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Effectiveness of a 16-Week High-Intensity Cardioresistance Training Program in Adults

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Abstract

Greenlee, TA, Greene, DR, Ward, NJ, Reeser, GE, Allen, CM, Baumgartner, NW, Cohen, NJ, Kramer, AF, Hillman, CH, and Barbey, AK. Effectiveness of a 16-week high-intensity cardioresistance training program in adults. *J Strength Cond Res* 31(9): 2528–2541, 2017—The purpose of this study was to determine the efficacy of a novel, 16-week high-intensity cardioresistance training (HICRT) program on measures of aerobic fitness, agility, aerobic power, muscular endurance, lower-body explosive power, and self-reported activity level. The intervention group ($N = 129$; 63 f, 24.65 ± 5.55 years) had a baseline $\dot{V}O_2$max of 39.83 ± 9.13. These individuals participated in 26, 70-minute exercise sessions, and 4 fitness testing sessions. Participants were matched with a nonexercise control group, paired by sex, age, and baseline $\dot{V}O_2$max. Matched controls ($N = 129$, 63 f, 24.26 ± 5.59 years) had a baseline $\dot{V}O_2$max of 39.86 ± 8.59 and completed preintervention and postintervention $\dot{V}O_2$max testing only. The results demonstrate that participants in the fitness intervention group significantly increased their $\dot{V}O_2$max (2.72 ± 0.31, $M_{diff} \pm SE$; $p < 0.001$) and reported being more physically active (0.42 ± 0.11, $M_{diff} \pm SE$; $p < 0.001$) after the intervention. The matched control group showed no significant pre–post intervention changes. Participants in the fitness intervention showed a significant improvement in 3 of 5 components of the fitness field tests. Specifically, significant improvements were observed for the 1-minute rower (5.32 ± 0.505, $M_{diff} \pm SE$; $p < 0.001$), 1-minute push-up (8.168 ± 0.709, $M_{diff} \pm SE$; $p < 0.001$), and 1.5-mile run tests (1.79 ± 0.169, $M_{diff} \pm SE$; $p < 0.001$). No significant improvements were observed for the shuttle run ($p = 0.173$) or standing long jump ($p = 0.137$). These findings demonstrate the efficacy of a novel, HICRT intervention across multiple dimensions of fitness for young- and middle-aged adults. High-intensity cardioresistance training affords flexibility for tailoring to meet desired health and fitness outcomes and makes perceivably daunting high-intensity functional training and multimodal sports training more accessible to general, traditionally nonathletic, populations.

Key Words aerobic fitness, intervention, functional training

Introduction

The vast benefits of physical activity and fitness on physical and mental health are widely known; yet, 29.6% of the adult population fails to participate in any leisure-time physical activity, and 60% are not participating at adequate levels to derive health benefits (25,64,81). Importantly, physically active and higher-fit individuals have lower relative risk for developing many chronic diseases (84). Initiating and continuing an exercise regimen may seem daunting for sedentary individuals, so attempts have been made to address common barriers to activity. Because perceived lack of time is one of the most common personal barriers to exercise participation, it is unsurprising that low-cost, time-efficient training strategies have become more appealing (19,29,38). Bodyweight training and high-intensity

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31(9)/2528–2541

Journal of Strength and Conditioning Research

interval training (HIIT) are the second and third top fitness trends for 2016, respectively, behind wearable technology (73). Some scientists fear risk of injury with high-intensity exercise training and claim the required intensity may be too difficult for nonathletes (16,54,73), though HIIT has been determined safe and well tolerated (2,18,86). Shepherd et al. (2015) found adherence to group-based high-intensity training to exceed that of steady-state training, though others have reported slightly lower adherence (43). Some report high-intensity exercise to be more enjoyable than steady-state training (11), but others find it more aversive (48), adding uncertainty as to whether such demanding training can ever be widely adopted by the general public. Lastly, most high-intensity training interventions have focused on purely running or cycling as the exercise stimuli, though some have begun to examine high-intensity functional training (HIFT). Empirical research on the efficacy of these types of activities is emerging in support of their capacity to improve fitness and health.

Pure HIIT workouts are generally short and involve around 10–12 minutes of aerobic, high-intensity exercise (accumulated through short bursts of activity) with 1–4 minutes of low-intensity recovery in between each interval, resulting in work-to-rest ratios of 1:1 or 1:4 in contemporary research models of this style of training (49,73). Different models of HIIT (10,23,55,66,90) have been shown to save time and provide similar aerobic fitness and health benefits to those of traditional, steady-state training (22,33,37,71), and sometimes, superior benefits (45,62,66,74,75). However, HIIT has been broadly interpreted as a number of different training formats, which incorporate high-intensity exercise. Generally, high-intensity exercise is completed at ≥80% of estimated maximal heart rate (HR) (52) or even >90–95% HRmax (20). A recent meta-analytic review of changes in $\dot{V}O_2$max over the course of both HIIT and continuous endurance training in young-to-middle-aged adults found relatively greater improvements in HIIT interventions (58).

Despite the many positive aspects of high-intensity exercise training programs, shortcomings of currently available protocols have been noted. Many protocols also seem to conflict with standard guidelines for improving muscular fitness (i.e., not providing enough rest/recovery) and inherently omit other important fitness components (e.g., flexibility; (15,29)). Also, although HIIT running has demonstrated similar effects as endurance running for enhancing cardiovascular fitness, it may not be as effective for lowering resting HR or as effective as strength training for increasing muscle mass (61). The Centers for Disease Control and Prevention (CDC) recommends 150 minutes of moderate or 75 minutes of vigorous aerobic activity each week, along with full-body strengthening activities 2 or more days per week (82). The American College of Sports Medicine (ACSM) Position Stand on quantity and quality of exercise for fitness enhancement mimics the CDC recommendation and further recommends 2–3 days per week of flexibility training (36). Previous research clearly demonstrates that mode-specific benefits emerge when strength training (i.e., increased bone mass and lean body mass), prolonged running (i.e., lower resting HR and diastolic blood pressure), and HIIT training (i.e., twofold increase in $\dot{V}O_2$max relative to that seen with prolonged running) are undertaken separately (61). However, a program that incorporates a combination of training modes may result in the most comprehensive adaptations in terms of fitness and health. An alternative multimodal program that addresses many of these concerns warrants investigation.

Popular methods that incorporate high-intensity exercise, along with Olympic weightlifting, and high-intensity continuous training (28) (among others) include bootcamps, extreme conditioning programs (15,53), and HIFT (15,43). High-intensity functional training is the process of developing strength, flexibility, coordination, and stamina through performance of exercises (at self-selected, high-intensity effort) that involve multiple joints and muscle groups with ultimate goals of (a) producing efficient movement patterns that can translate to the accomplishment of physical tasks encountered in daily living and (b) lowering a person's risk of injury during these activities (43,69). High-intensity functional training involves multimodal exercise performed continuously or at intervals and is sometimes completed in a circuit (50,59). Conventional emphasis has been placed on the proper execution of exercises such as squats and deadlifts, which replicate tasks of standing up from a seat and picking something up from the ground, respectively (69).

The high-intensity cardioresistance training (HICRT) program developed for the current intervention was designed to incorporate steady-state aerobic training, HIFT, and flexibility training aimed at enhancing whole-body fitness. The purpose of this study was to determine the efficacy of a novel, 16-week HICRT program to improve measures of aerobic fitness, agility and aerobic power, muscular endurance, lower-body explosive power, and self-reported activity level (AL). It was hypothesized that participants in the fitness intervention group would demonstrate significant improvements in $\dot{V}O_2$max, 60-yard shuttle run, push-ups and rowers completed per 1-minute period, and standing long jump (Army Physical Readiness Test [APRT]; (77,87)). Further, it was predicted that the fitness group would have a significantly greater $\dot{V}O_2$max and self-reported AL postintervention relative to a no-exercise control group.

Methods

Experimental Approach to the Problem

Individuals who received exercise training as part of their participation in the larger INSIGHT clinical trial (https://clinicaltrials.gov/ct2/show/NCT02780739) comprised the fitness intervention group. The fitness intervention was part of a randomized controlled trial known as "INSIGHT" with the primary outcome of fluid intelligence. The full INSIGHT Phase 1a clinical trial randomized participants into 5 groups

including 3 intervention groups who received some amount of cognitive training, one active control group, and one no-contact control group. Two of the 3 intervention groups received fitness training and only differed in receipt of high-definition transcranial direct current stimulation (HD-tDCS) or sham stimulation during the cognitive training sessions, and the other intervention group received cognitive training only. The active control group was an adaptive, active control condition and the no-contact control group continued with their regular activities at home, only attending pretesting and posttesting. As the receipt of HD-tDCS did not have a significant effect on primary fitness outcome measures, all participants who received exercise training were combined into one fitness group for the purpose of this article. Individuals who did not receive exercise training (i.e., cognitive training only, active controls, and no-contact controls) were combined into a single control group from which a subgroup of matched controls was selected for the purpose of this article. Participants who did not receive exercise training comprised the control group and were matched by sex, age, and baseline fitness with fitness intervention participants to make relevant pre–post intervention comparisons. High-intensity cardioresistance training was accomplished through concurrent training sessions (i.e., aerobic and resistance exercises). Participants in the fitness intervention began with 3 sessions per week in the first month, followed by 2 sessions per week in the second month, and one session per week for the third and fourth months. Efforts were made to schedule the recommended 48 hours between training sessions (36). Session frequency and duration (70 minutes) were dictated by the overarching aims of the INSIGHT trial.

