FUNCTIONAL FITNESS / HIGH INTENSITY FUNCTIONAL TRAINING FOR HEALTH AND PERFORMANCE

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FUNCTIONAL FITNESS / HIGH INTENSITY FUNCTIONAL TRAINING FOR HEALTH AND PERFORMANCE

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Editorial: Functional fitness/high intensity functional training for health and performance

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Editorial on the Research Topic
Functional fitness/high intensity functional training for health and performance

Introduction

Functional fitness training (FFT) is an emerging fitness trend that emphasizes functional, multi-joint movements, including aerobic (e.g., cycling, rowing, running) and strength exercises (e.g., weightlifting and derivatives: squat, snatch, clean and jerk, bench press, deadlift; bodyweight exercises: air squat, push-up, pull-up, muscle-up; plyometrics: box jumps, tuck ups) (Claudino et al., 2018; Feito et al., 2018). Researchers have shown that FFT may be not only suitable for professional athletes but also for populations with different fitness levels. Indeed, it is suggested that FFT elicits greater muscle recruitment than aerobic exercises alone, thereby improving both endurance and muscular strength and power (Bergeron et al., 2011; Claudino et al., 2018; Feito et al., 2018; Schlegel, 2020; Sharp et al., 2022). However, FFT units (i.e., workouts) are highly varied daily, and more research is needed to clarify its acute effects and its associated chronic training adaptations (Bergeron et al., 2011; Claudino et al., 2018; Feito et al., 2018; Schlegel, 2020; Sharp et al., 2022). Therefore, the aim of this Research Topic is to increase the knowledge of the evidence-based effects and adaptations of implementing FFT on health and performance in individuals with different biological conditions.

Terminology

CrossFit® has been used in research and practice to denominate FFT as a fitness trend. Importantly, the CrossFit® company (CrossFit® Inc., LLC) has revolutionized the fitness industry achieving, to date, more than 11,000 affiliated boxes worldwide and implemented competitiveness with the inclusion of structured competitions such as the "*CrossFit Games*" (Kuhn, 2013; Claudino et al., 2018; Dexheimer et al., 2019; Glassman, 2020; Martínez-Gómez et al., 2020). Furthermore, the CrossFit® brand is worth $4 billion, according to the prestigious Forbes journal (Ozanian, 2015). However, since CrossFit® is a registered brand and not an actual exercise modality, several terms have also been used in the scientific literature, along with CrossFit®, to equally denominate this fitness trend: high-intensity multimodal training, extreme conditioning programs, functional fitness training, high-intensity functional training, and mixed modal training (Bergeron et al., 2011; Feito et al., 2018; Marchini et al., 2019; Sharp et al., 2022).

An opinion article attempted to solve the problem with the terminology found in the scientific literature since the inclusion of FFT in the fitness industry worldwide. According to Dominski et al., FFT is the most comprehensive and inclusive term. It should be adopted both in research and practice since it is based on functional training and physical fitness terms to describe various characteristics and activities performed. Then, FFT is characterized by a variety of movement patterns (e.g., knee or hip dominant exercises, pull, push), activities (e.g., weightlifting, strength, gymnastics, metabolic and aerobic conditioning), and energy systems used (e.g., ATP-CP/phosphagen, glycolytic, and oxidative) (Dominski et al.). Subsequently, FFT should develop participants' competencies in aerobic capacity, strength, bodyweight endurance and skills, and power development (Dominski et al.).

Acute effects of functional fitness training

FFT is characterized by a wide variety of workouts, which differ in training duration (i.e., volume) and intensity (Claudino et al., 2018; Feito et al., 2018; Tibana and Frade De Sousa, 2018; Schlegel, 2020; Sharp et al., 2022). Training preparation and performance of FFT are usually connected with the principles of concurrent training, usually combining endurance-oriented (e.g., cycling, rowing, running) and strength-oriented (e.g., weightlifting, bodyweight exercises) activities within the workouts (Schlegel, 2020). Researchers have reported that FFT sessions induce remarkable fatigue levels with impairments in performance indicators and elevated levels of perceived effort (Tibana and Frade De Sousa, 2018; Schlegel, 2020; Dominski et al.). Furthermore, it is frequently reported that participants show high metabolic and cardiovascular stress (e.g., elevated blood lactate concentration and heart rate), high rates of perceived exertion, and elevated immune and hormonal responses (e.g., testosterone, cortisol, IL-6, IL-10) to FFT workouts (Tibana and Frade De Sousa, 2018; Schlegel, 2020; Sharp et al., 2022). Nonetheless, more research is needed to increase the knowledge of the acute effects of implementing FFT on health and performance.

In this Research Topic, two articles focused on the acute effects of FFT with important practical applications (Machado et al.; Saeterbakken et al.). Saeterbakken et al. demonstrated that performing the bench press throw (BPT) exercise using a bouncing technique (i.e., allowing the barbell to rebound off the chest) increased average power output (7.9–14.1%, $p \leq 0.001$, ES = 0.48–0.90), average velocity (6.5–12.1%, $p \leq 0.001$, ES = 0. 48–0.91), and decreased time to peak power (11.9–31.3%, $p \leq$ 0. 001–0.05, ES = 0.33–0.83) across a battery of loads (30–60 kg) in 27 resistance-trained men. In addition, descending the barbell with a higher velocity increased the power outputs, velocity, and time to peak power ($p \leq$ 0.001–0.003) during the subsequent BPT ascending phase. In theory, the athletes could use these findings to increase effectiveness and improve performance during workouts and benchmarks that implement the bench press exercise (e.g., "LINDA").

Machado et al. demonstrated that exercise distribution using body weight high-intensity interval training (HIIT)-based workouts promote alterations in training load parameters. In this study, 20 male participants performed three 20-min workouts, consisting of 20 sets of 30 s of body weight complexes performed at maximal intensity, followed by 30 of passive recovery. Three training designs matched the exercises but differed in order: A) jumping jack, burpee, mountain climb, and squat jump; B) jumping jack, mountain climb, burpee, and squat jump; C) burpee, squat jump, jumping jack, and mountain climb. The main findings of this study were that participants of design A performed significantly more repetitions (26–36%, $p <$ 0.001) and had higher values for perceived recovery (19–73%, $p <$ 0.001) despite no significant differences were found between protocols for relative heart rate, perceived exertion, and lactate concentration ($p > 0.05$). Therefore, based upon these results, participants of FFT are encouraged to adapt the exercise order during bodyweight HIIT-based workouts to improve their performance and recovery perceptions.

Neto et al. and Martínez-Gómez et al. aimed to study the time course of recovery and different recovery strategies after FFT, respectively. On the one hand, Neto et al. described the acute and delayed time course of recovery of eight trained male participants following the CrossFit® benchmark "KAREN" (i.e., 150 wall balls for time using a 9 kg med ball, aiming to hit a target 3 m high). Creatine kinase (CK) concentrations were significantly elevated (58%, p = 0.04) 24 h after the workout compared to the pre-exercise state. Similarly, the scale values of general, upper limbs, and lower limbs perceived recovery status were significantly lower 24 h post-exercise (39%, 12%, 47%, respectively, p = 0.

013–0.046). Interestingly, after 48 h post-exercise, CK concentrations returned to baseline levels, and the scales values of perceived recovery status were significantly greater ($p \leq 0.05$) compared with 24 h post-exercise. On the other hand, Martínez-Gómez et al. compared the effectiveness of three different recovery strategies: 1) low-intensity leg pedalling, 2) surface neuromuscular electrical stimulation (NMES), and 3) total (passive) rest after FFT. The authors concluded that, although there was a trend toward an improved perceived recovery with NMES compared with total rest ($p = 0.061$), low-intensity leg pedalling, NMES, and total rest promote a comparable recovery after a FFT session. These findings are of practical importance in real-world FFT since recovery status and strategies to improve recovery can help to optimize training monitoring while minimizing the potentially detrimental effects associated with the performance of repeated high-intensity efforts (Bishop et al., 2008; Balk and Englert, 2020).

Adaptations of functional fitness training

FFT has been proposed to increase participants' physical conditioning and performance with a broad range of fitness levels (Claudino et al., 2018; Feito et al., 2018; Schlegel, 2020; Sharp et al., 2022). Researchers have demonstrated that implementing FFT efficiently develops both strength and endurance adaptations in short-term and long-term programs (Feito et al., 2018; Schlegel, 2020; Sharp et al., 2022). Furthermore, the benefits can also be extended to psychosocial aspects since, elevated levels of sense of community, satisfaction, and motivation during FFT have commonly been reported in the literature (Claudino et al., 2018; Feito et al., 2018). Nonetheless, more research is needed to increase the knowledge on the resultant adaptations of implementing FFT in participants with different fitness levels. Additionally, it is essential to compare the effectiveness of FFT with other training programs.

In this Research Topic, two articles followed an intervention to elucidate the physiological adaptations of implementing FFT in men with different fitness levels (Sheykhlouvand et al.; Zuo et al., 2022). Besides, there was one correlational study that, although it was not a direct intervention, may be indicative of adaptations consequence of systematic FFT implementation (Mangine et al.). Finally, a randomized controlled trial of tangeretin supplementation on cortisol stress response induced by high-intensity resistance exercise was included (Liu et al., 2022).

Firstly, Sheykhlouvand et al. demonstrated that a new form of resistance-type HIIT (RHIIT) improved cardiac structure and hemodynamic, physiological adaptations, and performance of well-trained kayakers. In this study, twenty-four male kayakers were randomly assigned to one of three conditions (i.e., RHIIT, paddling-based HIIT [PHIIT], and a control group [CON]) for 8 weeks. Overall, RHIIT and PHIIT groups similarly improved cardiac structure, hemodynamic, other physiological parameters (e.g., maximal stroke volume, maximal oxygen uptake, maximal cardiac output, end-diastolic volume, ejection fraction, peak power output, and left ventricular end-systolic dimension, all $p \leq 0.05$), and performance of well-trained kayakers (e.g., 500-m and 1000-m paddling performance, $p \leq 0.05$). In addition, RHIIT group significantly improved maximum strength ($p \leq 0.05$). Secondly, Zuo et al. demonstrated that functional resistance training (FRT) is as effective as traditional resistance training (TRT) for improving the upper and lower limb muscular endurance and performance in untrained young men. In this study, twenty-nine untrained men were randomly assigned to FRT or TRT for 6 weeks. The results of FRT and TRT groups showed equally significant increments in muscular endurance ($p < 0.01$) and performance (i.e., throwing, jumping, 30-m sprint and pull-ups performance, $p < 0.01$). Therefore, based upon the results of these studies, implementing RHIIT and FRT should be considered as efficient FFT alternatives to develop strength, muscular endurance, and cardiorespiratory adaptations in men with different fitness levels, as previously suggested (Feito et al., 2018; Schlegel, 2020).

Mangine et al. examined the relationships between body composition and FFT performance during the benchmark "FRAN". In this cross-sectional study, fifty-seven men and thirty-eight women with different fitness levels completed a dual-energy X-ray absorptiometry assessment and were grouped by competition class (i.e., men, women, master's men, master's women) and percentile rank in the "FRAN" benchmark (i.e., ≤25th percentile, 25–75th percentiles, ≥ 75th percentile). The authors showed that "FRAN" performance varies by competition class and percentile rank in men and women. In men, greater body mass and bone mineral density were related to performance and muscle size, strength, and power ($p \leq 0.05$). Meanwhile, body and skeletal mass were not related to "FRAN" performance in women. Across percentile ranks, the higher-ranking participants (≥75th percentile) had more non-bone lean mass and less body fat than all other participants, and those who had more lean mass performed better ($p \leq 0.05$). Therefore, based upon the results of this study, it may be suggested that implementing FFT may increase non-bone lean mass - predominantly muscle mass - while reducing body fatness, especially in men.

Finally, Liu et al. (2022) conducted a randomized controlled trial to investigate the effects of 4 weeks tangeretin supplementation on the cortisol stress response induced by high-intensity resistance exercise (HIRE) in twenty-four male soccer players. Participants were randomly assigned to an experimental and a control group, all of them performing high-intensity bouts of resistance exercise to stimulate their cortisol stress responses. A dose of 200 mg/day of tangeretin was provided to the individuals of the experimental group while a placebo was ingested by those placed in the control group. The authors observed that 4 weeks of tangeretin supplementation can reduce serum cortisol and adreno-corticotropic hormone, and adaptation that could ameliorate the cortisol stress response in soccer players during high-intensity resistance exercise. In addition, tangeretin supplementation may also enhance antioxidant capacity, accelerate the elimination of inflammation, and shorten recovery time after high-intensity resistance exercise. Thus, 200 mg/day of tangeretin supplementation could mitigate the detrimental effects of cortisol stress response induced by FFT.

Limitations and future perspectives

In this Research Topic, there have been several contributions for increasing the body of evidence FFT for health and performance including: 1) terminology, 2) acute effects of FFT, and 3) adaptations of FFT. However, there are several limitations in the studies published in this Research Topic. First, (Feito et al., 2018) studies still have no consensus on the terminology used to refer to FFT (e.g., CrossFit®, high-intensity functional training, high-intensity resistance training, functional resistance training, HIRE, HIIT using whole-body exercise), thus making difficult the consistency in the scientific literature and the consensus among researchers and practitioners. Second, (Claudino et al., 2018) most articles on this Research Topic have been conducted on healthy young, moderately trained men. Therefore, more studies with men and women of different ages with different biological conditions and fitness levels are warranted (Claudino et al., 2018; Feito et al., 2018; Tibana and Frade De Sousa, 2018). Unfortunately, due to the participants' background in the studies covered by this Research Topic, caution must be taken when extrapolating the results to other populations. Third, (Bergeron et al., 2011) studies relating FFT performance to physiological and neuromuscular predictors are missed in this Research Topic. More research is needed to increase the knowledge of implementing FFT for health and performance, a training methodology increasingly gaining attention within the fitness community.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

DB was employed by the company iLOAD Solutions

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Comparison of Different Recovery Strategies After High-Intensity Functional Training: A Crossover Randomized Controlled Trial

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We aimed to determine whether voluntary exercise or surface neuromuscular electrical stimulation (NMES) could enhance recovery after a high-intensity functional training (HIFT) session compared with total rest. The study followed a crossover design. Fifteen male recreational CrossFit athletes (29 ± 8 years) performed a HIFT session and were randomized to recover for 15 min with either low-intensity leg pedaling ("Exercise"), NMES to the lower limbs ("NMES"), or total rest ("Control"). Perceptual [rating of perceived exertion (RPE) and delayed-onset muscle soreness (DOMS) of the lower-limb muscles], physiological (heart rate, blood lactate and muscle oxygen saturation) and performance (jump ability) indicators of recovery were assessed at baseline and at different time points during recovery up to 24 h post-exercise. A significant interaction effect was found for RPE ($p = 0.035$), and although *post hoc* analyses revealed no significant differences across conditions, there was a quasi-significant ($p = 0.061$) trend toward a lower RPE with NMES compared with Control immediately after the 15-min recovery. No significant interaction effect was found for the remainder of outcomes (all $p > 0.05$). Except for a trend toward an improved perceived recovery with NMES compared with Control, low-intensity exercise, NMES, and total rest seem to promote a comparable recovery after a HIFT session.

Keywords: performance, fatigue, CrossFit, exercise, electrical stimulation

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INTRODUCTION

Enhancing recovery between workouts is a key issue in competition sports, as it might allow athletes to cope (and adapt to) increasing training loads, ultimately contributing to an improved performance (Bishop et al., 2008). A fast recovery is even more important in those sports where athletes must face consecutive competition days or even different competition sessions in the same day (Bishop et al., 2008). Therefore, identifying methods that could foster recovery between sessions is of major relevance (Maté-Muñoz et al., 2017).

High-intensity functional training (HIFT, i.e., training programs that incorporate functional and multimodal movements performed at relatively high intensities) has become a popular exercise modality in recent years (Feito et al., 2018), with CrossFit among the most popular examples

(Claudino et al., 2018). Different studies have shown that HIFT sessions induce remarkable levels of fatigue, as reflected by an impairment of performance indicators (e.g., 1 repetition maximum, jump height, rate of force development), increased levels of biomarkers such as blood lactate or creatine kinase, and high values of perceptual fatigue (Maté-Muñoz et al., 2017; Timón et al., 2019). Indeed, a greater fatigue has been reported to occur after HIFT sessions compared with more "traditional" training sessions (Drum et al., 2017). However, despite the popularity of HIFT and its highly fatiguing nature, scarce evidence exists on which strategies could enhance recovery after this training modality.

A wide variety of strategies are commonly used by athletes of different sports to optimize recovery between exercise sessions (Reilly and Ekblom, 2005; Barnett, 2006; Bishop et al., 2008). Strong evidence suggests that active recovery, mainly low-intensity exercise, might be more effective than total rest (Signorile et al., 1993; Connolly et al., 2003). However, in practical terms performing actual exercise between sessions or competitions is not always feasible. In this effect, passive strategies such as low-frequency surface neuromuscular electrical stimulation (NMES, which elicits low-intensity involuntary muscle contractions through the application of intermittent electrical stimuli to skeletal muscles) might be a potentially effective recovery strategy, at least in part due to an improved blood flow and metabolite removal (Babault et al., 2011). Controversy exists, however, on the effectiveness of NMES as a recovery strategy, and indeed a meta-analysis reported mixed or no evidence compared to either passive or active recovery (Malone et al., 2014a). Later studies have reported a beneficial effect of post-exercise NMES over passive recovery on different outcomes including muscle inflow, lactate removal, or performance (Bieuzen et al., 2014; Taylor et al., 2015; Borne et al., 2017), although other authors have found similar effects with both strategies (Malone et al., 2012, 2014b). For instance, Malone et al. compared the effects of 30 min of NMES, active recovery (low-intensity cycling) and passive recovery after high-intensity intermittent exercise (consecutive Wingate anaerobic tests) in healthy trained male triathletes, and found a higher blood lactate removal with active recovery but overall comparable effects on performance across all recovery modalities (Malone et al., 2012). Another study reported no differences in blood lactate removal, perceived muscle soreness or performance between active recovery (walking), NMES or massage in healthy amateur athletes after a single bout of high intensity training (Akinci et al., 2020). Thus, evidence on whether NMES could provide superior benefits to total rest or comparable benefits to those induced by active recovery is mixed and scarce (Malone et al., 2012; Paradis-Deschênes et al., 2020).

The aim of the present study was to compare the effects of three different recovery strategies [active recovery (voluntary exercise), NMES, or total rest] following a HIFT session. Our main outcome was performance (i.e., jump height), but we also aimed to measure other secondary outcomes including subjective (e.g., perceived exertion) and physiological (e.g., blood lactate) measures of recovery. Following previous research (Malone et al., 2014a), we hypothesized that both NMES and active recovery would induce similar benefits on perceptual measures of recovery—in both cases superior to total rest—while no differences would be observed between conditions on performance measures.

MATERIALS AND METHODS

Subjects

Fifteen recreational male athletes from a local CrossFit center volunteered to participate [age (mean ± SD): 29 ± 8 years, weight: 81 ± 12 kg, height: 177 ± 6 cm]. All participants had previous training experience with HIFT (≥1 year, ≥3 training sessions/week) and were familiarized with all the exercises and testing procedures of our protocol. During the study, participants maintained their regular training program and dietary pattern, but were required to refrain from exercising or consuming ergogenic aids/stimulants (e.g., creatine, caffeine) ≥24 h and ≥72 h before and after each testing session, respectively. Participants provided written informed consent, and all procedures were conducted following the standards set by the Declaration of Helsinki and its later amendments. The study was approved by the Institutional Review Board (*Hospital Universitario Fundación Alcorcón*, Spain; #19/51).

Experimental Design

The present study followed a crossover randomized controlled trial design. A summary of the experimental protocol is shown in **Figure 1**. Participants performed a HIFT session on three occasions, each session from the next one by a minimum of 72 h and a maximum of one week. Participants were randomized using computer-generated random numbers to recover for 15 min after each HIFT session with either voluntary exercise (*Exercise*, low-intensity leg pedaling), passive muscle contractions (NMES to the lower limbs), or a control condition (*Control*, total rest).

Training Sessions

All training sessions were supervised by a specialist coach, who provided standardized encouragement and was blinded to participants' recovery conditions. Before each individual session participants performed a warm-up consisting of 5 min of low-intensity leg pedaling [rating of perceived exertion (RPE) of 6 out of 10] (Borg, 1982), 5 min of joint mobility and stability exercises, and 5 min of specific exercises (five push presses, five front squats, and five thrusters, respectively, first with a 20-kg bar and thereafter with a 43-kg bar). The main part of the HIFT session consisted of the Fran workout, a benchmark workout of the day (WOD) within CrossFit. This specific WOD consists of two exercises (thrusters with a loaded barbell of 43 kg and pull-ups) performed in alternating fashion in a descending 21-15-9 repetition scheme. That is, individuals completed 21 repetitions of thrusters followed by 21 repetitions of pull-ups, then 15 repetitions of these two exercises, and finally nine repetitions. The time needed to complete the WOD was registered.

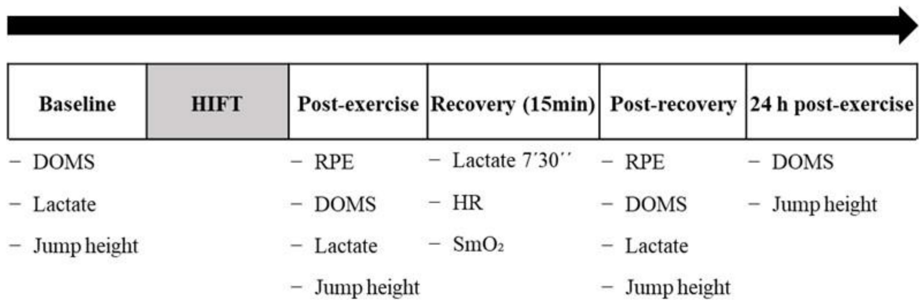

FIGURE 1 | Schematic figure representing the experimental protocol. Abbreviations: DOMS, delayed-onset muscle soreness; HR, heart rate; RPE, rating of perceived exertion; SmO_2, muscle oxygen saturation.

Recovery Methods

Following the WOD, participants recovered for 15 min with one of the three aforementioned strategies. During the control condition, participants remained seated for 15 min. During exercise, participants performed low-intensity leg pedaling (RPE of 6 out 10) on a cycle ergometer (Assault Fitness, Rogue Fitness Europe, Pori, Finland) with a self-selected cadence (Menzies et al., 2010). During NMES, an electrical stimulator (Compex SP 8.0, Geneva, Switzerland) with surface electrodes (5 × 5 cm, axion® GmBh, Leonberg, Germany) was used to evoke involuntary muscle contractions. We used six channels (three per leg) and two electrodes per channel, which were placed on the origin and muscle belly of the quadriceps (∼2/3 of the rectus femoris), hamstrings (∼2/3 of the biceps femoris and semitendinosus), and calves (∼2/3 of both gastrocnemius to Achilles' tendon) of both legs. We used a current of 5 Hz with a pulse duration of 300 μs at an individualized intensity so as to evoke visible muscle contractions without generating pain (i.e., intensity was increased until the device indicated that it had reached the minimum intensity that produced therapeutic effects), resulting in an average intensity of 22 ± 9 (range 9–41) and 23 ± 10 (range 9–42) mA for the left and right leg, respectively (Malone et al., 2014a).

Measures

Subjective Measures

Exercise-induced delayed-onset of muscle soreness (DOMS) of the lower-limb muscles was assessed at four time points (baseline, immediately post-WOD, post-recovery, and 24 h post-exercise, respectively) through a 0–10 visual analog scale (VAS) while participants performed a squat holding a 90-degree knee position for 5 s (Barnett, 2006). RPE was assessed on a 0–10 scale (Borg, 1982) post-WOD and post-recovery.

Physiological Measures

Blood lactate concentration was quantified using a portable analyzer (Lactate Scout, SensLab GmbH; Leipzig, Germany). Fingertip capillary blood samples (0.5 μL) were taken at baseline (before warm-up) and at several time points during the recovery phase (0, 7.5, and 15 min, respectively, after the WOD). Muscle oxygen saturation (SmO_2) of the right *vastus lateralis* muscle was determined continuously during the 15 min of the recovery phase (Humon, Cambridge, MA, United States) (Farzam et al., 2018). Heart rate (HR) was continuously monitored during the recovery phase with a chest band (BerryKing, BK-HB16-01; Herne, Germany) connected to a mobile app (Wahoo for iPhone 7, Apple Inc., CA, United States).

Performance Measures

Jump height attained in a countermovement (CMJ) and drop jump (DJ) was measured at baseline, post-WOD, immediately post-recovery and 24 h post-exercise, respectively, using a validated mobile app (MyJump2 for iPhone 7, Apple Inc., CA, United States) (Balsalobre-Fernández et al., 2014; Haynes et al., 2019). Participants performed three trials for both CMJ and DJ, with the best results used for analysis. During the CMJ, participants performed a downward movement and jumped when reaching a knee angle of ∼90°. For the DJ, participants stepped from a 40-cm bench and jumped as high as possible with the minimal possible ground contact time. Reactive strength index (RSI) was calculated as jump height in the DJ divided by contact time. Participants were instructed not to flex their knees during flight or landing phases (to avoid an overestimation of flight time) and to maintain their hands on their hips while performing the jumps.

Statistical Analysis

Based on the effect size [partial eta squared (η_p^2) = 0.217] reported by a previous study for the effect of NMES applied after a high-intensity training session on jump performance (Taylor et al., 2015), using GPower (version 3.1.9.2, Universität Düsseldorf, Germany) we estimated that a sample size of 15 participants would be appropriate to find significant differences between conditions in a within-subject research design ($\beta > 80\%$, $\alpha < 0.05$, number of groups = 3, number of measurements = 4).

Data are shown as mean ± SD. The normality and homoscedasticity of the data was tested using the Kolmogorov-Smirnov and Levene's test, respectively. Differences between recovery strategies were determined with a two-way repeated measures ANOVA, with both condition (i.e., recovery strategy) and time as within-subject factors. In order to minimize the risk of type I error, *post hoc* analyses (Bonferroni test) were performed only when a significant interaction (time by recovery strategy) effect was found. Effect sizes (η_p^2) were also computed. All analyses were performed using SPSS (version 23.0, Armonk, NY, United States) setting the level of significance at $p < 0.05$.

RESULTS

All participants completed the WOD. No significant differences were found between recovery methods for the time needed to complete the WOD (340 ± 101, 338 ± 101 and 315 ± 66 s for control, exercise and NMES, respectively; $p = 0.410$; $\eta_p^2 = 0.062$), and RPE reported immediately after the WOD (8.7 ± 0.9, 9.2 ± 1.0 and 9.0 ± 0.8 arbitrary units, respectively; $p = 0.106$; $\eta_p^2 = 0.148$), suggesting similar intensity levels for the three conditions.

When analyzed regardless of the experimental condition applied, no differences were found between sessions for performance nor for any analyzed outcome (all $p > 0.3$, data not shown), which suggests that there was no accumulated fatigue nor a learning/familiarization effect.

Subjective Measures

All three strategies resulted in a reduced RPE at post-recovery compared with post-exercise (time effect $p < 0.001$). In turn, a significant time by strategy interaction effect was observed ($p = 0.035$; $\eta_p^2 = 0.213$) with a non-significant trend toward a lower RPE with NMES compared with control ($p = 0.061$) but with no differences between NMES and exercise or between control and exercise (**Figure 2A**). DOMS increased above baseline values at post-exercise, post-recovery and 24 h later, respectively (time effect $p < 0.001$) and a significant interaction effect was observed ($p = 0.017$; $\eta_p^2 = 0.164$, **Figure 2B**). However, *post hoc* analyses revealed not pairwise differences across conditions at any time point ($p > 0.05$).

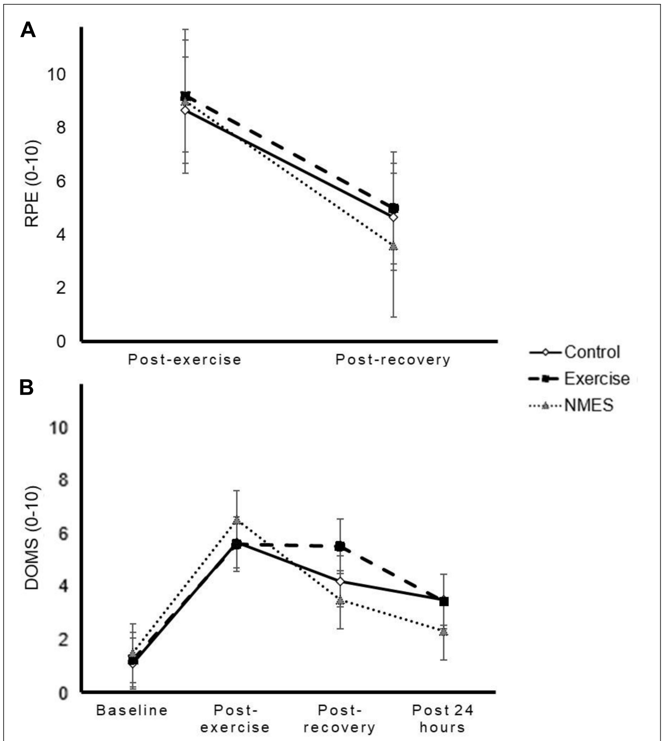

FIGURE 2 | Effects of low-intensity exercise (Exercise), surface neuromuscular electrical stimulation (NMES), or total rest (Control) on rating of perceived exertion (RPE, panel **A**) and delayed-onset muscle soreness (DOMS, panel **B**). A significant interaction effect was found for both variables ($p = 0.035$ and $p = 0.017$, respectively), but *post hoc analyses* revealed no significant differences at any time point.

Physiological Measures

A significant time ($p < 0.001$, $p = 0.004$, and $p = 0.030$, respectively) but no significant interaction effect [$p = 0.920$ ($\eta_p^2 = 0.023$), $p = 0.831$ ($\eta_p^2 = 0.026$), and $p = 0.694$ ($\eta_p^2 = 0.038$)] was noted for blood lactate (**Figure 3A**), HR (**Figure 3B**), and SmO_2 (**Figure 3C**).

Performance Measures

Jump performance significantly declined after exercise and kept below baseline levels after the recovery phase and 24 h later [time effect $p < 0.001$, $p < 0.001$, and $p = 0.059$ for CMJ (**Figure 4A**), DJ (**Figure 4B**), and RSI (**Figure 4C**)]. However, no differences were found between methods [interaction effect $p = 0.388$ ($\eta_p^2 = 0.071$), $p = 0.296$ ($\eta_p^2 = 0.081$), and $p = 0.390$ ($\eta_p^2 = 0.071$) for CMJ (**Figure 4A**), DJ (**Figure 4B**), and RSI (**Figure 4C**), respectively].

DISCUSSION

Our findings suggest a comparable effectiveness of NMES, low-intensity exercise or total rest for enhancing recovery after HIFT, with the former tending to lower perceived fatigue immediately after recovery compared with total rest. However, no additional benefits were found with NMES for other perceptual indicators (DOMS) or for physiological (blood lactate, HR, muscle oxygen kinetics) or performance (jump performance) outcomes.

