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Effects of Short-Term CrossFit™ Training: A Magnitude-Based Approach

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ABSTRACT

Drake N, Smeed J, Carper MJ, Crawford DA. Effects of Short-Term CrossFit™ Training: A Magnitude-Based Approach. **JEPonline** 2017;20(2):111-133. The purpose of this study was to examine the magnitude and direction of the effects of short-term CrossFit (CF) participation on measures of health and fitness. Six male participants completed 4 wks of CF training with outcomes assessed pre- and post-intervention. Statistical methods consisted of both traditional significance testing and evaluation of magnitude-based inferences. Beneficial effects are noted for the majority of the health and fitness parameters assessed. However, with negative perturbations in inflammatory status and mood states performance, these subjects may have reached a state of functional overreaching. With training intensity not monitored, continuous participation in CF may result in an overtrained individual. Moving forward, research on CF must investigate the utility of improved CF performance outside the gym and integrating appropriate monitoring strategies to improve participant recovery and adaptation while maintaining the integrity of the original programming philosophies.

Key Words: CrossFit™, Exercise, High-Intensity, Magnitude-Based

INTRODUCTION

Physical inactivity remains one of modern society's greatest health threats that accounts for nearly 5.3 million deaths in the United States annually (36). Currently, approximately 5% of adults meet federal guidelines for physical activity (54). Lack of time is often cited as a reason for non-compliance in achieving the combined aerobic and muscle strengthening activities (i.e., resistance training) currently recommended (23). CrossFit™ (CF) is a popular, group-based high-intensity training program consisting of combined aerobic and resistance-training components designed to increase general fitness in a time efficient manner (11). The CF training framework typically follows a 4-day training cycle (3 days training and 1 rest day), however a framework for the conventional workweek is also provided (5 training days and 2 rest days). Within these frameworks there are three distinct elements that form the basis for each training session: (a) monostructural aerobic exercise (M); (b) weightlifting (W); and (c) body weight gymnastic exercises (G). These elements are combined in a constantly varied fashion every session to form three unique training session designs: (a) element priority (EP); (b) task priority (TP); and (c) time priority (TmP). These session designs are rotated through each training cycle to create a training stimulus that does not focus solely on any one component of fitness, but rather seeks to develop competence in all aspect of fitness "across broad time and modal domains" (11).

Thus far, the literature base on CF demonstrates its efficacy for improving body composition (15,42,48,51,52), aerobic and anaerobic capacity (42,51,57), muscular strength (40,56), flexibility (15,57), and extremity power (6,40). Despite these encouraging findings, there is little, if any, evidence to show the potential magnitude of these effects. In order for CF to be considered a viable alternative to traditional exercise prescriptions, both the magnitude and direction of its effects must be determined. Further, there are concerns within both the popular media (43) and academic communities (13) about the safety of CF practices. While recent investigations suggest the injury rate in CF participation is no different than activities such as Olympic weightlifting and gymnastics (22,41), the tenacity of CF opponents has not diminished. However, with recent case studies published involving significant physical trauma (17,31,37) related to CF participation and conditions such as rhabdomyolysis (35) possible with high-intensity exercise, the relative safety of this practice should be investigated. With these limitations in mind, the purpose of the present study was to examine both the magnitude and direction of the potential health and fitness benefits associated with CF training. Concurrently, the effects of CF participation on biomarkers of skeletal muscle damage, systemic inflammation, and psychological changes associated with maladaptation to training (50) were examined. We anticipate short-term CF training to show small to moderate beneficial effects on components of health and fitness without significantly affecting skeletal muscle damage, systemic inflammation, or psychological status.

METHODS

Subjects

The subjects were recruited by email solicitation, direct contact, and flyers placed in the university recreation center. Interested individuals were screened prior to an invitation to a study information session held by the research team. Participants were considered eligible if were: (a) between the ages of 18 and 35; (b) English speaking; and (c) were recreationally active at least 2 $d \cdot wk^{-1}$ for ~1 $hr \cdot d^{-1}$. Participants were considered ineligible if they: (a) had any significant physical conditions that would keep them from participating in vigorous physical activity; (b) had participated in CF training within the previous 12 months; (c) were classified as stage I, II, or III obese; (d) had been diagnosed with type 2 diabetes; (e) had diagnosed osteoporosis; (f) reported the use of medications that may have an influence on cardiovascular function; and (g) reported use of nutritional supplements. Eight eligible participants were present at the study information session where they were informed of study protocols and provided written consent in accordance with guidelines established by the University Institutional Review Board. Of the 8 participants who were originally recruited, one did not meet the eligibility requirements after failing to disclose a history of seizures during intense exercise, and one withdrew prior to the baseline assessment for an undocumented reason. All remaining eligible participants completed all study protocols and the sample characteristics for these 6 subjects are presented in Table 1.

Table 1. Baseline Performance-Based Classifications of Study Participants (N = 6)

	Mean ± SD	Relative Strength	Classification	Percentile Rank
Age (yrs)	25.0 ± 5.4	-	-	-
Height (cm)	182.8 ± 8.6	-	-	-
Weight (kg)	84.3 ± 12.4	-	-	-
Body Fat (%)	22.4 ± 4.7	-	Elevated Risk	-
SBP (mm/Hg)	130.5 ± 10.3	-	Pre-hypertensive	-
DBP (mm/Hg)	78.6 ± 8.0	-	Normal	-
Upper Body Strength (kg)	100.7 ± 4.8	1.19	-	65th
Lower Body Strength (kg)	121.9 ± 4.7	1.44	Poor	-
Anaerobic Capacity (sec)	47.8 ± 4.3	-	Above Average	85th
Aerobic Capacity ($mL \cdot kg^{-1} \cdot min^{-1}$)	52.9 ± 4.2	-	Excellent	>90th

Procedures

Research Design

This study consisted of a prospective within-subjects pre-post intervention research design of university-based sample of 6 recreationally active men 18 to 32 yrs of age. Participation in the study consisted of 24 sessions of data collection and exercise training. The baseline assessment was conducted the first week of the study during two visits to the laboratory. The subjects were instructed to arrive for the first visit after an overnight fast. Their second visit was 48 hrs later. Then, the subjects completed 4 wks of CF training. Post-intervention assessment began immediately following the completion of the exercise intervention. All subjects were instructed to arrive at the laboratory for the first visit, again in an overnight fasted state, and report for the second visit 48 hrs later. Total required time for participation in the study was 6 wks.

Baseline Assessments

Anthropometrics and Body Composition

During the first visit, the subjects' anthropometrics (height and weight) were collected by a trained researcher using a stadiometer and digital scale (Tanita TBF-410, Tokyo, Japan). All measurements were recorded to the nearest 0.1 kg and 0.1 cm. Body composition was measured via dual energy x-ray absorptiometry (DXA; Discovery A QDR, Hologic Inc., Marlborough, MA). DXA is validated to assess body fat percentage (BF%), fat-free mass (FFM), fat mass (FM), and bone mineral density (BMD) in a variety of populations (29). Variables collected for pre-post intervention assessment were BF%, FFM, FM, and BMD.