Subjects

Participants were recruited through flyers, campus, and community webpage postings and electronic bulletin boards, local newspapers, a database of previous participants, and announcements in classrooms. Participants were included if they: (a) were between the ages of 18–45 years, (b) had no current or recent (within the past 2 months) medications affecting the central nervous system (CNS) or the ability to exercise safely, (c) had no medical, psychological, or physiological conditions affecting the CNS or the ability to exercise safely, including but not limited to pregnancy, concussion within the past 2 years, previous brain surgery, brain malformations, epilepsy/seizures, stroke, recurrent migraines, reading disability/dyslexia, depression, anxiety disorder, or attention-deficit hyperactivity disorder, (d) had normal or corrected-to-normal vision and hearing, (e) were proficient in English, and (f) passed the Physical Activity Readiness Questionnaire (72) with all "no" responses. Overall attrition from the INSIGHT study was 39%. Individuals were paid for their time spent participating at the rate of $7.50 per hour, with payment doubling on completion of the study. Participants were informed of the benefits and risks of the investigation before signing the approved informed consent document to participate in the study. This research was approved by the University of Illinois Office for the Protection of Research Subjects.

The fitness intervention group ($N = 129$; 63 f, 24.65 ± 5.55 years) had a baseline average $\dot{V}O_2$max of 39.83 ± 9.13 $ml \cdot kg^{-1} \cdot min^{-1}$. The sample varied from sedentary individuals to collegiate athletes, ranging in baseline aerobic fitness from 18.2 to 59.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for the fitness group and 16.6–58.4 $ml \cdot kg^{-1} \cdot min^{-1}$ for the control group. Participants entered the study at different points in their own personal training cycles; self-reported ALs are reported in Table 3. Over the course of 16-week intervention, this group participated in 28 fitness sessions (occurring from weeks 2 to 17): 26 exercise training sessions (70 minutes each) and 2 field fitness testing sessions, which served as pretest and posttest assessments (Figure 1). $\dot{V}O_2$max testing occurred on weeks 1 and 18, before and after the intervention. Individuals conducting pre and postmeasures of $\dot{V}O_2$max were blinded, whereas those who assessed field fitness tests were not. Participants were matched with a no-exercise control group, paired by sex, age, and baseline $\dot{V}O_2$max. The matched controls ($N = 129$, 63 f, 24.26 ± 5.59 years) had a baseline $\dot{V}O_2$max of 39.86 ± 8.59 $ml \cdot kg^{-1} \cdot min^{-1}$ and did not participate in any fitness training or field fitness testing.

Procedures

Participants enrolled and completed their participation over a period of <8 months through rolling admissions (Figure 2). As the study was conducted both indoors and outdoors in the Midwest, data collection occurred between April and November to best avoid ice and snow. All exercise sessions were led and supervised by trained fitness instructors and assisted by trained staff, who were all certified in cardiac pulmonary resuscitation and first aid. Participants exercised in groups of 1–5 per trainer with up to 3 groups per class and were encouraged to exercise at challenging resistance levels and relatively high intensities. This allowed participants to exercise alongside others who varied greatly in abilities and allowed flexibility in perceived effort. Each session consisted of 5 phases.

Phase 1: Warm-Up. To prepare the body for exercise and reduce the risk of acute musculoskeletal injury, each session began with submaximal aerobic activities and dynamic stretching (12,13). The warm-up remained constant across all 28 sessions, lasted approximately 4 minutes, and included the following exercises: jogging, backpedaling, butt kicks, high knees, skipping, knee-to-chest holds, lunges, standing kicks with slight trunk rotation, backward storks, lateral shuffling, carioca, bear crawls, and inch worms.

Phase 2: Walk/Run. The outdoor walk/run phase involved completing a designated activity (walking or running) within a specified amount of time or distance. Individuals trained in pyramidal fashion over the course of the intervention to complete 8, 10, 12, 15, 12, and 10 minutes and then 1, 1.5,

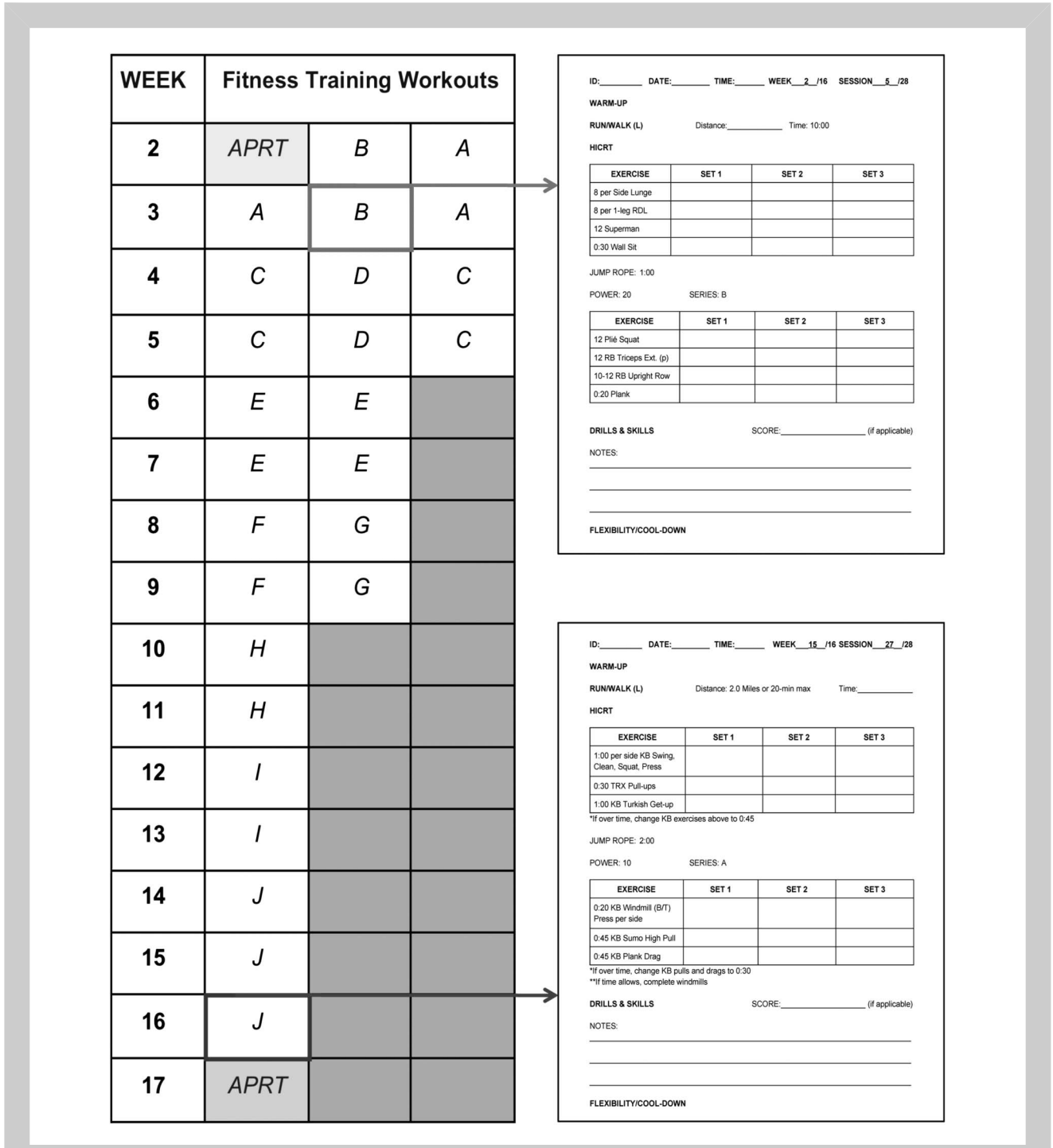

Figure 1. Block design of workouts in the 16-week fitness intervention. Weeks 1 and 18 were reserved for pre- and post-$\dot{V}O_2$max testing for both no-exercise control and fitness training groups. APRT = Army Physical Readiness Test; Ext. = extension; KB = kettlebell; B/T = bottom and top hands; L = clockwise run pattern; RB = resistance band; RDL = Romanian deadlift; p = partner exercise; TRX® = TRX® Suspension Trainer.

and 2 miles at gradually quicker paces, with a 20-minute cut-off time for the 2-mile distance. An alternate indoor routine involving hurdles and agility ladders was used in inclement weather.