Previous studies comparing the effectiveness of NMES and active recovery have yielded conflicting results (Heyman et al., 2009; Malone et al., 2012; Bieuzen et al., 2014; Taylor et al., 2015). Neric et al. (2009) found that, when applied with low-frequency, NMES might accelerate the removal of metabolites such as lactate compared with active recovery (sub-maximal swimming) after a sprint swim (200 yard). However, several studies have found no benefits with NMES or even lower benefits than those elicited by active recovery. Akinci et al. (2020) reported no differences between NMES and active recovery (walking at 40% heart rate reserve) on muscle strength, DOMS, or blood lactate removal after a HIT session. More recently, Paradis-Deschênes et al. (2020) reported no differences on muscle oxygen kinetics, blood lactate concentration, pH or performance when recovering with NMES or low-intensity exercise (cycling) between two consecutive 5-km cycling time trials. Other studies have also reported no beneficial effects on performance nor on other fatigue indicators such as heart rate, RPE, blood lactate,

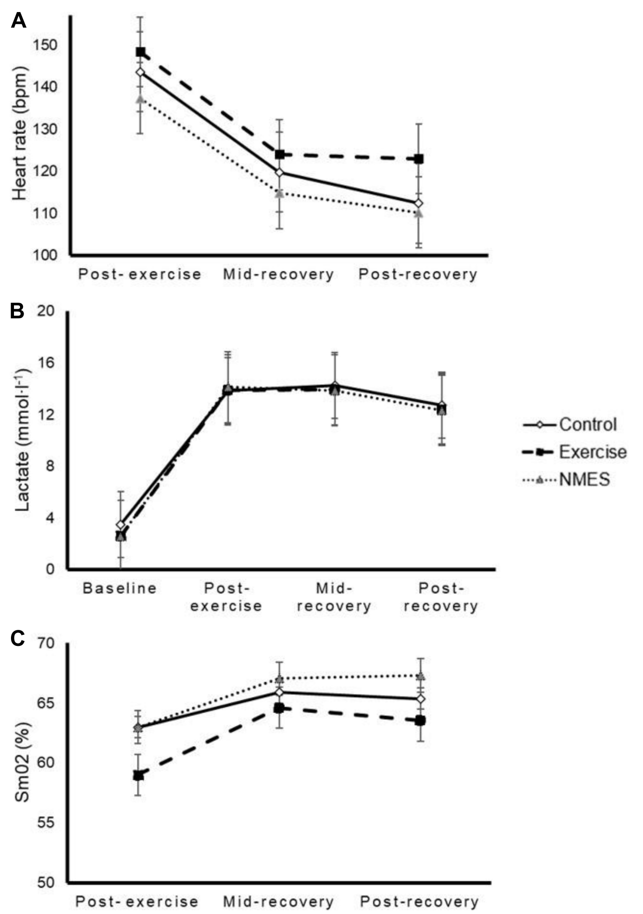

FIGURE 3 | Effects of low-intensity exercise (Exercise), surface neuromuscular electrical stimulation (NMES) or total rest (Control) on heart rate (panel **A**), blood lactate (panel **B**), and muscle oxygen saturation (SmO_2, panel **C**). No significant interaction effect was found ($p = 0.920$, $p = 0.831$, and $p = 0.694$, respectively).

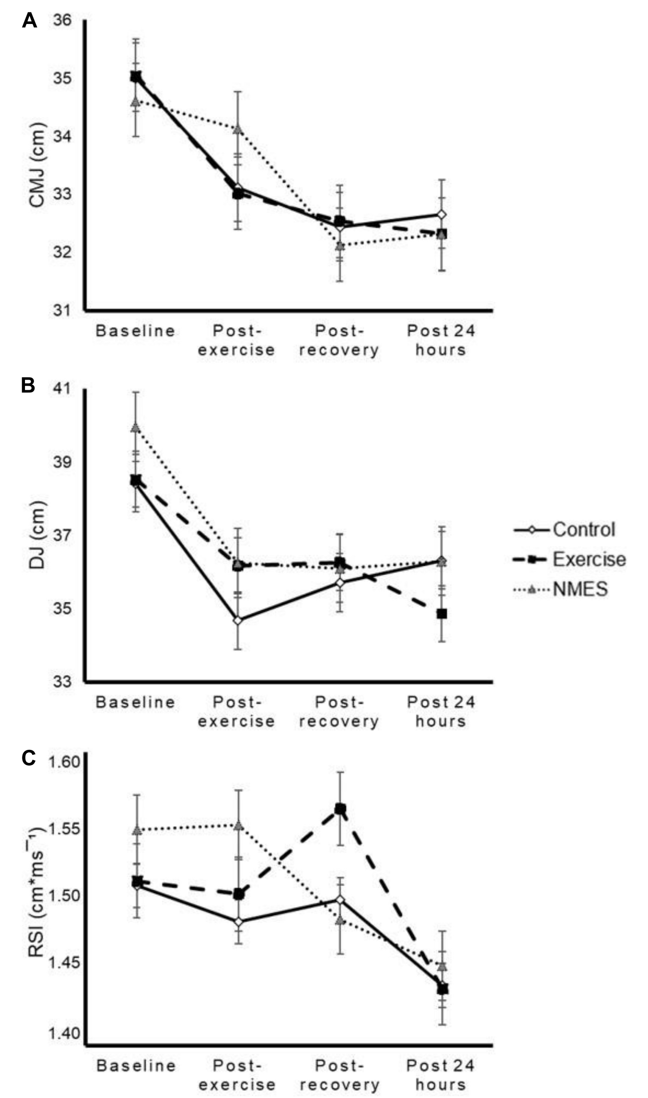

FIGURE 4 | Effects of low-intensity exercise (Exercise), neuromuscular electrical stimulation (NMES), or total rest (Control) on countermovement jump (CMJ, panel **A**), drop jump (DJ, panel **B**), and reactive strength index (RSI, panel **C**). No significant time by condition interaction effect was found ($p = 0.388$, $p = 0.296$, and $p = 0.390$, respectively).

or DOMS with NMES or active recovery after a futsal game or a high-intensity exercise bout (Lattier et al., 2004; Tessitore et al., 2008). Moreover, Bieuzen et al. reported a better short-term recovery between two bouts of exhausting exercise (Yo-Yo Intermittent Recovery tests) in female handball players with active recovery (low-intensity cycling) compared with NMES (Bieuzen et al., 2014). In the same line, Malone et al. reported an impaired blood lactate clearance and no benefits (or even performance impairments) with NMES recovery (30 min of self-intensity) compared with active recovery [30 min cycling at 30% maximal oxygen consumption (VO_{2max})] between consecutive high-intensity exercise bouts (consecutive Wingate Anaerobic tests) (Malone et al., 2012, 2014a).

Some controversy also exists regarding a hypothetical superiority of NMES over total rest. Borne et al. reported that, among several recovery strategies (total rest, blood flow restriction, placebo, NMES) applied after consecutive 30-s bouts of supramaximal exercise, NMES elicited the largest increases in calf arterial inflow and was the only one that allowed recovery of performance between exercise bouts (Borne et al., 2017). Other studies have provided further support to these findings. Notably, Bieuzen et al. showed that, after a high-intensity repeated-sprint test, NMES applied to the calf muscles for 15 min accelerated the return of pH and blood lactate to baseline values compared with total rest, also improving performance recovery (Bieuzen et al., 2014). Taylor et al. (2015) reported that NMES fostered performance recovery and resulted in lower levels of serum creatine kinase (an indicator of skeletal muscle damage) and muscle soreness 24 h after a repeated-sprints training session compared with total rest. Also, Barcala-Furelos et al. (2020) concluded that NMES applied immediately after a water rescue (200 m swimming with "false human victims") could be an effective recovery strategy to clear out blood lactate compared with total rest. In the present study, we observed a quasi-significant trend ($p = 0.061$) toward a greater perceived recovery with NMES compared with total rest, which is in line with previous research (Tessitore et al., 2008; Cortis et al., 2010). However, no benefits were found for any of the remaining outcomes. Similarly, Malone et al. (2012, 2014b) reported no differences when using NMES or total rest as recovery, on performance or different physiological markers (blood lactate, HR). Thus, further evidence is needed to support an eventual superiority of NMES over total rest for recovery after strenuous exercise, although the potential benefits we found on perceived recovery—which could also be due, at least partly, to a certain placebo effect—should not be overlooked.

Interestingly, our findings also suggest no benefits of active recovery over total rest. One of the main reasons for supporting a potential benefit of active recovery versus rest is the increased blood flow with the former, which could accelerate metabolite removal (e.g., lactate) and increase oxygen and nutrient supply to the muscle. The recruitment of these muscle fibers was confirmed by the high blood lactate concentrations recorded in "Fran session" (14.0 mmol l^{-1}) as Fernandez-Fernandez et al. reported about lactate responses to a CrossFit WOD with similar sample (Fernández et al., 2015). However, the practical relevance of a hastening blood lactate removal in terms of recovery remains questionable (Van Hooren and Peake, 2018). Although controversy exists and some benefits have been reported particularly on subjective measures (perceived recovery) (Ortiz et al., 2019) at present there is no consistent evidence supporting the superiority of active post-exercise recovery over total rest on physiological or performance parameters (Van Hooren and Peake, 2018).

Several factors could at least partly explain the lack of beneficial effects observed in the present study with NMES or even with active recovery compared with total rest. We observed no benefits after an exercise bout ("Fran WOD") that is physically demanding, as reflected by high RPE (~9 out of 10) and lactate values (>12 mmol l^{-1})—which is in line with the responses reported by other authors for the same WOD (Fernández et al., 2015). However, whether these strategies could be beneficial after other types of WOD requires further investigation. In this regard, it is important to note that the WOD performed in the present study included both lower- and upper-limb exercises, whereas the recovery strategies applied did only target the lower limbs. Research is therefore warranted to confirm whether whole-body recovery strategies could provide greater benefits in this type of exercise. On the other hand, methodological factors such as the intensity or stimulation frequency of NMES, or the intensity and exercise modality of active recovery, could also potentially conditionate their effectiveness. Moreover, the short duration of the recovery phase (15 min) could also explain the lack of beneficial effects observed with both NMES and active recovery.

Some limitations of the present study should be noted, such as the fact that we did not assess some important fatigue-related variables (e.g., serum creatine kinase, muscle glycogen levels, upper-body DOMS) or sport-specific (i.e., HIFT) performance. Moreover, our findings are applicable to the present protocol and not necessarily generalizable to other exercise stimuli. In turn, a major strength is that, to our knowledge, this is the first study to assess the effectiveness of different recovery strategies after a HIFT session. The variety of outcomes we determined (including perceptual, physiological and performance indicators) can also be considered a strength.

CONCLUSION

The present findings suggest that CrossFit athletes can attain a similar short-term recovery with either total rest, low-intensity exercise or NMES, with the former being in addition a simpler and more economical option. It must be noted, however, that NMES might result in a slightly, quasi-significant improvement in the subjective perception of recovery immediately after its application, although a potential placebo effect should not be disregarded.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Hospital Universitario Fundación Alcorcón. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RM-G and PV contributed equally to realize the study. DB-G and AL contributed to the design, analysis of the results, and to the writing of the manuscript. All authors contributed to the article and approved the submitted version.

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Effects of a New Form of Resistance-Type High-Intensity Interval Training on Cardiac Structure, Hemodynamics, and Physiological and Performance Adaptations in Well-Trained Kayak Sprint Athletes

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This study examined the effects of a resistance-type high-intensity interval training (RHIIT) matched with the lowest velocity that elicited $\dot{V}O_{2peak}$ (100% $v\dot{V}O_{2peak}$) in well-trained kayak sprint athletes. Responses in cardiac structure and function, cardiorespiratory fitness, anaerobic power, exercise performance, muscular strength, and hormonal adaptations were examined. Male kayakers (n = 24, age: 27 ± 4 years) were randomly assigned to one of three 8-wk conditions (N = 8): (RHIIT) resistance training using one-armed cable row at 100% $v\dot{V}O_{2peak}$; paddling-based HIIT (PHIIT) six sets of paddling at 100% $v\dot{V}O_{2peak}$; or controls (CON) who performed six sessions including 1-h on-water paddling/sessions at 70–80% maximum HR per week. Significant increases ($p < 0.05$) in $\dot{V}O_{2peak}$, $v\dot{V}O_{2peak}$, maximal cardiac output, resting stroke volume, left ventricular end-systolic dimension, 500-m paddling performance were seen pre- to post-training in all groups. Change in $\dot{V}O_{2peak}$ in response to PHIIT was significantly greater ($p = 0.03$) compared to CON. Also, 500-m paddling performance changes in response to PHIIT and RHIIT were greater (p = 0.02, 0.05, respectively) than that of CON. Compared with pre-training, PHIIT and RHIIT resulted in significant increases in peak and average power output, maximal stroke volume, end-diastolic volume, ejection fraction, total testosterone, testosterone/cortisol ratio, and 1,000-m paddling performance. Also, the change in 1,000-m paddling performance in response to PHIIT was significantly greater ($p = 0.02$) compared to that of CON. Moreover, maximum strength was significantly enhanced in response to RHIIT pre- to post-training ($p < 0.05$). Overall, RHIIT and PHIIT similarly improve cardiac structure and hemodynamics, physiological adaptations, and performance of well-trained kayak sprint athletes. Also, RHIIT enhances cardiorespiratory fitness and muscular strength simultaneously.

Keywords: oxygen consumption, cardiorespiratory fitness, intermittent exercise, water sports, exercise training

INTRODUCTION

High-intensity interval training (HIIT), repeated bouts at near-maximal to maximal intensities interspersed with recovery, has been shown to increase maximum oxygen uptake ($\dot{V}O_{2max}$), anaerobic power, and exercise performance (Laursen and Buchheit, 2019; Mallol et al., 2020). Optimizing exercise programs leading to these adaptations can be complex and involve modification of intensity, frequency, and duration, during prescription (MacInnis and Gibala, 2017). In addition, the modality of the exercise plays a key role in designing specialized programs (Fereshtian et al., 2017; Sheykhlouvand et al., 2018a).

Kayak sprint is an Olympic event and takes place on a flat-water course and races are contested by kayak. In a kayak, the athlete competes in a sitting position using a double-blade paddle. At the international level, the discipline is competed at four distances from 200 to 5,000-m, both individually and in crew of up to four. Kayak individual events include the 200-m (~38 s), 500-m (~100 s) and 1,000-m (~220 s) for world-level kayakers (International Canoe Federation).[1] To compete at this level, kayak sprint athletes need substantial upper-body aerobic and anaerobic power (Bishop, 2000; Michael et al., 2008; Zouhal et al., 2012; Borges et al., 2015; Sheykhlouvand et al., 2015; Sheykhlouvand and Forbes, 2017; Barzegar et al., 2021). For example, contribution of aerobic metabolism during kayak sprinting in elite athletes has been estimated using the accumulated oxygen deficit method to be ~37, 64–78, and 85–87% for 200, 500, and 1,000-m events, respectively. Contrary to 500 and 1,000-m performance, 200-m race performance is not related to maximum oxygen uptake ($\dot{V}O_{2max}$) but lactate threshold and anaerobic capacity/power (Paquette et al., 2018). On the other hand, upper-body strength and muscular endurance are strong determinants of kayak sprint performance, and augmenting the pulling motion enhances the pulling force throughout the pull phase of paddling and improves maintenance of speed (Ualí et al., 2012; McKean and Burkett, 2014). As the concurrent action of several physiological variables affects sport-specific performance (Sousa et al., 2020), kayak sprint athletes need to emphasize these factors in their programs to maximize exercise performance. Although paddling technique and economy play an important role in athletic performance, in this study we specifically focused on physical and physiological variables.

Kayak sprint paddlers often need to reach peak performance for competitions several times over an annual training cycle and require a training program to achieve fitness in a short period of time. Training programs capable of improving both metabolic conditioning and muscular strength are time-demanding (Haff and Triplett, 2016; Sheykhlouvand et al., 2016b) and cannot be prioritized over each other in kayak sprint. It is therefore common practice for athletes to engage in resistance training in combination with training aimed at enhancing cardiorespiratory and metabolic fitness (e.g., HIIT). In such situations, designing a sport-specific time-efficient training protocol with a combination of resistance and aerobic training capable of satisfying both ends of the strength-endurance continuum could be of value.

$v\dot{V}O_{2peak}$ is known as an optimal load to stimulate cardiorespiratory fitness adaptations (Buchheit and Laursen, 2013) and we recently showed that paddling-based HIIT using a kayak ergometer at the lowest velocity that elicited $\dot{V}O_{2peak}$ (100% $v\dot{V}O_{2peak}$) improves cardiorespiratory fitness and anaerobic power in trained paddlers (Sheykhlouvand et al., 2016a,b, 2018b). Ualí et al. (2012) demonstrated that one-armed cable row exercise may stress the muscles involved in kayak paddling, so in this study, we employed this modality to implement a new resistance-type HIIT regimen (RHIIT) matched with 100% $v\dot{V}O_{2peak}$ to perform a single-mode training to simultaneously stimulate upper-body muscular strength and cardiorespiratory fitness adaptations. In other words, we may perform a single-mode exercise to stimulate the adaptations related to both qualities instead of performing two isolated sessions for each training mode. Hence, we decided to test: (a) whether RHIIT might be considered as an effective stimulant as traditional HIIT to improve cardiorespiratory fitness and (b) if RHIIT may enhance both cardiorespiratory fitness and muscular strength simultaneously. Accordingly, the aim of this study was to investigate the effects of an 8-week resistance-type HIIT on cardiac structure and hemodynamics, aerobic and anaerobic power, muscular strength, and kayaking performance compared to traditional kayak-specific HIIT regimen in well-trained kayak sprint athletes. We hypothesized that both HIIT protocols will improve the cardiorespiratory fitness adaptations of well-trained kayakers compared to a control group. Also, resistance-type HIIT will enhance both cardiorespiratory fitness and muscular strength simultaneously.

MATERIALS AND METHODS

Participants

Twenty-four well-trained male kayakers (mean age=27 ± 4 years; height = 180 ± 2 cm; mass = 83 ± 5 kg; body fat = 9.4 ± 1.3%; years of experience = 11 ± 3 years) provided their written informed consent and volunteered to participate. All participants were members of the Iran national kayak sprint team and 18 were medalists of the Asian championships. Following screening for the presence of any unknown disease or conditions putting them at risk of adverse response to high-intensity exercise, participants were randomly assigned to paddling based HIIT (PHIIT), resistance-type HIIT (RHIIT), or a control group (CON). All procedures were in accordance with ethical principles of the Declaration of Helsinki and approved by the institutional review board of the University of Guilan and ethical committee of Sport Sciences Research Institute of Iran (approval ID: IR.SSRC.REC.1400.019).

Overview of Experimental Protocol

In order to become oriented with all devices, testing procedures, and training protocols, all participants performed some familiarization visits to the laboratory at least 3 days before baseline measurement. Pre-testing of cardiorespiratory

[1] www.canoeicf.com

fitness and anaerobic power, along with cardiac structure and hemodynamic parameters as well as blood and biochemical parameters was conducted before the beginning of pre-season training, with post-testing held immediately after completion of the exercise programs. Prior to the beginning of training period, participants completed 3 sessions of a 30-min paddling time trial on a kayak ergometer (Dansprint, Hvidovre, Denmark) at a self-selected pace and an incremental paddling test to volitional fatigue. Participants also performed two upper body 30-s Wingate tests on a separate day to become familiar with these performance tests.

In the pre- and post-training, participants completed an incremental exercise test to determine peak oxygen uptake ($\dot{V}O_{2peak}$) and related physiological variables. Time for which $v\dot{V}O_{2peak}$ can be maintained (Tmax), upper-body Wingate test, one repetition maximum (1RM) in one-armed cable row, and 500 and 1,000-m on-water paddling performances were also evaluated on separate days. Cardiac structure and hemodynamics were evaluated before and after training. Also, body composition was determined using bioelectrical impedance analysis (Inbody 520, South Korea). All the aforementioned tests were completed in the morning, with 24 h of recovery separating each test. **Figure 1** shows a schematic of the sequence of methods and order of the tests used in the present study.

Incremental Exercise Test

Using a breath-by-breath gas collection system (Cosmed K4B2, Rome, Italy), participants performed an incremental paddling test on a kayak ergometer to determine $\dot{V}O_{2peak}$, $v\dot{V}O_{2peak}$, maximal ventilation ($\dot{v}_E@\dot{V}O_{2peak}$), respiratory frequency ($R_f@\dot{V}O_{2peak}$), and tidal volume ($\dot{V}_T@\dot{V}O_{2peak}$). The test began at 6 $km \cdot h^{-1}$ and workload increased 1 $km \cdot h^{-1}$ every 1 min until volitional exhaustion (Sheykhlouvand et al., 2016a,b, 2018a,b). The drag of the ergometer was adjusted according to the kayakers' body mass as recommended by the producer to simulate on-water drag during paddling. When three or more of the following criteria were met, participants were considered to have reached their $\dot{V}O_{2peak}$: (I) the $\dot{V}O_2$ ceased to increase linearly despite the increase in workload and approached a plateau or decreased slightly with the last two values within $\pm$ 2 $ml^{-1} \cdot kg^{-1} \cdot min^{-1}$; (II) a respiratory exchange ratio reached to 1.1 (Sheykhlouvand et al., 2016a,b, 2018a,b). The $v\dot{V}O_{2peak}$ (or Vmax) was defined as the minimal speed at which the athlete was paddling when $\dot{V}O_{2peak}$ occurred.

Hemodynamic Function

The hemodynamic function was evaluated using a transthoracic electrical impedance cardiograph device (PhysioFlow, Manatec, France). This method has been validated and described by previous researches and is known as a reliable method at rest and exercise up to $\dot{V}O_{2max}$ (Charloux et al., 2000; Richard et al., 2001). Two electrodes were placed on the neck, two at the xiphoid sternum, and one on each side of the chest as recommended by the manufacturer. Once a 20-s calibration was completed, hemodynamic values were recorded. At termination of incremental exercise, maximal values for HR (HR_{max}), stroke volume (SV_{max}), cardiac output ($\dot{Q}_{max}$), end-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF) were obtained.

Upper-Body Wingate Test

Using a mechanically braked arm ergometer (891E; Monark, Vansbro, Sweden), participants completed a 30-s all-out effort to determine peak power output (PPO) and average power output. Participants were instructed to crank against the internal resistance of the ergometer as fast as possible and a load equivalent to 0.075 $kg \cdot kg^{-1}$ body mass (Forbes et al., 2014) was applied instantaneously (within 3 s). Participants were verbally encouraged to crank as fast as possible throughout the test. PPO and average power output were calculated using the devise software.

Time for Which $v\dot{V}O_{2peak}$ Can Be Maintained (Tmax)

After a warm-up comprising 5-min of paddling at 50% $v\dot{V}O_{2peak}$, 5 min stretching, and another 5 min of paddling at 60% $v\dot{V}O_{2peak}$, the paddling speed was increased to $v\dot{V}O_{2peak}$ and participants exercised on kayak ergometer until exhaustion. The test was terminated volitionally by the subject if the desired speed could not be maintained and the time maintained at $v\dot{V}O_{2peak}$ (Tmax) was recorded. Participants were verbally encouraged to paddle as long as possible. In the post-training, this test was repeated following identical procedures.

One Repetition Maximum (1RM) in One-Armed Cable Row

1RM testing started with a warm-up consisting of 5 min of paddling on an ergometer (Dansprint, Hvidovre, Copenhagen, Denmark) at 6 $km \cdot h^{-1}$ followed by upper-body joint mobilization exercises. Following a 2-min recovery, participants performed one set of 6 repetitions with a load equal to 60% estimated 1RM followed by one set of 2–3 repetitions at 80% estimated 1RM (Seated pulley cable row machine, Technogym, Italy). Thereafter, to control the work rate accurately and simplify the matching equation that will be explained in section "Exercise Training Protocols," the movement distance of the one-armed cable row was set at 1 meter (distance between the beginning and the end of motion) and participants performed 3–5 one-repetition sets only with one arm individually and with a 4-min recovery between sets to determine 1RM. The heaviest load that each subject could properly lift in a 1-m motion distance was considered to represent his 1RM (Ualí et al., 2012).

Transthoracic Echocardiography

Using a Vivid E95 Ultra edition machine (GE Healthcare, Chicago, Illinois, United States) and according to the recent guidelines (Lang et al., 2015), transthoracic echocardiography was performed at rest and in a left lateral decubitus position. HR was continuously measured by a single-lead electrocardiogram. In the two-dimensional view, structural parameters were recorded with linear internal measurements of the left ventricle (LV) acquired in the parasternal long-axis view. Stroke volume,

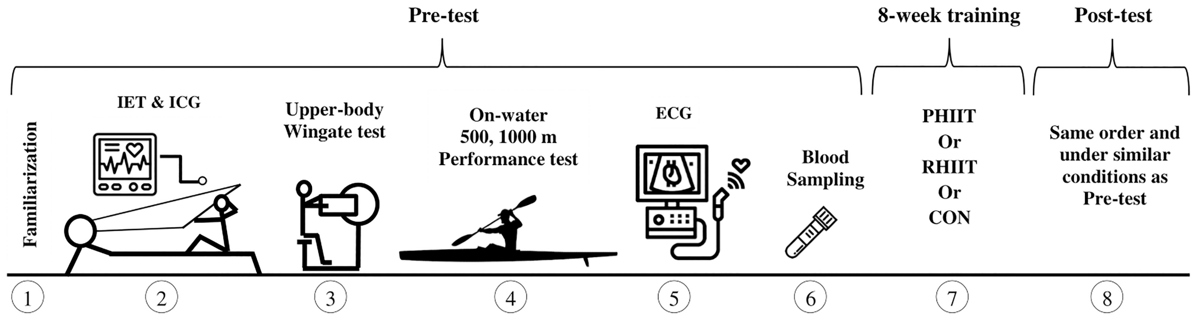

FIGURE 1 | Overview of the experimental protocol. ECG, echocardiography; IET, incremental exercise test; ICG, impedance cardiography; PHIIT, paddling-based HIIT; RHIIT, resistance-type HIIT. Numbers in circles denote sequences of testing procedure and training period.

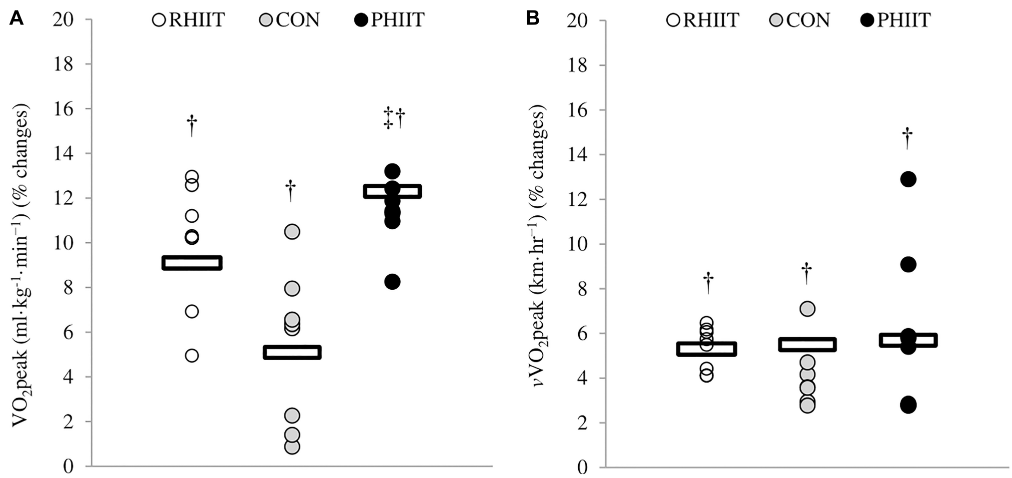

FIGURE 2 | Effects of paddling-based HIIT (PHIIT), resistance-type HIIT (RHIIT), and on-water kayak sprint (CON) training on changes in **(A)** $\dot{V}O_{2peak}$, and **(B)** $v\dot{V}O_{2peak}$. Circles show individual percentage change from baseline and horizontal bars show mean group percentage change from baseline (X-axes). *N* = 8 for each group. †Significantly different vs. pre-training ($p \leq 0.05$). ‡Significantly different vs. control group ($p \leq 0.05$).

interventricular septal wall thickness (IVSWT), left ventricle mass (LVM), and left ventricle end-systolic and end-diastolic diameters (LVESd and LVEDd) were recorded. All echocardiographic studies were reviewed by the same cardiologist blinded to group allocation.

Blood Sampling

Participants were sampled in the morning after an overnight fast exceeding 8 h. A 10-ml venous blood sample was collected in the pre- and post-training by venipuncture from an antecubital vein in the morning after an overnight fast exceeding 8 h. Seven milliliters of blood was immediately spun at 3,000 rpm for 15 min at 4°C and separated and stored at −80°C for measuring total testosterone and cortisol. Serum concentrations of total testosterone [Cayman Chemical, Ann Arbor, Michigan, United States; intra-assay coefficient of variation (CV) = 4.4%] and cortisol (Cayman Chemical, Ann Arbor, Michigan, United States; intra-assay CV = 6.7%) were determined by ELISA kits. Also, using an automated cell counter (Abacus C; Diatron, Budapest, Hungary), the remaining 3-ml blood sample was measured to record complete blood count. Also, plasma volume change was calculated using following equation (Rotstein et al., 1982):

$$\text{Plasma volume change} = 100\times \left[\frac{Hb_{pre}}{Hb_{post}} \times \frac{(1 - Hct_{post} \times 10^{-2})}{(1 - Hct_{pre} \times 10^{-2})}\right] - 100$$

Hb_{pre} = hemoglobin concentration before the exercise,
Hb_{post} = hemoglobin concentration after the exercise,
Hct_{pre} = hematocrit value before the exercise (%),
Hct_{post} = hematocrit value after the exercise (%).

On-Water Exercise Performance

In the pre- and post-training, participants completed 500- and 1,000-m on-water paddling tests over three consecutive days. The day first was dedicated to the 500-m test; participants then rest during the second day, and they completed the 1,000-m test on the third day. Prior to testing, they completed a standardized warm-up according to Borges et al. (2015). Each participant performed two trials of 500-m test and two trials of 1,000-m test interspersed with 1 h of passive recovery. Time was recorded using two synchronized stopwatches (Interval 2,000 XC Track and Field watch, Nielsen-Kellerman, Delaware, Pennsylvania, United States) and the best times were used for analysis. The tests were performed on flat water with an average tail wind of $\sim$3.2 m·s^{-1} at an ambient temperature of $\sim$23°C. The condition was almost the same during pre- and post-training.

Exercise Training Protocols

Approximately 48 h after the last baseline measurement, participants underwent 8-weeks of kayak ergometer training, on-water paddling program, or one-armed cable row. Participants undergoing HIIT (PHIIT and RHIIT) performed three HIIT sessions and three traditional on-water paddling sessions each week. In PHIIT, the subjects performed six intervals at 100% $v\dot{V}O_{2peak}$ with training volume varying each week (60, 70, 75, 75, 75, 75, 70, and 60)%Tmax from first to eighth week, respectively, using a 1:1 work to recovery ratio. Traditional on-water paddling sessions consisted of 60 min of paddling at 70–80% HRmax (55–75% $\dot{V}O_{2max}$; Haff and Triplett, 2016).