Cardiovascular Function

During the first baseline visit, following completion of the health history, physical activity, psychological questionnaires, and informed consent, the subjects were asked to put on a heart rate (HR) monitor (Polar T31-Coded; Kempele, Finland) across the chest and relax in a seated position for 10 min. After this rest period the subjects' resting HR was recorded, after which resting blood pressure (BP) was recorded using a manual sphygmomanometer by a trained researcher.

Fitness Assessment

Following the recording of anthropometrics, body composition, and cardiovascular function, the subjects were asked to complete a maximal graded exercise test to assess aerobic capacity. The subjects completed the Bruce treadmill protocol (7) while real-time oxygen consumption was collected via direct assessment with a commercially available metabolic cart (Mini-CPX, VacuMed Inc., Ventura, CA). Heart rate (HR), BP, and ratings of perceived exertion (RPE) (4) were determined during the last 30 sec of each graded stage. Test completion was determined when the subjects reached voluntary exhaustion. Maximum oxygen consumption (VO_2 max) was determined by the average VO_2 in $mL \cdot kg^{-1} \cdot min^{-1}$ during the last 30 sec of the stage in which voluntary exhaustion was reached.

During the second baseline visit, the subjects were asked to complete both upper and lower body maximal strength assessments. The upper body test selected was the one-repetition bench press (1RM Bench) while the lower body test was the one-repetition squat (1RM Squat). Both strength tests were performed using a standard one-repetition protocol (45). Following these tests, the subjects were given 15 min of rest prior to the next test. After the break, the subjects completed the anaerobic treadmill test (46) to assess anaerobic work capacity.

The last component of fitness tested was the CF-defined parameter of "work capacity". Work capacity (WC), as defined by CF developers, is the ability to perform maximal mechanical work in a given period of time across broad time and modal domains (11). The primary assessment for WC in this study was the CF "workout-of-the day" (WOD) known as "Fight Gone Bad" (FGB). This WOD was used as the primary CF-based performance outcome measure for this study. In the FGB, the subjects were required to complete three rounds of a multi-modal exercise tasks. The circuits began by performing: (a) a full squat with a 20-lb wall-ball (i.e., medicine ball) at the shoulders followed by tossing it to a 10 ft target on a wall; (b) a 75 pound sumo deadlift high-pulls; (c) 20-inch box jumps; (d) a 75-pound push-presses; and (e) rowing on an ergometer for calories (Model D PM3, Concept 2; Morrisville, VT). Each circuit was performed for 5 min (1 min at each station) with a 1-min break between each round. The subjects were attempting to complete the maximum number of repetitions in each station during each round. The number of reps completed for all rounds was used as the outcome score, and the subjects' performance was monitored by a qualified researcher. Following the 4-wk training phase of the study, the subjects were met at the beginning of the following week to complete the CF- based performance WOD and FGB for a second time.

Biochemical Measures
To assess baseline serum biomarkers of skeletal muscle damage (creatine kinase, CK) and systemic inflammation (C-reactive protein, CRP), whole blood samples were taken and collected during the first visit prior to the aerobic capacity assessment. Blood samples were collected in heparinized 6 mL tubes (Becton and Dickinson; Franklin Lakes, NJ) via antecubital venipuncture, allowed to sit at room temperature for 10 min, centrifuged at 2000 rev·min^{-1} for 10 min, aliquoted into 2 mL cryotubes, and stored at -80ºC for later analysis. All serum samples were analyzed by an established outside, independent agency (MagLab Inc.; Pittsburg, KS).

Psychological Status
Effects on psychological status were determined by assessing acute changes in mood states (Profile of Mood States 2nd Edition, POMS^2; MHS Inc.; North Tonowanda, NY) (32) pre-post intervention. The POMS^2 has been rigorously psychometrically tested with good estimated internal consistency (Cronbach's α = 0.78 – 0.96) and moderate test-retest reliability (r = 0.43 – 0.65). In addition, the POMS^2 has demonstrated discriminate validity between those who are non-clinical populations and those with diagnosed anxiety or depression. Further, its convergent validity with another validated tool (PANAS-X) has been documented.

Nutritional Status
To quantify nutritional status, the subjects were given a simple 3-day dietary log (precisionnutrition.com). The subjects were asked to document every food or beverage item they consumed between their first and second pre-testing sessions. This time period ended up being approximately 60 hrs per individual (2.5 days). Fat, protein, and carbohydrate distributions, and total calories consumed over this time period were divided by 2.5 to estimate total daily caloric intake and the macronutrient profile.

CF Intervention
Following baseline testing, the subjects completed 4 wks of CF training (5 d·wk^{-1} following the alternatively recommended scheme (11), ~1 hr each session). During the first week of training, all subjects learned and practiced movements and exercises (e.g., snatch and power clean) common to CF along with a conditioning WOD (10-min maximum) to familiarize them with CF practices. All training sessions were held at a local CF facility. They were taught and supervised by a certified CF Level 1 coach (author JS). During each training session the subjects were instructed to give maximum effort for each WOD attempted. Originally, a secondary study aim was to investigate differences between "traditional" and "real-world" CF programming. Following familiarization, subjects were randomly assigned to either traditional or real-world programming and Table 2 shows the post-familiarization programming for the traditional group. The real-world group completed programming designed by a randomly selected registered CF affiliate (*randomization procedures and training programming*

available upon request). No differences in study outcomes are present between groups and the data were pooled together for the analyses in the present study.

Table 2. Traditional CrossFit Intervention Programming.

WEEK 1
Day 1(M) - 5k row
Day 2 (GW)- 5 RFT- 12 push press/12 pullup
Day 3 (MGW) - AMRAP in 20 min: 50 double-unders, 20 push-ups, 10 hang power cleans
Day 4 (MG) - 3 RFT- 400 m run/25 box jumps
Day 5 (W) - Deadlift 5-5-5-5-5

WEEK 2
Day 1 (G) - 20 min of kipping pullup practice
Day 2- (GM) - 4RFT- 200 m run/ 8 power clean + jerk
Day 3- (GWM) - AMRAP in 20- 6 HSPU, 12 deadlifts, 500m row
Day 4- (GW) - 21-15-9 of Pullups/ Thrusters
Day 5- (M) - 5k Run

WEEK 3
Day 1- (W) - Push press 5-5-5-5-5
Day 2- (MG) - 4 RFT- 400 m run/ 30 air squats
Day 3- (WMG) - AMRAP in 20- 5 thrusters, 10 pullups, 15 double unders
Day 4- (WM) - 10-8-6-4-2 Power-clean/Calorie row
Day 5- (G) - 20 min of handstands, HSPU, handstand walk etc.

Training Session Measures
Prior to each session, HR, BP, and perceived muscular soreness (numeric pain rating scale, NPRS) (16) were collected. Immediately following the completion of the daily WOD, post-training heart rate (THR) using the same monitor as in the baseline testing procedures and RPE were also assessed. The duration (min) for each subject to complete daily WODs was also collected.

Post-Intervention Assessments
During the week immediately following the completion of the training phase of the study, two post-training data collection and testing sessions were required. Each session was separated by 48 hrs of which the exact protocols of the baseline testing sessions were followed. Once the two sessions were completed, the subjects were discharged from the study. Total duration of the study was 6 wk from enrollment to completion.