Phase 3: High-intensity cardioresistance training. This was the most critical phase and, therefore, took the most time to complete (i.e., approximately 30–40 minutes). The HICRT phase involved completion of 3 sets of 3–4 resistance

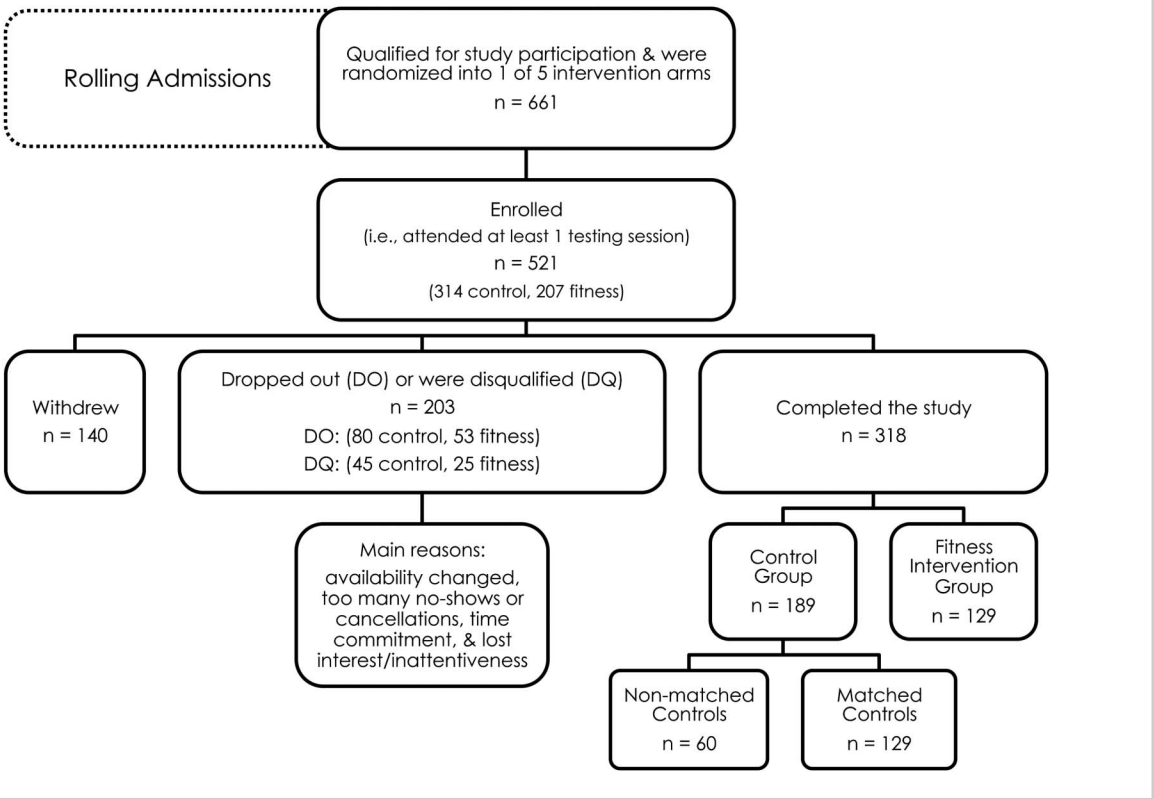

Figure 2. Flow chart of study participation.

training exercises (i.e., Part A), always followed by a 1- to-2-minute set of rope jumping, about 4 minutes of high-intensity cardiorespiratory exercises (i.e., "Power"), and another 3 sets of 2–4 resistance exercises (i.e., Part B). Jump rope duration increased in 15-second increments at sessions 14 (week 6), 20 (week 9), and 26 (week 15). During the Power activity, one of 12 lists of movements (Power 10, 20, 30, 40, 50, or 60 [versions A and B for each]) ranging in length from 24 distinct movements (Power 10; 10 seconds per 24 exercises) down to 4 movements (Power 60; 60 seconds per 4 exercises) was completed. The "Power 50" set lasted an additional 10 seconds because of the nature of multiplying 50 seconds by 5 exercises. Across levels (i.e., Power 10, 20, 30, etc.) lists were not mutually exclusive; however, each individual list and each version (e.g., Power 10A vs. 10B) contained distinct exercises with no repeats. Exercises included jumping jacks, lunges, push-ups, squats, skaters, burpees, various kickboxing exercises, mountain climbers, 1-leg hops, plié squats, squat jumps, tuck jumps, superman, swimmers, diagonal reaches, and numerous other calisthenics which varied by session.

During parts A and B, resistance training targeted major muscle groups including the quadriceps, hamstrings, abdominals, lower back, upper back, shoulders, triceps, biceps, and glutes; calves were addressed mainly through jumping rope and as stabilizers on lower-body exercises. The intervention began with bodyweight, battle rope, and resistance band exercises (weeks 2–5), incorporated body bars, medicine balls, and stability balls (weeks 6–7), introduced kettlebell and suspension training (weeks 8–9), and ended with primarily kettlebell and suspension training routines (weeks 10–16). Exercises were performed as supersets (antagonistic muscle groups), compound sets (same muscle group[s]), or staggered sets (noncompeting muscle groups; e.g., upper and lower body). When only 3 exercises were grouped together, participants completed them either as a circuit or as one standalone with rest and one subset pair. This strategy helped to accomplish the workout within the time constraints and maintain elevated HR and perceived effort. Training predominantly followed a 2-week block design (i.e., participants repeated a progressive version of each A/B pairing 2–4 times over each block; Figure 1). Training load was self-selected from designated options during each workout (e.g., a range of repetitions to complete for each set). Trainers encouraged participants to choose a resistance that made completion of the last 2–

Table 1. Participant demographics.*†

Measure	No-exercise control group, $N = 129$ (63 f)	Fitness intervention group, $N = 129$ (63 f)
Age (y)	24.26 ± 5.59	24.65 ± 5.55
Height (cm)	173.12 ± 0.83	173.28 ± 0.88
Weight (kg)	73.27 ± 1.58	74.50 ± 1.47
BMI ($kg \cdot m^{-2}$)	24.35 ± 0.47	24.76 ± 0.43
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	39.86 ± 8.59	39.83 ± 9.13

*BMI = body mass index.
†Preintervention values.

3 repetitions of a set challenging to perform without compromising form and suggested increases when appropriate. Participants had differing levels of baseline fitness and experience and progressed at different rates; therefore, overload was achieved through gradual increases in intensity dictated by the repetitions and resistance, as well as by varying the exercises performed (32). Rest intervals were often short, <30 seconds between exercises, resulting in negative rest (i.e., longer work to shorter rest periods). More substantial breaks were provided when participants were learning new exercises or required/requested longer recovery time. The end of the intervention (weeks 13–15) involved relatively more challenging sets with longer rest periods. Longer (i.e., 30-second to 3-minute) breaks were provided between phases or workout segments (e.g., between Power and HICRT Part B).

Phase 4: Drills and Skills. Phase 4 involved approximately 5–15 minutes of whole-body training in a scenario-based setting, providing the opportunity for individuals to experience their conditioning in action (i.e., training for functional performance). Activities included "as many rounds as possible" drills, speed and agility drills (e.g., with ladders, cones, hurdles, and parachutes), games, and obstacle courses. This interactive portion of the program also aimed to build enthusiasm, motivation, and camaraderie.

Phase 5: Flexibility/Cool-Down. The final phase was approximately 5–10 minutes and included yoga-inspired flexibility training. Individuals practiced a daily yoga pose followed by a Sun Salutation and a series of 20-second static stretches for quadriceps, hip flexors, inner thighs, hamstrings, glutes, hips, shoulders, triceps, chest, biceps, and upper back.

Measures

Continuous Heart Rate and Metabolic Equivalents. Polar E600 HR monitors and H7 transmitters (Polar Electro, Kempele, Finland) were used to record continuous HR during each session. Heart rates were visible to participants throughout all sessions on their own watch faces, but this was not used for any real-time intensity manipulations by the fitness trainers. Data were used to quantify exercise intensity (average HR, %HRmax) and to calculate metabolic equivalents (METs). Estimated energy cost of each session is presented through METs. Each participant's HR data were averaged per session and converted to %HRmax using HRmax achieved during pre $\dot{V}O_2max$ testing. Using the formula: $\%HRmax = 0.64 \times \%\dot{V}O_2max + 37$ (70), HR data were converted to $\%\dot{V}O_2max$. These $\%\dot{V}O_2max$ values were converted to $\dot{V}O_2max$ values and divided by 3.5 to convert to METs. Metabolic equivalents are provided in absolute values and as percentages of maximal METs, for relative comparisons with other research (36).

Table 2. Heart rate training zones across 26 sessions ($n = 124$).*†

HR zone	Max HR%	Average time spent training (min per session)	Percentage of time spent training (% per session)
Very light	<50	0.44 ± 0.50	0.68 ± 0.75
Light	50 ≤ 64	5.08 ± 4.32	7.81 ± 6.49
Moderate	64 ≤ 77	17.03 ± 6.65	25.95 ± 9.92
Vigorous (hard)	77 ≤ 94	34.41 ± 7.15	51.97 ± 10.65
Vigorous (extremely hard)	94 ≤ 100	6.43 ± 4.49	9.93 ± 6.78
Maximal	100	2.32 ± 4.93	3.65 ± 7.64

*HR = heart rate.
†Zones from the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (1).

Aerobic Fitness ($\dot{V}O_2max$). Cardiorespiratory fitness was assessed at both baseline and postintervention, using a test of maximal oxygen consumption ($\dot{V}O_2max$). A modified Balke protocol (83) was used using a motor-driven treadmill at a constant speed with 2.0% increases in grade every 2 minutes until volitional exhaustion. Performance on the test was assessed relative to age and sex based on guidelines provided by the ACSM (1). $\dot{V}O_2max$ was measured using a computerized indirect calorimetry system (True Max 2400; Parvo Medics, Sandy, UT, USA) with averages for oxygen uptake ($\dot{V}O_2$) and respiratory exchange ratio (RER) assessed every 20 seconds. A Polar HR monitor (Model A1; Polar Electro) measured HR throughout the test, and ratings of perceived exertion (RPE; (17)) were assessed every 2 minutes. Relative peak oxygen consumption is expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ and is evidenced by the subject achieving 2 of the following 4 criteria: (a) a plateau in oxygen consumption corresponding to an increase of less than 2 $ml \cdot kg^{-1} \cdot min^{-1}$ despite an increase in workload, (b) a peak HR of at least 85% of age-predicted maximum (i.e., 220–age), (c) RER greater than 1.10; or (d) perceived exertion greater than 17. Height and weight were measured at the beginning of this session using a stadiometer (model 240; Seca, Hamburg, Germany) and a digital scale (WB-300 Plus; Tanita, Tokyo, Japan). The ratio of weight to height ($kg \cdot m^{-2}$) was calculated to determine body mass index.