The participants performing RHIIT completed one-armed cable row training matched with PHIIT with respect to total work and training duration. As the training mode was one-armed, the hands were alternated during efforts. For matching the total work, work rate at 100% $v\dot{V}O_{2peak}$ [Watts (W)] was recorded from the kayak ergometer. Each W is equal to 1 Joule·s^{-1} where each Joule is a result of force [Newton (N)] multiplied by distance [meter (M)] leaving:

$$\text{Power (W)} = \frac{\text{Force (N)} \times \text{Distance (M)}}{\text{Time (sec)}}$$

Considering time commitment of %Tmax (sec) leads to the following equation:

$$\text{Work (Force [N]} \times \text{Distance [M])} = \text{Power (W)} \times \text{Time (sec [\%Tmax])}$$

By multiplying work (Newton-force Meter) by 0.10197, we can convert it to Kilogram-force Meter and the equation would be:

$$\text{Work}\left(\text{Force}\left[\text{kg}\right] \times \text{Distance [M]}\right) = \text{Power (W)} \times \text{Time}$$

$$\text{(sec [\%Tmax])} \times 0.10197$$

Subsequently, 1RM of one-armed cable row in a 1-m motion distance was evaluated and target 1RM [%1RM (kg)] was identified. The PHIIT regimen requires a high-volume training with respect to the time (%Tmax), the RHIIT and PHIIT were performed in the strength endurance phase of the kayakers' yearly training program where the intensity of repetitions is low to moderate (50–75% 1RM) and the volume is high (Haff and Triplett, 2016). Then, the force (kg) that must be carried in 1-m distance divided by target 1RM [50% 1RM (kg)] and the number of repetitions in one-armed cable row in 1-m distance was specified. On this occasion, as the distance of motion in one-armed cable row is 1 m, the value of force (kg) and work [force (kg) multiplied by distance (1)] would be the same and the number of repetitions will be as follow:

$$\text{Number of repetitions} = \frac{\text{Force (kg)}}{\text{50\% 1RM (kg)}}$$

Considering that each athlete had his own 1RM and Tmax, the number of repetitions was specialized and varied among the participants.

With such a matching method, the total work performed during PHIIT and RHIIT would be the same. The key point is the difference between imposed force by each stroke (during paddling HIIT) and each repetition (during resistance HIIT) and the total number of strokes or reps during the working time (Tmax). The difference is that the number of strokes during paddling HIIT is more than the number of repetitions during RHIIT but the imposed force in each repetition in RHIIT is greater than that of each paddling stroke in PHIIT.

The participants in CON performed six sessions of on-water kayak paddling per week including 60 min of traditional endurance paddling at 70–80% HR_{max}. Also, all three groups performed 1 d/wk of Fartlek training [45 min of long slow distance run (LSD)] and 2 sessions per week of weight training consisting of 3 sets of 8–12 repetitions at 70% 1RM including bench pull, bench press, seated row, bicep curl, military press, pulley pushdowns and trunk rotation) and push-ups, sit-ups, and pull-ups.

Dietary Control

To avoid potential confounding of the results mediated by taking supplements and stimulants, participants were directed to continue the same habitual nutrition intake during the experiment. Consuming the same diet 48 h prior to and post-training assessment was encouraged. In addition, subjects were asked to refrain from participating in vigorous activity and to avoid the consumption of caffeinated food and beverages in the 24-h period prior to testing.

Statistical Analyses

Sample size for three groups (N = 8) was calculated using G*Power software (Faul et al., 2007) and Statistical analyses were performed using SPSS, version 25.0 (Statistical Package for Social Science, Chicago, IL). Results were expressed as mean ± *SD*. The Shapiro-Wilk test was used to test the normality and Levene's test was used to assess homogeneity of variances. The data were analyzed using a two-factor mixed analysis of variance (ANOVA) with the between factor "group" (PHIIT, RHIIT, and CON) and repeated factor "time" (pre-training, post-training). Significant interactions or main effects were subsequently analyzed using a Tukey's honestly significant difference *post-hoc* test. One-way ANOVA was used to analyze difference between changes in plasma volume in different groups. Pearson product–moment correlations were used to examine

TABLE 1 | Change in gas exchange indices, power output and 1RM in response to training.

	Group		
	PHIIT	**RHIIT**	**CON**
$\dot{V}_E$@$\dot{V}O_{2peak}$ (l.min^{-1})			
Pre	131.81 (10.80)	130.85 (8.09)	137.73 (12.19)
Post	151.82 (15.61) †	143.88 (13.63) †	144.82 (10.81)
%Δ	+ 15.2	+ 9.9	+ 5.1
$\dot{V}_T$@$\dot{V}O_{2peak}$ (l.b^{-1})			
Pre	2.35 (0.17)	2.24 (0.35)	2.35 (0.29)
Post	2.34 (0.23)	2.27 (0.33)	2.36 (0.21)
%Δ	–0.04	+ 1.3	+ 0.04
R_f@$\dot{V}O_{2peak}$ (b.min^{-1})			
Pre	56.17 (2.66)	59.06 (6.57)	55.36 (4.78)
Post	62.25 (3.35) †	63.58 (4.02) †	57.75 (5.54)
%Δ	+ 10.8	+ 7.6 ‡	+ 4.3
PPO (W)			
Pre	530.95 (35.0)	512.16 (49.3)	514.70 (72.1)
Post	570.10 (42.4) †	564.83 (52.8) †	535.67 (67.1)
%Δ	+ 7.3	+ 10.3	+ 4.1
Average PO (W)			
Pre	396.71 (51.8)	387.57 (50.8)	374.20 (37.14)
Post	430.07 (56.4) †	409.95 (46.2) †	379.50 (27.97)
%Δ	+ 8.4	+ 10.5	+ 1.4
1RM in OACR with right hand (kg)			
Pre	69.1 (5.7)	67.1 (2.9)	68.9 (4.6)
Post	71.9 (3.9)	72.2 (2.8) †	72.0 (4.1)
%Δ	+ 4.0	+ 7.6	+ 4.5
1RM in OACR with left hand (kg)			
Pre	66.6 (5.2)	64.5 (2.8)	66.1 (3.6)
Post	69.6 (4.2)	69.4 (3.0) †	68.7 (3.4)
%Δ	+ 4.5	+ 7.5	+ 3.9

Values are means (± SD).
PPO, peak power output; $\dot{V}_E$, ventilation; $\dot{V}_T$, tidal volume; R_f, respiratory frequency; 1RM, one repetition maximum; OACR, one-armed cable row; N, 8 for each group.
†Significantly greater than pre-training value ($p < 0.05$). ‡Significantly different change compared with CON group ($p < 0.05$).
N = 8 for each group.

TABLE 2 | Change in biochemical outcomes in response to training.

	Group		
	PHIIT	**RHIIT**	**CON**
TT (μg·dl^{-1})			
Pre	0.588 (0.14)	0.624 (0.14)	0.586 (0.09)
Post	0.716 (0.10) †	0.733 (0.15) †	0.599 (0.11)
%Δ	+ 21.7	+ 17.4	+ 2.2
Cortisol (μg·dl^{-1})			
Pre	20.12 (1.88)	19.97 (5.10)	18.65 (4.90)
Post	19.47 (2.28)	18.55 (4.08)	18.43 (4.67)
%Δ	-3.3	-7.6	-1.1
T/C ratio			
Pre	0.029 (0.00)	0.032 (0.00)	0.034 (0.01)
Post	0.037 (0.00) †	0.042 (0.01) †	0.035 (0.01)
%Δ	+ 27.6	+ 31.2	+ 2.9
RBC (Mill·mm^{-3})			
Pre	5.59 (0.24)	5.48 (0.29)	5.72 (0.44)
Post	5.42 (0.37)	5.60 (0.49)	5.73 (0.30)
%Δ	-3.1	+ 2.1	+ 0.1
Hb (g·dl^{-1})			
Pre	15.70 (0.72)	15.23 (1.43)	15.36 (1.44)
Post	15.38 (1.09)	15.23 (1.38)	15.65 (1.35)
%Δ	-2.0	0.0	+ 1.8
Hct (%)			
Pre	47.13 (1.51)	46.78 (2.02)	47.11 (2.29)
Post	46.26 (2.20)	46.48 (2.29)	47.01 (2.56)
%Δ	-1.8	-0.6	-0.2

Values are means (± SD).
Hb, hemoglobin; Hct, hematocrit; RBC, red blood cell; TT, total testosterone; T/C, testosterone/cortisol. N, 8 for each group.
†Significantly greater than pre-training value ($p < 0.05$).
N, 8 for each group.

relationships between variables. Effect size was calculated using Cohen's d (d). Alpha level was set at 0.05.

RESULTS

Change in Maximal Gas Exchange Variables, Power Output and One Repetition Maximum

No pre-training difference was observed between groups for these physiological parameters. After the 8-week training program, a significant time-regimen interaction (p = 0.04) was found in $\dot{V}O_{2peak}$. As shown in **Figure 2A**, the change in $\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1}) in response to PHIIT was significantly greater compared to CON (p = 0.03, d = 2.02). $\dot{V}O_{2peak}$ was significantly increased in PHIIT (Post: 54.35 ± 3.65 vs. Pre: 48.39 ± 3.91 ml·kg^{-1}·min^{-1},%Δ = 12.3, p = 0.0006, d = 1.6), RHIIT (Post: 52.31 ± 4.97 vs. Pre: 47.59 ± 4.48 ml·kg^{-1}·min^{-1}, %Δ = 9.1, p = 0.002, d = 1.0), and CON (Post: 48.31 ± 2.13 vs. Pre: 45.95 ± 2.73 ml·kg^{-1}·min^{-1}, %Δ = 5.1, p = 0.003, d = 0.9) compared with pre-training.

After the 8-week training period, $v\dot{V}O_{2peak}$ significantly increased in PHIIT (Post: 18.2 ± 0.5 vs. Pre: 17.2 ± 0.9 km·h^{-1}, %Δ = 5.7, p = 0.001, d = 1.2), RHIIT (Post: 17.8 ± 0.5 vs. Pre: 16.9 ± 0.6 km·h^{-1}, %Δ = 5.3, p = 0.0004, d = 1.5), and CON (Post: 17.7 ± 0.4 vs. Pre: 16.8 ± 0.4 km·h^{-1}, %Δ = 5.5, p = 0.006, d = 2.5) compared with pre-training, but there was no time-regimen interaction (p = 0.91) (**Figure 2B**).

Maximal $\dot{V}_E$ significantly increased from pre- to post-training in PHIIT and RHIIT (p = 0.003, d = 1.4 and 1.2, respectively) but not in CON and there was no between-group difference for this variable (p = 0.65). In addition, a significant increase occurred in R_f@$\dot{V}O_{2peak}$ from pre- to post-training in PHIIT and RHIIT (p = 0.001 and 0.004, d = 2.0 and 0.8, respectively) but not CON. Also, the change in R_f@$\dot{V}O_{2peak}$ in response to RHIIT was significantly greater compared to the change in CON (p = 0.03, d = 1.2). There was no change in $\dot{V}_T$@$\dot{V}O_{2peak}$ across time ($p > 0.05$).

There were no between-group differences for PPO or average PO (p = 0.64 and 0.25, respectively). PPO significantly increased

TABLE 3 | Change in cardiac structure and hemodynamics in response to training.

	Group		
	PHIIT	**RHIIT**	**CON**
SV_{max} (ml·b^{-1})			
Pre	131.62 (17.2)	128.12 (15.2)	127.37 (17.5)
Post	147.25 (10.5) †	143.62 (12.3) †	132.62 (13.4)
%Δ	+ 11.9	+ 12.1	+ 4.1
HR_{max} (b·min^{-1})			
Pre	185.6 (4.4)	191.2 (10.8)	187.0 (4.5)
Post	187.3 (3.6)	193.6 (5.4)	191.1 (4.8)
%Δ	+ 0.9	+ 1.2	+ 2.2
$\dot{Q}_{max}$ (l·min^{-1})			
Pre	24.5 (3.2)	24.3 (2.0)	23.8 (3.5)
Post	27.5 (1.7) †	27.7 (1.9) †	25.4 (2.9) †
%Δ	+ 12.2	+ 13.9	+ 6.7
EDV (ml)			
Pre	171.4 (14.8)	170.7 (14.6)	169.6 (4.7)
Post	186.7 (10.3) †	187.2 (9.9) †	174.8 (3.4)
%Δ	+ 8.9	+ 9.6	+ 3.0
ESV (ml)			
Pre	40.8 (2.5)	42.6 (1.43)	42.2 (4.1)
Post	39.7 (2.1)	42.3 (1.38)	42.1 (4.2)
%Δ	-2.8	-0.7	-0.2
EF (%)			
Pre	75.7 (3.6)	73.8 (3.5)	74.7 (2.29)
Post	79.8 (1.5) †	77.6 (3.2) †	75.6 (2.56)
%Δ	+ 5.4	+ 5.1	+ 1.2
SV_{rest} (ml·b^{-1})			
Pre	80.3 (5.0)	78.2 (4.4)	81.2 (5.8)
Post	84.9 (6.7) †	82.3 (4.0) †	84.3 (4.6) †
%Δ	+ 5.7	+ 5.2	+ 4.8
IVSWT (mm)			
Pre	8.03 (0.6)	8.07 (0.8)	7.93 (0.4)
Post	8.05 (0.6)	8.09 (0.7)	7.93 (0.5)
%Δ	+ 0.2	+ 0.2	+ 0.0
LVM (g)			
Pre	180.4 (26.0)	181.6 (29.1)	184.3 (36.0)
Post	180.7 (25.4)	182.0 (28.6)	184.5 (37.1)
%Δ	+ 0.1	+ 0.2	+ 0.1
LVESd (mm)			
Pre	42.0 (4.0)	41.7 (2.9)	41.0 (3.0)
Post	40.1 (3.2) †	39.7 (2.7) †	39.2 (3.4) †
%Δ	-4.7	-5.0	-4.6
LVEDd (mm)			
Pre	53.1 (3.8)	52.1 (4.3)	53.7 (3.1)
Post	54.3 (3.6)	52.7 (4.1)	54.3 (3.9)
%Δ	+ 2.2	+ 1.1	+ 1.1

Values are means (± SD).
EF, ejection fraction; EDV, end-diastolic volume; ESV, end-systolic volume; HR, heart rate; IVSWT, interventricular septal wall thickness; LVM, left ventricular mass; LVESd, left ventricular end-systolic diameters; LVEDd, left ventricular end-diastolic diameters; $\dot{Q}$, cardiac output; SV, stroke volume. N, 8 for each group.
†Significantly greater than pre-training value ($p < 0.05$).
N, 8 for each group.

after training in PHIIT, RHIIT, and CON (p = 0.0003, 0.003, and 0.002, d = 1.1, 1.0, and 0.3, respectively). Average PO was significantly increased in response to PHIIT (p = 0.001, d = 0.7) and RHIIT (p = 0.05, d = 0.5) compared with pre-training but not CON (**Table 1**).

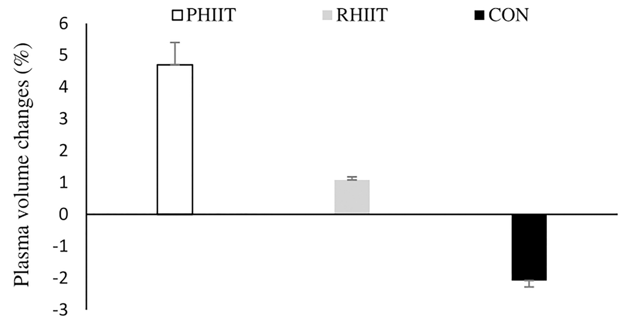

FIGURE 3 | Effects of paddling-based HIIT (PHIIT), resistance-type HIIT (RHIIT), and on-water kayak sprint (CON) training on plasma volume changes. *N* = 8 for each group.

Maximum strength expressed as 1RM in one-armed cable row significantly improved over time for right and left hand in response to RHIIT (p = 00008, 0.00001; d = 1.7, 1.6, respectively). No training-induced increase in this variable was observed in PHIIT and CON with no between-group difference for the magnitude of changes pre- to post-training.

Change in Biochemical Outcomes in Response to Training

There was no pre-training difference ($p > 0.05$) observed between groups for any biochemical variables. **Table 2** presents the resting hormone concentrations and hematological changes in response to the 8-week training period. Compared to pre-training, a significant increase was observed in total testosterone concentration in PHIIT and RHIIT (p = 0.02 and 0.03, d = 1.0 and 0.7, respectively). No significant differences were observed among groups (p = 0.35). There was a training-induced increase in Testosterone/Cortisol ratio (T/C ratio) in PHIIT and RHIIT (p = 0.05, d = 0.8) but not in CON ($p > 0.05$). Also, there was no between-group difference for T/C ratio (p = 0.76). Results showed no change in cortisol, hemoglobin (Hb), red blood cell (RBC), or hematocrit (Hct) in response to training ($p > 0.05$). Plasma volume changes over time were 4.7, 1.1, and –2.1% in PHIIT, RHIIT, and CON groups, respectively (**Figure 3**). No between-group difference was found for change in plasma volume (p = 0.13).

Change in Cardiac Structure and Hemodynamics in Response to Training

No pre-training difference was observed between groups for cardiac morphology or hemodynamics. As indicated in **Table 3**, SV_{max} significantly increased after training in response to PHIIT (p = 0.006, d = 1.0) and RHIIT (p = 0.003, d = 1.1) but there was no change in CON (p = 0.23). $\dot{Q}_{max}$ showed a significant main effect for time in PHIIT (p = 0.006, d = 1.2), RHIIT (p = 0.001, d = 1.7), and CON (p = 0.05, d = 0.5), but there was no time-regimen interaction for $\dot{Q}_{max}$ (p = 0.41). EDV and EF significantly increased from pre- to post-training in PHIIT (p = 0.004 and 0.05, d = 1.2 and 0.9, respectively) and RHIIT (p = 0.002 and

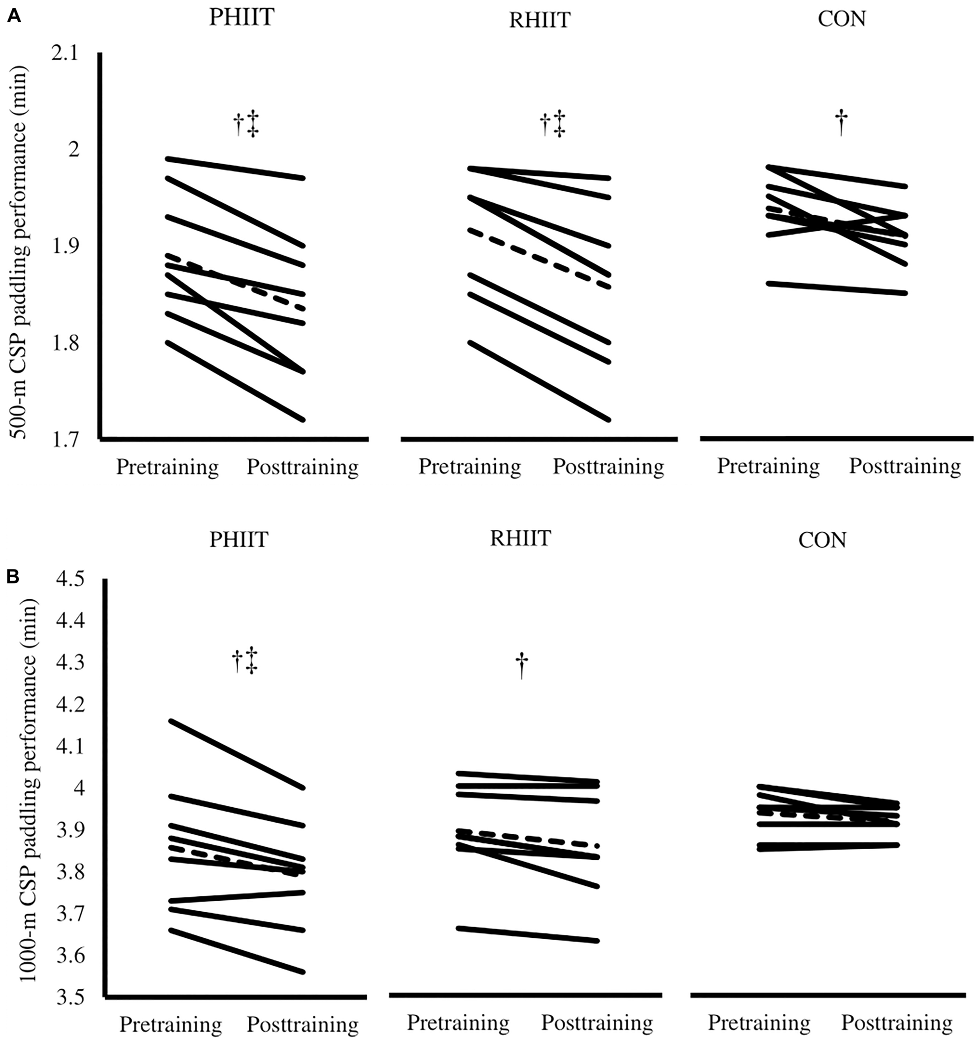

FIGURE 4 | Effects of paddling-based HIIT (PHIIT), resistance-type HIIT (RHIIT), and on-water kayak sprint (CON) training on **(A)** 500-m on-water kayak sprint paddling performance, and **(B)** 1,000-m on-water kayak sprint paddling performance. N = 8 for each group. Each line represents an individual participant and the dotted line represents the mean response. †Significantly different compared with pre-training ($p \leq 0.05$). ‡Significantly different vs. control group ($p \leq 0.05$).

0.03, d = 1.3 and 0.5, respectively) groups, but not in CON. Data showed no change in ESV or HR_{max} across time in groups.

Resting values of SV and LVESd were significantly increased across time in PHIIT (p = 0.01 and 0.01, d = 0.7 and 0.5, respectively), RHIIT (p = 0.01 and 0.01, d = 0.9 and 0.7, respectively), and CON (p = 0.005 and 0.01, d = 0.6 and 0.5, respectively). No significant difference was observed for resting values of IVSWT, LVM, and left LVEDd compared with pre-training ($p > 0.05$). No between group difference was observed in the change in cardiac dimensions over time (**Table 3**).

Change in on-Water Kayak Sprint Performance in Response to Training

No pre-training difference ($p > 0.05$) was observed between groups for 500- and 1,000-m paddling performance. **Figures 4A,B** show changes in 500- and 1,000-m kayak sprint performance from pre- to post-training. A significant time-regimen interaction (p = 0.05) was found in 500-m paddling performance as the change in 500-m paddling performance in response to PHIIT and RHIIT was significantly greater compared to the change in CON (p = 0.02, d = 0.6; and p = 0.05, d = 0.4, respectively). In response to training, 500-m paddling time significantly decreased in PHIIT (Post: 109.1 ± 5.1 vs. Pre: 112.5 ± 4.1 s, Δ≈ −3.4 s, p = 0.0008, d = 0.7), RHIIT (Post: 110.3 ± 4.9 vs. Pre: 114.0 ± 3.9 s, Δ≈ −3.7 s, p = 0.0006, d = 0.8), and CON (Post: 114.7 ± 2.1 vs. Pre: 116.6 ± 2.3 s, Δ≈ −1.9 s, p = 0.02, d = 0.8).

As shown in **Figure 4B**, a significant time-regimen interaction (p = 0.04) was found in 1,000-m paddling performance. The change in 1,000-m paddling performance in response to PHIIT was significantly greater compared to the change in CON (p = 0.05, d = 0.9). The 1,000-m paddling time was significantly decreased in PHIIT (Post: 227.1 ± 8.6 vs. Pre: 231.0 ± 7.4 s,

$\Delta \approx -3.9$ s, $p = 0.0001$, $d = 0.5$) and RHIIT (Post: 231.6 ± 7.8 vs. Pre: 233.7 ± 6.9 s, $\Delta \approx -2.1$ s, $p = 0.0004$, $d = 0.6$) but not in CON (Post: 235.1 ± 2.2 vs. Pre: 236.0 ± 3.9 s, $\Delta \approx -0.9$ s, $p = 0.17$) compared with pre-training.

Also, 500- and 1,000-m paddling performances were negatively correlated to $\dot{V}O_{2peak}$ in pre- and post-training ($r = -0.92$, $p = 0.00001$; $r = -0.91$, $p = 0.000001$, respectively) and post-training ($r = -0.91$, $p = 0.00001$; $r = -0.81$, $p = 0.000001$, respectively).

DISCUSSION

This study examined changes in cardiorespiratory fitness, hemodynamics, exercise performance, and muscular strength in response to resistance training HIIT matched with the lowest velocity that elicits $\dot{V}O_{2peak}$ (100% $v\dot{V}O_{2peak}$) and compared the adaptations vs. paddling-based interval exercise at 100% $v\dot{V}O_{2peak}$ and traditional endurance paddling in well-trained kayak sprint athletes. The major findings from this study were that 8 weeks of either RHIIT or PHIIT improved cardiorespiratory fitness and kayak sprint performance, resting values of cardiac dimensions, maximum stroke volume and cardiac output, to a similar extent. In the case of $\dot{V}O_{2peak}$ and 500- and 1,000-m paddling performances, these responses were superior to traditional continuous paddling. Also, RHIIT enhanced maximal strength and cardiorespiratory fitness adaptations simultaneously.

As a primary determinant of aerobic endurance, $\dot{V}O_{2peak}$ has been identified as the primary contributor in improving on-water kayak sprint paddling performance after HIIT (Dolci et al., 2020; Gharaat et al., 2020). This contention is verified by our data showing enhanced paddling performances that was consequent with an increase in $\dot{V}O_{2peak}$ as 500- and 1,000-m paddling performances were negatively correlated to $\dot{V}O_{2peak}$ in pre- and post-training. All training groups revealed an increase in $\dot{V}O_{2peak}$ compared to pre-training, although this increase was superior in response to PHIIT vs. control. It is generally accepted that improvements in $\dot{V}O_{2peak}$ may occur through increases in both oxygen delivery and/or its utilization within the active organs (Sheykhlouvand et al., 2018a,b). Although RBC and Hb remained unchanged pre- to post-training, $\dot{Q}_{max}$ significantly enhanced in all training groups indicating improved oxygen crying capacity. The major purpose of the increase in cardiac output is to meet the muscles' increased demand for oxygen. In fact, it is likely that $\dot{V}O_{2max}$ is ultimately limited by the inability of cardiac output to increase further (Kenney et al., 2012). Our findings support the study of Astorino et al. (2017) and Mahjoub et al. (2019) who reported increased cardiac output in response to HIIT in active men and women. In these studies, an increase in maximal SV_{max} led to the increase in $\dot{Q}_{max}$ which supports our results. Improved SV_{max} in response to HIIT can be attributed to increased EDV, increased force of contraction, and/or an increase in blood volume (Warburton et al., 2004). Nevertheless, neither PHIIT nor RHIIT modified ESV or cardiac morphology, leading to the conclusion that in elite athletes, increased contractile force through structural changes of the heart is not able to improve EDV following PHIIT and RHIIT. However, resting values of LVESd significantly decreased after the training period (**Table 3**) and SV_{rest} significantly increased in all training groups showing improved ventricular contractility. Significantly increased EDV and SV_{max} in PHIIT could in part be an explanation of the superior $\dot{V}O_{2peak}$ observed compared to CON. One of the likely mechanisms explaining enhanced EDV is an increase in plasma volume via interval training which occurred even following short-term HIIT (3–6 sessions) (Warburton et al., 2004) causing an increase in blood volume and thus greater diastolic filling (Astorino et al., 2017). However, our results showed no between-group difference for plasma volume changes pre- to post-training. Despite an increase in both SV_{max} and EDV, we showed an increase in EF indicating greater changes in SV_{max} compared to EDV. This could be influenced by factors other than increased blood volume and diastolic filling. In support of this, Kenney et al. (2012) mentioned that contractility can increase by increasing sympathetic nerve stimulation or circulating catecholamines (epinephrine, norepinephrine), or both. Also, excitation-contraction coupling in cardiomyocytes which is susceptible to change by exercise training can be enhanced through the faster systolic rise and faster diastolic decay of the Ca^{2+} transient, with the magnitude of contractility corresponding to the extent of cell shortening and relaxation rates (Wisløff et al., 2009). An improved force of contraction can increase SV with or without an increased EDV by increasing the ejection fraction.

During exercise, the cardiovascular and respiratory systems operate as an integrated "machine" for the transport of respired gases (McConnell, 2013). Our data show an increase in $\dot{V}_E@\dot{V}O_{2peak}$ following both HIIT interventions. This increase can be attributed to enhanced $R_f@\dot{V}O_{2peak}$ as $\dot{V}_T@\dot{V}O_{2peak}$ remained unchanged pre- to post-HIIT. At lower intensities, an increase in both R_f and $\dot{V}_T$ is responsible for the enhanced $\dot{V}_E$. However, at higher intensities, the respiratory muscles become actively involved, and respiratory muscle fatigue may develop (Sheykhlouvand et al., 2018a) leading to rapid shallow breathing, a plateau in $\dot{V}_T$, and consequent steep rise in R_f to meet the need for an escalating $\dot{V}_E$ (McConnell, 2013).

In accordance with our hypothesis, maximal strength increased in response to RHIIT when expressed as 1RM in one-armed cable row in both right and left hands. Neurological adaptations in the early stages of resistance training, along with enhanced muscle hypertrophy by continuing the training over weeks, are the main contributing factors in strength gain following resistance training as classically proposed (Deschenes, 1989; Chesley et al., 1992).

PPO and average PO were significantly increased in response to both HIIT modalities compared with pre-training, but not in CON. However, the magnitude of these improvements was not different between PHIIT and RHIIT indicating beneficial effects of both protocols. These findings support other investigations reporting increases in peak and mean anaerobic power in response to different HIIT regimens (Farzad et al., 2011; Sheykhlouvand et al., 2016b; Dolci et al., 2020; Hoffmann et al., 2020). Dolci et al. (2020) stated that only 2 weeks of HIIT in active men increases the discharge rate of high-threshold motor units and improves power output. Sheykhlouvand et al. (2018b) reported that an increased muscle buffering capacity may in part be responsible for the enhanced peak and mean power output in response to 4 weeks of training in elite athletes. Increased total creatine content of muscle and a significant increase in type II fiber size are other possible explanations for these changes (Hoffmann et al., 2020).