Statistical Analyses

Traditional descriptive statistics, frequencies, and normality testing was conducted for all variables prior to hypothesis testing. Differences in between training session variables were compared using a one-way MANOVA. Associations between RPE, pain, and training session workload were assessed using Pearson's r correlations. All primary pre-test and post-test outcomes including the demographics, POMS subscales, physiological measures, and performance variables were analyzed using paired samples *t*-tests. Serum CK and CRP were analyzed with a repeated measure MANOVA. Significant multivariate effects were followed by separate univariate ANOVAs. All significant univariate effects were followed with *post hoc* comparisons using adjustments with Tukey's least significant difference. All analyses were performed using SPSS v. 21 (IBM, Armonk, New York). An alpha level was set P≤0.05 for statistical significance.

As traditional null hypothesis testing does not provide enough information to make clinical or practical decisions on an interventions efficacy, for the present study we also applied the use of magnitude-based inferences (MBI) (3). To evaluate the magnitude of effects observed in this study, we followed guidelines proposed by Durlak et al. (14) for reporting procedural processes associated with utilizing MBI. Effect size point estimates (PE) were calculated using a modified version of the Cohen's *d* standardized effect size estimate (34). This modified version of Cohen's *d*, known as Cohen's $d_{rm,}$ uses the mean difference between pre- and post-measures and accounts for the potential correlations in pre-post means possible in a within-subjects research design, resulting in a more conservative estimate of effect size. The formula for Cohen's d_{rm} is as follows:

$$Cohen's\ d_{rm} = \frac{M_{diff}}{\sqrt{SD_1^2 + SD_2^2 - 2 \times r \times SD_1 \times SD_2}} \times \sqrt{2(1-r)}$$

Following the work of Hopkins (26), the goal of magnitude-based inference is to estimate the true population value of the effect and the likelihood that the true value of the effect signifies a meaningful change, whether harmful or beneficial, in the outcome variable of interest. 95% confidence intervals (CI) for all primary outcome effect size PE were calculated and used to generate likelihoods of substantivenss for all effects. The PE and CI were evaluated against the thresholds set forth by Cohen (10) for small (0.2), moderate (0.5), and large (0.8) effects. The sign of the effect size PE (positive or negative) determined if the effect was *beneficial* or *harmful*. The likelihoods that an effect is trivial, beneficial, or harmful were calculated for each possible threshold using a spreadsheet created by Hopkins (27). If the likelihood an effect meets a threshold was >75% the effect was deemed *possibly* to have an effect, >90% the effect was deemed *likely* to have an effect, >95% the effect was deemed *very likely* to have an effect, and if 100% the effect was deemed *most likely* to have an effect (3). An effect was deemed *unclear* if the likelihood for the true population value of the effect was >5% for all three categories of substantivenss (i.e., beneficial, trivial, and harmful) (3).

RESULTS

Magnitude-Based Inferences

Table 3 displays all relevant data to make MBI, including correlation coefficients. These data are necessary to disclose as they allow for exact replication by other investigators. Figure 1 presents the forest plot for all primary outcome effect size PE and their associated 95% CI. Table 4 contains the likelihoods of substantivenss for each magnitude-based threshold.

Body Composition Outcomes

There were no significant differences for any outcomes associated with subjects' body composition pre- to post-intervention. MBI analysis reveals that effects on FFM are *very likely* to *most likely trivial* for all magnitude thresholds (PE = 0.02; 95% CI -0.09, 0.14). Effects on FM (PE = 0.13; 95% CI -0.05, 0.31) and BF% (PE = 0.15; 95% CI -0.02, 0.33) are *possibly* *trivial* with 18.4% and 25.1% likelihood of small benefit, respectively. Effects on BMD (PE = 0.14; 95% CI -0.35, 0.63) are *unclear* as there is a 38.3% likelihood of small benefit and 6.8% likelihood of small harm.

Table 3. Data for Statistical and Magnitude-Based Inferences of Substantivenss.

	Mean ± SD						
	Pre	Post	Mean Diff ± SD	CI (95%)	P value	*Pearson r*	Cohen's d_{rm}
Resting Heart Rate (bpm)	70.1±9.6	68.6±6.6	1.5±7.3	-6.2 to 9.2	.640	.645	0.17
Systolic BP (mm/Hg)	130.5±10.3	132.6±6.8	-2.1±9.4	-12.0 to7.7	.599	.453	0.23
Diastolic BP (mm/Hg)	78.6±8.0	82.6±8.7	-4.0±5.6	-9.8 to 1.8	.142	.777	0.47
Upper Body Strength (kg)	100.7±10.8	99.2±13.9	1.4±5.1	-3.9 to 6.8	.513	.944	0.09
Lower Body Strength (kg)	121.9±11.9	125.3±9.6	-3.4±2.9	-11.1 to 4.2	.301	.793	0.30
Anaerobic Capacity (sec)	47.8±10.9	49.0±14.6	-1.1±7.2	-8.8 to 6.4	.711	.878	0.07
Aerobic Capacity ($mL \cdot kg^{-1} \cdot min^{-1}$)	52.9±9.5	50.4±8.8	2.4±3.6	-1.3 to 6.3	.157	.923	0.26
"CF-based Work Capacity" (reps)	240.3±27.8	266.0±17.4	-25.6±25.3	-52.2 to 0.9	.056	.451	1.06
Body Fat (%)	22.4±4.7	21.6±4.2	0.8±0.9	-0.1 to 1.8	.082	.985	0.15
Lean Mass (kg)	62.3±6.4	62.5±6.4	-0.1±0.7	-0.9 to 0.6	.678	.993	0.02
Fat Mass (kg)	19.3±6.1	18.4±5.5	0.9±1.2	-0.3 to 2.1	.126	.984	0.13
Bone Mineral Density ($g \cdot cm^{-3}$)	1.18±0.07	1.19±0.05	-0.01±0.03	-.05 to .02	.498	.889	0.14
Total Mood Disturbance	40.1±5.1	43.0±6.6	-2.8±4.8	-7.9 to 2.2	.211	.692	0.46
Anger-Hostility	41.3±2.7	42.5±7.4	-1.1±7.0	-8.5 to 6.2	.702	.333	0.19
Confusion-Bewilderment	38.5±3.3	39.0±3.2	-0.5±1.7	-2.3 to 1.3	.518	.860	0.15
Depression-Dejection	41.6±1.0	42.0±1.6	-0.3±0.8	-1.1 to 0.3	.363	.926	0.16
Fatigue-Inertia	38.0±8.8	39.1±7.3	-0.6±6.5	-7.5 to 0.8	.813	.689	0.07
Tension-Anxiety	36.8±2.1	40.8±6.6	-4.0±5.0	-9.3 to 1.3	.111	.814	0.48
Vigor-Activity	47.5±5.0	42.3±6.8	5.1±5.1	-0.2 to 10.6	.059	.661	0.82
Friendliness	49.3±5.7	42.3±10.1	7.0±8.0	-1.4 to 15.4	.086	.606	0.77

Cardiovascular Outcomes

For all cardiovascular outcomes there were no significant differences from baseline. The effects on HR (PE = 0.17; 95% CI -0.71, 1.00) and systolic BP (PE = -0.23; 95% CI -0.50, 0.96) are *unclear* for both small (46.7% benefit, 16.4% harm for HR; 17.1% benefit, 52.8% harm for SBP) and moderate (18.9% benefit, 5.4% harm for HR; 6.8% benefit, 27.0% harm for SBP). There is a *possibly harmful* small effect on diastolic BP (PE = -0.47; 95% CI -1.20, 0.22) with an 81.1% chance of harm. The likelihood of moderate effects, however, is *possibly trivial* with only a 42.7% chance of harm.

Fitness-Based Outcomes

For all fitness-related outcomes, no significant differences are noted post-intervention compared to baseline assessment. The effect on upper extremity strength (PE = -0.09; 95% CI -0.42, 0.24) is *possibly trivial* with a 21.5% chance of small harm. The effect on lower extremity strength (PE = 0.30; 95% CI -0.37, 0.97) is *possibly beneficial* with a 65.3% chance of small benefit. The effects on anaerobic capacity (PE = 0.07; 95% CI -0.39, 0.53) are *unclear* with a 24.9% chance of small benefit and 9.5% chance of small harm. The effect on aerobic capacity (PE = -0.26; 95% CI -0.66, 0.14) is *possibly harmful* with a 64.2% chance of small harm. The effects on CF-based “work capacity” (PE = 1.06; 95% CI -0.04, 2.20) are *very likely beneficial* for small effects (95% likelihood), *likely beneficial* for moderate effect (87.6% likelihood), and *possibly beneficial* for large effects (71.5% likelihood).

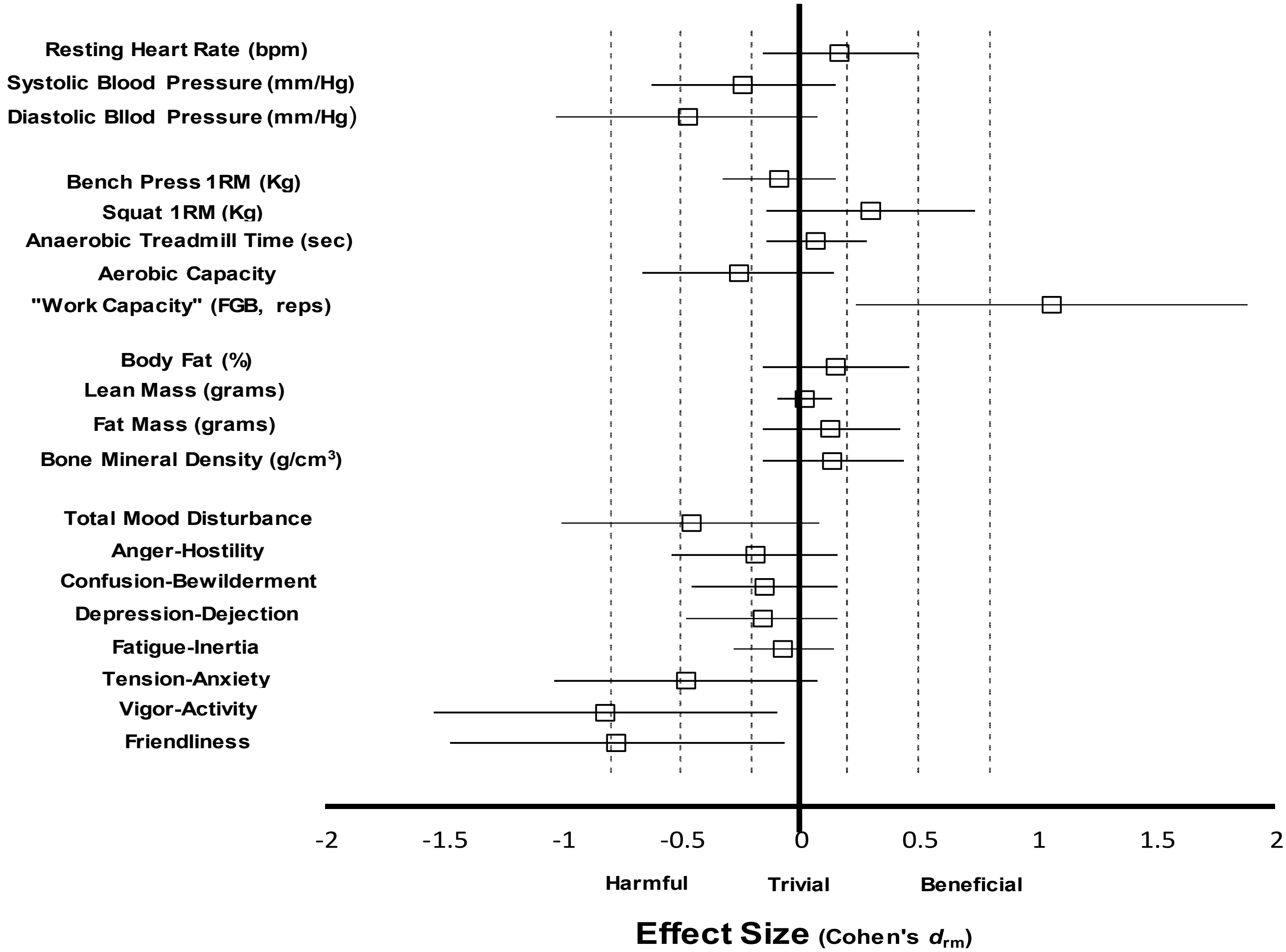

Figure 1. Population Effect Size Point Estimates and Confidence Intervals.

Psychological Outcomes

For both the TMD and all related subscales of the POMS, no significant differences are present. While there are *possibly harmful* small effects on overall TMD (PE = -0.46; 95% CI -1.3, 0.36) with a 77.3% likelihood of harm, there is variation in the effects of POMS subscales. Effects on anger-hostility (PE = -0.19; 95% CI -1.4, 1.0; 49.2% harm, 22.5% benefit), confusion-bewilderment (PE = -0.15; 95% CI -1.1, 0.8; 41.3% harm, 8.3% benefit), and fatigue-inertia (PE = -0.07; 95% CI -0.79, 0.65; 33.1% harm, 19.0% benefit) are all *unclear*, with *possibly harmful* small effects on tension-anxiety (PE = -0.48; 95% CI -1.1, 0.16) with an 84.5% likelihood of harm. For both vigor-activity (PE = -0.82; 95% CI -1.7, 0.46) and friendliness (PE = -0.77; 95% CI -1.7, 0.16) there are *likely harmful* small effects, 93.8% and 91.2% chance of harm respectively. In addition, there are 80.7% and 75.6%, respectively, of *possibly harmful* moderate effects for these subscales. Further, there are even *possibly harmful* large effects for vigor-activity (52.3% chance of harm).