Army Physical Readiness Test. Field assessments of physical fitness were completed during the first and last sessions of the fitness intervention using the U.S. APRT (76,77), which incorporates 5 events to assess strength, endurance, and mobility. Only participants in the fitness intervention group completed the APRT. The APRT was conducted in the following order: 60-yard shuttle run, standing long jump, 1-minute rowers, 1-minute push-ups, and timed 1.5-mile run. The 60-yard shuttle run involved a timed run to cones placed 5, 10, and 15 yards away (pivoting and returning to start between each cone). For the push-ups test (78), modified push-ups were permitted whether the individual did not think they could complete standard push-ups at pretest and tested with the same modification at posttest. Rowers tested lower body and core endurance (87) and have low, positive correlations with push-ups ($r = 0.337$, $p < 0.001$) and sit-ups ($r = 0.266$, $p < 0.001$) for combined male and female data (80). The standing long jump was completed from a simultaneous bilateral takeoff. Measurements were taken from the back edge of the foot nearest to the starting line, and the better of 2 attempts was recorded. The long jump has a reliability coefficient of 0.90 in adults (79), and it has good validity as a measure of Wingate peak power ($r = 0.334$, $p < 0.05$) and mean power ($r = 0.499$, $p < 0.01$) (5). The 1.5-mile run was completed outdoors and has measures of physiological validity ranging from −0.68 to −0.92 (79) and average validity of −0.82 (80).

Physical Activity Behavior. Responses to the second item of the Godin Leisure Time Exercise Questionnaire (GLTEQ;

Table 3. Changes in weight, BMI, $\dot{V}O_2max$, and physical activity behaviors postintervention.*†

	No-exercise control group					Fitness intervention group				
Measure	*N*	Pre M (*SE*)	Post M (*SE*)	Sig.	ICCR (95% CI)	*N*	Pre M (*SE*)	Post M (*SE*)	Sig.	ICCR (95% CI)
Weight (kg)	129	73.27 (1.58)	73.48 (1.57)	0.307	0.991 (0.988, 0.994)	129	74.50 (1.47)	74.76 (1.43)	0.323	0.983 (0.976, 0.988)
BMI ($kg \cdot m^{-2}$)	129	24.35 (0.47)	24.48 (0.47)	0.085	0.984 (0.977, 0.989)	129	24.76 (0.43)	24.83 (0.41)	0.510	0.969 (0.956, 0.978)
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	129	39.86 (0.76)	39.53 (0.77)	0.202	0.944 (0.921, 0.960)	129	39.83 (0.80)	42.55 (0.82)	<0.0001	0.926 (0.897, 0.947)
Activity Level	124	3.04 (0.12)	2.96 (0.13)	0.470	0.594 (0.467, 0.697)	121	3.09 (0.12)	3.51 (0.10)	<0.001	0.508 (0.363, 0.629)
LTE	126	1.10 (0.07)	1.10 (0.06)	1	0.514 (0.373, 0.632)	121	2.15 (0.06)	2.26 (0.06)	0.069	0.515 (0.372, 0.635)

*BMI = body mass index; LTE = leisure-time exercise; ICCR = intraclass correlation coefficient for reliability.
†Adjustments for multiple comparisons: Bonferroni.

(39,40)) are reported herein. This item asked participants to respond on a 3-point Likert scale to the following prompt: "During a typical 7-day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?" Responses were scored as: 1 = Never/Rarely, 2 = Sometimes, 3 = Often. The GLTEQ was administered to participants and controls, before and after the intervention. Self-reported physical activity was measured through response to a single item which asks individuals to choose the activity range which best describes their usual pattern of daily physical activity: 1-Inactive; 2-Low levels of exertion ≥5 days per week for ≥10 minutes at a time; 3-Moderate levels of exertion 20–60 minutes per week; 4-Moderate levels of exertion 1–3 hours per week; 5-Moderate levels of exertion >3 hours per week (modified from Ref. (47)).

Statistical Analyses

Data analysis was conducted using SPSS 22.0.0 for Windows. Data were initially inspected for any outlying data points, but no outliers were identified or removed. Independent sample *t* tests were used to compare baseline condition characteristics. Paired sample *t* tests were used to compare within-group changes in APRT outcomes. Multivariate analyses of variance (ANOVA) with repeated measures were used to assess between-group effects of the intervention on aerobic fitness and physical activity behavior. Bonferroni correction was applied and statistical significance was set at $p \leq 0.05$. Test-retest reliability for each outcome variable was calculated using a 2-way mixed effects model for the intraclass correlation coefficient (3,1); Tables 3 and 4 for coefficients and 95% confidence intervals.

Results

Participants

Participant demographics can be found in Table 1. There were no significant differences between fitness and control groups at baseline (Table 1). Of the 207 individuals who began the fitness intervention, 37.98% dropped out or were disqualified. For comparison, 39.81% of the 314 in the no-exercise arms of the intervention dropped out or were disqualified (Figure 2). Average attendance for the 129 completers of the fitness intervention was 96.76% over 28 sessions. The 53 individuals who dropped out of the fitness intervention completed 36.32%, or 10.17 ± 7.49 of 28 sessions, before dropping.

Study Fidelity

Average time recorded from each 70-minute session was 65.71 ± 2.61 minutes. Across the 26 training sessions, average HR was 153.53 ± 11.01 b·min^{-1} (i.e., 81.19% of maximal HR), ranging from 122.11 to 177.82 b·min^{-1}. The majority of each session (i.e., 65.55%) was spent between vigorous and maximal training zones; meeting the proposed requirements of a high-intensity exercise stimulus (Table 2). The energy cost of the exercise stimulus was also quantified in terms of METs. Average energy cost per session was 7.76 ± 1.65 METs, ranging from 3.63 to 11.92 METs.

Fitness and Behavior Outcomes

Aerobic Fitness ($\dot{V}O_2max$). One major aim of the fitness intervention was to show that a multimodal HICRT intervention could elicit significant improvements in aerobic fitness. Changes for all $\dot{V}O_2$max assessments are reported in Table 3. Changes in aerobic fitness (i.e., $\dot{V}O_2$max) were assessed using a between-subjects factor of Condition (2: Fitness, Control) and within-subjects factor of Time (2: pre, post) repeated-measures ANOVA. The Condition effect ($p = 0.174$, $\eta^2_{part} = 0.007$) was not significant, but the Time effect ($p < 0.001$, $\eta^2_{part} = 0.120$) and Condition × Time interaction [$F_{(1, 256)} = 56.59$, $p < 0.001$, $\eta^2_{part} = 0.181$] were significant. At baseline (i.e., pre), there were no differences in $\dot{V}O_2$max between fitness and control groups (0.03 ± 1.10 ml·kg^{-1}·min^{-1}; M_{diff} ± *SE*; 95% confidence interval [CI]: −2.15, 2.20, $p = 0.980$); however, postintervention $\dot{V}O_2$max was significantly higher for participants in the fitness

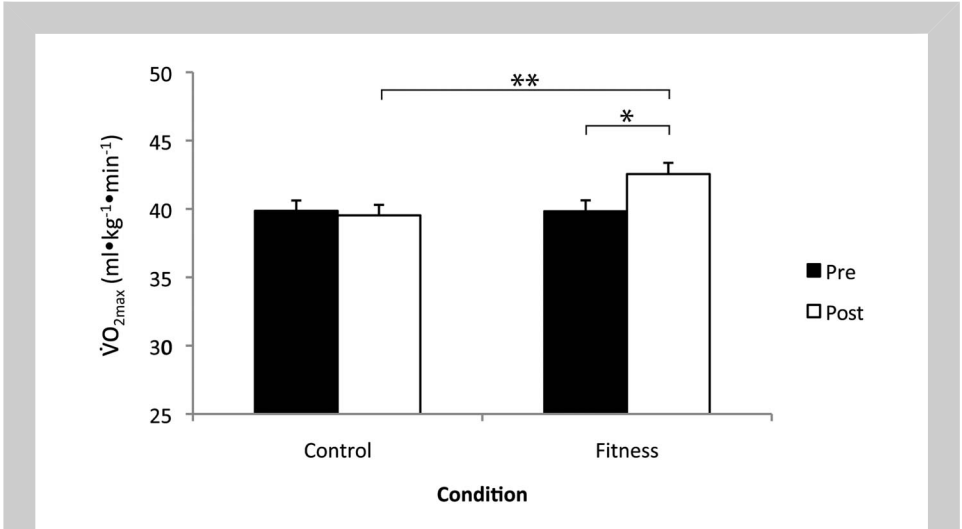

Figure 3. Changes in aerobic fitness over time and pre–post differences between groups. At baseline (i.e., pre), there were no differences in $\dot{V}O_2$max between fitness and control groups (0.03 ± 1.10 ml·kg^{-1}·min^{-1}; M_{diff} ± *SE*; 95% confidence interval: −2.15, 2.20, $p = 0.980$). In addition, control group participants showed no change in $\dot{V}O_2$max from preintervention to postintervention ($p = 0.252$). *$p < 0.001$; **$p < 0.008$.