Both PHIIT and RHIIT protocols increased total testosterone levels and T/C ratio, but there was no change in serum cortisol. To determine the physiological strain of the training, the T/C ratio is frequently used as an indicator of catabolic-anabolic balance (Farzad et al., 2011; Sheykhlouvand et al., 2016a). Hence, the observed improvements following both HIIT protocols may indicate anabolic adaptations. These results support our previous findings in professional canoe polo paddlers in which paddling-based HIIT with incremental volume and intensity (60 s paddling at 100–130% $v\dot{V}O_{2peak}$; 1:3 work to recovery) improves T/C ratio. In addition, Farzad et al. (2011) demonstrated increases in T/C ratio following HIIT (6 × 35-m sprint running with 10 s rest between reps). The increased T/C ratio may be attributed to the enhanced serum levels of TT as cortisol remained unchanged over time. Potential adaptations in TT synthesis and the secretory capacity of the Leydig cells could be possible explanations for our findings (Kraemer and Ratamess, 2005).

A limitation of this study was an inability to strictly monitor dietary practices of athletes during training. Moreover, we only recruited men, and our results cannot be applied to women competing in kayak sprinting. Our results only apply to our specific HIIT regimens, and it is unknown if similar adaptations would occur in response to higher volume HIIT or low volume sprint interval training. Although the environmental conditions were mostly similar during pre- and post-training, there was a slight difference in tail wind and ambient temperature pre- to post-training. We did not evaluate the water temperature, but the values were mostly identical within the period when we performed the experiment.

In conclusion, the results of this study showed that PHIIT and RHIIT similarly improve $\dot{V}O_{2peak}$, maximal values of cardiac output and stroke volume, and resting values of cardiac dimensions in kayak sprint athletes. Results indicated that the improved 500 and 1,000-m on-water kayak sprint paddling performance following PHIIT and RHIIT are associated with the enhanced cardiorespiratory adaptations. Moreover, an elevated T/C ratio suggests that both HIIT protocols induce an anabolic-type hormonal adaptation indicating positive responses to training. Similar cardiorespiratory fitness increases following PHIIT and RHIIT could be justified by the similarity in total work performed during both protocols. Considering that the adaptations in response to RHIIT and PHIIT were mostly identical, kayak sprint athletes and their coaches can use either type of program to elicit improvements in exercise performance, cardiorespiratory fitness, and anabolic profile. Given that RHIIT effectively improved both cardiorespiratory fitness and maximal strength, this method could serve as a novel time-efficient strategy to simultaneously improve both qualities in well-trained kayak sprint athletes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Sport Sciences Research Institute of Iran (approval ID: IR.SSRC.REC.1400.019). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MS contributed to project administration, conceptualization, methodology, visualization, and investigation. HA supervised the project, methodology, and data analysis and contributed to conceptualization, reviewing, and editing of the manuscript. TA and KS contributed to reviewing, and editing of the manuscript. All authors contributed to the article and approved the submitted version.

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GLOSSARY

HIIT	High-intensity interval training
RHIIT	Resistance-type HIIT
PHIIT	Paddling-based HIIT
$\dot{V}O_{2max}$	Maximum oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
$v\dot{V}O_{2peak}$	Velocity at $\dot{V}O_{2peak}$
Tmax	Time to exhaustion at $v\dot{V}O_{2peak}$
1RM	One repetition maximum
$\dot{V}_E$	Ventilation
$\dot{V}_T$	Tidal volume
R_f	Respiratory frequency
SV	Stroke volume
$\dot{Q}$	Cardiac output
EDV	End-diastolic volume
ESV	End-systolic volume
EF	Ejection fraction
LV	Left ventricle
IVSWT	Interventricular septal wall thickness
LVM	Left ventricle mass
LVESd	Left ventricle end-systolic diameters
LVEDd	Left ventricle end-diastolic diameters
CV	Coefficient of variation
Hb	Hemoglobin
RBC	Red blood cell
Hct	Hematocrit
PPO	Peak power output
M	Meter
N	Newton
W	Watts
Kg	Kilograms
S	Seconds
ANOVA	Analysis of variance

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Effects of 4-Week Tangeretin Supplementation on Cortisol Stress Response Induced by High-Intensity Resistance Exercise: A Randomized Controlled Trial

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Objective: This study aimed to investigate the effects of 4-week tangeretin supplementation on the cortisol stress response induced by high-intensity resistance exercise.

Methods: A randomized controlled trial of twenty-four soccer players was conducted during the winter training season. The experimental group (EG) took the oral supplement with tangeretin (200 mg/day) and the control group (CG) took placebo for 4 weeks. Before and after the 4-week intervention, all players performed a high intensity bout of resistance exercise to stimulate their cortisol stress responses. Serum cortisol, adreno-corticotropic hormone (ACTH) and superoxide dismutase (SOD) were obtained by collecting blood samples before (PRE), immediately after (P0), and 10 (P10), 20 (P20) and 30 minutes (P30) after the exercise.

Results: The serum cortisol level (PRE, $p = 0.017$; P10, $p = 0.010$; P20, $p = 0.014$; P30, $p = 0.007$) and ACTH (P10, $p = 0.037$; P30, $p = 0.049$) of experimental group significantly decreased after the 4-week intervention. Compared with control group, EG displayed a significantly lower level of the serum cortisol (PRE, $p = 0.036$; P10, $p = 0.031$) and ACTH (P30, $p = 0.044$). Additionally, EG presented significantly higher superoxide dismutase activity level compared with CG at P30 ($p = 0.044$). The white blood cell of EG decreased significantly (PRE, $p = 0.037$; P30, $p = 0.046$) and was significantly lower than CG at P20 ($p = 0.01$) and P30 ($p = 0.003$).

Conclusion: Four-week tangeretin supplementation can reduce serum cortisol and ACTH, which may ameliorate the cortisol stress response in soccer players during high-intensity resistance exercise training. It can also enhance antioxidant capacity, accelerate the elimination of inflammation throughout the body, and shorten recovery time after high-intensity exercise.

Keywords: tangeretin, exercise test, cortisol stress responses, resistance exercise, serum cortisol, antioxidant capacity

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1 INTRODUCTION

The adrenal gland responds when the body is confronted with psychological or physiological stress by releasing cortisol (Simons et al., 2017). The stress response could regulate the metabolism of various energy sources and substances in blood (Viru and Viru, 2004). Although the cortisol response plays an irreplaceable role on maintaining normal physiological function, the overt stress response or chronic elevation of blood cortisol concentration could negatively affect many physiological functions, such as protein metabolism, inflammatory processes and glucose-alanine cycle (Cadegiani and Kater, 2017; Hodes et al., 2018; Walter et al., 2018). Nutritional interventions have been proved valuable for moderately attenuating the cortisol response induced by intense exercise or chronic mental stress in the human body (Kraemer et al., 1998; Córdova et al., 2019; Tsuda et al., 2020). The dietary supplements of plant origin, due to the properties of natural compounds and free of banned substances, have gradually become the prior choice of nutritional interventions for cortisol regulation (Assini et al., 2013; Kioukia-Fougia et al., 2017).

Plant flavonoids, widespreading in fruits and vegetables, are often reported to effectively modulate cortisol concentrations (Ruijters et al., 2014; Szelényi et al., 2019). Tangeretin (TG, **Figure 1**), a citrus flavonoid extracted from citrus peel, has been proved possessing excellent antioxidant, anti-inflammatory and neuroprotective properties (Liu et al., 2018; Zhao et al., 2018). TG was previously found to enhance the activity of antioxidant enzymes, reduce the level of oxidative stress and dramatically extend the swimming time to exhaustion in mice (Kou et al., 2018; Kou et al., 2019). Further, in our previous study, TG intervention (200 mg/d) for 30 days was detected to significantly increase the maximal oxygen uptake and time to exhaustion in athletes with exercise-induced bronchoconstriction (Liu et al., 2021; Liu and Gao, 2022). The aforementioned studies suggest that TG may possess anti-fatigue property. In another study, we found that blood cortisol and uric acid concentrations significantly decreased in weightlifters after orally taking TG supplementation (200 mg/d) for 5 weeks (Liu et al., 2019). However, it is difficult to determine the role of TG on decrement of blood cortisol concentrations because we did not include a control group and illuminate effects of dietetic food.

The model of acute intense resistance exercise has been proved dramatically increasing blood cortisol concentration (Kraemer and Ratamess, 2005). Increased cortisol concentration is usually associated with anticipation of high-intensity exercise in human beings (Jamurtas et al., 2018; Wang et al., 2019), which indicates that acute intensity resistance exercise may be a suitable method for examining the benefits of TG supplementation. Therefore, this study aimed to determine the effects of TG supplementation on cortisol responses induced by an acute intense resistance exercise, and its potential impacts on adreno-corticotropic hormone (ACTH), superoxide dismutase (SOD) and WBC. We hypothesized that TG supplementation would contribute to regulating cortisol response and reducing blood cortisol concentrations before and after the acute intense resistance exercise.

2 MATERIALS AND METHODS

2.1 Participants

Participants were recruited from soccer players of the Chongqing Li-Fan professional football club. According to inclusion and exclusion criteria, eligible respondents were randomly grouped into experimental group (EG) or control group (CG). The flow diagram of study was presented in **Figure 2**.

Twenty-four players (10F/14M) finally completed the experiment in this study. All the players have prior experience of resistance hemolysis (5.3 ± 1.2 years). Their mean (standard deviation, SD) age and height were respectively 20.3 ± 1.2 years and 172.6 ± 6.1 cm. According to one-repetition maximum (1RM) test adopted from the study by Kraemer et al. (2005), their 1RM of bench press, back squat, shoulder press and deadlift were 68.2 ± 24.3 kg, 118.9 ± 38.1 kg, 59.3 ± 22.4 kg and 102.9 ± 30.1 kg, respectively. Additionally, their training program (frequency, duration and intensity) and schedule (training and resting day) were similar throughout the study. Their training daily information is presented in detail in **Supplement S1**. Each player was informed the experimental procedures, benefits and risks and provided signed written consent before data collection.

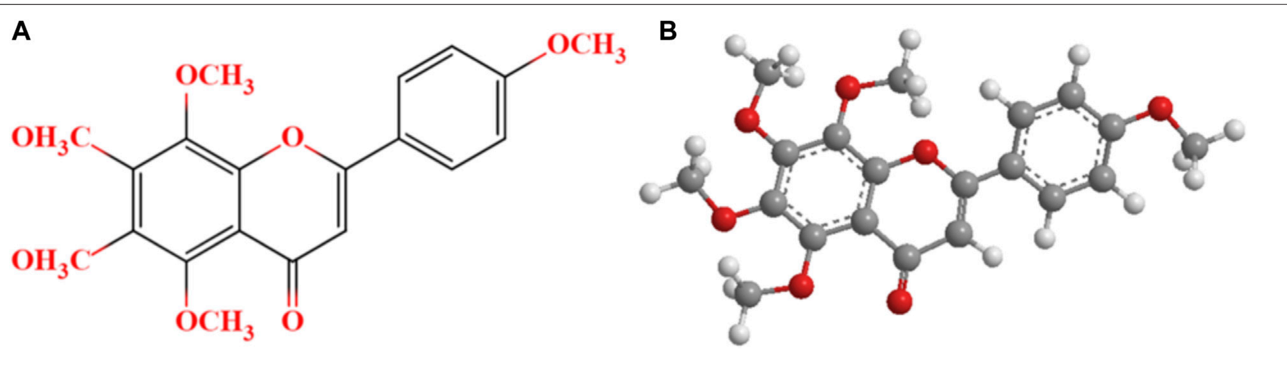

FIGURE 1 | The chemical structure **(A)** and 3D chemical structure **(B)** of tangeretin.

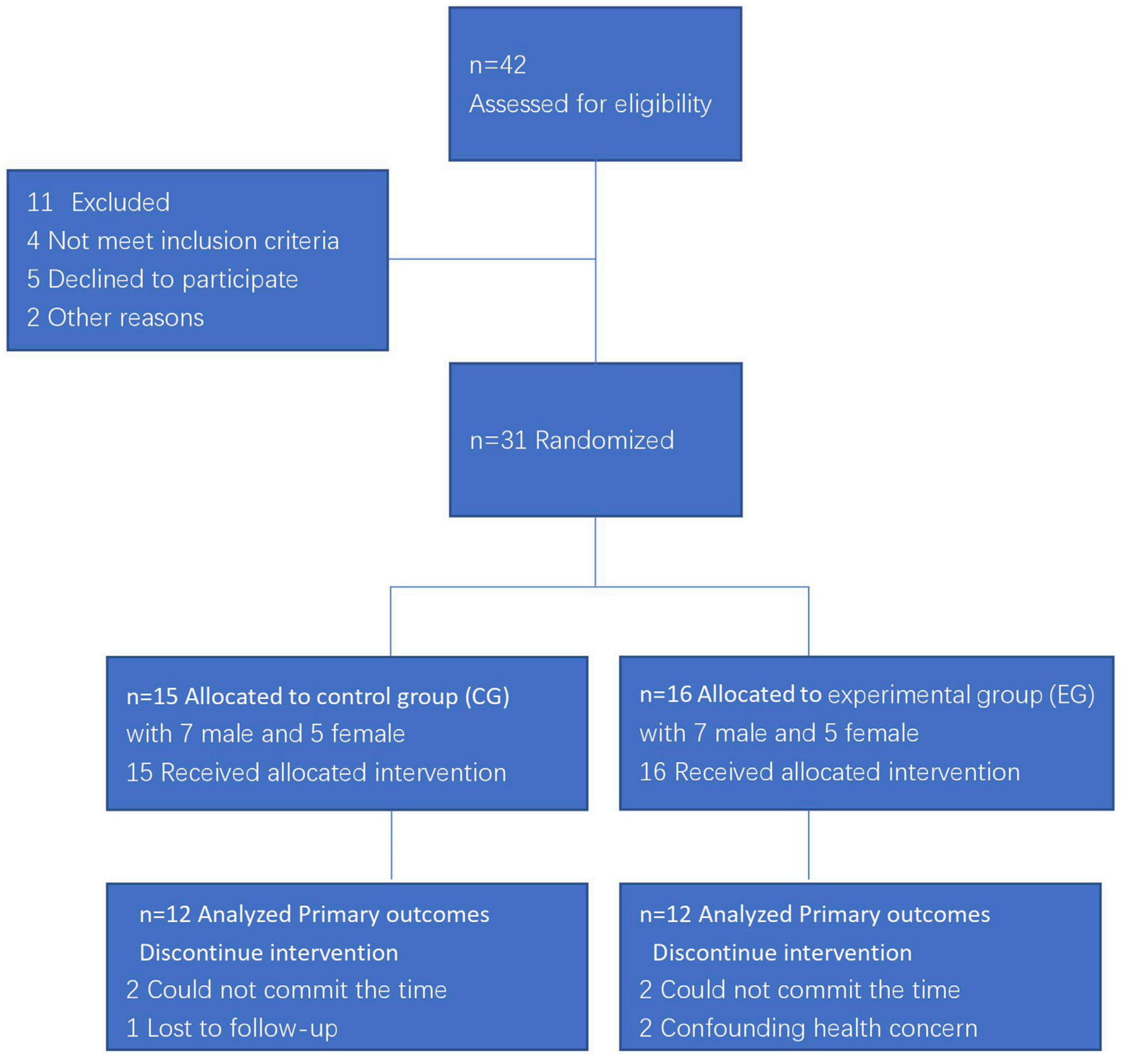

FIGURE 2 | The flow diagram of study.

This study was approved by the Academic and Human Rights Ethics Committee, Shanghai University of Sport.

An *a priori* sample size was estimated through G*Power 3.1 using the effect size data (Cohen's $d = 0.79$), which was calculated based on the blood cortisol concentration (15.15 ± 4.36 μg/dl vs 12.21 ± 2.91 μg/dl) before and after 4-week intervention in 12 sprinters (Liu et al., 2021). Considering 20% attrition, 13 participants were deemed to sufficient to obtain a desired power of 80% at $\alpha = 0.05$.

2.2 Methods

A paired, randomized, double-blind experimental protocol was used in this study. All the players were paired according to sex, height, weight and sports level. They were numbered and randomly divided into EG or CG using a computer to generate random numbers, with seven men (NO.1-NO.7) and five women (NO.8-NO.12) in each group (**Figure 3A**). The players of both EG and CG were instructed to complete the supplement intervention, exercise stimulation test and body composition test. Grouping methods and intervention assignments (tangeretin vs placebo) were blinded to both researchers and the players.

2.2.1 Supplement Intervention

Each day, all the players were required to enter the laboratory in early morning (7:30–8:30 a.m.). Each received a bottle of supplement drink (200 ml). The supplement drink was packed in a sealed opaque glass bottle and prepared in advance by a research assistant, who was blind to the component of the supplement drink. The bottle was labeled using each players'

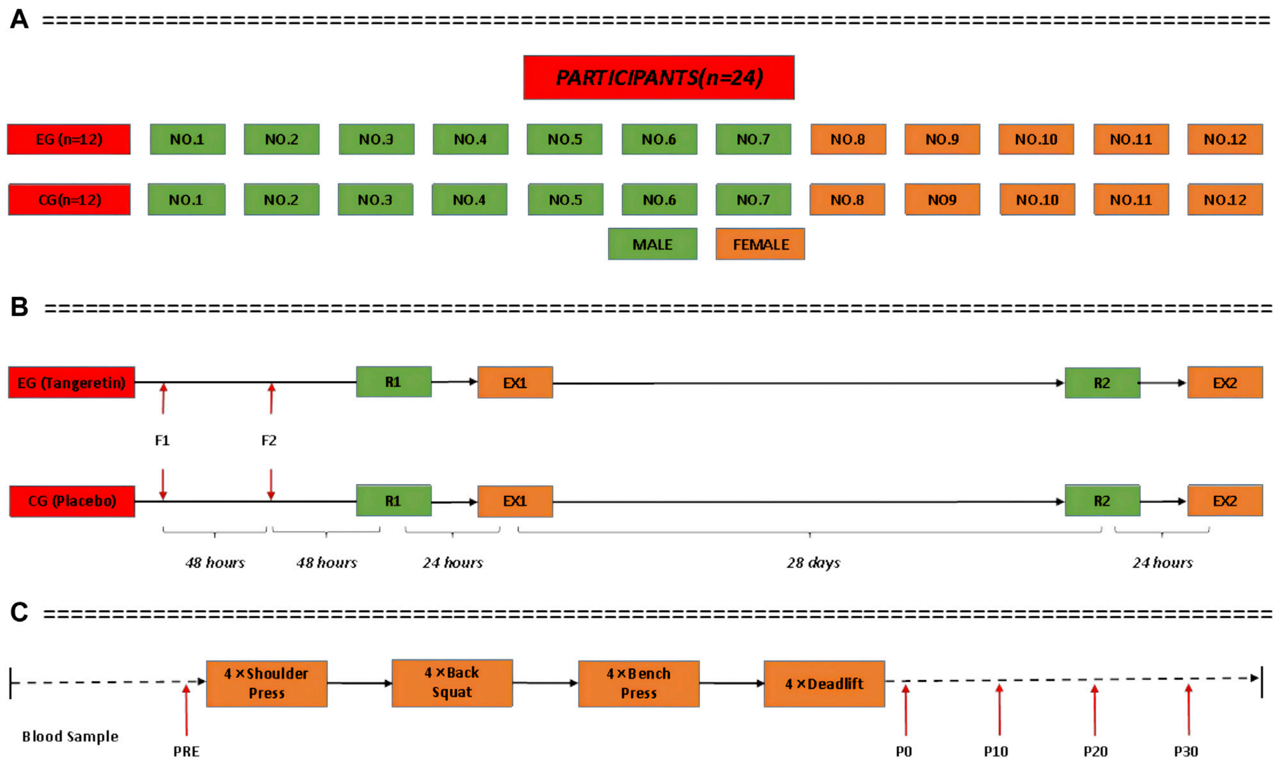

FIGURE 3 | Participants paired according to sex, height, weight and sports level.

pseudonym ID. Each player was asked to oral the corresponding supplement drink and was not informed the component of the drink. For EG, the supplement drink was made using a self-developed and commercially available supplement product (Qinguoren tangeretin supplement®; China Anti-Doping Center test report number: 2019FD234) referring to 19.8 g whey protein isolate powders (≥95% purity, CanSure, Vancouver, BC, Canada; China Anti-Doping Center test report number: 2019FD279) and 200 mg tangeretin (99.79% purity). The Qingguoren® tangeretin supplement has yet to mass produce and right now can only be purchased from Southwest Institute of Fruits Nutrition. For CG, the supplement drink contained a placebo supplement, consisting of only 20 g whey protein isolate powders. The drinks were identical in terms of aesthetics, weight, and flavor, with the only difference being the presence or omission of tangeretin. The supplement drink was prepared daily by the research assistant.

The dose of 200 mg/day was chose based on evidence from previous studies. Based on findings from previous animal experiment (Nakajima et al., 2020), daily intaking tangeretin for 1–5 mg per kilogram bodyweight did not cause any side effects. Other studies (Hu et al., 2020; Kou et al., 2018; 2019) detected certain benefits when daily intaking tangeretin supplementation for 3–4 mg per kilogram bodyweight. Moreover, our preliminary human trial studies (Liu et al., 2019; 2021) indicated that athletes orally taking tangeretin supplementation for 200 mg per day for 5 weeks or 30 days improved their physical function (i.e., serum testosterone, cortisol, etc.) and was free of any uncomfortable symptoms (i.e., dizziness, vomiting, etc.).

Throughout the study period (a total of 43 days), all players only consumed food, including snacks and fruit, which was supplied by the Chongqing Competitive Sports Training Center. To minimize effects of food and condiment (Cheng and Li, 2012), dietary advice was provided and ingredient selection was monitored. Except the Gatorade sports drinks, all players were also prohibited from any other supplement, including traditional Chinese medicine. All players reported no signs or symptoms of discomfort throughout the study period.

2.2.2 Exercise Stimulation Experiment

For the cortisol stress response provocation test, each player was instructed to complete a standard high-intensity resistance exercise (EX) protocol on the day before and after the intervention (**Figure 3B**). The protocol consisted of four weightlifting (shoulder press, back squat, bench press and deadlift), four sets each weightlifting, and interval of 2 min for rest (**Figure 3C**). For each player, the weight for each lift was equal to his/her 10RM (the maximum weight allowing to perform a lift for only ten repetitions per time). The 10RM was predetermined for each player during the familiarization session (F) using a standard protocol adopted from the study by Kraemer et al. (2005). The method was confirmed to be reliable with intra-class correlation coefficient being 0.98 for two consecutive exercise sessions (**Figure 3B**). A professional coach provided supervision throughout the weightlifting to maximum each players' cortisol stress response and to minimize the risk of injury. All the players were allowed to consume water as well as some snacks if required.

The goal of the familiarizations was to create a reliable workout that could be highly replicated to produce a similar (if not identical) physiological stress response. During the experimental workout, resistances were reduced to allow only 10 repetitions to be performed but both experimental workouts used very similar (if not identical) resistances in the workout sequences because of careful familiarization and practices of the experimental protocol (Kraemer et al., 1990).

Blood samples were collected immediately before (PRE, immediately before the exercise) and after each provocation test (**Figure 3C**). Sampling took place between 2:00 p.m. and 5:00 p.m. A 3 ml sample of venous blood was taken each time (tube A: 1 ml, tube B: 2 ml). Blood samples were collected at four time points after the provocation test: immediately (P0, immediately after the exercise), 10 min (P10), 20 min (P20), and 30 min (P30) (**Figure 3C**). The white blood cell (WBC) level of tube A samples was measured with a hematology analyzer (Mindray BC-5150, China) at 10 min after collection. Serum samples were separated from tube B blood samples on a high-speed centrifuge (Shuke TG16, China) at 2000 R/min for 15 min, within 30 min after collection, and stored at −80°C in a medical freezer (Boke BDF-86V158, China). Analysis was performed at the end of the provocation test by a researcher (Mindray SAL-6000, China; BioTek-Epoch, United States). Serum cortisol, superoxide dismutase (SOD), adreno-corticotropic hormone (ACTH), and WBC were measured and recorded. In addition, the blood lactate level of each athlete was measured with a portable blood lactate analyzer (EKF, Germany) at the PRE and P0 time points for each provocation test. In order to collect more accurate data from blood samples, the appearance of the sample was first qualitatively ranked by trained laboratory technologists from "no visible hemolysis" to "4 + hemolysis," and its hemoglobin concentration was determined by the benzidine method (Crosby et al., 1954).

2.2.3 Body Composition Test

Body composition was measured for all players before (R1) and after (R2) the intervention using a multi-frequency bioelectrical impedance analyzer (InBody® 570, BioSpace Inc, Seoul, Korea), see **Figure 3B**. This method was validated using dual-energy x-ray absorptiometry and confirmed to be valid and reliable (Miller et al., 2016). During the test, each player was instructed to wear light clothes and statically stand on the analyzer in barefoot. Body weight, muscle mass and body fat percentage were obtained and analyzed.

2.3 Statistical Analysis

Statistical analysis was conducted with SPSS 25.0 package. The results were showed as mean ± SD.

Following check for normality (Shapiro-Wilk), sphericity of each dataset (Mauchly's test), and homogeneity of variance between groups (Levene's test), the 10RM values of athletes in the four resistance exercise sessions (shoulder press, back squat, bench press, and deadlift) and various biochemical indices of the cortisol stress response (serum cortisol, SOD, ACTH, WBC and blood lactate) were analyzed with two-way analysis of variance (ANOVA) with repeated measurements (2 groups × different time points). If a significant difference was indicated, pairwise comparison was carried using the least significance difference (LSD) test. The significance level was set at $p < 0.05$.

3 RESULTS

3.1 Comparison of Body Composition

There were no statistical differences in body weight, body fat percentage and muscle mass before and after the intervention in both group (**Table 1**).

3.2 Effects on 10RM of Resistance Exercises and Blood Lactate

The 10RM values of the four resistance exercises (shoulder press, back squat, bench press, and deadlift) before and after the intervention were presented in **Table 2**. There were no group differences before and after the intervention. Although the 10RM values of both groups increased slightly after the intervention, the difference was not statistically significant. There were also no statistical differences in the level of blood lactate between EG and CG before and after the intervention. The level of blood lactate increased significantly in both groups after the high-intensity resistance exercise (**Table 3**).

3.3 Effects on Serum Cortisol, ACTH, SOD and WBC

For the first resistance exercise sessions (before the 4-week intervention), no significant difference was observed in the biochemical indices (serum cortisol, SOD and WBC) in EG and CG (A in **Figure 4**). After the 4-week intervention, the serum cortisol level of EG was significantly lower at PRE (p = 0.017), P10 (p = 0.010), P20 (p = 0.014), and P30 (p = 0.007) of the later resistance exercise sessions, compared to the values of the first resistance exercise sessions before intervention. The serum cortisol level of EG was also significantly lower than CG at PRE (p = 0.036) and P30 (p = 0.031) (**Figure 4** serum cortisol-A). Similarly, ACTH decreases significantly in EG at P10 (p = 0.037) and P30 (p = 0.049), compared to pre-intervention values, and ACTH concentration of EG was significantly lower than that of CG at P30 (p = 0.044) (**Figure 4** ACTH-B). The SOD activity of EG was significantly higher than that of CG in each time points after the intervention, with a significant drop at PRE (p = 0.037) and P30 (p = 0.046) throughout the provocation test (**Figure 4** SOD-B). The SOD activity was significantly higher after intervention in CG at P30 (p = 0.003) than that in EG

TABLE 1 | Effects of tangeretin intervention on body composition.

	Body weight (kg)		Body fat percentage (%)		Muscle Mass (kg)	
	R1	R2	R1	R2	R1	R2
EG	61.8 ± 6.0	61.9 ± 5.9	13.3 ± 4.4	12.9 ± 3.7	30.5 ± 4.3	30.8 ± 4.3
CG	59.1 ± 9.8	59.3 ± 10.3	12.9 ± 4.7	13.1 ± 4.6	28.6 ± 5.3	28.9 ± 5.7
Main effect - Time	p = 0.408; η^2 = 0.063		p = 0.665; η^2 = 0.020		p = 0.353; η^2 = 0.087	
Main effect - Group	p = 0.448; η^2 = 0.053		p = 0.459; η^2 = 0.056		p = 0.050; η^2 = 0.332	
Interaction - Time× Group	p = 0.921; η^2 = 0.001		p = 0.115; η^2 = 0.229		p = 0.869; η^2 = 0.003	

CG: control group; EG: experimental group

TABLE 2 | Comparison of 10RM of the back squat, bench press, deadlift, and shoulder press (kg).

	Shoulder Press (kg)		Back Squat (kg)		Bench Press (kg)		Deadlift (kg)	
	T1	T2	T1	T2	T1	T2	T1	T2
EG	54.3 ± 19.1	58.2 ± 21.8	91.1 ± 22.4	93.2 ± 23.5	49.6 ± 17.2	52.9 ± 16.4	93.2 ± 22.7	94.3 ± 23.2
CG	53.6 ± 18.2	54.6 ± 17.9	89.6 ± 21.7	92.1 ± 22.3	48.2 ± 16.2	50.7 ± 15.1	95.4 ± 23.6	97.1 ± 25.2
Main effect - Time	p = 0.396; η^2 = 0.056		p = 0.110; η^2 = 0.184		p = 0.065; η^2 = 0.238		p = 0.518; η^2 = 0.033	
Main effect - Group	p = 0.029; η^2 = 0.318		p = 0.138; η^2 = 0.161		p = 0.001; η^2 = 0.610		p = 0.055; η^2 = 0.254	
Interaction - Time × Group	p = 0.241; η^2 = 0.104		p = 0.583; η^2 = 0.024		p = 0.165; η^2 = 0.143		p = 0.612; η^2 = 0.020	

CG: control group; EG: experimental group. T1: Before 4-week tangeretin intervention; T2: After 4-week tangeretin intervention

TABLE 3 | Comparison of blood lactate before and after high-intensity resistance exercise test (mmol/L).

	1st High-Intensity Resistance Exercise		2nd High-Intensity Resistance Exercise	
	PRE	P0	PRE	P0
EG	2.3 ± 1.1	15.3 ± 3.5**	2.4 ± 0.9	14.9 ± 3.1**
CG	2.6 ± 0.9	14.9 ± 3.3**	2.5 ± 1.1	15.1 ± 3.5**
Main effect - Time	p = 0.886; η^2 = 0.003		p = 0.918; η^2 = 0.002	
Main effect - Group	p = 0.000; η^2 = 0.962		p = 0.000; η^2 = 0.974	
Interaction - Time × Group	p = 0.540; η^2 = 0.056		p = 0.895; η^2 = 0.003	

*CG: control group; EG: experimental group. **p < 0.01 vs. PRE*

(**Figure 4** SOD-A). **Figure 4** WBC-B showed the WBC of the EG decreased significantly (PRE, $p = 0.037$; P30, $p = 0.046$) and was significantly lower than that of the CG (P20, $p = 0.01$; P30, $p = 0.003$).

4 DISCUSSION

This study aimed to investigate the effect of 4-week tangeretin supplementation on the cortisol stress response triggered by high-intensity resistance exercise. We found that the serum cortisol level of athletes in EG decreased significantly after taking a 200 mg/day tangeretin (TG) supplement for 4 weeks. This result supports the initial hypothesis of the study: a significant reduction in serum cortisol level was also observed after the provocation test of high-intensity resistance exercises (shoulder press, back squat, bench press, and deadlift). The level of serum cortisol in EG is also lower compared with the CG. Other than serum cortisol, it was also noticed in this study that after TG supplementation, ACTH and WBC levels in the EG were reduced substantially and were lower than in the CG. SOD activity was higher in the EG than in the CG. These results suggest that TG supplementation during high-intensity resistance exercise helps to regulate cortisol stress response in the human body, suppress the excessive synthesis and secretion of cortisol, and improve the resilience against oxidative stress of the whole body. TG also helps the attenuation of inflammation response.

High-intensity resistance exercise is effective at triggering a cortisol stress response in humans, resulting in a rapid rise in cortisol levels (Kraemer et al., 2005; Wang et al., 2019; Tsuda et al., 2020). Compared to other types of stimulation such as fear and visual stimulation, high-intensity resistance exercise is more controllable, repeatable and non-invasive. It is the preferred method for studying the inherent relationship between external stimulation and the cortisol stress response (Finke et al., 2018; Wang et al., 2019). According to Kraemer et al. (2005), the four resistance exercise sessions, i.e., shoulder press, back squat, bench press, and deadlift, could effectively activate all

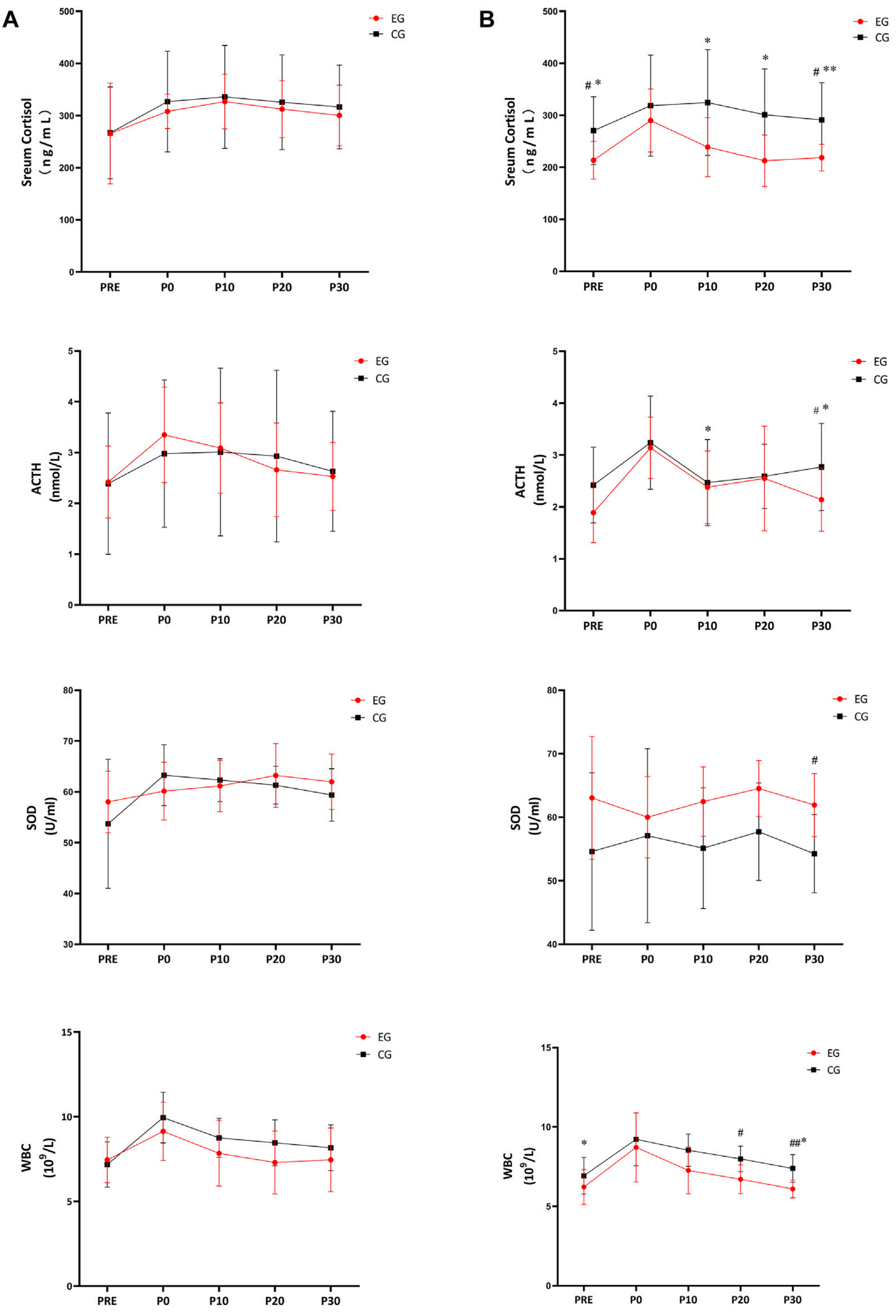

FIGURE 4 | Effects of 4-week tangeretin supplementation and high-intensity resistance exercise on serum cortisol, ACTH, SOD and WBC. Notes: **(A)** first high-intensity resistance exercise; **(B)** second high-intensity resistance exercise; CG: control group; EG: experimental group; #*p* < 0.05, EG vs CG; ##*p* < 0.01, EG vs CG; **p* < 0.05, vs. PRE; ***p* < 0.01 vs PRE.

major muscle groups of the human body quickly and trigger the optimum cortisol stress response when the workload is four sets × 4 repetitions × 10 RM (with a 2-min rest between sets and repetitions). Based on the above findings (Kraemer et al., 2005), the same resistance exercise regimen and workload are adopted in this study. Studies have found that after high-intensity resistance exercise, serum cortisol level of both EG and CG rises significantly, as does the blood lactate level, with an increase >14 mmol/L in both cases (Kraemer et al., 2005). These results show that the high-intensity resistance exercise stimulation performed here could effectively provoke cortisol stress response of human body, and the aforementioned exercise model can be used to investigate the effect of TG on the human cortisol stress response.

Flavonoids can effectively modulate the cortisol stress response and inhibit cortisol synthesis and secretion (Ohno et al., 2002; Loerz and Maser, 2017). In 2016, Kuebler found that the cortisol stress response in healthy participants was effectively suppressed by ingesting 50 g dark chocolate (containing 600 mg of total flavonoids) 2 h before the Trier Social Stress Test. A significant decline in serum cortisol level was also observed. Kraemer et al. (2005) also reported that a 4-week intervention with a flavonoid supplement mixture significantly alleviated the cortisol stress response triggered by high-intensity resistance exercise and accelerates the post-exercise recovery of serum cortisol level, which may be due to quercetin (a polymethoxyflavones) in the supplement inhibiting the conversion of 11-dehydro-17-hydroxycortisone to cortisol in adrenal cells. Quercetin and TG are both members of the same PMH flavonoid subfamily (Zhao et al., 2018). Preliminary studies by our research group have shown the positive regulatory role played by TG on cortisol. For example, after oral ingestion of 200 mg/d TG for 5 weeks, a significant decrease was seen in the level of fasting serum cortisol in the morning (Liu et al., 2019). Based on these results, our study further delineates the effect of 4-week TG supplementation on the cortisol stress response. After a 200 mg/d tangeretin supplementation intervention for 4 weeks, the serum cortisol level of the EG decreased significantly at 10 min (P10), 20 min (P20), and 30 min (P30) following provocation test. The cortisol level in the EG was significantly lower than that of the CG at P30. This suggested TG can lower the level of serum cortisol in the resting state and relieve the cortisol stress response induced by high-intensity resistance exercise. These findings lay the foundation for the application of nutritional supplements that provide rapid recovery from physical fatigue and inhibition of protein catabolism caused by high-intensity exercise.

The regulatory effect of flavonoids on the human cortisol stress response is also seen with ACTH, the key regulator of cortisol secretion and synthesis. When the body is fighting stress, ACTH secretion is accelerated in the hypothalamus, promoting the synthesis and secretion of cortisol in large quantities (Kuebler et al., 2016). An et al. reported a significant drop in ACTH and serum cortisol levels in experimental rats fed with the Heart Nourishing Tonic (total flavonoids content: 50 mg/kg) for 4 weeks (An et al., 2008). The researchers posited that flavonoids reduce human cortisol levels by inhibiting ACTH secretion. Kraemer et al. conducted provocation test with high-intensity resistance exercises to study the effect of flavonoid supplement mixtures containing quercetin on cortisol stress response (Kraemer et al., 2005). They believed that, after oral ingestion of the flavonoid supplement mixture for 4 weeks, the experimental group showed a significantly lower ACTH level than the control group at corresponding time points. At 5 min and 10 min after the provocation test, the ACTH level in the experimental group was also substantially lower than at pre-intervention times. The decrease in ACTH levels was shown to correspond well with the decrease in serum cortisol levels. Similar results were observed in our study. After 4 weeks of TG supplementation, a significant decrease in ACTH level was observed in EG at 10 min (P10) and 30 min (P30) after the stimulation experiment. Moreover, the ACTH level in EG was significantly lower than that of the CG at P30, which was consistent with the variation trend of serum cortisol level.

The human adrenocortical tumor cell line H295R is an ideal candidate for studying cortisol synthesis and secretion (Bertazza et al., 2019). Through *in vitro* study, Li et al. found that 24 h after the addition of 30 μM/unit of quercetin to H295R cell cultures, the expression of 11β-hydroxysteroid dehydrogenase (11-βHSD) mRNA decreased by 50% (Cheng and Li, 2012). They believe quercetin effectively limits the gene expression of 11-βHSD and in turn inhibits the conversion of 11-dehydro-17-hydroxycortisone (cortisone) to cortisol. Through forskolin stimulation (Hasegawa et al., 2013), found that addition of 30 μM naringin or 10 μM hesperetin to each unit of an H295R cell culture effectively reduces the activity of 3β-hydroxysteroid dehydrogenase (3β-HSD) and significantly lowers the level of cortisone. Moreover, Ohno et al. (2002) discovered that the mono-hydroxy flavone M6 (IC50 = 0.5–2.7 μM) could inhibit the activity of cytochrome P450 enzymes and 3β-HSD, thus reducing the synthesis and secretion of cortisol in H295R cells. TG and the four active compounds mentioned above (quercetin, naringin, hesperetin, and mono-hydroxy flavone M6) are all polymethoxyflavones (PMFs) with highly similar chemical structures and biochemical activities (Zhao et al., 2018). Therefore, we speculate that TG modulates the cortisol stress response by attenuating the gene expression of 11-βHSD and the activity of cytochrome P450 enzymes and 3β-HSD. This postulate, however, remains to be proven.

Supplementation with naturally derived antioxidants could effectively clear the large quantity of free radicals produced during high-intensity exercises, accelerating fatigue recovery and reducing serum cortisol levels (Kraemer et al., 2005; Braakhuis and Hopkins, 2015; Wu et al., 2019). TG is a naturally occurring antioxidant found in fruit and vegetables with three verified mechanisms of antioxidant activity. Results from chemical assays have shown that TG can effectively scavenge the free radicals of diammonium 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonate (ABTS+•) and 1,1-diphenyl-2-trinitrophenylhydrazine (DPPH•), with scavenging rates of 8 and 10%, respectively (Tarozzi et al., 2006). One study based on cell models showed that TG significantly reduces the oxidative damage on HepG2 cells induced by tert-butylhydroperoxide (t-BHP) and enhances free radical scavenging efficiency (Selmi et al., 2017). Studies based on animal models (Kou et al., 2018; 2019) suggest that TG supplementation for 4 weeks (50 mg/d/kg) significantly increases antioxidant enzyme activity in mice and substantially alleviates the myocardial and skeletal muscle injury caused by oxidative stress from high-intensity, exhaustive exercise. In this study, we found that after 4 weeks of TG supplementation, the SOD activity of the EG remained stable during high-intensity resistance exercise, while that of the CG decreased gradually and was significantly lower than in the test group at corresponding time points. This study further confirms the high antioxidant capacity of TG in humans. Based on these results, we conclude that TG supplementation could boost antioxidant activity in humans and indirectly inhibit the synthesis and secretion of cortisol.

The strong stimulation of high-intensity resistance triggers a series of immune response changes in human skeletal muscles and other organs and leads to a sharp increase in the level of inflammatory factors, such as WBC and neutrophils, in the blood (Szlezak et al., 2016). We found that after two stimulation experiments via resistance exercise, the WBC count of all athletes showed a significant increase at P0, and then decreased gradually. After the second exercise stimulation experiment, the percent decline of WBC in the EG was significantly higher than that of the CG. This is thought to be related to the anti-inflammatory and immunomodulatory activities of TG. Molecular studies have shown that TG could significantly lower the level of pro-inflammatory cytokine TNF-α and enhance the activity of anti-inflammatory cytokine IL-1α (Arab et al., 2016). Animal studies have shown that a 14-day TG intervention (25 mg/kg/day) significantly reduces the level of inflammatory cytokines such as Th2 and Th17 in P12 mice and effectively inhibits the bronchitis inflammation induced by exhaustive exercise (Liu et al., 2017). Previous studies (Liu et al., 2019) suggest that after oral administration of TG (200 mg/day) for 5 weeks, joint and muscle pain and the risk of acute muscle strain both decrease slightly during high-intensity exercise in weightlifters and WBC count level decreases significantly on the next morning. Some studies have reported the anti-inflammatory, anti-stress, and immune hypersensitivity-inhibiting functions of cortisol (Fantidis, 2010; Walter et al., 2018). This compound is thus important in eliminating inflammation and repairing muscle after exercise. However, our study showed that a 4-week TG supplementation regimen does not damage the overall anti-inflammatory function of the body even though the WBC count was significantly reduced before and after high-intensity resistance exercise. This means taking TG supplements for 4 weeks may facilitate the repair and regeneration of muscle and other tissues, and indirectly promote functional recovery. However, the internal mechanism of these activities requires further research for revelation.

5 CONCLUSION

This study explored the effect of tangeretin supplementation on the cortisol stress response stimulated by high-intensity resistance exercise. We found that a 4-week tangeretin supplementation (200 mg/day) effectively reduces the cortisol stress response triggered by high-intensity resistance exercise, reduces serum cortisol and ACTH levels, and enhances the resilience of the body toward oxidative stress and inflammation. No adverse physiological or emotional reactions such as insomnia, nausea, or irritability were observed in the athletes during the period of tangeretin supplementation. Thus, tangeretin can be used to as a promising sports supplements to achieve a specific physical performance or health benefit in training and competitions, especially for high-intensity resistance exercises such as sprinting and weightlifting.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by This study was approved by the Academic and Human Rights Ethics Committee, Shanghai University of Sport. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Conceptualization, ML and ZZ; methodology, CQ; software, ML, ZZ and LB; validation, SM, TL and BG; formal analysis, ML and ZZ; investigation, ML, ZZ and CQ; resources, LB; data curation, ML, ZZ, CQ, LB; original draft preparation, ML and ZZ; review and editing, ML and ZZ; visualization, SM, TL and BG; supervision, SM, TL and BG; funding acquisition, BG All authors have read and agreed to the published version of the manuscript.

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OPINION
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"Functional Fitness Training", CrossFit, HIMT, or HIFT: What Is the Preferable Terminology?

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INTRODUCTION

Our objective in this letter is initially to analyze the terminology related to one of the main trends in exercise science and practice and then to propose a term that could be deemed preferable considering the comprehensive approach of this type of training.

Recently, from the 2000's onwards, a new exercise trend emerged worldwide, driven mainly by a brand, to improve physical fitness through the optimization of several components, such as aerobic capacity, muscular strength and endurance, speed, coordination, agility, balance, flexibility, and stamina (Glassman, 2002). This trend revolutionized the fitness world. Until its inception, no type of training had included so many components of physical fitness in the same training session, with participation of populations with different fitness levels. To perform this training, sessions include a wide range of functional movements involving the whole body and universal motor recruitment patterns, including some activities that can be extrapolated to daily life. There are activities such as calisthenics, strength/power, weightlifting, gymnastic movements, plyometric exercises, cycling, running, and rowing, which can be performed at a high intensity (Tibana et al., 2019). Challenge, scalability, enjoyment, affiliation, and the constant variation of workouts are characteristics that may explain the exponential growth among practitioners of different levels of physical fitness (Dominski et al., 2020), including a wide range of populations, including healthy individuals, obese individuals, and athletes. The growth in training with high intensity has aroused the interest of researchers, including our research group, mainly focusing on psychological (Dominski et al., 2020) physiological benefits (Tibana et al., 2022) as well as injuries (Dominski et al., 2021).

Several terms to denominate this type of training have been used both in science and practice. The terminology (terms) is provided in **Table 1**. In practice, the term CrossFit®, which is a company, it is widely used in situations covering from the media to informal conversations, as well as in scientific research. However, in recent years, in research and practice, we have seen an increase in the variety of terms used, sometimes to describe the same thing, but also to describe different types of fitness training programs, including CrossFit®, high-intensity functional training (HIFT), high-intensity multimodal training (HIMT), functional fitness training (FFT), extreme conditioning program (ECP), and Mixed Modal Training.

Despite this, according to Sharp et al. (2022), there is a lack of an operational term that broadly encompasses all types of exercise and physical fitness. Therefore, there is no full agreement among the scientists and athletes or the community (Schlegel, 2020). Recently, different definitions have emerged in some articles published, and this letter to the editor proposes a discussion of these terms, in addition to a proposition of a preferable term.

TABLE 1 | Terminology.

Terms	Definition	Organization/reference
CrossFit	CrossFit is a strength and conditioning system built on constantly varied, if not randomized, functional movements executed at high intensity.	CrossFit Inc. Glassman, 2007
High-intensity multimodal training (HIMT)	HIMT involves exercise programs that mix many different exercise modalities (e.g., weightlifting, powerlifting, gymnastic, calisthenics, plyometric, running, and others) and train multiple physical capacities at the same time (e.g., cardiorespiratory, muscle strength, and flexibility) HIMT encompasses all relevant styles of combined aerobic, resistance and/ or bodyweight training (i.e., HIFT, bodyweight HIIT, CrossFit) performed at a high or vigorous intensity	Carnes and Mahoney, 2019 Sharp et al., 2022
Extreme conditioning programs (ECP)	High-volume aggressive training workouts that use a variety of high-intensity exercises and often time a maximal number of repetitions with short rest periods between sets.	Bergeron et al., 2011
Functional fitness	A sport that aims to develop athletes' proficiency across a variety of movement patterns, activities, and energy systems. Training must develop the competency in various realms, including demonstrations of their aerobic capacity, strength, bodyweight endurance, bodyweight skill, mixed modal capacity, and power.	The International Functional Fitness Federation, iF3
High-intensity functional training (HIFT)	A training style [or program] that incorporates a variety of functional movements, performed at high intensity [relative to an individual's ability], and designed to improve parameters of general physical fitness (e.g., cardiovascular endurance, strength, body composition, flexibility, etc.) and performance (e.g., agility, speed, power, strength, etc.)	Feito et al., 2018
Mixed modal training	An approach that combines several physical training modalities in a single program	Marchini et al., 2019

DISCUSSION

In a quick search in the PubMed database to gain an overview of the number of studies (title field on 14th April, 2022), we observed different results according to the terms searched. We chose the terms in accordance with those discussed here. The search "crossfit" resulted in 101 documents, while "functional fitness" resulted in 75, "functional fitness training" in 2, "high-intensity functional training" in 29, "extreme conditioning program*" in 6, "high-intensity multimodal training" and "Mixed Modal Training" showed no results. Below we will discuss some aspects of each of the terms, thus since 2000 additional terms have been used over time, as shown in **Figure 1** (Timeline of appearance of terms and the respective references).

CrossFit® is a company (CrossFit® LLC) founded in 2000, but its inception by Greg Glassman occurred in 1996 in the USA. According to Official CrossFit® Affiliate Map (2022) there are more than 11,000 affiliated gyms worldwide (Official CrossFit Affiliate Map, 2022). CrossFit® is composed of a central branded organization (CrossFit® Headquarters) and a network of licensed affiliates–the gyms that are unofficially called boxes (Edmonds, 2021). Regarding modality, CrossFit® has a hybrid nature as both sport and exercise, due to the mixture of elite sport and practice for the health, enjoyment and conditioning of the general population (Edmonds, 2021). The key aspects of CrossFit® are constantly varied, high intensity, functional movement, but according to Edmonds (2021) (Edmonds, 2021) simply performing training with these characteristics does not mean one is doing CrossFit® - CrossFit Inc. needs to legally recognize as an official affiliate. To use the term CrossFit® some aspects should be respected: the affiliated gym, the CrossFit® methodology designed by the brand (official classes and/or exercises), and the inclusion of a certified CrossFit trainer. The affiliation of a physical location used for training allows the owners to legally use the CrossFit® trademark subject to the fulfillment of several requirements, such as obtaining at least a Level 1 Certificate to teach, some personal factors (such as the background, what CrossFit affiliation means to the coach, among others), the cost of affiliation through a fee payment, as well as criteria related to location and insurance. If an individual or entity is using CrossFit's intellectual property (e.g., trademarks or copyrights) without a license, confidential reports can be submitted to the legal department.

Although widely used, the brand name CrossFit® may decrease over time in publications, mainly due to the researchers' fear of possible lawsuits from CrossFit® Inc., but also from publishers and scientific journals (Tibana et al., 2016), which is becoming increasingly common. CrossFit® is a term that, unlike others, does not come from research but exclusively from the brand. Some journals, in the evaluation process, ask for confirmation that the study incorporates and/or assesses the true nature of the CrossFit LCC brand, including the gym where the exercise regime took place, official classes and/or exercises, and a certified CrossFit trainer. In this sense, we (Tibana et al., 2016) were instructed to change the title of our article (from CrossFit to extreme conditioning programs) because the data collection was not performed in a CrossFit® affiliated box from CrossFit® LLC. According to the guidelines given by the brand itself at the time of this publication, a workout can only be described as "CrossFit" if it is executed by CrossFit Inc., or by a group licensed by CrossFit Inc., including the journal's guidance to use the term "fitness training." Thus, the scientific community has adopted other terms, either under the guidance of the journal editors and reviewers and/or because the authors decided to definitely use another term to describe this type of training.

In 2011 a group of researchers published a Consortium for Health and Military Performance and American College of Sports Medicine consensus paper on extreme conditioning programs in military personnel (Bergeron et al., 2011). The term extreme conditioning program, as discussed previously by

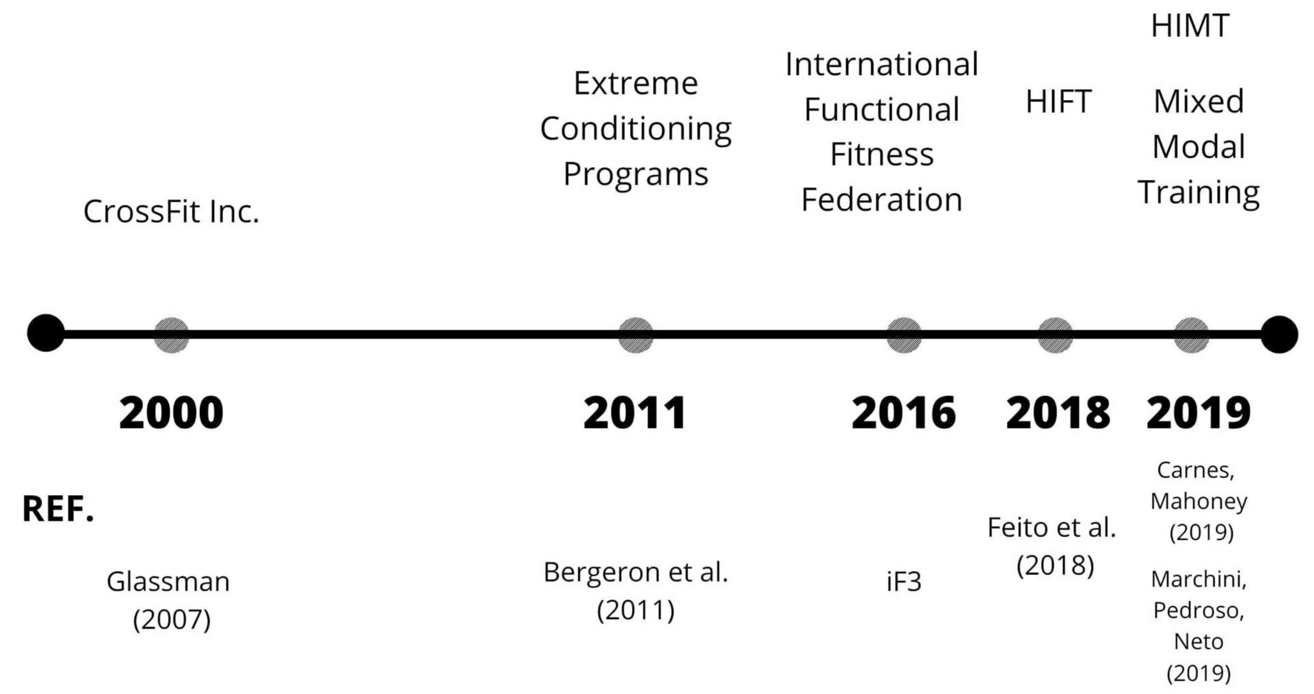

FIGURE 1 | Timeline of appearance of terms and references.

Feito and Mangine (2017), is certainly misleading and might be misinterpreted. Although a few authors have referred to CrossFit® as being extreme, it may be more appropriately referred to as "metabolic conditioning," "high-intensity functional training," or as its military roots have termed, "general physical preparedness" (Glassman, 2002). We infer that the term "extreme" automatically suggests abnormal activity, when in reality this is a training methodology currently employed by hundreds of thousands of individuals worldwide, with different levels of physical fitness, with scalability (modification options for the activities, movements, and exercises) being a strong point of the methodology.

Later, other groups of researchers adopted terms referring to high intensity, such as: HIFT (Feito et al., 2018) and HIMT (Carnes and Mahoney, 2019; Gentil et al., 2021). Recently, Carnes and Mahoney (2019), Gentil et al. (2021) and Sharp et al. (2022) used HIMT and included in this definition several terms such as CrossFit®, HIFT, bodyweight HIIT, cross-training, and others. Feito et al. (2018) proposed a definition to guide future publications about this training style [or program] as HIFT: "HIFT incorporates a variety of functional movements, performed at high-intensity [relative to an individual's ability], and designed to improve parameters of general physical fitness (e.g., cardiovascular endurance, strength, body composition, flexibility, etc.) and performance (e.g., agility, speed, power, strength, etc.)." However, these terms are associated only with a specific part of the modality's training session, popularly known as metabolic conditioning (METCON), as recognized recently by Sharp et al. (2022). Usually this part corresponds to the end of the training session in the gyms (CrossFit® affiliated or not). Thus, the use of the terms HIFT and HIMT would be correct only when the authors referred to METCON performed at high-intensity and not the modality in a broad way, as it includes the development of power, strength, and cardiovascular fitness in both periodization and training sessions.

Recently, Ide et al. (2022), recommended that the terms functional training, high-intensity functional training, and functional fitness training no longer describe any physical training program. The exercise programs, according to the authors, can be classified as strength, power, endurance, and flexibility. However, the authors do not suggest any specific term to describe a comprehensive type of training which includes strength, power, endurance, and metabolic conditioning training. However, mentioning specific types of exercises performed, as suggested by Ide et al. (2021), such as strength, plus endurance, or others, it is not viable. Furthermore, contrary to what Ide et al. (2022) claim, functional fitness training is not HIFT, and the difference found between functional fitness training and HIFT (the specific part of the modality's training session known as METCON) programs is consistent, as described above. Furthermore, Ide et al. (2022) affirmed that functional fitness training "could be easily described as strength training." However, the development of strength is only a specific part of the training session, as shown in **Table 2** (e.g., bench press and front squat).

We propose the adoption of "functional fitness training (FFT)" as the preferable term, at the present to describe this comprehensive type of training, characterized by

TABLE 2 | Functional fitness training in a week (designed for one person).

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Weightlifting	Snatch High Pull + Hang Snatch High Pull + Hang Snatch + Snatch 50%-1 55%-1 60%-1 65%-1 65%-1 70%-1	High Hang Clean + Hang Clean + Clean + Split Jerk 50%-1 55%-1 60%-1 65%-1 65%-1 70%-1	Accessory Exercises EMOM 18 min, rotating: 1) 10 GHD Hip Extension 2) 10 Mini Band Wall Slides 3) 10 Banded Face Pulls 4) 10 Drop and catch in 90° of shoulder abduction (R/L) 5) 15m Dumbbell Overhead Carry 6) Rest	Rest	Power Clean + Split Jerk 50%-3 (2x) 55%-3 (2x) 60%-3 (2x) 65%-3 (2x)	Accessory Exercises EMOM 18 Min, rotating: 1) 5 Single Arm Front Rack Curtsy Lunge 2) 30 m Dual KB Front Rack Carry 3) 10 Psoas March (each side) 4) 30" Glute Bridges Hold 5) 10 Rower Pike Up 6)-Rest	Rest
Strength	Bench Press 50%-3 60%-3 70%-3 80%-3 85%-2	Front squat 50%-3 60%-3 70%-3 80%-3 85%-2			RDL (%1RM Front Squat) 50%-3 60%-3 70%-3 80%-3 85%-3		
Gymnastic conditioning	4 Sets: 1 Bar Muscle-Up 2 Toes to Bar 3 Chest to Bar Pull-ups 2 Toes to Bar 1 Bar Muscle-Up Rest as little as needed between unbroken sets.		-		AMRAP 5 min 21 Burpees 21 Pull ups 21 Double Dumbbell Deadlift Rest 2 Min AMRAP 4 min: 15 Burpees 15 Pull ups 15 Double Dumbbell Deadlift Rest 2 Min AMRAP 3 min: 9 Burpees 9 Pull ups 9 Double Dumbbell Deadlift	Reckless 50 Wall Ball (9/6 kg) 40 Cal Row 30 Dual Dumbbell Box Step Up (22/16 kg) 30 meters Hand Stand Walking (5 meters segment unbroken) 30 Dual Dumbbell Box Step Up (22/16 kg) 40 Cal Row 50 Wall Ball	
Metabolic conditioning	3 Rounds: 20 Toes to bar 50 Double unders	"Death by Triplet" Complete as many rounds as possible during 20 min .8 Burpee Box Jump Overs/ 8 Hang Power Cleans (40/30 kg) / 8 Thrusters (40/30 kg)					
Aerobic conditioning	BikeErg Workout 2 x 5,000 m	Rowing Workout 2 x 3,000 m	Running Workout 4,000 m -		SkiErg Workout 20 min		

AMRAP, As many repetitions as possible; EMOM, Every Minute on The Minute; GHD, Glute Ham Developer; KB, Kettlebell; L, Left; R, Right; RDL, Romanian deadlift.

a variety of movement patterns (see some examples in **Table 2**), activities (which include weightlifting, strength, gymnastic conditioning, metabolic conditioning, aerobic conditioning), and energy systems used (ATP-CP/phosphagen, glycolytic, and oxidative). This term is based on two other terms: functional training and physical fitness.

Functional training can be understood, although with different definitions, as a way to increase performance in some functional tasks (e.g., activities of daily living or tests related to athletic performance) (Fleck and Kraemer, 2014). This definition was pointed out as the most rational definition of functional training according to Ide et al. (2022). Part of this term is due to the concept of physical fitness. According to Caspersen et al. (1985) physical fitness is a set of attributes related to health (such as cardiorespiratory endurance, muscular endurance, muscular strength, body composition, and flexibility) or skills (athletic ability), both present in functional fitness training, even when considering only one training session.

Functional fitness training is the most comprehensive and inclusive term to describe the variety of activities performed (see an example of training in **Table 2**). Functional fitness training must develop the people's competency in various realms, including demonstrations of aerobic capacity, strength, bodyweight endurance, bodyweight skills, and power. In this sense, CrossFit® is a type of functional fitness training.

Furthermore, there is an International Functional Fitness Federation, the iF3, which is the International Governing Body for Competitive Functional Fitness (The International Functional Fitness Federation, iF3). A specific organization can provide support to fuel the growth of functional fitness as a sport. This is an organization which aims to implement a standardized rulebook and clear movement standards. In addition, this organization has written safety guidelines for event organizers and increased competitive opportunities for athletes, being composed of several committees (technical, adaptive, medical, gender equality, athletes, and ethics–including a set of Anti-Doping Rules). There are several current national federations recognized by the International Federation (4 in Africa, 14 in America, 8 in Asia, 25 in Europe, and 1 in Oceania), totalizing 52 countries.

Functional fitness training was also recognized and regarded as one of the Top 20 Worldwide Fitness Trends for 2022. This trend first appeared in the ranking in 2007 and currently appears as trend n.14 (Thompson Walter, 2007). The limitation in the use of the proposed term is temporal. It may take time to establish the term compared to the brand.

It is relevant to agree on a new term to describe this type of training both in research and practice, considering sports scientists who are investigating this type of training as a "sport," and practitioners, athletes, and spectators interested in the practice, so they know what it is just by the term. The standardization of a term helps in research, because when we adopt only one term, it is possible to promote consistency in study protocols, to aid comparisons, and to find a greater number of articles in a search in databases, both for original articles and for the writing of systematic reviews. Regarding practitioners, the adoption of a term like the one proposed here, avoids that this type of training is linked to a brand, as it has been since then, which is susceptible to different interests–administrative and management, political, financial and others.

Considering the analysis about the terminology related to one of the main trends in exercise science and practice, we propose that the term functional fitness training could be more suitable than CrossFit®, HIFT, HIMT, or others.

AUTHOR CONTRIBUTIONS

FD: writing (review and editing) of the preliminary text and of the article. RT: idea conception and writing (review and editing). AA: supervision. All authors made significant individual contributions to this manuscript.

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ORIGINAL RESEARCH
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Relationships Between Body Composition and Performance in the High-Intensity Functional Training Workout "Fran" are Modulated by Competition Class and Percentile Rank

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This study examined relationships between body composition and high-intensity functional training (HIFT) workout performance. Fifty-seven men (31.4 ± 6.9 years, 177.2 ± 7.5 cm, 84.7 ± 8.5 kg) and thirty-eight women (29.2 ± 6.4 years, 166.6 ± 6.1 cm, 66.5 ± 7.7 kg) with HIFT experience (≥6 months) reported completing "Fran" (21-15-9 repetitions of barbell thrusters and pull-ups) in 4.78 ± 2.22 min and 6.05 ± 2.84 min, respectively, and volunteered to complete dual-energy X-ray absorptiometry assessments. Participants were grouped by competition class (men, women, master's men, master's women) and percentile rank in "Fran" (≤25th percentile, 25–75th percentiles, ≥75th percentile). Two-way analyses of variance revealed expected differences ($p < 0.001$) between men and women in non-bone lean mass (NBLM), fat-free mass index, and fat mass, and more NBLM (10.6–10.8 kg) and less fat mass (2.7–5.2 kg) in >75th percentile compared to other percentiles. Most body composition measures were significantly ($p < 0.05$) related to performance in men and women but limited in master's men; no relationships were seen in master's women. "Fran" time was negatively correlated to NBLM and fat-free mass index in all percentile groups (ρ = -0.37 to -0.64) and bone mineral characteristics for >25th percentile (ρ = –0.41 to –0.63), and positively correlated to fat mass in 25–75th percentiles (ρ = 0.33–0.60). No other relationships were seen in ≤25th percentile. The influence of body composition on "Fran" time appears to vary by both competition class and percentile rank. Though training to increase lean mass always seems relevant, reducing body fat only appears relevant in mid-skilled trainees and when it is outside healthy parameters.

Keywords: CrossFit®, athlete, dual energy X-ray absoptiometry, HIFT, body fat percentage, bone mineral denisty

INTRODUCTION

High-intensity functional training (HIFT) variably programs multimodal, functional movements designed to be performed at a relatively high intensity (within the context of prescribed repetitions or durations) in an effort to promote general physical fitness across multiple physiological parameters (Feito et al., 2018b). This method is reflected in the design of HIFT competition workouts, which require aptitude in various combinations of fitness domains (e.g., strength, cardiorespiratory fitness, and sports-specific skill). Indeed, relationships have been observed between most investigated physiological traits and HIFT performance (Bellar et al., 2015; Butcher et al., 2015; Feito et al., 2018a; Dexheimer et al., 2019; Carreker and Grosicki, 2020; Mangine et al., 2020; Zeitz et al., 2020) and it is unclear which is most important. Without clarity, those aiming to train effectively have little choice but to address all relevant areas of fitness. One reason for the lack of clarity is that most studies have limited their examination to only one or a few specific fitness domains (Bellar et al., 2015; Butcher et al., 2015; Feito et al., 2018a; Dexheimer et al., 2019; Carreker and Grosicki, 2020; Zeitz et al., 2020). That is, few comparisons have been made among traits as to their relative importance. To the best of our knowledge, only one investigation attempted to comprehensively determine the relative importance of multiple physiological characteristics (e.g., body composition, muscle morphology, hormonal concentrations, resting metabolism, aerobic capacity, and anaerobic power), in addition to training experience and sport-specific skill (Mangine et al., 2020). Though most variables were related to performance (in six competition workouts), the most consistent predictor involved some measure of body composition (i.e., body fat percentage, body density, or skeletal muscle cross-sectional area). This was an uncommon finding compared to other studies on this topic.

Body composition was not previously considered to be statistically important (Bellar et al., 2015; Butcher et al., 2015; Feito et al., 2018a; Dexheimer et al., 2019; Zeitz et al., 2020), likely because its role in those studies was limited to descriptive purposes. Only three studies have used it as a predictor and in limited capacity (Butcher et al., 2015; Carreker and Grosicki, 2020; Zeitz et al., 2020). Butcher et al. (2015) reported that body mass was related to, but not the best predictor of "Grace" (r = −0.67) and the CrossFit® Total (r = 0.77). Zeitz et al. (2020) reported that body mass and body fat percentage, measured by bioelectrical impedance analysis, were related (r = -0.46 and r = 0.53, respectively) to a 15-min circuit of 19 wall balls and 19 calories on a rowing ergometer where the goal was to complete "*as many repetitions as possible*" (AMRAP), but not a modified version of "Fran" that replaced pull-ups with bar-facing burpees. Stronger correlations ($r \geq 0.56$) were seen from several other performance measures collected in that study, with aerobic capacity being the best predictor (r = 0.68) of the 15-min circuit. In fact, the only other study to observe body composition as the best predictor of HIFT used the results of dual-energy X-ray absorptiometry (DXA) in relation to a scaled version of "Murph" (Carreker and Grosicki, 2020), an uncommonly long HIFT workout. Though analyzed alongside several physiological measures of strength, power, and aerobic endurance, body fat percentage was the only significant correlate of overall time, explaining ~51% of variance. Nevertheless, the lack of methodological consistency across studies limits the ability to make generalized conclusions about the role of body composition on HIFT performance.

Sample characteristics, particularly about experience, also differed greatly across the four studies relating body composition to HIFT (Butcher et al., 2015; Carreker and Grosicki, 2020; Mangine et al., 2020; Zeitz et al., 2020). Participants ranged from having no experience (Zeitz et al., 2020), 6–24 months of experience (Carreker and Grosicki, 2020; Mangine et al., 2020), or they had several years of HIFT experience, including regional and international competition experience (Butcher et al., 2015; Mangine et al., 2020). More time spent participating in a sport provides an athlete with more opportunities to develop and refine relevant skills and strategies that may help them overcome a physically or physiologically superior opponent. Still, HIFT experience is yet another documented predictor of performance that has received limited attention (Bellar et al., 2015; Mangine et al., 2020; Mangine and McDougle, 2022). This is interesting because one of the first HIFT prediction studies found years of experience to be the best predictor for two novel workouts; it was a better predictor than age, aerobic capacity, and anaerobic power (Bellar et al., 2015). However, that finding was slightly misleading because athletes with several, high-level HIFT competition experiences were being compared to those with no HIFT experience. It remained unclear whether experience with the traditional training modalities that comprise HIFT (e.g., resistance training, gymnastics, endurance training), years of HIFT participation, or the participants' competition experiences were driving those relationships. This question was partially addressed in a later study that found that HIFT competition experience (and ranking) was more influential on performance than years of resistance training or HIFT experience (Mangine et al., 2020). Competition experience was then further evaluated and found to differentially influence performance and this was based on whether the athlete possessed experience as an individual or team competitor at open/local, regional, and international events (Mangine and McDougle, 2022). Though competition performance would seem to be the most standard and reliable metric for quantifying skill in HIFT, not all studies have recruited participants with such experience. Thus, an alternative could be to use the individual's performance in benchmark workouts as a descriptor and/or inclusionary criteria. These are familiar, standardized workouts that more frequently appear in programming and are often tracked on HIFT-related message boards and social media websites (e.g., CrossFit, 2022). Despite being limited by the self-reported nature, normative values have been established from leaderboard data for five of the most common benchmark workouts appearing in HIFT (Mangine et al., 2018).

Unlike most physiological and performance measures, the relevance of body composition to performance is less obvious. Greater non-bone lean mass (NBLM), bone mineral content (BMC), and bone mineral density (BMD) are characteristics that support greater force and power expression (Lieber and Fridén, 2000; Schipilow et al., 2013; Stock et al., 2017). Conversely, athletes with less fat-mass (FM) and a lower percentage of body fat (PBF) may sustain effort better than individuals with greater non-functional mass due to a reduced relative workload, and potentially, a more efficient thermoregulatory system (O'Connor and Slater, 2011; Dervis et al., 2016). Still, any advantage awarded by superior body composition would seem to be modulated by the individual's overall skill in that sport. Greater familiarity with a movement pattern leads to greater and more efficient muscle activation and a reduced relative workload (Krakauer et al., 2019). Likewise, strategies learned from participating in a sport may limit the occurrence of inefficient and unnecessary actions (Brenner, 2016; Myer et al., 2016). These advantages would collectively be useful in HIFT competition, which may require sustained activity, precise weightlifting and gymnastic movement execution, strength and power to lift heavier loads, or a combination of all three. How experience or sports skill may affect these needs remains unexplored. Therefore, the purpose of this study was to begin examining the influence of competition class and skill on the relationships between body composition and HIFT performance, where skill was defined by their performance in one of the most popular benchmark workouts (i.e., "Fran"). It was hypothesized that differences in all measures would exist between competition classes and percentile ranks. However, regardless of competition class and percentile rank, the relationships between measures of body composition and performance would be the same.

MATERIALS AND METHODS

Study Design

To examine differences in and relationships between body composition and HIFT performance across sex, skill level, and competition class, recreationally active adults with at least 6 months of HIFT experience were recruited for this study. During enrollment, participants were asked to provide their personal best time-to-completion for the benchmark workout "Fran." This workout was selected because of its status as a benchmark workout that users may upload scores for on the most popular HIFT leaderboard (CrossFit, 2022). Additionally, its expected duration (approximately 2–9 min) consistently appears in HIFT (Feito et al., 2018b; Mangine et al., 2018) and unlike longer duration workouts appearing on leaderboards, its execution is more easily standardized across training facilities. Participants were grouped according to their sex- and age-determined competition class and by their within-class percentile rank for "Fran." Published normative values by Mangine et al. (2018) were used to appropriately place men (<35 years), women (<35 years), master's men (≥35 years), and master's women (≥35 years) into their respective interquartile range (i.e., ≤25th percentile, 25–75th percentiles, or ≥75th percentile). Following enrollment, participants were then scheduled to complete all body composition assessments via dual-energy x-ray absorptiometry (DXA). Comparisons were initially made between competition classes and percentile ranks for all body composition variables. Then, relationships between body composition variables and "Fran" performance were assessed for the entire sample, each competition class, and percentile rank grouping.

Participants

Following a description of all study procedures, a convenience sample of ninety-five adults [31.0 ± 6.8 years (19–56 years), 173.0 ± 8.7 cm (156.2–193.0 cm), 77.4 ± 12.0 kg (51.7–106.1 kg) who possessed an average "Fran" time of 5.3 ± 2.6 min (2.1–18.1 min) provided his or her written informed consent to participate in this study. Based on previously reported differences among competition classes (Mangine et al., 2018), G*Power (v. 3.1.9.7, Heinrich-Heine-Universität, Düsseldorf, Germany) determined that a minimum of 44 participants were needed to sufficiently observe differences between competition groups (Effect size of $f = 0.68$, $\alpha = 0.05$, $\beta = 0.95$). All participants had been regularly (≥2 sessions per week) and currently participating in HIFT for at least 6 months and were free of any injury or health condition (i.e., pregnancy, cardiovascular, pulmonary, metabolic disease, or orthopedic) known to impact physical activity, as determined by health and physical activity questionnaire. The University's Institutional Review Board approved all testing protocols and procedures for this study.

Workout Performance

All participants provided their personal best score (i.e., time to completion) for the benchmark workout "Fran." Briefly, "Fran" is a 3-round circuit of thrusters (i.e., barbell front squat into an overhead press) and pull-ups (Mangine et al., 2018; CrossFit, 2022). For each round the thruster load remains the same [Men: 95 lbs. (43.1 kg); Women: 65 lbs. (29.5 kg)] but repetitions for each exercise descend from 21 repetitions (round 1) to 15 repetitions (round 2) to 9 repetitions (round 3). Each set of thrusters begins with the loaded barbell on the floor. The athlete must pick up the barbell into the front rack position and descend to a full squat. The crease of the hip must clearly pass below the top of the knees in this position. The athlete must return to the starting position and immediately progress into an overhead press. A repetition is considered complete when the knees, hips, and arms are at full extension with the barbell overhead. For pull-ups, each repetition begins with the athlete hanging from a standard pull-up bar with their arms extended and feet off the ground. Athletes must pull themselves vertically so that their chin breaks the horizontal plane of the bar before returning to the start position. Pull-ups may be performed using strict control or with a "kipping" or "butterfly" technique, so long as the arms return to full extension at the bottom of each repetition. Repetitions are discounted and must immediately be repeated before progressing through the remaining workload if technical standards are not met. All participants completed the workout at their normal training facility under the supervision of a Level 1 certified coach prior to enrollment in this study.

Body Composition Assessment

The Participants arrived at the Exercise Physiology Laboratory after having fasted for 4 h and having avoided caffeine and vigorous exercise for at least 12 h to complete body composition assessments. Initially, anthropometric measures were collected using an electronic scale (Tanita WB 3000, Arlington Heights, IL) to measure height (±0.1 cm) and body mass (±0.1 kg), which were then used to calculate body mass index [BMI; body mass divided by height (in m) squared]. Anthropometric measures were completed with participants

TABLE 1 | Main effects and interactions between competition classes and percentile ranks.

	Competition class			Percentile rank			Interaction		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Height	14.7	<0.001	0.35	1.0	0.359	0.02	0.2	0.969	0.02
BMI	13.7	<0.001	0.33	0.1	0.951	0.00	1.4	0.243	0.09
FFMI	33.1	<0.001	0.55	7.2	<0.001	0.15	0.9	0.502	0.06
Body mass									
Total mass	29.8	<0.001	0.52	0.7	0.518	0.02	0.7	0.675	0.05
Fat mass	0.9	0.425	0.03	7.9	<0.001	0.16	1.3	0.271	0.09
Non-bone lean mass	50.1	<0.001	0.64	7.7	<0.001	0.16	0.4	0.859	0.03
Percentage fat									
Android	0.5	0.672	0.02	11.3	<0.001	0.22	0.8	0.576	0.05
Gynoid	22.5	<0.001	0.45	13.3	<0.001	0.24	1.5	0.186	0.10
Total body	10.8	<0.001	0.28	14.0	<0.001	0.25	1.0	0.457	0.07
Bone mineral									
Content	18.8	<0.001	0.41	3.0	0.057	0.07	1.2	0.306	0.08
Density	8.5	<0.001	0.24	1.4	0.251	0.03	1.1	0.397	0.07
Fran performance									
Time	13.6	<0.001	0.33	127.8	<0.001	0.76	0.7	0.660	0.05
Percentile rank	0.2	0.914	0.01	146.0	<0.001	0.78	0.4	0.906	0.03

TABLE 2 | Significant differences between competition classes, regardless of percentile rank [mean ± SD (range)].

	Men		Women		M. Men		M. Women	
	n = 42		n = 30		n = 15		n = 8	
Height (cm)	176 ± 7	(160–193)	167 ± 6	(156–184)†,‡	181 ± 7	(167–192)	166 ± 5	(157–172)†,‡
BMI (kg m^{-2})	27.3 ± 2	(20.4–30.5)	24.2 ± 1.8	(20.2–29.1)†	26.1 ± 2.3	(21.9–30.3)	23 ± 3.4	(20.2–28.4)†,‡
FFMI (kg m^{-2})	23.7 ± 2.2	(18.6–27.2)	19.5 ± 1.8	(15.6–24.1)†,‡	22.9 ± 2.1	(19.1–26.0)	18.4 ± 1.6	(16.2–20.4)†,‡
Body mass (kg)								
Total mass	84.4 ± 8.9	(66.7–106.1)	67.3 ± 7.5	(51.7–90.8)†,‡	85.4 ± 7.3	(67.8–95.2)	63.5 ± 7.9	(55.2–78.6)†,‡
Fat mass	14.4 ± 5	(7.2–29.6)	15.6 ± 4.8	(8.5–29.5)	14 ± 4.6	(7.2–26)	15.2 ± 5.9	(9.7–25.2)
Non-bone lean mass	70 ± 8.4	(52.4–85.8)	51.7 ± 7.2	(42.2–78.1)†,‡	71.4 ± 7	(56.4–78.6)	48.4 ± 4.6	(41.7–55.2)†,‡
Percentage fat (%)								
Android	18.7 ± 8.7	(8–43)	19.7 ± 8.5	(8.7–43.3)	17.4 ± 6.8	(8.6–29.2)	19.5 ± 8.4	(10.4–31.3)
Gynoid	17.7 ± 5.7	(8.7–32.4)	27 ± 6.5	(13.2–44.8)†,‡	16 ± 3.4	(9.2–20.6)	29.2 ± 7.7	(20.9–42.4)†,‡
Total body	17.8 ± 5.4	(10.1–30.1)	23.4 ± 6	(13.3–40.9)†,‡	16.5 ± 3.7	(10.3–22.9)	24.4 ± 6.8	(17.2–35.1)†,‡
Bone mineral								
Content (kg)	3.47 ± 0.53	(2.3–4.48)	2.71 ± 0.39	(2.13–3.74)†,‡	3.54 ± 0.41	(2.73–4.31)	2.58 ± 0.38	(1.93–3.11)†,‡
Density (g cm^{-2})	1.39 ± 0.13	(1.16–1.71)	1.26 ± 0.1	(1.09–1.41)†	1.37 ± 0.12	(1.19–1.6)	1.19 ± 0.15	(0.95–1.4)†,‡
Fran performance								
Time (sec)	279 ± 128	(125–566)	337 ± 127	(155–721) †,‡	309 ± 149	(140–660)	460 ± 271	(254–1085)†,‡
Percentile rank (%)	53.2 ± 32.7	(11.9–99.9)	50.2 ± 22.9	(16.5–98.4)	59.6 ± 32.4	(15–100)	56.7 ± 30.7	(20.4–100)

†, significantly ($p < 0.05$) *different than men.*
‡, significantly ($p < 0.05$) *different than masters men.*

standing barefoot, feet together, on the scale while wearing athletic clothing. Subsequently, participants were further assessed by DXA (Lunar iDXA, Lunar Corporation, Madison, WI) performed by the same researcher using standardized positioning procedures. Participants were asked to remove any metal or jewelry prior to laying supine on the DXA table for an entire body scan in "standard" mode using the supplied algorithms. Quality assurance was assessed by daily calibrations performed prior to all scans using a calibration block provided by the manufacturer. In addition to total PBF (±0.1%), BMC (±0.01 kg), BMD (±0.01 g cm^{-2}), fat mass (FM; ±0.1 kg), and NBLM (±0.1 kg), gynoid and android PBF (±0.1%) were obtained using manufacturer algorithms and used for statistical analyses. NBLM values were used to calculate fat-free mass index (FFMI; NBLM + BMC divided by height [in m] squared) (VanItallie et al., 1990).

Statistical Analysis

The Shapiro-Wilks test indicated that most variables were not normally distributed. Therefore, data was logarithmically transformed to satisfy this assumption prior to assessing differences and relationships. Separate two-way (Competition

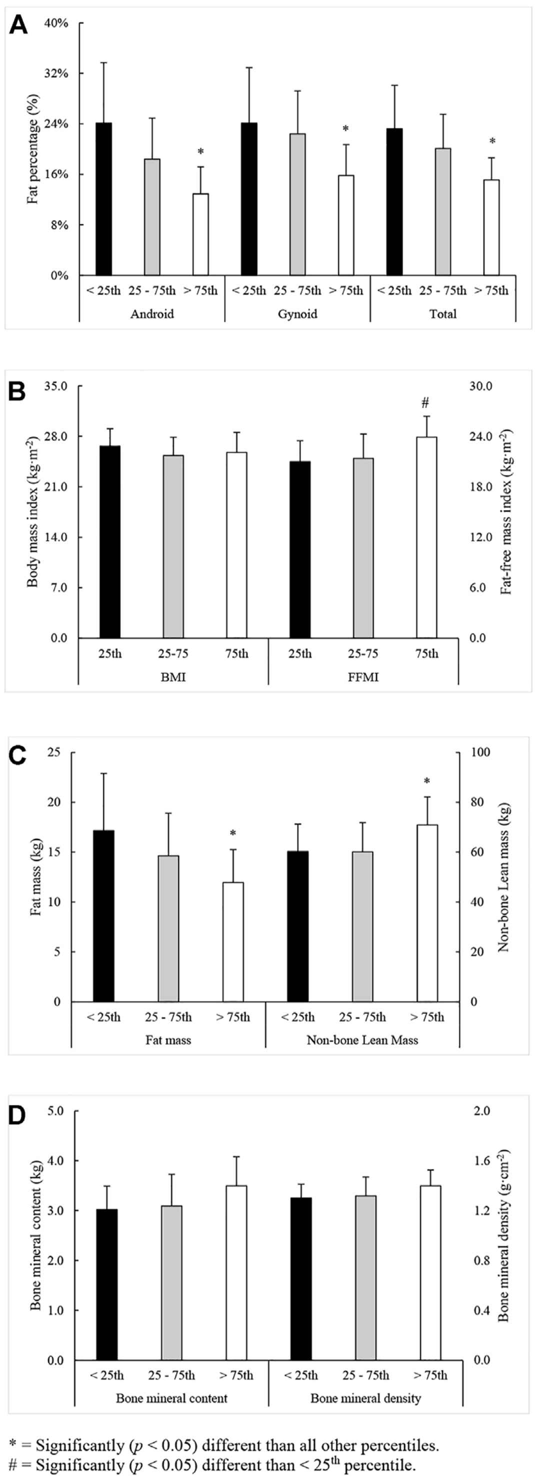

FIGURE 1 | Significant differences between percentiles in measures of **(A)** body fat percentage, **(B)** body mass and fat-free mass index, **(C)** fat and non-bone lean mass, and **(D)** skeletal mass characteristics (mean ± SD). * = Significantly ($p < 0.05$) different than all other percentiles. # = Significantly ($p < 0.05$) different than <25th percentile.

class x Percentile Rank) analyses of variance (ANOVA) were conducted on all transformed measures of body composition and “Fran” time. All significant main effects and interactions were further assessed using the Tukey’s Honest Significant Difference test. All between group differences were also evaluated using effect sizes (η_p^2: Partial eta squared) at the following levels: small effect (0.01–0.058), medium effect (0.059–0.137) and large effect (>0.138) (Cohen, 1988). Spearman’s bivariate and partial correlations were performed between “Fran” time and all body composition variables. The strength of observed relationships were interpreted using the following criteria: Trivial (<0.10), small (0.10–0.29), moderate (0.30–0.49), high (0.50–0.69), very high (0.70–0.90), or practically perfect (>0.90) (Hopkins et al., 2009). All statistical analyses were performed using JASP 0.14.1.0 (Amsterdam, Netherlands) with a criterion alpha set at $p \leq 0.05$. All data is presented, untransformed, as mean ± SD.

RESULTS

The results of each ANOVA are presented in **Table 1**. No significant interactions between competition class and percentile rank were noted for any variable.

Main effects for competition class were observed for all variables except fat mass and the percentage of android fat. Post hoc analysis indicated that men and master’s men possessed greater height (mean difference = 9.0–13.9 cm, $p \leq 0.008$), total body mass (mean difference = 15.6–21.7 kg, $p < 0.001$), NBLM (mean difference = 16.8–23.3 kg, $p < 0.001$), FFMI (mean difference = 3.3–5.3 kg m^{-2}, $p < 0.001$), and BMC (mean difference = 0.66–0.96 kg, $p < 0.001$), as well as lower percent total body fat (mean difference = 5.2–8.1%, $p \leq 0.006$) and percentage gynoid fat (mean difference = 8.5–13.3%, $p < 0.001$), than women and master’s women. Men also possessed a higher BMI (mean difference = 2.6–4.4 kg m^{-2}, $p < 0.001$) and greater BMD (mean difference = 0.11–0.20 g cm^{-2}, $p \leq 0.012$) than women and master’s women, whereas BMI (mean difference = 3.2 kg m^{-2}, $p = 0.003$) and BMD (mean difference = 0.18 g cm^{-2}, $p = 0.004$) were only greater in master’s men compared to master’s women. Further, although men and master’s men completed “Fran” faster than their female counterparts (mean difference = 51–160 s, $p \leq 0.009$), no differences in percentile rank were seen. No other differences were found between competition classes. Significant differences between competition classes are presented in **Table 2**.

Significant main effects for percentile rank were observed for “Fran” performance, body fat percentage (android, gynoid, and total), FM, FFMI, and NBLM. Regardless of competition class, individuals from >75th percentile (“Fran” time = 167 ± 32 s, 81 ± 3 percentile rank, $p < 0.001$) completed “Fran” faster than those within the 25th–75th percentiles (“Fran” time = 283 ± 74 s, 53 ± 16 percentile rank) and below (“Fran” time = 485 ± 144 s, 10 ± 9 percentile rank). Those ranking between the 25th–75th percentiles were also faster ($p < 0.001$) than those ranking below. Those from >75th percentile possessed lower fat percentage (android, gynoid, and total), less FM, and more NBLM than all other percentiles. Those ranking above the 75th percentile also possessed a greater FFMI than those below the 25th percentile. No other differences were seen between percentiles. The differences between percentiles for measures of body composition are illustrated in **Figure 1**.

Bivariate and partial correlations between “Fran” time and body composition measures are presented in **Table 3**. Significant ($p < 0.05$) bivariate and partial (controlling for competition class) correlations were found between “Fran” time and all measures of body composition, with differences in each’s ability to explain variance ranging between 5.0% and 34.6%. These relationships were altered when the analysis was repeated after splitting the sample by competition class. In men, all body composition measures except for height were related to “Fran” time, whereas significant ($p < 0.05$) relationships were limited to percent fat (android, gynoid, total), FM, NBLM, and FFMI in women. Within the master’s class, fewer relationships were seen. Percent android and total fat, as well as FFMI, were the only measures related to “Fran” time in master’s men, and no significant relationships were seen in master’s women.

Except for FM and percent android fat, all measures were again significantly ($p < 0.05$) related to “Fran” time when controlling for the influence of percentile rank. The ability of each variable in explaining variance in “Fran” time ranged between 9.6% and 36.0%. When the analysis was repeated with the sample split by percentile rank groupings, different combinations of significant relationships were seen within each grouping. All variables except FM were related to “Fran” time for participants ranking between the 25th and 75th percentiles. Likewise, all body composition variables, except those relating to fat distribution [i.e., FM and percent fat (android, gynoid, total)], were related to “Fran” time in >75th percentile. In contrast, only NBLM and FFMI were related to “Fran” time in participants from <25th percentile. The effects of percentile rank on relationships between “Fran” time and measures of body composition are illustrated in **Figures 2–5**.

DISCUSSION

This study aimed to assess the influence of competition class and percentile rank on relationships between body composition and HIFT performance using the benchmark workout “Fran.” Though nearly a handful of studies have reported relationships between various measures of body composition and one or more HIFT workouts (Butcher et al., 2015; Carreker and Grosicki, 2020; Mangine et al., 2020; Zeitz et al., 2020), any consensus is clouded by several methodological differences existing amongst these studies. One limited relationships to simply height and body mass (Butcher et al., 2015), two related performance to DXA-derived PBF (Carreker and Grosicki, 2020; Zeitz et al., 2020), and only one examined multiple body composition compartments (Mangine et al., 2020). The strength of their reported relationships, including whether they were significant, also depended on the specific workout being used to define HIFT performance. Across all studies (Butcher et al., 2015; Carreker and Grosicki, 2020; Mangine et al., 2020; Zeitz et al., 2020), the included HIFT workouts only appeared once except for the CrossFit® total (i.e., the sum of 1-RM deadlift, back squat, and overhead press) (Butcher et al., 2015; Zeitz et al., 2020). More importantly, and relevant to this study, none of the studies considered the influence of competition class and percentile rank on these relationships. Here, we built upon past work (Butcher et al., 2015; Zeitz et al., 2020) by reexamining “Fran” with a much larger sample, a more comprehensive usage of DXA, and by distinguishing relationships by competition class and percentile rank.

Men generally possessed more lean mass and less fat mass, and their “Fran” times were faster than those seen in women, but no differences were seen across age groups. In healthy, athletic populations, men are well-known to possess more muscle and less fat than women, and these differences may help explain why men typically perform better (Tseng et al., 2014; Jagim et al., 2019; Huebner and Perperoglou, 2020). HIFT programming tries to account for the known physiological differences between men and women by scaling workouts. For “Fran,” this is accomplished by prescribing different intensity loads for thrusters [i.e., 95 lbs. (43.1 kg) for men and 65 lbs. (29.5 kg) for women] but nothing is altered for pull-ups (Feito et al., 2018b; Mangine et al., 2018). The rationale for why pull-up prescription is the same for men and women is not clear. A recent study reported a strong correlation between “Fran” time and maximum strict pull-ups ($r = -0.598$) (Leitão et al., 2021). Although stronger relationships were seen with thruster strength and endurance ($r = -0.608$ to -0.822), upper-body strength endurance is clearly important. Indeed, an individual must have the capacity to complete a total of 45 pull-ups to finish “Fran.” While there is evidence of women being more resistant to upper-body fatigue than men (Hunter, 2016), they have historically had more difficulty performing multiple, consecutive pull-ups (Flanagan et al., 2003). This is likely because the intensity of pull-ups is defined by the individual’s body mass. Body mass and lean mass have been previously associated (negatively) with pull-up performance (Johnson et al., 2009; Sánchez Moreno et al., 2016). On average, body mass and composition, particularly when considering its distribution, are not the same between men and women (Tseng et al., 2014; Jagim et al., 2019; Huebner and Perperoglou, 2020). Being heavier, men should have a more difficult time performing consecutive pull-ups. However, because men typically possess more upper-body lean mass, they have more relevant, functional mass to devote to pull-ups. Even when normalizing for body mass and lean mass (i.e., per kg), greater pull-up strength has been documented in men (Johnson et al., 2009). Women only equaled men when the load was perfectly equated (i.e., as a covariate) (Johnson et al., 2009), an inappropriate statistical procedure when natural differences between groups prevent random assignment (Weir and Vincent, 2005). Women might overcome this natural disadvantage by employing a “kipping” or “butterfly” technique and redirecting some of the work to the lower-body (Williamson and Price, 2021), but since both sexes are permitted this option, the gap between sexes remains. This is supported by “Fran” time generally being related positively to fat mass and PBF, and negatively to NBLM and FFMI.

TABLE 3 | Significant relationships between “Fran” time and measures of body composition.

	Bivariate	Partial Correlation		Men	Women	M. Men	M. Women
				>25th percentile	25–75th percentile	>75th percentile	-
Height (cm)	-0.26*	Competition class	-0.22*	-0.19	-0.24	0.20	-0.36
		Percentile rank	-0.31*	-0.12	-0.38*	-0.45*	-
BMI (kg m^{-2})	-0.31*	Competition class	-0.25*	-0.31*	0.11	-0.47	-0.24
		Percentile rank	-0.48*	-0.36	-0.49*	-0.53*	-
FFMI (kg m^{-2})	-0.58*	Competition class	-0.55*	-0.65*	-0.40*	-0.59*	-0.38
		Percentile rank	-0.60*	-0.63*	-0.59*	-0.51*	-
Body mass (kg)							
Total	-0.35*	Competition class	-0.30*	-0.40*	0.06	-0.17	-0.17
		Percentile rank	-0.47*	-0.32	-0.49*	-0.57*	-
Fat mass	0.39*	Competition class	0.39*	0.34*	0.55*	0.41	0.29
		Percentile rank	0.12	0.11	0.25	-0.03	-
Non-bone lean mass	-0.50*	Competition class	-0.46*	-0.57*	-0.41*	-0.44	-0.62
		Percentile rank	-0.52*	-0.37*	-0.54*	-0.63*	-
Percentage fat (%)							
Android	0.50*	Competition class	0.51*	0.53*	0.53*	0.53*	0.11
		Percentile rank	0.16	0.01	0.33*	-0.02	-
Gynoid	0.53*	Competition class	0.50*	0.48*	0.68*	0.28	0.43
		Percentile rank	0.48*	0.32	0.60*	0.37	-
Total	0.59*	Competition class	0.57*	0.53*	0.65*	0.53*	0.43
		Percentile rank	0.41*	0.23	0.53*	0.27	-
Bone mineral							
Content (kg)	-0.44*	Competition class	-0.40*	-0.52*	-0.23	-0.08	-0.24
		Percentile rank	-0.46*	-0.24	-0.52*	-0.62*	-
Density (g cm^{-2})	-0.41*	Competition class	-0.37*	-0.47*	-0.12	-0.06	-0.24
		Percentile rank	-0.41*	-0.24	-0.41*	-0.59*	-

*, *significant* ($p < 0.05$) *relationship between variables.*

The lack of differences between age groups, as well as the fewer significant relationships seen between body composition and “Fran time” in the master’s class, are most likely the consequence of reduced statistical power. There were nearly three times as many younger participants as those who were older than age 35 years. While this may be viewed as a limitation to this study, and potential source of type II error, these numbers are consistent with the ratios seen between master’s and younger athletes in Open and international competition (Leaderboard, 2021). Nevertheless, an equal or greater (but non-significant) correlation coefficient was seen in master’s participants for approximately one-third of the variables found to be significantly related to “Fran” time in younger participants. Additionally, the master’s class begins at age 35 years, and the oldest participant in the present study was 56 years old. Despite this 20-year range, appreciable changes to physiology, particularly in physically-active, resistance-trained adults, are less common than they are with similarly aged, sedentary adults (McGregor et al., 2014; Larsson et al., 2019). Since no significant differences were found between younger and older participants, theoretically, the relationships between body composition and “Fran” time should have been the same. Thus, for the time being, these findings should be viewed as preliminary.

Participants from >75th percentile possessed less fat mass and more NBLM than all other participants. Meanwhile, no differences were seen among the lower percentile groups or with any measure of bone health. The size, architecture, and quality of skeletal muscle reflect its ability to produce force (Lieber and Fridén, 2000; Stock et al., 2017). The mass and density of bone are also thought to contribute to force production by providing a stable structure through which force may transfer and elicit human movement. However, there is less evidence available documenting an advantage from exercise-induced gains in bone size (Schipilow et al., 2013) and adaptations require longer training periods (6–8 months) (Kohrt et al., 2004). In the present study, NBLM and FFMI were related to “Fran” time for all percentile ranks, whereas BMC and BMD were related to performance in everyone except the lowest percentile. It is possible that lower-ranked individuals must sufficiently develop a variety of physiological traits and/or sport-specific skills before bone mass becomes a relevant factor. Regardless, these findings provide support for previous reports of “Fran” time being highly correlated to performance measures of muscular strength (Butcher et al., 2015; Zeitz et al., 2020; Leitão et al., 2021) and endurance (Leitão et al., 2021).

Interestingly, PBF measures were only relevant to those ranking within the interquartile range (i.e., 25th–75th percentile). A leaner individual might use less energy when performing repeated movements at a given intensity, and assuming proper hydration and ventilation, thermoregulate better than someone with a higher body fat percentage during exercise (O’Connor and Slater, 2011; Dervis et al., 2016). Together, these could prolong the onset of fatigue and better facilitate sustained movement during extended-duration exercise.

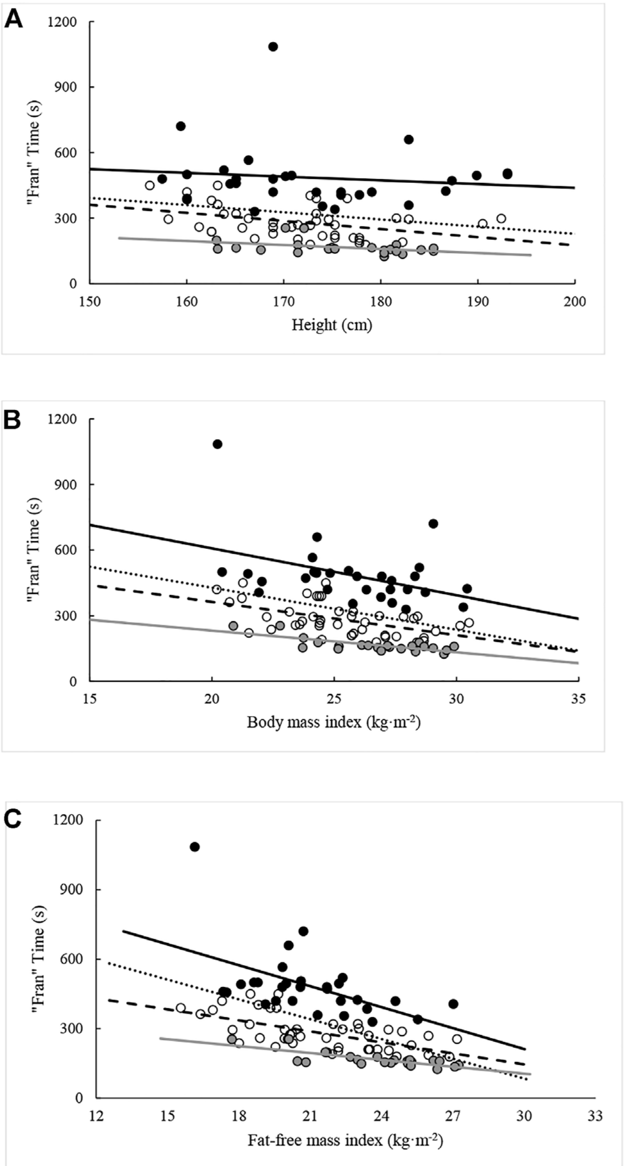

FIGURE 2 | Relationships between "Fran" time and **(A)** height, **(B)** BMI, and **(C)** FFMI across percentile ranks. Note: Dotted regression line (*n* = 95), black spheres and regression line (*n* = 29, <25th percentile), open spheres and dashed regression line (*n* = 44, 25–75th percentiles), and grey spheres and regression line (*n* = 22, >75th percentile).

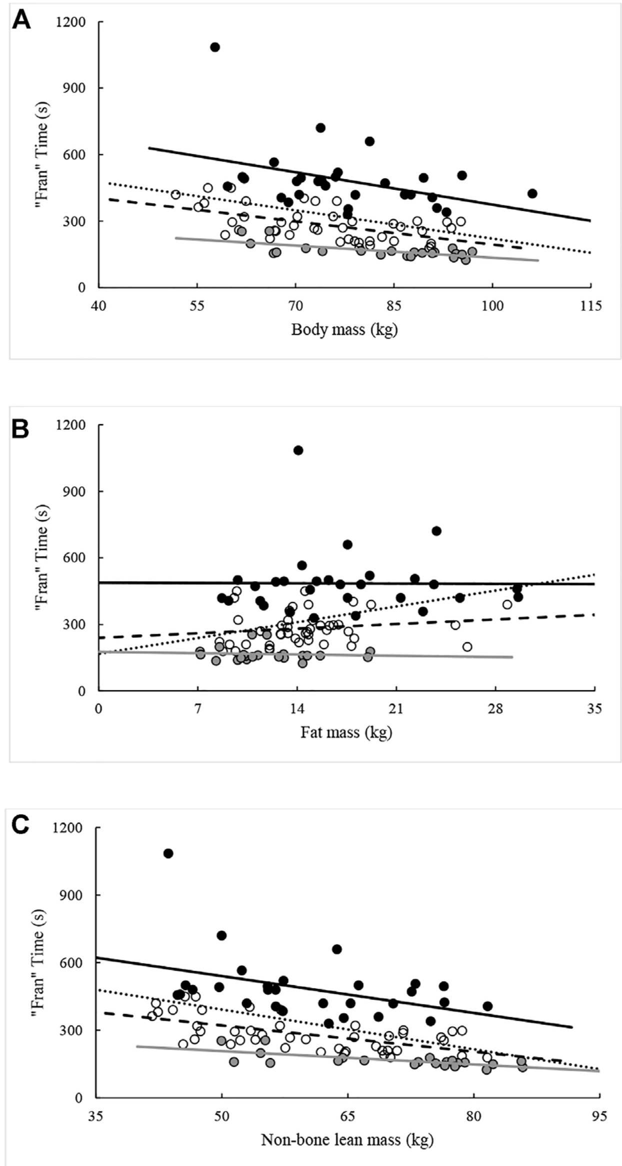

FIGURE 3 | Relationships between "Fran" time and **(A)** body mass, **(B)** fat mass, and **(C)** non-bone lean mass across percentile ranks. Note: Dotted regression line (*n* = 95), black spheres and regression line (*n* = 29, <25th percentile), open spheres and dashed regression line (*n* = 44, 25–75th percentiles), and grey spheres and regression line (*n* = 22, >75th percentile).

However, the relevance of this advantage to "Fran" is unclear. For most individuals, regardless of competition class, the average completion time for "Fran" ranges between 4 and 6 min (Mangine et al., 2018), which more closely resembles anaerobic effort than a long-duration aerobic event. Indeed, respiratory exchange ratio values have been reported to be greater than 1 (indicating anaerobic metabolism) for more than 75% of "Fran" (Fernandez-Fernandez et al., 2015), and the workout is also highly correlated (r = 0.673) with the 2K rowing time (Interquartile range = 7.3–7.7 min) (Leitão et al., 2021), another predominantly anaerobic event. For the lowest-ranking participants in this study, the need to improve lean mass appears to supersede all other needs (physiological and technical). Their average times ranged between 7.3 and 11.4 min, and up to 18.1 min. Within the context of this workout, being unable to lift the assigned thruster load for multiple repetitions, or perform pull-ups sequentially, would seem to be the most likely explanations. Meanwhile, the highest-ranked individuals, who also possessed the healthiest body composition, may have reached a point where continued focus on PBF reduction was either unnecessary or unhealthy. Instead, continuing to improve lean mass to further force production capabilities, and possibly

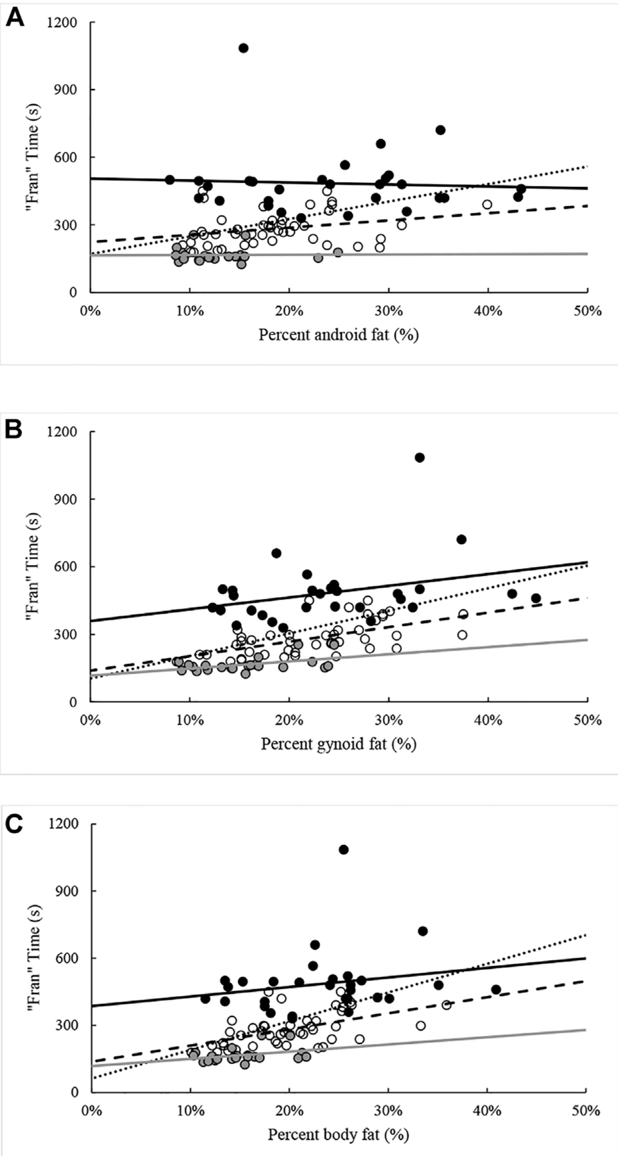

FIGURE 4 | Relationships between “Fran” time and percentage **(A)** android fat, **(B)** gynoid fat, and **(C)** total fat across percentile ranks. Note: Dotted regression line (*n* = 95), black spheres and regression line (*n* = 29, <25th percentile), open spheres and dashed regression line (*n* = 44, 25–75th percentiles), and grey spheres and regression line (*n* = 22, >75th percentile).

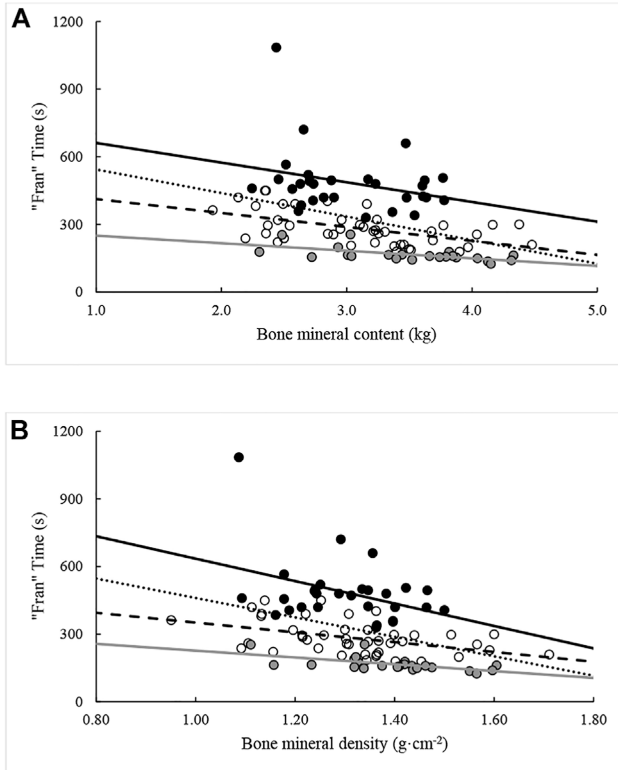

FIGURE 5 | Relationships between “Fran” time and bone mineral **(A)** contend and **(B)** density across percentile ranks. Note: Dotted regression line (*n* = 95), black spheres and regression line (*n* = 29, <25th percentile), open spheres and dashed regression line (*n* = 44, 25–75th percentiles), and grey spheres and regression line (*n* = 22, >75th percentile).

perfecting technique may prove more beneficial. In contrast, though middle-ranked individuals may still benefit from improved lean mass, more rapid improvements in “Fran” might happen with a healthier PBF.

Conclusion

The findings of this study indicate that the various sub-categories of body composition are all related to “Fran” performance, but their individual relevance is modulated by competition class and skill. Despite the compositional differences seen between men and women, relationships to performance were similar for each sex. The lack of age group differences within each sex, and significant relationships to performance in the master’s class, are contrary to this conclusion. However, this was likely because less participants qualified for the master’s class and thus, reduced statistical power. A more deliberate effort in recruiting sufficient participants within each competitive class will help to clarify this disagreement. Across percentile ranks, the higher-ranking participants (>75th percentile) possessed more NBLM and less body fat than all other participants, and those who possessed more lean mass (NBLM, FFMI, BMC, and BMD) performed better. Although middle- (25th–75th percentiles) and lower-ranking (<25th percentile) participants possessed similar body composition, the relationships of each sub-category to performance were different. Moderate to high correlations with “Fran” time were noted for all sub-categories (except FM) in middle-ranking participants, whereas NBLM was the only sub-category associated with performance in the lower-ranking participants. Including assessments of muscular strength in the thruster exercise and maximal pull-up repetitions (using all relevant styles) would have helped to better explain the practical importance of NBLM to performance. These findings are also limited to self-reported "Fran" times. Future studies may want to confirm our findings by directly testing "Fran" or expand on them by including a greater variety of benchmark workouts. Nevertheless, this appears to be the first study to examine the influence of competition class and percentile rank on relationships between any physiological measure and HIFT performance.

Practical Applications

The findings of this study suggest that relationships between "Fran" time and body composition are important for both men and women. Striving for a healthy ratio of NBLM to fat mass appears to be related to a faster "Fran" time but men and women may accomplish this differently. In men, greater body mass and bone mineral content/density were relevant to performance, and these traits are typically enhanced when long-term training goals are to develop muscle size, strength, and power. In women, body and skeletal mass were not related to "Fran" time. Though the reasons for this are unknown, it may imply a greater reliance on movement efficiency rather than strength to complete workout tasks. Significant relationships were not found in master's participants. Still, it may be prudent to assume that this was the consequence of reduced power. Master's class adults should seek to model their training goals after their younger counterparts. When the analysis considered percentile rank, NBLM was related to performance in all participants, and the strength of this relationship increased in those who completed "Fran" in less time. By improving NBLM, strength is presumably increased, and this would reduce the relative intensity of the fixed loads prescribed for this workout. Meanwhile, attention to PBF and fat mass reduction only appears to be relevant for moderately ranked individuals. More skilled participants possessed the healthiest fat-to-lean mass ratio, and this seems to suggest that a threshold exists where continued focus on this goal has no additional benefit. In the lowest ranked participants, the only relationship observed was between NBLM and "Fran" time. This may reflect a need to improve strength, technique, pacing strategy, or possibly all three. Any concerted effort to reduce fat mass at this stage seems to be premature.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Kennesaw State University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Acute Effects of Barbell Bouncing and External Cueing on Power Output in Bench Press Throw in Resistance-Trained Men

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The aims of this study were to compare power output during a bench press throw (BPT) executed with (BPT_{bounce}) and without (BPT) the barbell bounce technique, and examine the effect of cueing different barbell descent velocities on BPT power output in resistance-trained males. In total, 27 males (age 23.1 ± 2.1 years; body mass 79.4 ± 7.4 kg; height 178.8 ± 5.5 cm; and 4.6 ± 1.9 years of resistance training experience) were recruited and attended one familiarization session and two experimental sessions (EXP 1 and EXP 2). The force–velocity profile during maximal BPT and BPT_{bounce} (randomized order) under different loads (30–60 kg) was established (EXP 1), and the effect of varying external barbell descent velocity cues "slow, medium, and as fast as possible" (i.e., "fast") on the power output for each technique (BPT and BPT_{bounce}) was examined (EXP 2). Comparing two BPT techniques (EXP 1), BPT_{bounce} demonstrated 7.9–14.1% greater average power ($p \leq 0.001$, ES = 0.48–0.90), 6.5–12.1% greater average velocity ($p \leq 0.001$, ES = 0.48–0.91), and 11.9–31.3% shorter time to peak power ($p \leq$ 0.001–0.05, ES = 0.33–0.83) across the loads 30–60 kg than BPT. The cueing condition "fast" (EXP 2) resulted in greater power outcomes for both BPT and BPT_{bounce} than "slow." No statistically significant differences in any of the power outcomes were observed between "medium" and "slow" cuing conditions for BPT (p = 0.097–1.000), whereas BPT_{bounce} demonstrated increased average power and velocity under the "medium" cuing condition, compared to "slow" (p = 0.006–0.007, ES = 0.25–0.28). No statistically significant differences were observed in barbell throw height comparing BPT and BPT_{bounce} under each cuing condition (p = 0.225–1.000). Overall, results indicate that both bouncing the barbell and emphasizing barbell descent velocity be considered to improve upper body power in athlete and non-athlete resistance-training programs.

Keywords: stretch-shortening cycle, descending velocity, upper limb power, kinematic, force–velocity relationship

INTRODUCTION

Barbell bench press is one of the most frequently used resistance exercises for developing upper body strength and mechanical power (van den Tillaar, 2004; Bragazzi et al., 2020; Sakamoto and Sinclair, 2012; Cormie et al., 2011), particularly in sports involving explosive upper limb actions (e.g., throwing and striking). These movements require high velocity rather than high maximal strength in the upper body, as the ability of muscles to produce force decreases with increasing movement velocity (Young, 2006; Cormie et al., 2010). Establishing the force–velocity profile for a specific exercise enables the highest mechanical power output and the intensity (i.e., load and velocity) at which it is produced to be characterized on an individual basis (Wilson et al., 1993; Cronin et al., 2001a; Samozino et al., 2012; Jaric, 2015). Depending on the exercise type, equipment used, training status, and muscle groups elicited, power output is shown to be the greatest at intensities ranging between 30–70% of one repetition maximum (RM) (Wilson et al., 1993; Cronin et al., 2001b; Sakamoto et al., 2018; Đurić et al., 2021).

The traditional bench press technique adopted during power training is characterized by a large acceleration at the beginning of the barbell lift (ascent phase) (Newton et al., 1997; Baker and Newton, 2005; Tillaar and Ettema, 2013). However, high force generation, which produces barbell acceleration, is only observed during a small part of the ascent phase and is followed by a deceleration phase at the end of the barbell lift (Elliott et al., 1989; van den Tillaar and Ettema, 2009; van den Tillaar and Ettema, 2010; Pérez-Castilla et al., 2020). Furthermore, the deceleration phase is accompanied by a reduction in agonist muscle activity (Elliott et al., 1989; Newton et al., 1996; Sakamoto and Sinclair, 2012), which suggests that the traditional barbell technique may not provide the best approach to train maximal neuromuscular adaptions. In order to overcome the delimited reduction in active force production at the end of the ascent phase, the effect of implementing ballistic actions (e.g., projecting the barbell) has been studied (Newton et al., 1996; McEvoy and Newton, 1998; Sakamoto and Sinclair, 2012; Sakamoto et al., 2018; Pestaña-Melero et al., 2020; Løken et al., 2021). For example, Newton et al. (Newton et al., 1996) demonstrated that using a bench press throw technique (BPT) resulted in barbell acceleration during 96% of the ascent phase, compared to 60% using a traditional, non-ballistic bench press action. Furthermore, at intensities of 30–60% of 1-RM, greater peak angular velocity at the elbow (Sakamoto et al., 2018), higher peak and mean barbell velocity (Newton et al., 1996; Cronin et al., 2001a; Pestaña-Melero et al., 2020), and greater mean force and peak power (Newton et al., 1996; Pestaña-Melero et al., 2020) have been demonstrated for BPT than for non-ballistic, traditional bench press.

Typically, explosive actions exploit stored elastic strain energy and enhanced neural drive to agonist muscles derived from the stretch-shortening cycle (SCC) (Komi, 1984; Fukutani et al., 2020). Performance-enhancing effects of SCC typically result from an eccentric action (e.g., barbell descending phase) immediately preceding an explosive action (e.g., dynamic barbell ascent), as observed during throwing, jumping, or ball striking (Morriss and Bartlett, 1996; McMaster et al., 2014). In the context of bench press, concentric-only actions (i.e., barbell lifting) have been compared with actions involving both eccentric and concentric phases (e.g., barbell lowering followed immediately by barbell lifting) at different intensities (15–100%) of 1-RM, with greater velocity, acceleration, force, and power output reported for the eccentric-concentric action (Newton et al., 1997; Cronin et al., 2001b; Pérez-Castilla et al., 2020). These findings are in accordance with the generally agreed principle of implementing SSC components in training regimens aiming to increase velocity and power (Wilson et al., 1993; Newton et al., 1997; Cronin et al., 2001b; Boffey et al., 2019). However, the potential for barbell velocity during the lowering (i.e., eccentric) phase to affect power output during bench press has not been conclusively demonstrated. For example, Pryor et al. (Pryor et al., 2011) compared the effect of different lowering velocities at 80% of 1-RM during bench press lifting and demonstrated that higher barbell descending velocity (1 s descent phase) resulted in greater peak and average power output during the lifting phase, compared with a lower velocity (4 s descent phase). Carzoli et al. (Carzoli et al., 2019) demonstrated an increase in peak lifting velocity after a higher velocity descent phase, compared with the usual barbell descent cadence, at both 60 and 80% of bench press 1-RM. In experienced, bench press-trained participants, a fast-eccentric bench press action resulted in the greater mean and peak concentric barbell velocity, compared to a concentric-only action, but was similar to a controlled-eccentric action (1.5 s) under light and medium loads (30- and 50% of 1-RM) (Janicijevic et al., 2020). However, none of the studies cited implemented the bounce technique (BPT_{bounce}) or the ballistic BPT during the bench press action (Pryor et al., 2011; Carzoli et al., 2019; Janicijevic et al., 2020).

Traditionally, it is recommended that the barbell should only lightly touch the chest and not rebound (i.e., bounce) off it (Løken et al., 2021). Theoretically, the bounce bench press may enable greater acceleration of the barbell than traditional approaches to the bench press technique, increasing power output during the exercise, particularly in the early part of the lift (ascent phase). However, Loken et al. (Løken et al., 2021) compared the training effects of bench press, with or without bouncing the barbell, in amateur handball players and found no difference in throwing velocity, 1-RM strength, or power output between the two approaches. Elsewhere, Krajewski et al. (Krajewski et al., 2019) compared a conventional deadlift, performed with and without bouncing the barbell, and demonstrated increased acceleration during the first 0.1 s of the lifting phase for the bounce technique. However, the effect of varying barbell lowering velocity with BTP_{bounce} during bench press throw (BPT) has not been explored.

Therefore, the present study aimed to characterize the acute effects of performing BPT with and without the bounce technique on mechanical power and barbell kinematics, and second, to examine whether externally cueing lowering velocity had an impact on power output in resistance-trained males. Based on the findings from previous studies (Newton et al., 1997; Cronin et al., 2001b; Pryor et al., 2011; Pérez-Castilla et al., 2020), we hypothesized greater power output for BPT_{bounce} than BPT, and that higher velocity during the barbell descent phase would increase the power outcomes.

MATERIALS AND METHODS

Participants

With reference to Loken et al. (Løken et al., 2021) and with α = 0.05 and β = 0.80, the sample size of 24 subjects appeared to be necessary to detect significant differences in mean power between BPT bounce and BPT. In total, 27resistance-trained men (age 23.1 ± 2.1 years, body mass 79.4 ± 7.4 kg, height 178.8 ± 5.5 cm, and 4.6 ± 1.9 years of resistance training experience) were recruited. To be included, participants had to be free of injury, pain-free during maximal lifting, performing bench press as part of their weekly training routine, and with a 1-RM bench press of at least their own body weight. Participants were informed verbally and in writing regarding the implications and potential side effects of participating in the experiment, and were asked to refrain from any strenuous activity 48 h prior to testing. The study was conducted in accordance with the Declaration of Helsinki and confirmed by the Norwegian Centre for Research Data (ref. 288211).

Study Design

The study used a within-subjects cross-sectional design. Participants visited the test location three times (one familiarization and two experimental visits: EXP1 and EXP2). The bench press throw (BPT) was conducted in a Smith machine (Pivot 680L, Pivot Fitness, Tianjin, China). In the familiarization session, BPT and BPT_{bounce} techniques were performed across a range of loads (20, 30, 40, 50, 60, and 70 kg) to ensure correct BP lifting and bouncing techniques were used. Each participant was given two to three attempts at each load for both BPT techniques. In EXP1, subjects performed maximal effort BPT, using both techniques in a randomized order, with loads ranging from 30 to 60 kg. All participants achieved peak power for loads in the 30–60 kg range. In EXP2, participants performed BPT and BPT_{bounce} under three externally cued lowering velocity conditions: "slow," "medium," and "as fast as possible" (i.e., "fast"), using the loads established in EXP1 corresponding to individual peak power output for each BPT technique. In addition, participants' 1-RM for bench press (BP) was measured using the traditional BP technique.

Procedures

Participants attended the lab three times over a period of 2 weeks; each visit was separated by 4–5 days. In the first session, participants were familiarized with BPT performed with and without the bounce technique. Session two examined the participants' force–velocity profile across a range of loads (EXP 1) and session 3 (EXP 2) investigated the effect of different barbell lowering cues on BPT, with and without barbell bounce. Before entering the lab, participants completed a 5-min general warm-up (jogging or cycling). The warm-up continued in the lab with dynamic stretches for the pectoralis, anterior deltoid, and triceps brachii muscles, followed by 10 B P repetitions at 20kg, four repetitions at 50% of self-reported 1-RM, and two repetitions at 75% of self-reported 1-RM. Participants used their preferred grip- and feet-width, which were measured initially and then controlled before each subsequent lift in all sessions (Saeterbakken et al., 2011).

Familiarization with the BPT and BPT_{bounce} involved completing two to three trials (loading range: 20–70 kg) to lift the barbell using each technique. In BPT trials, participants were instructed to lower the barbell, lightly touch the chest (sternum position), and immediately press upward aiming for the maximal voluntary velocity of the barbell to the point of projection (i.e., barbell throw). Similar instructions were used for BPT_{bounce} trials, with the additional instruction to "bounce" the barbell off the sternum. For both techniques, participants were given the following instructions: "the aim is to lift the bar as fast as possible and lower the barbell fast, but with control." For BPT, trials were rejected if the barbell bounced or if the lowering phase terminated at a visible distance (≥2 cm) above the chest. For BPT_{bounce}, trials were rejected if the bar did not clearly make contact and then bounce off the chest. For both techniques, trials were rejected if the hips lifted off the bench, or if any hesitation occurred in the transition between the lowering and lifting phases.

In EXP1, power output for BPT and BPT_{bounce} was determined across the range of loads used. Typically, maximum power in BPT is produced with a load corresponding to approximately 50% of 1-RM (Baker et al., 2001; Sreckovic et al., 2015). Therefore, 30, 40, 50, and 60 kg loads were used to identify the load which elicited each participant's average and peak power, average and peak velocity, and time to peak power and velocity. Previous studies examining BPT have demonstrated reliable measurement of power and velocity variables (within-participants coefficient of variation <5%, intra-class correlation coefficient >0.946) (García-Ramos et al., 2018a; García-Ramos et al., 2018b). Participants performed all lifts in a randomized order (i.e., either BPT or BPT_{bounce}) under each loading condition, beginning with the lowest load. Immediate feedback on power output was used to motivate participants toward maximal effort. The average lower velocity was 0.99–1.04 m s^{-1} for BPT_{bounce} and 0.59–0.64 m s^{-1} for BPT. Rest between loads ranged from 1 to 3 min with 3 min rest between techniques. Three acceptable trials were performed at each load; however, only the trial with the highest average power (i.e., calculated from data gathered during the entire range of the ascending phase) was used in further analyses.

In EXP2, the effect on the power output of cueing three lowering velocities: "slow," "medium," and "fast" was examined for both BPT and BPT_{bounce}. "Fast" corresponded to the same velocity achieved in the familiarization session and EXP1. A lift was not accepted if a participant increased the lowering velocity of the bar during the last part of the descent phase, that is, did not maintain a steady lowering velocity. In EXP 2, the load used corresponded to participants' highest average power output for each BPT technique obtained in EXP1. The participants executed BPT and $BPTb_{ounce}$ in a randomized order under each of the three lowering instructions.

After completing lifts using both techniques under all three lowering cues, a bench press 1-RM test was performed in the

Smith machine at 90% of self-reported 1-RM, with 2.5–5.0 kg added stepwise, until the participant and test leader agreed that 1-RM was achieved. 1-RM was obtained within two to five attempts. A 5-min rest separated each trial.

To calculate power output, a linear encoder (Ergotest Innovation A/S, Porsgrunn, Norway) was attached to the barbell in both experimental sessions (EXP1; EXP2) to identify barbell peak velocity (pV), average velocity (aV), time to peak velocity (tpV), peak power (pP), average power (aP), time to peak power (tpP), and vertical displacement and velocity during the barbell lifting phase. The linear encoder had a resolution of 0.019 mm and a sampling rate of 200 Hz. Data were analyzed with the commercial software (Musclelab v.10.4.37.4073, Ergotest Innovation A/S, Porsgrunn, Norway). Unpublished data from the Norwegian School of Sport Sciences show that the encoder is reliable and valid for average velocity (r = 0.993, CV = 2.54) and displacement (r = 0.993, CV = 1.92) when compared with Qualisys Motion Capture Systems (Qualisys AB, Sweden).

In addition, the linear encoder was used to calculate barbell lowering distance (i.e., displacement from the start of the lowering phase to the point where the barbell touched the chest) for both BPT and BPT_{bounce} under each cueing condition. Accordingly, the lowering distance was subtracted from the ascending displacement to calculate the barbell throw height.

Statistical Analysis

All baseline variables were tested for normality (Shapiro–Wilk test). Barbell lowering velocity and power output at each load were compared (i.e., BPT *versus* BPT_{bounce}) using a paired t-test using SPSS statistical software (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). To determine the effects of the three lowering cues, a two-way split-plot repeated analyses of variance (ANOVA) [within-subject factor: lowering cue (slow, medium, and fast)] x [between-subject factor: condition (BPT and BPT_{bounce})] was used. When differences were detected with ANOVA, paired t-tests with Bonferroni *post hoc* correction were applied. The magnitude of the effect was determined using Cohen's d and interpreted according to the following scale: 0.0–0.2 (trivial), 0.2–0.5 (small), 0.5–0.8 (moderate), and >0.8 (large) (Komi, 1984). All data were reported as mean ± SD. The significance level was set to $p < 0.05$.

RESULTS

The participants'1-RM in bench press was 105 ± 16 kg corresponding to a relative strength (1-RM load/body weight) of 1.32. The load corresponding to the greatest average power out was 5.7% greater using the BPT_{bounce} compared to BPT (51.3 ± 11.3 kg vs. 48.5 ± 9.1kg, p = 0.022, ES = 0.27), and loads tested (30, 40, 50, and 60 kg) represented intensities of 29.1% (±3.9), 38.8% (±5.2), 48.5% (±6.5), and 58.3% (±7.9), respectively, of the participants' bench press 1-RM. There were no differences in barbell lowering velocity across the loads for BPT_{bounce} (p = 0.666–0.901) or BPT (p = 0.280–0.622); however, the BPT lowering velocity was lower for all loads than BPT_{bounce} (p < 0.001–0.007).

BPT_{bounce} vs. BPT (EXP 1)

Comparing the two BPT techniques, BPT_{bounce} demonstrated 7.8–14.1% greater average power ($p \leq 0.001$, ES = 0.5–0.9), 6.5–12.1% greater average velocity ($p \leq 0.001$, ES = 0.5–0.9), and 11.9–31.3% shorter time to peak power ($p \leq$ 0.001–0.05, ES = 0.3–0.8) across 30–60 kg than BPT (**Table 1**; **Figure 1**). BPT_{bounce} demonstrated 8.5–18.5% greater peak power than BPT for all loads (p = 0.003–0.007, ES = 0.4–0.7, **Table 1**), except for 30 kg (p = 0.369). For the variables' peak velocity and time to peak velocity, no differences were observed between the two techniques at 30 and 60 kg (p = 0.057–0.875); however, BPT_{bounce} elicited 2.9 and 2.8% greater peak velocity and 4.7 and 7.9% shorter time to peak power at 40 kg ($p \leq 0.001$, ES = 0.2–0.3) and 50 kg ($p \leq$ 0.001–0.011, ES = 0.1), respectively, than BPT (**Table 1**).

Lowering Cues (EXP 2)

There was a significant interaction between condition and lowering cue for the following outcomes: average power (F = 5.574, p = 0.005), average velocity (F = 4.193, p = 0.020), and time to peak power (F = 3.307, p = 0.045), whereas for peak power, peak velocity, time to peak velocity, barbell lowering distance, and lowering velocity, no interaction (F = 0.304–3.058, p = 0.078–0.736) or main effect of condition (F = 0.037–1.441, p = 0.242–0.849) was observed, but there was a main effect for lowering cue (F = 197.623–8.465 $p \leq$ 0.001–0.003). For barbell throw height, no interaction (F = 2.101, p = 0.139) or main effect (F = 0.049–0.298, p = 0.716–0.827) was observed. All *post hoc* tests are presented in **Figures 2A–F**, **Table 2**, and **Supplementary Tables S1, S2**.

DISCUSSION

The aim of this study was to compare the effects of BPT_{bounce} with BPT and different external lowering cues on power outcomes. The main findings were that 1) BPT_{bounce} displayed greater average and peak power, and barbell velocity than BPT for the loads 40, 50, and 60 kg; 2) lowering the barbell "fast" demonstrated resulted in higher average and peak power, average and peak barbell velocity, independent of BPT technique, than "slow"; and 3) independent of lowering cue, BPT_{bounce} displayed greater average power than BPT.

In agreement with our hypothesis, whereas performance, characterized by higher output in all variables except average power and velocity, was greater for BPT_{bounce} at 40 and 50 kg, greater power and velocity were displayed at 30 and 50 kg. In the BPT_{bounce} technique, the barbell is brought down against the chest before being re-accelerated into the lifting phase. This action may improve the transition of energy from the descending to the ascending phase, resulting in greater acceleration and barbell velocity than the traditional BPT technique (**Figure 1**). The chest wall and its enveloping facia, which give the thorax its structural flexibility and contribute to

TABLE 1 | Power output, velocity, and time in BPT with and without bounce.

Load (kg)	BPT technique	aP (w)	aV ($m \cdot s^{-1}$)	pP (w)	tpP (sec)	pV ($m \cdot s^{-1}$)	tpV (sec)
30	Bounce	488 ± 52[a]	1.31 ± 0.12[a]	927 ± 139	0.21 ± 0.07[a]	2.13 ± 0.20	0.28 ± 0.03
	No bounce	453 ± 44	1.23 ± 0.10	916 ± 129	0.23 ± 0.05	2.10 ± 0.17	0.28 ± 0.04
40	Bounce	572 ± 69[a]	1.18 ± 0.11[a]	1,026 ± 214[a]	0.20 ± 0.12[a]	1.83 ± 0.22[a]	0.32 ± 0.05[a]
	No bounce	512 ± 65	1.08 ± 0.11	945 ± 160	0.27 ± 0.07	1.77 ± 0.20	0.33 ± 0.05
50	Bounce	616 ± 93[a]	1.04 ± 0.13[a]	1,086 ± 294[a]	0.23 ± 0.15[a]	1.54 ± 0.23[a]	0.35 ± 0.06[a]
	No bounce	544 ± 78	0.94 ± 0.11	916 ± 167	0.33 ± 0.08	1.50 ± 0.20	0.38 ± 0.07
60	Bounce	606 ± 118[a]	0.88 ± 0.14[a]	988 ± 280[a]	0.33 ± 0.18[a]	1.30 ± 0.23	0.42 ± 0.12
	No bounce	530 ± 118	0.79 ± 0.15	873 ± 226	0.42 ± 0.13	1.26 ± 0.27	0.47 ± 0.12

[a]*Significant difference between BPT techniques* ($p < 0.05$).
aP, average power; aV, average velocity; pP, peak power; tpP, time to peak power; pV, peak velocity; tpV, time to peak velocity.

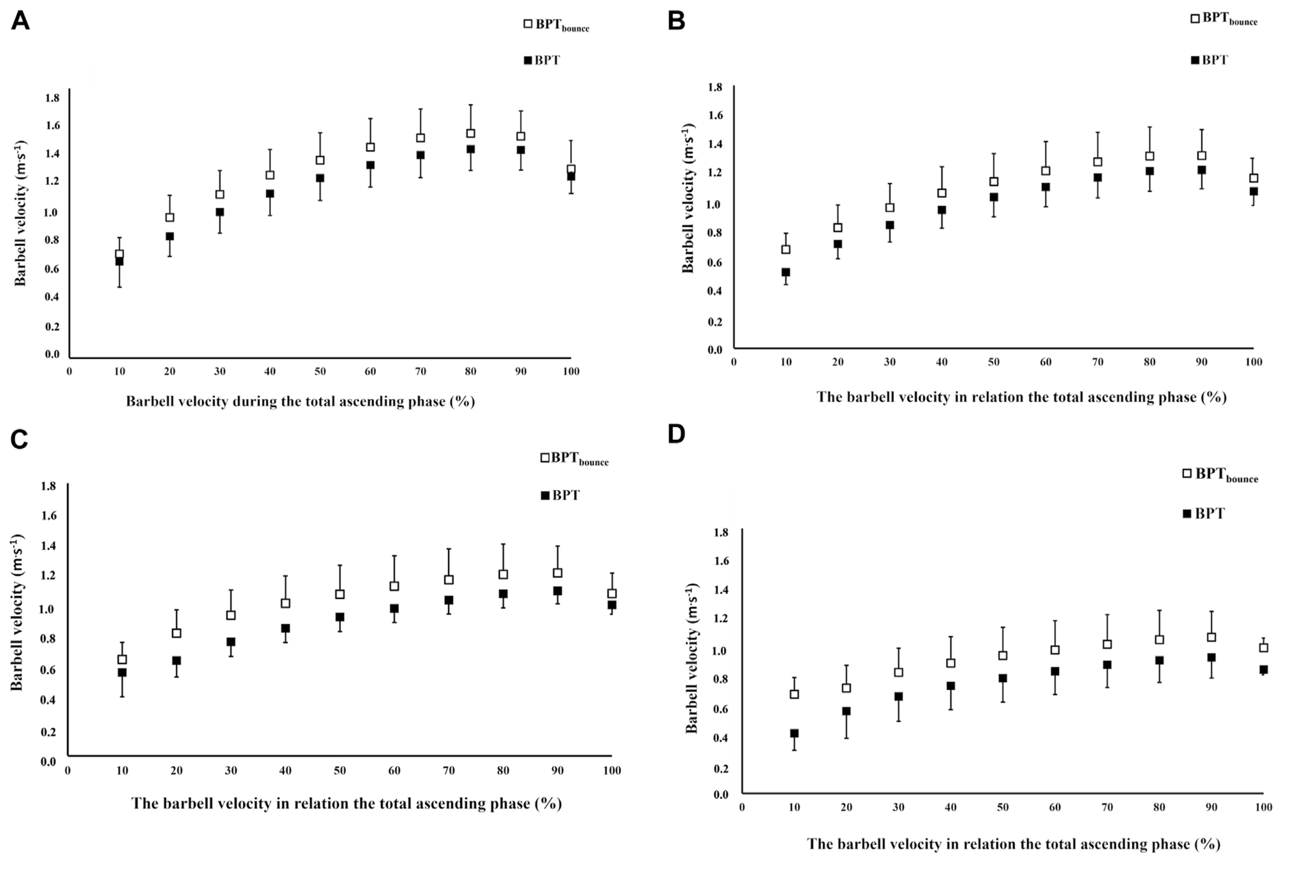

FIGURE 1 | Barbell velocity relative to the barbell position to the ascending phase for the BPT_{bounce} technique and BPT for each 30 kg **(A)**, 40 kg **(B)**, 50 kg **(C)**, and 60 kg **(D)**.

respiratory mechanics (Smith et al., 2018), have the potential to be compressed, which may cause a "spring effect" as the barbell is bounced off the chest. Using a rebounding action (lowering + lifting) has been shown to elicit greater power output and barbell velocity rather than employing a lifting only action (Newton et al., 1997; Cronin et al., 2001b; García-Ramos et al., 2018b; Janicijevic et al., 2020; Pérez-Castilla et al., 2020; Pestaña-Melero et al., 2020). However, none of these studies included the barbell bounce technique, which could potentially utilize the SSC to derive performance gains to a greater extent than the rebounding-only action. To the best of our knowledge, only one previous study has examined acute effects of the bounce technique on force profile outcomes during deadlift at 75% of 1-RM (Krajewski et al., 2019). Krajewski and others (Krajewski et al., 2019) demonstrated that less force was required and lifting time was reduced, during both the initial lifting phase and throughout the barbell ascent. This study is not directly comparable with the present one in bench press however, as Krajewski and others (Krajewski et al., 2019) compared outcomes from five repetitions, under different loads, and for a different resistance exercise, that is, compound

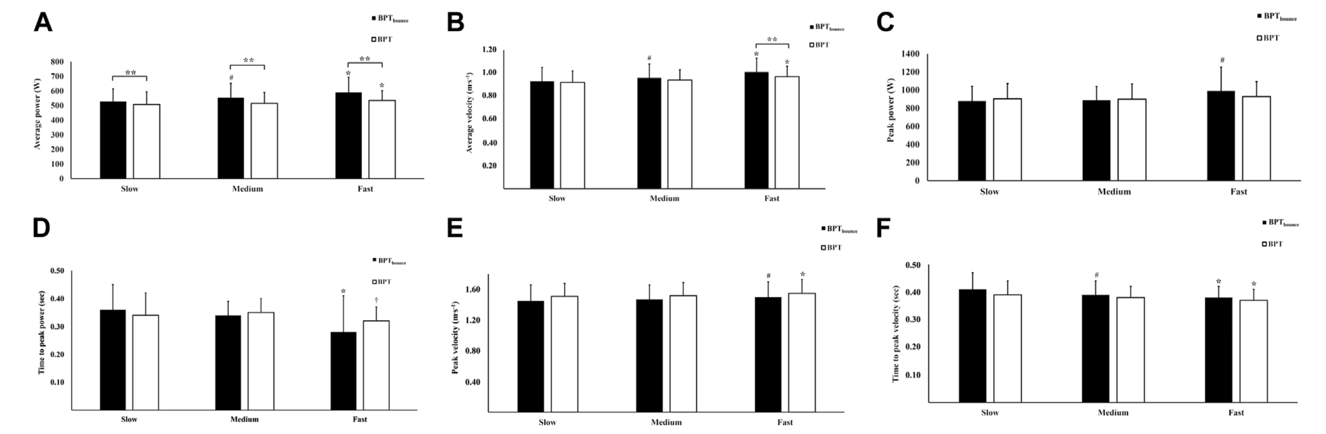

FIGURE 2 | Effect of verbal cueing on bench press performance variables for the BPT_{bounce} technique and BPT on average power **(A)**, average velocity **(B)**, peak power **(C)**, time to peak power **(D)**, peak velocity **(E)**, and time to peak velocity **(F)**. *Significant difference compared to the other lowering cues. #Significant difference compared to "slow" lowering cue. †Significant difference compared to "medium" lowering cue. **Significant difference compared to BPT_{bounce}.

TABLE 2 | Effects of externally cued lowering velocities on barbell kinematics.

Lowering cue	BPT technique	Ld (cm)	LV ($m{\cdot}s^{-1}$)	BPT height (cm)
Slow	Bounce	40.65 ± 5.40	0.34 ± 0.17	17.83 ± 3.74
	No bounce	37.80 ± 5.83	0.28 ± 0.12	16.33 ± 5.75
Medium	Bounce	39.98 ± 5.08	0.54 ± 0.16[b]	18.66 ± 3.40
	No bounce	37.50 ± 5.97	0.48 ± 0.15[b]	16.37 ± 6.23
Fast	Bounce	42.07 ± 5.15[a]	0.92 ± 0.18[a]	16.33 ± 5.75
	No bounce	38.49 ± 6.34	0.79 ± 0.17[a]	18.40 ± 4.06

[a]Significant difference compared to the other lowering cues.
[b]Significant difference compared to "slow."
Ld, lowering displacement; LV, lowering velocity; BPT, bench press throw.

action. Furthermore, the mechanics of deformation (compression) and elastic recoil from an object striking the chest wall compared with the floor cannot be directly compared.

Of note is the finding that at 30 and 60 kg, no advantage was observed for the bounce technique on time to peak velocity or peak velocity, which could be related to the participants' background in resistance training rather than athlete conditioning. Potentially, and according to the force–velocity relationship and training specificity principles (Behm and Sale, 1993), strong or powerful athletes demonstrate greater power output at either a higher or lower percentage of 1-RM (Cronin et al., 2000; Cronin and Sleivert, 2005; Loturco et al., 2019). However, none of the participants were athletes involved in throwing or striking, but were experienced in resistance training focusing on maximal strength and muscle hypertrophy (i.e., high force generation with relatively low barbell velocity). Probably, and as a result of their training background, the greatest average power output was achieved at 49% (51.3kg, BPT_{bounce}) and 46% (48.5 kg, BPT) of 1-RM. This may explain why 30 kg did not demonstrate any advantage for the bounce technique for the outcomes of peak power, peak velocity, and time to peak velocity. Alternatively, lighter loads may result in less compression (i.e., deformation) of the thoracic cage and therefore reduce the potential advantage (i.e., spring effect) of the bounce technique. Of interest, Cronin et al. (Cronin et al., 2001b) examined power output in males with an athletic background across a range of loads (30–80% of 1-RM) and reported the greatest average power at 50% of 1-RM in BPT. It is also possible that the heaviest load (60 kg) may have caused participants to self-calibrate their output (e.g., reducing barbell velocity as it collides with the chest for reasons of safety), which could compromise the potential of the bounce technique to elicit high power output at increased loads.

The advantages of bouncing the barbell, compared to using the traditional technique, may be derived from its effect on lowering velocity (Janicijevic et al., 2020). As a direct consequence of bouncing the barbell, barbell lowering velocity was greater than that for BPT. In traditional bench press, lowering the barbell rapidly has been shown to result in greater average barbell velocity than lowering at a controlled pace (1.5 s descent phase) for loads ranging between 30–75% of 1-RM (Janicijevic et al., 2020). However, as Janicijevic and others (Janicijevic et al., 2020) did not examine either the BPT or BPT_{bounce} technique, we cannot infer from their results that differences in lowering velocity in our study caused the present findings.

In general, and supporting our hypotheses, cueing barbell descent velocity at different speeds using external verbal instruction had an impact on power outcomes, with the largest effect observed for comparison between "fast" and "slow," which is not unexpected. Furthermore, for both BPT techniques, performance was superior (i.e., power indices increased) using the cue to lower "fast," which supports the practice of using external verbal encouragement to enhance power outcomes during RT with the bench press. No difference was observed between the "medium" and "slow" velocity cueing conditions for BPT, a finding which could be of value in applied settings, as it suggests that lowering the bar more slowly may not result in power reduction, which could benefit less experienced practitioners, who may be technically less adept at throwing the bar, aiming to use this technique to enhance strength adaptations. Unlike for BPT, using BPT_{bounce}, greater average power and velocity, and time to peak velocity were observed for the lowering cue "medium" compared to "slow." This finding suggests that technical capacity should be sufficient to perform this variation in technique at a faster than controlled (e.g., 1.5 s descent phase) velocity, to access performance gains attributed to SSC-related mechanisms, as proposed here.

Theoretically, lowering the bar at a higher velocity could generate greater chest bounce (elastic recoil) in addition to eliciting greater stretch–reflex activation, increasing storage of energy in the tendons, promoting neurosensory pre-activation, and enhancing cross-bridge kinetics (Fukutani et al., 2020; Janicijevic et al., 2020). It should be noted that differences in velocity between the three cueing conditions were significant and lowering velocity increased by approximately 50% between each level of cueing (**Table 2**). Nevertheless, the present study found only limited evidence to support the speculation that the barbell bouncing technique exploits tissue biomechanical properties relating to the SSC which, if demonstrated, could offer a mechanistic explanation for findings elsewhere that BTP_{bounce} improves the power profile during BTP (Janicijevic et al., 2020). It is important to consider that at a higher barbell lowering velocity, greater force is required to decelerate the barbell, either to lightly touch the chest (BPT) or to strike against it and bounce off (BPT_{bounce}). However, as none of the participants conducted bench press using the bounce technique regularly, it is possible that participants' focus was directed towards the descending phase (barbell lowering) and not necessarily on the transition between movement phases. Therefore, lack of familiarization with technical aspects of actions examined (i.e., power training, bench press throw, and bouncing) and individual differences in responsiveness to external auditory cues (lowering instructions) could have influenced the results. Still, previous studies have demonstrated highly acceptable reliability for power and velocity outcomes in BPT, at similar loads and participants' training status as the present study (García-Ramos et al., 2018a; García-Ramos et al., 2018b). Despite the potential limitation of only one familiarization session, the time to peak velocity was shorter under the "fast" cueing condition than that under the other velocity conditions, which is in agreement with our hypothesis. This could be explained by greater capacity to derive and then utilize SSC gains when the barbell was lowered at higher velocity, even though mean and peak velocity were similar across all lowering instructions.

Present findings are difficult to be compared with those of previous studies. For example, Pryor and others (Pryor et al., 2011) examined sets of bench press at 80% of 1-RM to fatigue and reported higher repetitions to failure, and greater average and peak power, for 1 *versus* 4 s lowering phase. In the present study, lowering time under the "slow" instruction was 1.25 s and under the "medium" instruction was 0.8 s, which are closer to, and less than the "fast" condition examined by Pryor et al. (Boffey et al., 2019). Elsewhere, in resistance-trained men, Carzolie et al. (Carzoli et al., 2019) examined the effect of bench press at 60 and 80% of 1-RM under two conditions: 0.75 (slow) and 2.0 (fast) times the individual's normal lowering velocity, and found that both slow and fast lowering velocity resulted in greater peak and average ascending velocity than the participants' normal velocity for the 60% of the 1-RM load (Carzoli et al., 2019). More recently, and supported by the findings of the present study (EXP 2), Janicijevic et al. (Janicijevic et al., 2020) demonstrated greater mean velocity for bench press at 30, 50, and 75% of the 1-RM load for fast, compared to controlled (duration of 1.5s), barbell lowering velocity. Compared with controlling lowering velocity, greater mean velocity was only reported under the heaviest load condition (75% of 1-RM), a finding which is comparable to results observed for the lowering cue "slow" in the present study.

Comparing BPT with BPT_{bounce}, bouncing the barbell resulted in greater average power under all velocity cueing conditions. For BPT_{bounce}, using the cue to lower the barbell "fast," the average velocity was greater than that for BPT. For the other power outcomes, non-significant differences between BPT techniques and lowering cues were observed. This suggests lowering velocity is a more significant influence on power output than whether the bounce technique is included or not. Of note, a non-significant increase in barbell lowering displacement was observed using the bounce technique compared with BPT, which tends to confirm that participants produced a distinct bounce action, increasing the barbell's path of movement by 2.5–3.5 cm (**Table 2**). A longer movement path, in addition to greater barbell acceleration in the early phase, may explain why average power was the only outcome variable that increased using the BPT_{bounce} technique compared with BPT, whereas peak power and other variables examined did not differ between techniques.

No difference in barbell throw height was found under any cueing condition, or comparing between the two BPT techniques. For both techniques, loads that elicited the greatest average power in the trial phase were used, which could explain why no significant differences in barbell throw height were found, as the load for BPT_{bounce} was 5.7% greater than that for BPT. Typically, the greatest benefits of the bouncing technique are evident in the early part of the barbell ascent phase (Krajewski et al., 2019), but may not necessarily translate into improvements in later parts of the lifting phase. In the terminal phase of the lift, barbell velocity increases (Saeterbakken et al., 2020; van den Tillaar and Saeterbakken, 2013), which influences the ability to apply high force at high velocities (Loturco et al., 2019). For example, Loturco et al. (Loturco et al., 2019) demonstrated greater power production among power-trained athletes in BPT than hypertrophy-trained athletes, which suggests that factors other than absolute strength, such as technique and timing, may influence force profile outcomes during the bench press. Previous studies have shown greater power output and velocity using the BPT than the traditional bench press technique (i.e., ending the barbell lift with fully extended elbows) (Newton et al., 1996; Cronin et al., 2001b). The proposal that greater lowering velocity enhances potential SSC gains remains debatable. For example, in the context of SSC in the lower limb, Ruffieux et al. (Ruffieux et al., 2020) demonstrated greater jump height with countermovement jump training than drop jump training among non-professional female volleyball players. Similarly, this finding has been reproduced at different drop jump heights (30–70 cm), although no difference in absolute jump height was demonstrated (Taube et al., 2012). Furthermore, Loken et al. (Løken et al., 2021) examined the effects of BPT_{bounce} compared with BPT (40–60% of 1-RM, three sets, three to five repetitions, twice per week) on throwing velocity, power output, and strength among handball players, and found no difference between the groups after 8 weeks. The authors speculated that the relative 1-RM strength level of the bounce group was too low to exploit potential gains from utilizing the bounce technique.

Even though the present study presents novel findings, some limitations need to be addressed. Loads corresponding to the greatest average power output (EXP1) were used to examine the impact of varying lowering velocity cues (EXP2). It is plausible that using other loads in EXP2, results might have been different, although we deliberately used mean power and not peak power to prescribe loads in EXP2. Several investigators have argued that peak power is a more reliable measure than mean power (García-Ramos et al., 2018a; Pestaña-Melero et al., 2020); however, none of these studies examined BPT_{bounce}. Furthermore, although all participants were resistance-trained, they did not use the bounce technique in their regular training; therefore, familiarization with both a novel technique and external velocity cueing may have required more than the single session allocated. In addition, as the present study only included resistance-trained males, findings cannot be generalized to other populations. Small sample size, large variation between individual participants in training exposure and technical capacity, and conservative *post hoc* corrections may increase the risk of a type II error, when comparing the effect of varying lowering velocities on force profile outcomes. Of note, none of the participants experienced injuries as a result of this study, but some reported minor chest soreness from the bouncing technique.

CONCLUSION

At loads of 30–60 kg, BPT_{bounce} elicited greater average power, average velocity, and time to peak power than BPT, and may therefore be superior, if high power output throughout the BP action is the desired outcome of prescribing BP training. Our findings suggest that if the bounce technique is preferred to throwing the barbell, technical proficiency should be sufficient to perform the descent phase action at a higher velocity, as power outputs were significantly greater at medium than controlled (1.5 s) descent velocity of the barbell for this technique. Overall, lowering the barbell at higher velocity increased power outputs across all variables, and seems to be of more importance than whether BPT with or without the bounce technique is adopted. In conclusion, while athletes involved in throwing-related sports may benefit from bouncing the barbell, irrespective of technique, emphasizing velocity during barbell descent is recommended to maximize power output.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

According to Norwegian laws and regulations, the Regional Committee for Medical and Health Research Ethics waives the requirement for ethical approval for such studies. Therefore, this study has been conducted in accordance with institutional requirements. Approval for data security and handling was obtained from the Norwegian Centre for Research Data project (ref. 288211). The study was conducted in accordance with the latest version of the Declaration of Helsinki. Prior to data collection, all participants provided written informed consent to voluntarily take part in the study. The participants were informed that they could withdraw from the study at any point in time without providing a reason for doing so. All participants included in this study were over 18 years.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization and the design of the study, critically revised the work and checked important intellectual content, and approved the final manuscript. JL performed the experiments, and AS analyzed the data and prepared the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fphys.2022.899078/full#supplementary-material

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Time Course of Recovery Following CrossFit® Karen Benchmark Workout in Trained Men

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The establishment of fatigue following the acute exercise stimulus is a complex and multifactorial process, that might arise due to a range of distinct physiological mechanisms. However, a practical method of assessing CrossFit® athletes' recovery status has been neglected entirely in real-world sporting practice. The study describes the acute and delayed time course of recovery following the CrossFit® