2-3 x 5 max individual squat jumps; 2-3 x 5 max squat jumps in series Circuit – 3 x 40-50s squats, push ups, lunges, sit ups, calf raises 14 wk reduced resistance volume period – 1x/wk S_{max} - 3 x 6-8 at 75-80% 1RM; 2 x 10-12 at 60-70% 1RM knee extension/flexion, lat pull down, calf exercises, bench press S_{exp} – 3 x 6 at 30-40% 1RM explosive squats; 3 x 10s scissor jumps with 20 kg load; 3 x 5 max squat jumps in series; 2 x 10-12 @ 60-70% 1RM lat pull down, calf exercises, bench press Circuit – 3 x 50s squats, push ups, bench press, lunges, sit ups, calf raises, back extensions, planks, step ups		6 wk preparatory period – 20 -30 min low intensity run 8 wk intervention period (hr:min/wk)– S_{max} 4:49, S_{exp} 4:43, Circuit 4:03 14 wk reduced resistance volume period (hr:min/wk) – S_{max} 5:20, S_{exp} 4:52; Circuit 4:50		Improvements in strength; vVO_{2max} in both groups; improvement in running economy in explosive training group

Appendix. continued.

Study	**Subjects**	**Strength training**	**HIIT**	**Endurance training**	**Run Performance**	**Physiological variables**
Trank et al. (2001)	N = 1703 male Navy recruits at boot camp	3-5 d/wk for 8 wks 15-30 min of calisthenics (push-ups, sit-ups, crunches, lunges, etc.)		Daily movement logged for each division – included all movement miles (e.g. marching) and running (days and miles) – Range – (over 8 wks) 11.5-43.5 running miles, 110-202 movement miles	Improved 1.5 mile run performance	
Van Etten et al. (1994)	N= 34, sedentary	2 d/wk, 12 wks, 10-15 reps/set (flys, seated lat pulley, leg press, butterfly, tricep pushdown, sit-ups calf raises, leg curl, chest press, leg extension, overhead lats pulley, shoulder raises, preacher bench curl, leg raises)				Improved strength levels, Max aerobic power did not change with weight training
White et al. (2003)	N (total) = 11 NCAA D-II Female cross country athletes N (run) = 6 N (run/cycle) = 5			7 d/wk for 5 wks R – 40-50 miles/wk at 75-80% HR_{max} R/C – run and cycle on alternate days at 75-80% HR_{max} (cycling two times the run time to get equivalent volume in training but run mileage reduced by 50%)	No statistically significant difference in 3 km run time between groups	