Table 4. Changes in APRT postintervention (fitness group only).*†

Measure	*N*	Pre (M ± *SE*)	Post (M ± *SE*)	Sig.	ICCR (95% CI)
Shuttle run (s)	124	16.26 ± 0.18	16.07 ± 0.19	0.173	0.715 (0.617, 0.791)
Long jump (inches)	125	69.75 ± 1.38	70.80 ± 1.49	0.137	0.881 (0.835, 0.915)
1-min towers	125	28.65 ± 0.59	33.97 ± 0.67	<0.0001	0.682 (0.576, 0.766)
1-min push-ups	125	27.58 ± 1.06	35.75 ± 1.14	<0.0001	0.794 (0.719, 0.851)
1.5-mile run (min)	124	15.36 ± 0.35	13.57 ± 0.27	<0.0001	0.850 (0.793, 0.892)

*APRT = Army Physical Readiness Test; ICCR = intraclass correlation coefficient for reliability.
†Adjustments for multiple comparisons: Bonferroni.

intervention (3.02 ± 1.13 $ml \cdot kg^{-1} \cdot min^{-1}$, $M_{diff} \pm SE$; 95% CI: 0.80, 5.24, $p = 0.008$) relative to those in the no-exercise control group. In addition, control group participants showed no change in $\dot{V}O_2$max from preintervention to postintervention ($p = 0.252$), whereas participants in the fitness group demonstrated a significant increase in $\dot{V}O_2$max (2.72 ± 0.29 $ml \cdot kg^{-1} \cdot min^{-1}$, $M_{diff} \pm SE$; 95% CI: 2.15, 3.28, $p < 0.001$) (Figure 3).

Army Physical Readiness Test. Participants showed improvement in 3 of 5 components of the APRT (Table 4). Participants demonstrated improvements in 1-minute rowers (5.32 ± 0.51, $M_{diff} \pm SE$; 95% CI: 6.32, 4.32; $t(124) = 10.54$, $p < 0.001$), 1-minute push-ups (8.17 ± 0.71, $M_{diff} \pm SE$; 95% CI: 9.57, 6.76; $t(124) = 11.52$, $p < 0.001$), and the 1.5-mile run (1.79 ± 0.17 minutes, $M_{diff} \pm SE$; 95% CI: 1.46, 2.13; $t(123) = 10.61$, $p < 0.001$). No significant improvements were observed for the shuttle run ($p = 0.173$) or standing long jump ($p = 0.137$).

Physical Activity Behavior. Changes in AL and the time spent performing leisure exercise were examined with a between-subjects factor of Condition (2: Fitness, Control) and within-subjects factor of Time (2: pre, post) repeated-measures ANOVA. For AL, The Time ($p = 0.028$, $\eta^2_{part} = 0.020$), Condition ($p = 0.038$, $\eta^2_{part} = 0.018$), and Interaction effects ($p = 0.001$, $\eta^2_{part} = 0.042$) were all significant. Specifically, fitness participants showed a significant increase in AL (0.42 ± 0.11, $M_{diff} \pm SE$; 95% CI: 0.21, 0.67, $p < 0.001$), whereas control participants showed no change in AL (0.08 ± 0.11, $M_{diff} \pm SE$; $p = 0.457$) after the 16-week intervention. In addition, at baseline, there was no difference in AL between fitness and control participants (0.05 ± 0.17, $M_{diff} \pm SE$; $p = 0.764$), whereas fitness participants reported a significantly higher level of activity postintervention (0.55 ± 0.16, $M_{diff} \pm SE$; 95% CI: 0.24, 0.87, $p = 0.001$) relative to control. For leisure-time exercise, the Condition effect ($p = 0.007$, $\eta^2_{part} = 0.029$) was significant, but the Time ($p = 0.224$, $\eta^2_{part} = 0.006$) and Interaction effects ($p = 0.224$, $\eta^2_{part} = 0.006$) were not. Participants in the fitness group reported spending significantly more time performing leisure exercise (0.26 ± 0.09, $M_{diff} \pm SE$; 95% CI: 0.10, 0.43, $p = 0.002$) postintervention, relative to controls, although there was no difference between groups at baseline ($p = 0.095$).

Discussion

The HICRT intervention successfully improved fitness, increased self-reported physical ALs, and demonstrated relatively good adherence of individuals ranging from 18 to 45 years. The measured increase in $\dot{V}O_2$max of 6.83% is not entirely surprising. Even moderate intensity training programs have been shown to increase $\dot{V}O_2$max, with higher intensity training leading to greater changes (41,71). Other high-intensity, concurrent training interventions have demonstrated similar changes in estimated $\dot{V}O_2$max of about 6% (8 weeks (44)) and 7% (6 weeks (21)) in healthy adults. For comparison, pure HIIT programs have reported increases in $\dot{V}O_2$peak of 8% with 11-minute cycling sessions (2 per week for 8 weeks; (3)) and 10.7% with four 4-minute running intervals each separated by 3 minutes of active recovery (3 per week for 8 weeks; (42)). It is thought that these improvements are due, in part, to high-intensity training-induced leakage of calcium ions into the sarcoplasmic reticulum, which stimulates the generation of mitochondria in the presence of sufficient reactive oxygen species (63). What is of importance to highlight with the current design is that even though the final 8 weeks had only one fitness contact day each, because of the tapered frequency of the intervention (i.e., 3 days, then 2 days, and then 1 day per week), there was still a significant improvement in $\dot{V}O_2$max. Further, this improvement rivaled changes produced by 2 similar interventions reported in the literature (though those were both accomplished in tactical athlete populations) (30,44).

Crawley et al. (30) trained police cadets 3 days per week for 16 weeks. Their 1-hour sessions involved a dynamic warm-up, static stretching, and varying combinations of steady-state running and sprinting, plyometric training, bodyweight calisthenics, obstacle courses, sport games, and resistance training. Similar to our results, sit-ups, push-ups, and aerobic endurance (half-mile shuttle run) improved; however, vertical jump and upper-body power did not (30). Although Crawley et al. totaled 180 minutes per week

of exercise, the HICRT intervention only required an average of 122 minutes per week. Heinrich et al. (44) studied members of the Army ($N = 34$, 27.3 ± 5.7 years, 82.4% male) over 8 weeks (45-minute sessions, about twice a week). They compared HIFT training to an Army Physical Readiness Training program (78). High-intensity functional training was accomplished as a circuit of 15 exercises, with 60–90 seconds per station (44). Heinrich et al. (2012) reported improvements in relative $\dot{V}O_2max$ of 2.39 ± 5.93 $ml \cdot kg^{-1} \cdot min^{-1}$, push-ups (4.2 ± 5.4), sit-ups (0.7 ± 4.9), and 2-mile run (−1.40 ± 1.17 minutes) for their HIFT group, compared with the improvements in relative $\dot{V}O_2max$ (2.72 ± 3.56 $ml \cdot kg^{-1} \cdot min^{-1}$), push-ups (8.17 ± 7.93), rowers (5.32 ± 5.64), and 1.5-mile run (−1.79 ± 1.88 minutes; an 11.65% improvement) measured in our HICRT intervention. For comparison, a running HIIT regimen (4 × 800 minute sprints, with 1:1 work-to-rest ratio) elicited a 9.2% improvement in 1.5-mile run time (3 per week for 8 weeks; (60)). The greatest strengths of HICRT compared with the HIFT of Heinrich et al. (2012) are the inclusion of yoga, flexibility, and steady-state endurance training and any associated health benefits.

Although the current intervention failed to reveal significant changes in long jump and shuttle run performance, other high-intensity, concurrent training interventions have demonstrated improvements in the broad jump (21,44) and a shuttle run variation (6). The run/walk at the beginning of every session may have interfered with lower-body strength gains (89), partially explaining the lack of improvement in the long jump, but the absence of changes likely reflected the prioritization of training: aerobic fitness first, then muscular endurance, then strength, followed by flexibility, power, and agility.

The average intensity achieved during HICRT was 7.76 ± 1.65 METs, or 8.60 ± 1.82 MET-hours per training session. For perspective, any MET value greater than or equal to 6 METs is considered to reflect vigorous intensity, though it has been recognized that a corrected MET value may need to be used in persons whose resting metabolic rates are lower than 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (4). More than 65% percent of each session was spent at or above each individual's vigorous intensity HR zone, with an average HR of 81.19% HRmax during the sessions. Intensity of other high-intensity concurrent aerobic resistance training interventions has varied from at least 75% heart rate reserve (HRR) (56,62) to 76 ± 7% HRmax (24) to 85 ± 3% HRmax (59) to 8–10 of 10 RPE (57) to subjective "all-out" or "high-intensity" levels (21,43,44). Williams and Kraemer (88) reported a peak HR of 87.5% of HRmax, for young men who completed 12 minutes of Tabata-style kettlebell training. Their exercise stimulus is similar to that of parts A and B of the HICRT intervention, particularly in weeks 8–16. High HRs like these can likely be attributed to both the absolute intensity of the exercises performed and the continuous nature (i.e., quick transitions and short rests) of the training (67,88).

Session duration (70 minutes) for HICRT was longer than many other successful high-intensity training protocols with durations of 20 minutes or shorter (43,57), 30–45 minutes (6,44,59), and close to an hour (21,62). In comparison, pure HIIT programs have ranged from 20 minutes or shorter (3,22,61) to around 30–45 minutes (42,46,66), to close to an hour (60). The 16-week HICRT intervention seems to also be one of the longer training interventions to incorporate high-intensity exercise and concurrent training. Similar multimodal concurrent training interventions have reported 4–12 weeks of training (2,6,9,21,43,44,56,57,59,62) with the exception of one 16-week study (30), whereas pure HIIT studies have reported 3–16 weeks of training (3,22,33,42,46,60,61,66,68,74,90). Most interventions have had a constant exercise frequency of 2–3 days per week, whereas the HICRT program had an unprecedented tapered frequency design compared with other HIFT programs. Session compliance in the current study (96.76%) was about equal to or higher than reported compliance to other high-intensity, multimodal training studies of shorter durations which ranged from 70.8% in patients with cancer (2), to 80% in young adult females (21) and middle-aged overweight men (62), to 100% in college-aged adults (57). Likely contributors to this were effective instructors and a positive social environment, as these have been linked to greater enjoyment and intentions to participate in such activities in the future (34).

Certain limitations of this research are present. The current outcomes analyzed were unable to address whether fitness improved gradually over time, improved initially and was maintained, or had peaked during the intervention and was declining (but had not reverted to pretest levels). This may further explain the lack of significant improvements seen in long jump and shuttle run performance. A review by Wenger and Bell (85) suggested that 2 days per week of high intensity training may be required to continue seeing improvements in untrained individuals' aerobic capacities, with higher-fit individuals (i.e., $\dot{V}O_2max > 50$ $ml \cdot kg^{-1} \cdot min^{-1}$) requiring at least 3 days per week. Thus, future attempts at such a tapered frequency design for a HICRT intervention should assess fitness at midpoint (or more often) to examine the trajectory of change for important outcomes. Also, because this intervention was of relatively short duration (fewer than 6 months), maintenance of such a program is unknown and requires future investigation. It must be noted that monetary compensation may have impacted study adherence of participants in both control and fitness groups. Lastly, sharing quality training time across multiple modes of exercise may result in mode-specific adaptations that are likely lesser in degree to what they would be if only one mode had been incorporated into the program (31). Concurrent training was appropriate for enhancing total-body fitness within the constraints of the current trial, but there is evidence that combining aerobic and resistance exercise compromises skeletal muscle adaptations normally seen

with solely resistance training, ultimately attenuating what would have been feasible strength and hypertrophy gains in a similar time frame (7,14,27), namely, the interference effect of concurrent training (see Ref. (89) for a meta-analytic review). However, murine evidence of this effect has not been well replicated in human exercise research (see Ref. (35) for a review). In defense of the HICRT design, intrasession sequencing placed the longest segment of endurance training before strength training. This has been shown to be superior to the opposite order and similar or better at improving aerobic capacity when compared with split routines (6,26). This has also been the accepted sequencing in terms of skeletal muscle adaptations from resistance training (51). The relative effectiveness of HICRT for improving both aerobic and muscular fitness compared with purely dyadic intrasession sequencing, however, cannot be commented on because cardiorespiratory activity of moderate-to-high intensities was still interspersed among resistance training throughout the session.

These findings demonstrate the efficacy of a novel HICRT intervention across multiple dimensions of fitness for a sample of primarily young, but also middle-aged, adults and replicate success of high-intensity training in a group format, outside of a standard laboratory setting (68). Delivery of a 16-week intervention to over 120 individuals was accomplished in fewer than 8 months (inclusive of preassessment and postassessment). The HICRT affords a strategy for comprehensive fitness enhancement that could help promote robust population adherence to physical activity guidelines and elicit meaningful health benefits, perhaps pushing the boundaries of exercise intensity at which the general public has the faculty to endure.

Practical Applications

Sports teams have successfully combined warm-up, steady-state run, high-intensity training (e.g., ladder runs and burpees), skill practice, scrimmages (often including sporadic, all-out sprints), cool-down, and stretching all within the same session. The current results provide evidence-based support for an effective formula that can be used to improve fitness. This pattern of training has developed exceptional athletes; so, incorporating activities of varied modes and intensities within individual sessions of a fitness training program for the general public affords a prudent plan. The current HICRT intervention provided a similar stimulus, with the addition of resistance training. Practitioners can use this format to train large groups of individuals with varying levels of fitness, simultaneously. This becomes particularly useful for fitness coaches working with corporate wellness programs, masters-level teams, or intramural teams. On the other hand, elite sports team coaches can also benefit from using the HICRT design. Coaches have begun to appreciate the utility of incorporating more diverse programming for their athletes (e.g., yoga and HIIT); however, scheduling the time and financing the resources needed to accomplish all these training sessions in any given training week can be daunting. This HICRT design provides an alternative, condensed format to address multiple aspects of fitness in a single session. Further, the tapering component is suitable for the weeks leading up to the peak of in-season competition by allowing for completion of effective training sessions under time constraints, allowing still for recovery days. The HICRT design can also be easily tailored to address specifically desired outcomes (general health and fitness, strength, aerobic fitness, sport performance, etc.). It could also be suitable for researchers hoping to examine the effects of physical fitness on brain health and cognition, allowing additional opportunity for the investigation of transient effects of exercise participation on such outcomes because of its tapered pattern of exercise frequency. Coaches should keep in mind the presence of fatigue-related interference with physiological training adaptations that are inherent to long-duration HIFT. An incapacity to perform at constant, absolute highest intensity is certainly because of fatigue and is largely contributable to the failure of the anaerobic energy systems to recuperate quickly enough to accommodate demands of maximal power for an extended period of time (i.e., greater than 3 minutes) (8). Placement of pushing movements before pulling movements, for instance, could reduce the impact of general fatigue on maximal strength adaptations (65). In practice, longer recovery between exercises will be more desirable for programs emphasizing power, maximal strength, or hypertrophy.

Acknowledgments

The authors thank all the members of the Neurocognitive Kinesiology (NCK) Laboratory and Beckman Institute of the University of Illinois at Urbana-Champaign who assisted in participant recruitment and data collection. They also thank the University YMCA for the provision of the space used to carry out the intervention. Implementation of the intervention was made possible by fitness trainers and staff: Leya Allind, Jon Bartolotta, Megan Bending, Angela Caselli, Annmarie Chizewski, Stanley Dayan, Brittany DiNello, Rachel Eng, Chris Eurich, Eric Ferrell, Jeremy Ha, Grace Harmon, Dana Jorgenson, Jessica Lanis, Courtney Lepcin, Jon North, David Pluta, Nick Rahimi, Linsey Rock, Kathryn Rougeau, Shengzhang Su, and Alif Tisha. Graded exercise testing was performed by NCK Laboratory Staff: Jad Bahhur, Joe Batherson, Oliver Beirne, Travis Hill, Chris Komisarz, Derrick Mathy, Deborah Romero, Florencia Romero, Daniel Shlyak, Jack Skelton, and Lindsey Tucker. Finally, they thank all the participants who chose to spend their time volunteering for this research.

The authors have no conflicts of interest to report.

The research is based upon work supported by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), through Contract 2014-13121700004 to the University of Illinois at

Urbana-Champaign (PI: Barbey). The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the ODNI, IARPA, or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for governmental purposes not withstanding any copyright annotation thereon.

References

1. *ACSM's Guidelines for Exercise Testing and Prescription* (8th ed.). Baltimore, MD: Lippincott, Williams, & Wilkins, 2010.
2. Adamsen, L, Quist, M, Andersen, C, Møller, T, Herrstedt, J, Kronborg, D, Baadsgaard, MT, Vistisen, K, Midtgaard, J, Christiansen, B, Stage, M, Kronborg, MT, and Rørth, M. Effect of a multimodal high intensity exercise intervention in cancer patients undergoing chemotherapy: Randomised controlled trial. *BMJ* 339: B3410, 2009.
3. Adamson, S, Lorimer, R, Cobley, JN, Lloyd, R, and Babraj, J. High intensity training improves health and physical function in middle aged adults. *Biology (Basel)* 3: 333–344, 2014.
4. Ainsworth, BE, Haskell, WL, Herrmann, SD, Meckes, N, Bassett, DR Jr, Tudor- Locke, C, Greer, JL, Vezina, J, Whitt-Glover, MC, and Leon, AS. *The Compendium of Physical Activities Tracking Guide.* Healthy Lifestyles Research Center, College of Nursing & Health Innovation, Arizona State University, 2011. Available at: https://sites.google.com/site/compendiumofphysicalactivities/. Accessed February 20, 2016.
5. Almuzaini, KS and Fleck, SJ. Modification of the standing long jump test enhances ability to predict anaerobic performance. *J Strength Cond Res* 22: 1265–1272, 2008.
6. Arazi, H, Faraji, H, Moghadam, MG, and Samadi, A. Effects of concurrent exercise protocols on strength, aerobic power, flexibility and body composition. *Kinesiology* 43: 155–162, 2011.
7. Babcock, L, Escano, M, D'Lugos, A, Todd, K, Murach, K, and Luden, N. Concurrent aerobic exercise interferes with the satellite cell response to acute resistance exercise. *Am J Physiol Regul Integr Comp Physiol* 302: R1458–R1465, 2012.
8. Baechle, TR and Earle, RW, eds. *Essentials of Strength Training and Conditioning* (2nd ed.). Champaign, IL: Human Kinetics, 2000.
9. Banitalebi, E and Baghanari, HB. Effect of sequence order of combined training (resistance and endurance) on strength, aerobic capacity, and body composition in older women. *Middle East J Rehabil Health* 2: e28514, 2015.
10. Bar-Or, O. The Wingate anaerobic test: An update on methodology, reliability and validity. *Sports Med* 4: 381–394, 1987.
11. Bartlett, JD, Close, GL, MacLaren, DPM, Gregson, W, Drust, B, and Morton, JP. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: Implications for exercise adherence. *J Sport Sci* 29: 547–553, 2011.
12. Behm, DG, Blazevich, AJ, Kay, AD, and McHugh, M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: A systematic review. *Appl Physiol Nutr Metab* 41: 1–11, 2016.
13. Behm, DG and Chaouachi, A. A review of the acute effects of static and dynamic stretching on performance. *Eur J Appl Physiol* 111: 2633–2651, 2011.
14. Bell, GJ, Syrotuik, D, Martin, TP, Burnham, R, and Quinney, HA. Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. *Eur J Appl Physiol* 81: 418–427, 2000.
15. Bergeron, MF, Nindl, BC, Deuster, PA, Baumgartner, N, Kane, SF, Kraemer, WJ, Sexauer, LR, Thompson, WR, and O'Connor, FG. Consortium for Health and Military Performance and American College of Sports Medicine consensus paper on extreme conditioning programs in military personnel. *Curr Sports Med Rep* 10: 383–389, 2011.
16. Biddle, SJH and Batterham, AM. High-intensity interval exercise training for public health: A big HIT or shall we HIT it on the head? *Int J Behav Nutr Phy* 12: 95, 2015.
17. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* 2: 92–98, 1970.
18. Boutcher, SH. High-intensity intermittent exercise and fat loss. *J Obes* 2011: 868305, 2011.
19. Brownson, RC, Baker, EA, Housemann, RA, Brennan, LK, and Bacak, SJ. Environmental and policy determinants of physical activity in the United States. *Am J Public Health* 91: 1995–2003, 2001.
20. Buchheit, M and Laursen, PB. High-intensity interval training, solutions to the programming puzzle–Part I: Cardiopulmonary emphasis. *Sports Med* 43: 313–338, 2013.
21. Buckley, S, Knapp, K, Lackie, A, Lewry, C, Horvey, K, Benko, C, Trinh, J, and Butcher, S. Multimodal high-intensity interval training increases muscle function and metabolic performance in females. *Appl Physiol Nutr Metab* 40: 1157–1162, 2015.
22. Burgomaster, KA, Howarth, KR, Phillips, SM, Rakobowchuk, M, MacDonald, MJ, McGee, SL, and Gibala, MJ. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *J Physiol* 586: 151–160, 2008.
23. Burgomaster, KA, Hughes, SC, Heigenhauser, GJF, Bradwell, SN, and Gibala, MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *J Appl Physiol* 98: 1985–1990, 2005.
24. Butcher, SJ, Judd, TB, Benko, CR, Horvey, KJ, and Pshyk, AD. Relative intensity of two types of CrossFit exercise: Acute circuit and high-intensity interval exercise. *J Fitness Res* 4: 13, 2015. ISSN 2201-5655 © 2015, Australian Institute of Fitness. Available at: http://fitnessresearch.edu.au/journal-view/relative-intensity-of-two-types-of-crossfit-118#ixzz49mqgGvtj. Accessed May 21, 2017.
25. Centers for Disease Control and Prevention (CDC). *Adding Physical Activity to Your Life: Overcoming Barriers to Physical Activity.* Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion, 2011. Available at: http://www.cdc.gov/physicalactivity/basics/adding-pa/barriers.html. Accessed December 12, 2015.
26. Chtara, M, Chamari, K, Chaouachi, M, Chaouachi, A, Koubaa, D, Feki, Y, Millet, GP, and Amri, M. Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *Br J Sport Med* 39: 555–560, 2005.
27. Chtara, M, Chaouachi, A, Levin, GT, Chaouachi, M, Chamari, K, Amri, M, and Laursen, PB. Effect of concurrent endurance and circuit resistance training sequence on muscular strength and power development. *J Strength Cond Res* 22: 1037–1045, 2008.
28. Cochran, AJR, Percival, ME, Tricarico, S, Little, JP, Cermak, N, Gillen, JB, Tarnopolsky, MA, and Gibala, MJ. Intermittent and continuous high-intensity exercise training induce similar acute but different chronic muscle adaptations. *Exp Physiol* 99: 782–791, 2014.
29. Costigan, SA, Eather, N, Plotnikoff, RC, Taaffe, DR, and Lubans, DR. High-intensity interval training for improving health-related fitness in adolescents: A systematic review and meta-analysis. *Br J Sport Med* 49: 1253–1261, 2015.
30. Crawley, AA, Sherman, RA, Crawley, WR, and Cosio-Lima, LM. Physical fitness of police academy cadets: Baseline characteristics and changes during a 16-week academy. *J Strength Cond Res* 30: 1416–1424, 2016.
31. Dolezal, BA and Potteiger, JA. Concurrent resistance and endurance training influence on basal metabolic rate in nondieting individuals. *J Appl Physiol* 85: 695–700, 1998.

32. Fonseca, RM, Roschel, H, Tricoli, V, de Souza, EO, Wilson, JM, Laurentino, GC, Aihara, AY, de Souza Leão, AR, and Ugrinowitsch, C. Changes in exercises are more effective than in loading schemes to improve muscle strength. *J Strength Cond Res* 28: 3085–3092, 2014.

33. Foster, C, Farland, CV, Guidotti, F, Harbin, M, Roberts, B, Schuette, J, Tuuri, A, Doberstein, ST, and Porcari, JP. The effects of high intensity interval training vs steady state training on aerobic and anaerobic capacity. *J Sport Sci Med* 14: 747–755, 2015.

34. Fox, LD, Rejeski, WJ, and Gauvin, L. Effects of leadership style and group dynamics on enjoyment of physical activity. *Am J Health Promot* 14: 277–283, 2000.

35. Fyfe, JJ, Bishop, DJ, and Stepto, NK. Interference between concurrent resistance and endurance exercise: Molecular bases and the role of individual training variables. *Sports Med* 44: 743–762, 2014.

36. Garber, CE, Blissmer, B, Deschenes, MR, Franklin, BA, Lamonte, MJ, Lee, IM, Nieman, DC, and Swain, DP; American College of Sports Medicine Position Stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sports Exerc* 43: 1334–1359, 2011.

37. Gist, NH, Fedewa, MV, Dishman, RK, and Cureton, KJ. Sprint interval training effects on aerobic capacity: A systematic review and meta-analysis. *Sports Med* 44: 269–279, 2014.

38. Godin, G, Desharnais, R, Valois, P, Lepage, L, Jobin, J, and Bradet, R. Differences in perceived barriers to exercise between high and low intenders: Observations among different populations. *Am J Health Promot* 8: 279–285, 1994.

39. Godin, G and Shephard, RJ. A simple method to assess exercise behavior in the community. *Can J Appl Sports Sci* 10: 141–146, 1985.

40. Godin, G and Shephard, RJ. Godin leisure-time exercise questionnaire. *Med Sci Sports Exerc* 29(Suppl 6): S36–S38, 1997.

41. Gormley, SE, Swain, DP, High, R, Spina, RJ, Dowling, EA, Kotipalli, US, and Gandrakota, R. Effect of intensity of aerobic training on VO_{2max}. *Med Sci Sports Exerc* 40: 1336–1343, 2008.

42. Hatle, H, Støbakk, PK, Mølmen, HE, Brønstad, E, Tjønna, AE, Steinshamn, S, Skogvoll, E, Wisløff, U, Ingul, CB, and Rognmo, Ø. Effect of 24 sessions of high-intensity aerobic interval training carried out at either high or moderate frequency, a randomized trial. *PLoS One* 9: e88375, 2014.

43. Heinrich, KM, Patel, PM, O'Neal, JL, and Heinrich, BS. High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: An intervention study. *BMC Public Health* 14: 789, 2014.

44. Heinrich, KM, Spencer, V, Fehl, N, and Poston, WSC. Mission essential fitness: Comparison of functional circuit training to traditional Army Physical Training for active duty military. *Mil Med* 177: 1125–1130, 2012.

45. Helgerud, J, Høydal, K, Wang, E, Karlsen, T, Berg, P, Bjerkaas, M, Simonsen, T, Helgesen, C, Hjorth, N, Bach, R, and Hoff, J. Aerobic high-intensity intervals improve VO2max more than moderate training. *Med Sci Sports Exerc* 39: 665–671, 2007.

46. Hottenrott, K, Ludyga, S, and Schulze, S. Effects of high intensity training and continuous endurance training on aerobic capacity and body composition in recreationally active runners. *J Sport Sci Med* 11: 483–488, 2012.

47. Jurca, R, Jackson, AS, LaMonte, MJ, Morrow, JR Jr, Blair, SN, Wareham, NJ, Haskell, WL, van Mechelen, W, Church, TS, Jakicic, JM, and Laukkenan, R. Assessing cardiorespiratory fitness without performing exercise testing. *Am J Prev Med* 29: 185–193, 2005.

48. Kilpatrick, MW, Bortzfield, AL, and Giblin, LM. Impact of aerobic exercise trials with varied intensity patterns on perceptions of effort: An evaluation of predicted, in-task, and session exertion. *J Sport Sci* 30: 825–832, 2012.

49. Kilpatrick, MW, Jung, ME, and Little, JP. High-intensity interval training: A review of physiological and psychological responses. *ACSMs Health Fit J* 18: 11–16, 2014.

50. Klika, B and Jordan, C. High-intensity circuit training using body weight: Maximum results with minimal investment. *ACSMs Health Fit J* 17: 8–13, 2013.

51. Kraemer, WJ and Szivak, TK. Strength training for the warfighter. *J Strength Cond Res* 26: S107–S118, 2012.

52. Kravitz, L. *ACSM Information On…High-intensity Interval Training.* American College of Sports Medicine, a product of ACSM's Consumer Information Committee, 2014. Available at: https://www.acsm.org/docs/brochures/high-intensity-interval-training.pdf. Accessed June 12, 2016.

53. Kravtiz, L. *ACSM Information on…Extreme Conditioning Programs.* American College of Sports Medicine, a product of ACSM's Consumer Information Committee, 2015. Available at: https://www.acsm.org/docs/default-source/brochures/extreme-conditioning-programs.pdf?sfvrsn=4. Accessed February 19, 2016.

54. LaForgia, J, Withers, RT, and Gore, CJ. Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *J Sport Sci* 24: 1247–1264, 2006.

55. Little, JP, Safdar, A, Wilkin, GP, Tarnopolsky, MA, and Gibala, MJ. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: Potential mechanisms. *J Physiol* 588: 1011–1022, 2010.

56. Ludin, AFM, Saat, NZM, Umar, NA, and Haari, NM. High intensity circuit training on body composition, cardiovascular risk factors and physical fitness status among overweight and obese female students. *J Phys Activity, Sports Exerc* 3: 40–48, 2015.

57. Meier, J, Quednow, J, and Sedlak, T. The effects of high intensity interval-based kettlebells and battle rope training on grip strength and body composition in college-aged adults. *Int J Exerc Sci* 8: 124–133, 2015.

58. Milanović, Z, Sporiš, G, and Weston, M. Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO_{2max} improvements: A systematic review and meta-analysis of controlled trials. *Sports Med* 45: 1469–1481, 2015.

59. Miller, MB, Pearcey, GEP, Cahill, F, McCarthy, H, Stratton, SBD, Noftall, JC, Buckle, S, Basset, FA, Sun, G, and Button, DC. The effect of a short-term high-intensity circuit training program on work capacity, body composition, and blood profiles in sedentary obese men: A pilot study. *Biomed Res Int* 2014: 191797, 2014.

60. Musa, DI, Ademoram, SA, Dikko, AU, and Sayers, SP. The effect of a high-intensity interval training program on high-density lipoprotein cholesterol in young men. *J Strength Cond Res* 23: 587–592, 2009.

61. Nybo, L, Sundstrup, E, Jakobsen, MD, Mohr, M, Hornstrup, T, Simonsen, L, Bülow, J, Randers, MB, Nielsen, JJ, Aagaard, P, and Krustrup, P. High-intensity training versus traditional exercise interventions for promoting health. *Med Sci Sports Exerc* 42: 1951–1958, 2010.

62. Paoli, A, Pacelli, QF, Moro, T, Marcolin, G, Neri, M, Battaglia, G, Sergi, G, Bolzetta, F, and Bianco, A. Effects of high-intensity circuit training, low-intensity circuit training and endurance training on blood pressure and lipoproteins in middle-aged overweight men. *Lipids Health Dis* 12: 131, 2013.

63. Place, N, Ivarsson, N, Venckunas, T, Neyroud, D, Brazaitis, M, Cheng, AJ, Ochala, J, Kamandulis, S, Girar, S, Volungevičius, G, Paužas, H, Mekideche, A, Kayser, B, Martinez-Redondo, V, Ruas, JL, Bruton, J, Truffert, A, Lanner, JT, Skurvydas, A, and Westerblad, H. Ryanodine receptor fragmentation and sarcoplasmic reticulum Ca2+ leak after one session of high-intensity interval exercise. *PNAS* 112: 15492–15497, 2015.

64. Reiner, M, Niermann, C, Jekauc, D, and Woll, A. Long-term health benefits of physical activity-A systematic review of longitudinal studies. *BMC Public Health* 13: 813, 2013.

65. Robbins, DW, Young, WB, and Behm, DG. The effect of an upper-body agonist- antagonist resistance training protocol on volume load and efficiency. *J Strength Cond Res* 24: 2632–2640, 2010.

66. Rognmo, Ø, Hetland, E, Helgerud, J, Hoff, J, and Slørdahl, SA. High intensity aerobic interval exercise is superior to moderate intensity exercise for increasing aerobic capacity in patients with coronary artery disease. *Eur J Prev Cardiol* 11: 216–222, 2004.

67. Seiler, S and Hetlelid, KJ. The impact of rest duration on work intensity and RPE during interval training. *Med Sci Sports Exerc* 37: 1601–1607, 2005.

68. Shepherd, SO, Wilson, OJ, Taylor, AS, Thøgersen-Ntoumani, C, Adlan, AM, Wagenmakers, AJM, and Shaw, CS. Low-volume high-intensity interval training in a gym setting improves cardio-metabolic and psychological health. *PLoS One* 10: e0139056, 2015.

69. Showman, N, and Henson, P. U.S. Army physical readiness training protocols. *Mil Rev* 94: 12–23, 2014.

70. Swain, DP, Abernathy, KS, Smith, CS, Lee, SJ, and Bunn, SA. Target heart rates for the development of cardiorespiratory fitness. *Med Sci Sports Exerc* 26: 112–116, 1994.

71. Tabata, I, Nishimura, K, Kouzaki, M, Hirai, Y, Ogita, F, Miyachi, M, and Yamamoto, K. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. *Med Sci Sports Exerc* 28: 1327–1330, 1996.

72. Thomas, S, Reading, J, and Shephard, RJ. Revision of the physical activity readiness questionnaire. *Can J Sport Sci* 17: 338–345, 1992.

73. Thompson, WR. Worldwide survey reveals fitness trends for 2016: 10th anniversary edition. *ACSM's Health Fitness J* 19: 9–18, 2015.

74. Tjønna, AE, Lee, SJ, Rognmo, Ø, Stølen, TO, Bye, A, Haram, PM, Loennechen, JP, Al-Share, QY, Skogvoll, E, Slørdahl, SA, Kemi, OJ, Najjar, SM, and Wisløff, U. Aerobic interval training versus continuous moderate exercise as a treatment for metabolic syndrome: A pilot study. *Circulation* 118: 346–354, 2008.

75. Trapp, EG, Chisholm, DJ, Freund, J, and Boutcher, SH. The effects of high-intensity intermittent exercise training on fat loss and fasting insulin levels of young women. *Int J Obes* 32: 684–691, 2008.

76. U.S. Army. *New Army PT Tests: Army Physical Readiness Test, Army Combat Readiness Test.* TRADOC for STAND-to!, 2011. Available at: http://www.army.mil/article/55446/new-army-pt-tests-army-physical-readiness-test-army-combat-readiness-test/. Accessed February 21, 2016.

77. U.S. Army. *TRADOC Revises Army Physical Fitness Test.* Ms. Kelly Schloesser (TRADOC), 2011. Available at: http://www.army.mil/article/52548. Accessed February 21, 2016.

78. U.S. Army. *U.S. Army Training and Doctrine Command: Army Physical Readiness Training Circular (TC 3-22.20).* Washington, DC: Headquarters, Department of the Army, 2010.

79. U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). *Technical Report No 12-HF-01Q9D-04, The Case for Pre-enlistment Physical Fitness Testing: Research and Recommendations (Prepared by Knapik, J. J. et al.).* Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine, 2004.

80. U.S. Army Public Health Command (USAPHC). Public Health Report: Correlations between physical fitness tests and performance of military tasks: A systematic review and meta-analyses, 2014. Approved for public release, distribution unlimited, PHR No. 12-02-0614, General Medicine: 500A (prepared by Hauschild, V, DeGroot, D, Hall, S, Deaver, K, Hauret, K, Grier, T, and Jones, B). Available at: http://www.dtic.mil/docs/citations/ADA607688. Accessed June 13, 2016.

81. U.S. Department of health and human Services (US DHHS). Office of Disease Prevention and Health Promotion. *Healthy People 2020.* Washington, DC, 2011. Available at: https://www.healthypeople.gov/2020/topics-objectives/topic/physical-activity. Accessed May 21, 2017.

82. U.S. Department of Health and Human Services (US DHHS). *Physical Activity Guidelines for Americans.* Washington, DC, 2008. Available at: https://health.gov/paguidelines/guidelines/adults.aspx. Accessed May 21, 2017.

83. Voss, MW, Chaddock, L, Kim, JS, Vanpatter, M, Pontifex, MB, Raine, LB, Cohen, NJ, Hillman, CH, and Kramer, AF. Aerobic fitness is associated with greater efficiency of the network underlying cognitive control in preadolescent children. *Neuroscience* 199: 166–176, 2011.

84. Warburton, DER, Nicol, CW, and Bredin, SSD. Health benefits of physical activity: The evidence. *Can Med Assoc J* 174: 801–809, 2006.

85. Wenger, HA and Bell, GJ. The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. *Sports Med* 3: 346–356, 1986.

86. Weston, KS, Wisløff, U, and Coombes, JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. *Br J Sports Med* 48: 1227–1234, 2014.

87. Whittemore, R. Train like an athlete: Keys to a successful training program for the new Army Physical Fitness Test. *NSCAs TSAC Rep* 18: 18.1–18.13, 2011.

88. Williams, BM and Kraemer, RR. Comparison of cardiorespiratory and metabolic responses in kettlebell high-intensity interval training versus sprint interval cycling. *J Strength Cond Res* 29: 3317–3325, 2015.

89. Wilson, JM, Marin, PJ, Rhea, MR, Wilson, SMC, Loenneke, JP, and Anderson, JC. Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. *J Strength Cond Res* 26: 2293–2307, 2012.

90. Wisløff, U, Støylen, A, Loennechen, JP, Bruvold, M, Rognmo, Ø, Haram, PM, Tjønna, AE, Helgerud, J, Slørdahl, SA, Lee, SJ, Videm, V, Bye, A, Smith, GL, Najjar, SM, Ellingsen, Ø, and Skjaerpe, T. Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients: A randomized study. *Circulation* 115: 3086–3094, 2007.