Biomarker Outcomes

For both serum CK and CRP there are no significant differences between any time points. **Figure 2** illustrates the time course changes in both biomarkers throughout the study duration. The effect on serum CRP (PE = -0.33; 95% CI -2.0, 1.3) is *unclear* for with >5% likelihoods of harm and benefit present for all magnitude thresholds. For serum CK, there are *possibly harmful* small effects (i.e., increases) following the initial week of training (Pre to BW-2; PE = -0.33; 95% CI -2.0, 1.3). From the beginning to the end of the second week (BW-2 to EW-2; PE = -0.33; 95% CI -2.0, 1.3) the effects are *unclear* for all magnitude thresholds. However, from the beginning to end of both weeks three (BW-3 to EW3) and four (BW-4 to EW-4), there are *very likely* large harmful effects (with the likelihood of harm being 99.8% and 96.1% respectively).

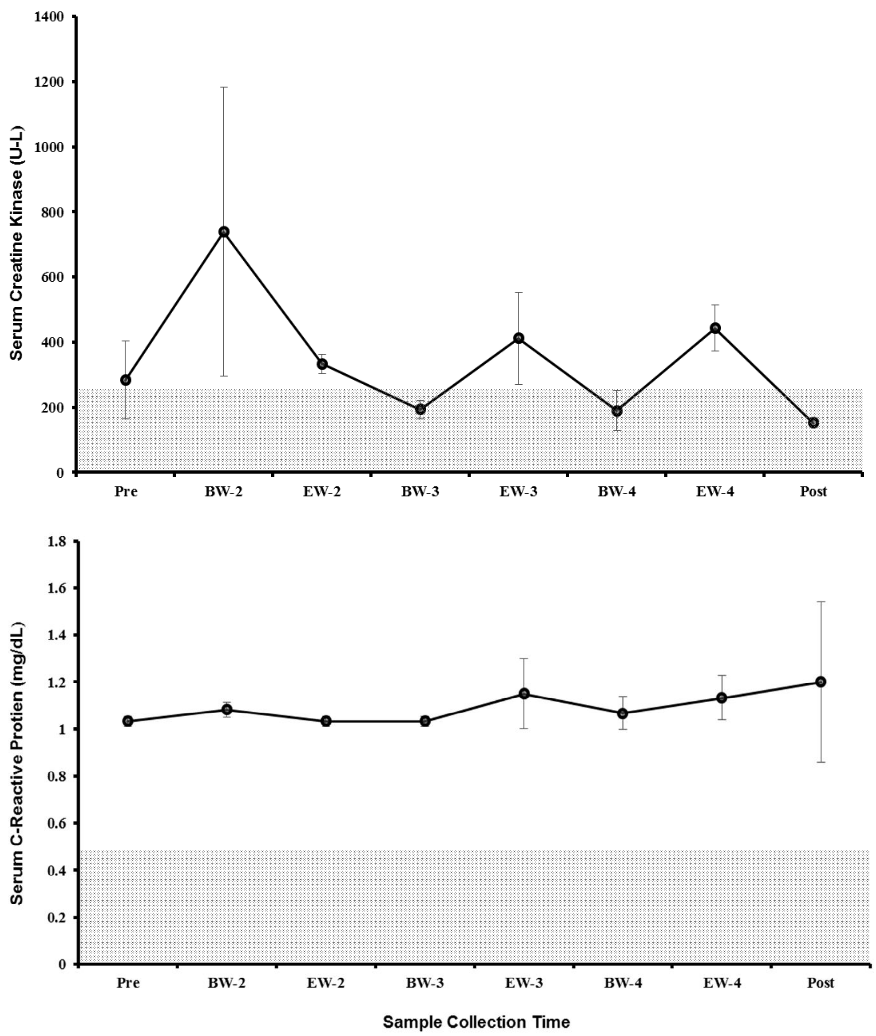

Figure 2. Serum CRP and CK Responses throughout Training Intervention.

Table 4. Likelihood of Magnitude-Based Substantivenss.

Effect Threshold:	0.2 (Small)		0.5 (Moderate)		0.8 (Large)	
Variable	**Likelihoods**	**Inference**	**Likelihoods**	**Inference**	**Likelihoods**	**Inference**
Resting Heart Rate	**46.7 / 36.9 / 16.4**	*Unclear*	**18.9 / 75.7 / 5.4**	*Unclear*	6.2 / **92.0** / 1.8	*Likely Trivial*
Systolic Blood Pressure	**17.1 / 30.1 / 52.8**	*Unclear*	**6.8 / 66.3 / 27.0**	*Unclear*	2.7 / **86.2** / 11.2	*Possibly Trivial*
Diastolic Blood Pressure	2.7 / 16.2 / **81.1**	*Possibly Harmful*	0.7 / **56.6** / 42.7	*Possibly Trivial*	0.2 / **88.1** / 11.7	*Possibly Trivial*
Upper Body Strength	3.6 / **74.9** / 21.5	*Possibly Trivial*	0.3 / **98.5** / 1.2	*Very Likely Trivial*	0.0 / **99.8** / 0.2	*Very Likely Trivial*
Lower Body Strength	**65.3** / 30.2 / 4.5	*Possibly Beneficial*	23.8 / **74.8** / 1.4	*Likely Trivial*	5.6 / **94.0** / 0.4	*Likely Trivial*
Anaerobic Capacity	**24.9 / 65.5 / 9.5**	*Unclear*	3.0 / **95.7** / 1.2	*Very Likely Trivial*	0.5 / **99.3** / 0.2	*Very Likely Trivial*
Aerobic Capacity	1.6 / 34.2 / **64.2**	*Possibly Harmful*	0.2 / **90.5** / 9.3	*Likely Trivial*	0.1 / **99.0** / 0.9	*Very Likely Trivial*
“Work” Capacity	**95.0** / 3.4 / 1.6	*Very Likely Beneficial*	**87.6** / 11.6 / 0.7	*Likely Beneficial*	**71.5** / 28.1 / 0.4	*Possibly Beneficial*
Body Fat %	**25.1 / 74.7** / 0.2	*Possibly Trivial*	0.2 / **99.8** / 0.0	*Very Likely Trivial*	0.0 / **100** / 0.0	*Most Likely Trivial*
Lean Mass	0.5 / **99.3** / 0.2	*Very Likely Trivial*	0.0 / **100** / 0.0	*Most Likely Trivial*	0.0 / **100** / 0.0	*Most Likely Trivial*
Fat Mass	**18.4 / 81.3** / 0.3	*Possibly Trivial*	0.2 / **99.8** / 0.0	*Very Likely Trivial*	0.0 / **100** / 0.0	*Most Likely Trivial*
Bone Mineral Density	**38.3 / 54.8 / 6.8**	*Unclear*	6.0 / **93.0** / 1.0	*Likely Trivial*	0.9 / **98.9** / 0.2	*Very Likely Trivial*
Total Mood Disturbance	4.7 / 18.0 / **77.3**	*Possibly Harmful*	1.5 / **53.2** / 45.3	*Possibly Trivial*	0.6 / **82.6** / 16.9	*Possibly Trivial*
Anger-Hostility	**22.5 / 28.6 / 49.2**	*Unclear*	**10.1 / 63.1 / 26.9**	*Unclear*	4.4 / **83.1** / 12.5	*Possibly Trivial*
Confusion-Bewilderment	**8.3 / 50.4 / 41.3**	*Unclear*	1.5 / **90.2** / 8.3	*Likely Trivial*	0.4 / **98.2** / 1.5	*Likely Trivial*
Depression-Dejection	3.7 / **55.7** / 40.6	*Possibly Trivial*	0.5 / **95.2** / 4.3	*Very Likely Trivial*	0.1 / **99.4** / 0.5	*Very Likely Trivial*
Fatigue-Inertia	**19.0 / 47.8 / 33.1**	*Unclear*	4.9 / **85.8** / 9.3	*Possibly Trivial*	1.3 / **96.2** / 2.4	*Very Likely Trivial*
Tension-Anxiety	2.0 / 13.5 / **84.5**	*Possibly Harmful*	0.5 / **52.5** / 46.9	*Possibly Trivial*	0.2 / **87.1** / 12.7	*Possibly Trivial*
Vigor-Activity	1.5 / 4.8 / **93.8**	*Likely Harmful*	0.6 / 18.7 / **80.7**	*Possibly Harmful*	0.2 / 47.5 / **52.3**	*Possibly Harmful*
Friendliness	2.2 / 6.6 / **91.2**	*Likely Harmful*	0.8 / 23.6 / **75.6**	*Possibly Harmful*	0.4 / **52.8** / 46.8	*Possibly Trivial*

Likelihoods are reported as: % beneficial / % trivial / % negative

Training Session Outcomes

Figure 3 illustrates the differences in THR and RPE between the distinct training session types typical within CF programming. There are significant differences for THR (*F*=8.63; P=0.001) and RPE (*F*=15.26; P<0.001) between training session designs. Element priority training sessions (127.4±8.9 beats·min^{-1}) have lower THR than both task priority (167.0±5.5; P=0.001) and time priority (172.4±7.7; P=0.001) designs. Element priority training sessions (9.4±0.8) also have lower associated RPEs than both task priority (14.8±0.5; P=0.000) and time priority (14.7±0.7; P=0.000) designs. There is a significant correlation between session RPE and workload (i.e., THR x duration; *r* = .426; P=0.019). No significant correlations between pain and RPE or pain and workload are present.

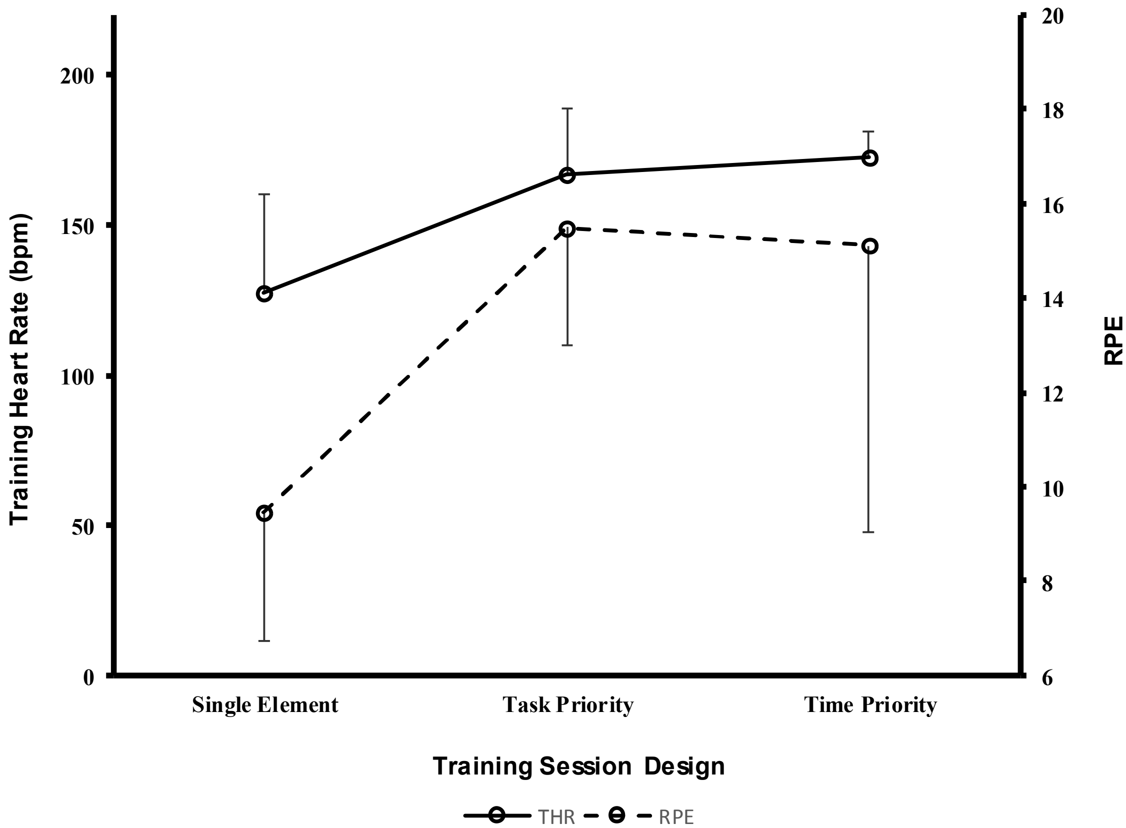

Figure 3. RPE and Heart Rate Responses between Training Session Designs.

Nutritional Status

There are no significant pre-post mean differences for total calories (-15.33; 95%CI -193.9, 163.2; P=0.823), fat (-0.66; 95%CI -9.8, 8.4; P=0.850), carbohydrates (-0.33; 95%CI -6.4, 5.8; P=0.887), or protein (-5.16; 95%CI -25.2, 14.9; P=0.514).

DISCUSSION

The goal of the present study was to determine the scope, magnitude, and direction of effects associated with short-term CF participation in healthy individuals. Further, there was interest in determining if participation had any potential negative effects on markers of skeletal muscle damage, systemic inflammation, or psychological status. The present findings partially support the original hypothesis that short-term CF participation can induce small beneficial effects on measures of health and fitness.

For measures of body composition observed, the effects are small, possibly trivial, very likely trivial, and unclear. Any moderate to large effects on body composition changes remain very likely to most likely trivial. While effects on BF% and FM are possibly trivial within these data, there are small likelihoods (25.1% and 18.4%, respectively) that an individual experienced improvements in these measures. These likelihoods, in combination with prior research showing significant change (15,42,48,51,52) in BF% and FM, illustrate the potential for even short-term CF interventions to benefit these parameters of health. Further, the subjects did not have any significant changes in their dietary intake or habits (i.e., the distribution of macronutrients) throughout the duration of the study. In combination with dietary changes, CF may produce even larger beneficial effects on BF% and FM in the short-term. The effects on LM observed are very likely trivial with greater than 99% chance of no change. While it may be counterintuitive to consider no change in LM a beneficial effect, participation in continuous high-intensity or long duration exercise can result in a loss of skeletal muscle mass (9). A loss of LM may produce adverse effects such as reducing resting metabolic rate (12) or increase in fall risk (49), and the ability of CF to maintain LM may point to its utility as an effective intervention in clinical populations (e.g., obese and elderly adults). While the effects on BMD in the present study are unclear and require more data, there is a 38.3% likelihood of benefit. These unclear effects on BMD are supported by the literature where some note potential clinically significant increases and others report a significant decrease following CF interventions (25,52). The largest percent change in BMD noted in this sample was approximately 4%, which may be of clinical significance for populations with low bone mass (28). In addition to trivial body composition changes, resting cardiovascular functions did not undergo significant changes during the current intervention. The subjects' HR shows likely trivial results and BP showed likely trivial results. However, DBP showed possibly harmful effects on a small effect size due to the slight increase in resting DB, which is potentially problematic if combined with other factors. Together, the results indicate that participation in CF, even for short durations, may produce favorable changes in body composition measures associated with overall health.

Unlike the generally beneficial effects observed for body composition measures, the study effects on components of fitness are more diverse. While we anticipated similar responses with respect to maximal strength in the upper and lower extremity muscle strength, we note differences in the directions of these effects. As expected, the effect on lower body strength is possibly beneficial with a 65.3% likelihood of improvement. However, the effects on upper body strength are possibly trivial with a 74.9% chance of no change and 21.5% likelihood of decrement in maximal strength. Similarly, we report divergence in the effects on aerobic and anaerobic capacity. Even though the effects on anaerobic capacity are unclear there is a 24.9% likelihood of improvement. However, the effects on aerobic capacity are possibly harmful with a 64.2% chance of the subjects' reducing their capacity. With these conflicting effects in mind, we propose a hypothesis by where CF interventions, at least in the short-term, will produce effects on components of fitness with varying direction depending on the baseline characteristics of its subjects. In the present study, the subjects experienced a progression in below average measures (i.e., lower body strength), regression in above average measures (i.e., aerobic capacity), with the relative maintenance of average measures (i.e., upper body strength and anaerobic capacity). Given the "constantly varied" nature of CF methodology, short-term intervention may not provide enough stimulus (i.e., volume) for progression of already high relative levels of fitness while areas of deficiency may expect positive results. However, over the long-term, CF may provide enough volume to produce positive effects, even in individuals with initial high relative levels of fitness, as there will be greater time spent training each potential component of fitness (6,48,51,56,57). Thus, it would be of interest to determine the time threshold for transitioning from "deficiency correction" to overall improvement of fitness components.

The greatest magnitude of effects observed in the present study is on the CF-defined area of WC with there being very likely small effects, likely moderated effects, and possibly large effects. Both the magnitude and direction of this improvement in CF-based WC should not come as surprise when one considers the principle of specificity (39) and other data showing increases in WC from CF interventions (44). Further, Butcher et al. (8) show that performance in CF benchmark WODs is predicted most accurately by whole-body strength than by any other traditional component of fitness (e.g., aerobic capacity or lactate threshold). These data support this contention as the subjects improved their lower extremity strength while maintaining their upper body strength, thus increasing whole-body strength levels. While increasing WC will no doubt make an individual better at performing CF-related activities, the more interesting question is whether or not this increase in WC has any utility outside of this intrinsic value. For example, what populations are most likely to benefit from this general, highly varied type of exercise program? We propose those with solely general health and fitness goals, those who may be early in their training age (i.e., adolescent athletes), and those who have a wide variety of physical disabilities to address may benefit from this type of programming. All together, these data suggest that short-term CF participation will increase overall fitness via the correction of physical deficiencies resulting in significant improvement in WC.

Skeletal muscle damage, systemic inflammation, and psychological status were evaluated to determine if there were any potential negative effects from short-term CF often associated with maladaptation to exercise training (50). Biochemical markers of skeletal muscle damage, such as CK, are commonly used as an indirect biomarker of tissue damage. After intense exercise, CK levels will elevate outside of the normal physiologic range (45-235 U/L), but will return to baseline within 48 to 72 hrs post-exercise (2,24). While this response may be indicative of the normal muscle stress and/or repair process that is necessary for positive adaptation, excessively high levels of serum CK are present in overtraining syndrome (OTS) and conditions such as rhabdomyolysis (21,47). If CK levels remain elevated following consecutive days and weeks of training it may be representative of underlying tissue micro-trauma and a maladaptive response to training (50). In the present study, the initial serum CK response was elevated with a large amount of between subject variability. This initial pattern is most likely due to individual differences in exercise training patterns (mode, frequency, and duration) between the subjects prior to study. Hence, the subjects may be high or low responders dependent on their prior training habits. Further, by the end of the first week serum CK lowers considerably, still outside normal range, along with the inter-subject variability. This may indicate the presence of an “acclimation” period to CF training. In support of this thinking, by the beginning of the second week, serum CK levels returned to within the normal physiologic range. At the end of the second week serum CK is again elevated above the normal range, but returns to normal by the beginning of the following week. This pattern continues for the remainder of the training program, which represent a normal progression of the adaptive/recovery process expected during chronic exercise training.

The biomarker CRP is a marker of low-grade systemic inflammation. It is increased in CRP in overtrained athletes (50). The present findings show no significant increase in serum CRP levels during CF training. However, inter-subject variability increases throughout the study intervention, with the highest level of inter-subject variability occurring at the final data collection time point. These data are supported by Bains et al. (1) who reported a reduced inflammatory response evidenced by increases in CRP. Their data follows an 8-wk intervention with an increase in serum CRP, yet was not significantly different from the baseline assessment. However, in contrast to the present study, Bains et al. (1) purposely controlled the exercise intensity during the first 4 wks of their intervention. Meaning, subjects were instructed to not give full effort in every training session, but instead progressively increased their level of effort with each successive week of training. This gradual increase in effort/intensity may potentially allow participants an opportunity to acclimate appropriately to CF protocols that would result in the modulation of increases in serum CRP.

Effects on psychological mood states ranged from unclear to possibly harmful, with some states showing likely harmful effects. For Total Mood Disturbance, we observed a small effect that is possibly harmful. The largest effects on mood states are for “tension-anxiety”, “vigor-activity”, and “friendliness”. These findings diverge from data presented by Heinrich et al. (23) that indicate women report more enjoyment and likelihood to continue CF training compared to concurrent RT and moderate intensity aerobic exercise. Further, negative changes in psychological status are an early symptom of overtraining syndrome (18,19) in athletes. The greater volume and/or intensity of the training stimulus within the current study, when compared to other published CF interventions, may explain the negative mood state changes for these participants. Together, these data suggest that the subjects in the present study approached training volumes that may begin to inhibit adaptation.

Based on increases in serum CRP variability and negative changes in mood states, we propose a second hypothesis by which the subjects approached a state of functional overreaching. This hypothesis is supported by the negative alterations in mood states and inflammatory status, yet still observed increases in CF-related performance. We suggest that the subjects in the present study were exposed to a training stimulus that maximally stressed their ability to recover from individual training sessions. This phenomenon is known as the maximum recoverable volume (MRV) (30), which states there is a maximum amount of training volume that an individual can recover from. Training below MRV allows an individual to recovery and adapt to the training stimulus. Training at a volume too close to MRV will allow for recovery, but likely disrupt training adaptation. Optimal training is a delicate balance between eliciting a strong enough stimulus to disrupt homeostasis while still allowing enough time for recovery and adaptation. To this end, there is another critical training volume metric known as the maximum adaptive volume (MAV) (30). The MAV is the training volume, below

MRV, which allows an individual to both recover and adapt optimally. Training consistently at MRV can lead to overreaching that is a key checkpoint prior to the development of overtraining syndrome with two potential outcomes: functional and non-functional overreaching (18,30,38,53). Non-functional overreaching trends toward OTS syndrome while functional overreaching, a brief period of time spent at MRV, may provide performance increases when adequate rest is applied directly following the training period. The accumulation of fatigue during time spent above MRV is what necessitates the usage of deload periods prior to the observed improvement in performance measures. We suggest that if individuals are giving maximal effort on a consistent basis during short-term CF training, then, it may potentially lead to an overreached state via continued exposure to their MRV. Further, if the training volume of this magnitude and intensity continues into the long-term, it is possible that individuals may develop OTS.

Further, the MRV concept may explain the “deficiency correction” of the fitness parameters assessed in the present study. If there is a maximum amount of training volume that can be recovered from, perhaps, the various components of fitness will respond differently to an individual multi-modal training session. That is, during a CF WOD where all components of fitness can be stressed, components that are below average in an individual will be stressed to a greater degree than those that may be above average. In this scenario, below average components progress while above average parameters may only be maintained or even regress. Thus, we propose that MRV must be applied individually to all distinct components of fitness when incorporating multi-modal training sessions. Within the high-intensity, multi-modal nature of CF methodologies, it would be impossible to provide the appropriate level of training stimulus for each individual component of fitness to optimize recovery and adaptation. Hence, one might posit that the component of fitness with the lowest relative capacity may serve as a limiting factor when considering an individual’s MRV during CF training interventions. Further it may be difficult if not impractical to properly monitor the response of each distinct fitness component throughout a CF intervention. An appropriate monitoring strategy for this type of training program may be a systemic marker such as heart rate variability (HRV). HRV indirectly estimates overall autonomic stress in the human body (33) and may be the most feasible strategy to monitor recovery and adaptation to multi-modal style training. Training programs adjusted for volume and intensity based on HRV show more favorable results than traditional progressive overload training alone (53,55). HRV is even hypothesized to be a potential early indicator of musculoskeletal overuse injuries (20). Future research on CF interventions should compare HRV-regulated intensity versus traditional maximum effort intensity intervention programming (5). Based on these data, individuals should be able to modulate their level of effort between training sessions accurately when using the RPE scale as a frame of reference. Table 3 illustrates that the subjects were able to accurately perceive their level of intensity during training sessions (as measured by THR). Using RPE, individuals may be able to adequately adjust their training intensity while still completing the prescribed work during CF sessions. This could potentially lead to consistent training below MRV, at the MAV, thus negating the development/progression of overreaching and optimize adaptation and recovery.

The present study presents several avenues for future research worth noting. First, we propose that CF interventions, at least in the short-term, will produce varying results based on the initial training status of study participants. Following this, in the short-term, CF will result in substantial improvements in WC via correction of individuals’ fitness deficiencies. As the largest effects observed in the present study, the concept of WC must be examined to determine its utility beyond improving CF performance. We propose that athletes early in their training age (i.e., adolescents), individuals with general health and fitness goals, or individuals with high levels of disability may benefit the most from this training methodology. For example, early in one's training age it may be beneficial to place importance on improving all aspects of fitness to negate the development of deficiencies. Similarly, individuals concerned with general health will also benefit from emphasizing complete fitness rather than specialization on any one component as both strength and aerobic capacity are associated with early mortality. Further, this type of training may provide general enough stimuli to help improve a wide range of disabilities associated with chronic disease. Given the multi-modal nature and the broad benefits likely in CF participation, we acknowledge it is a potentially powerful training stimulus. Consequently when each training session is completed with maximum effort/intensity, as advocated by the program developers, there is the potential to realize a functionally overreached state in the participants in the short-term. Future research should investigate this phenomenon further as well as investigating if participation over the long-term contributes to the development of non-functional overreaching or OTS. With this in mind, we propose that a systemic marker like HRV may be the most appropriate method for monitoring the recovery/adaptive response to this method of training. Training intensities regulated by HRV may appropriately modulate training stimuli to optimize both recovery and adaptation CF interventions.

Limitations of this Study

The present study is not without its limitations. First, and foremost, are the concerns with study sample size. This sample is not only small (n=6) but is entirely male. Replication of the present study should include both males and females along with an adequate sample size. However, the statistical methods employed in this study (i.e., MBI) provide inferences on the potential magnitude of effects at the population level. Further, we purposely selected a more conservative confidence interval (95% vs. 90%) than what is recommended to offset our small sample size. For this reason, we contend that the data presented, even though only a small sample, should still hold true at the population level. We anticipate larger sample sizes will corroborate and narrow the effect size CI obtained in this study. Second, the current study lacked collection of real-time heart rate during the training sessions. Using real-time HR data to more accurately reflect training session workloads (i.e., average THR x duration) may allow for more effective intervention monitoring. Lastly, there are limitations in the ability to compare results of currently published studies investigating the efficacy of CF interventions. At this time, there is little, if any, consistency in the design of CF interventions. Very few have utilized an intervention design that is consistent with the recommendations of the original program developers. This not only makes comparison with other research difficult, but also calls into question the validity of these studies for truly reflecting the potential effects of CF. A strength of the present study is its attentiveness in following one of the two recommended program structures (5 days on; 2 days off) and proper element sequencing (i.e., appropriate session type and element structures within microcycles). For future CF research to be considered a valid representation of program philosophies and assessment of outcomes, interventions must not deviate from original programming recommendations.

CONCLUSIONS

This study illustrates the efficacy of CF interventions for affecting a wide variety of health and fitness measures, making it a potentially powerful exercise stimulus. Beyond efficacy, these data provide valuable information as to areas for future investigation into this training methodology. We propose that effects of short-term CF interventions will vary, improving below average components of fitness and maintaining above average components, based on initial individual differences in relative fitness capacities. Further, we acknowledge that the strength of the CF methodology is its attentiveness on consistently high effort/intensity. This attentiveness is simultaneously the program's greatest asset and, potentially, the most pressing area of need.

In the present study, we contend that the subjects approached a state of functional over-reaching, as we observed improvement in overall performance, yet negative perturbations in mood states and inflammatory status. In the short-term this is not a significant concern, yet if maximal intensity is maintained over the long-term, this may progress into non-functional overreaching or OTS. To limit the potential for overtraining in a continuous high intensity multi-modal exercise intervention, such as CF, we recommend the use of a systemic marker of physical stress like HRV. The largest magnitude of effects noted in this study is for CF-related WC. It will be of central importance to exercise physiologists and other professionals to determine the utility of this increased WC beyond CF performance. We propose that its greatest utility may be with the adolescent populations, those interested in general health, and for reducing disability associated with chronic disease. Future research investigations on CF need to address these questions while maintaining integrity of original programming for this potent intervention.

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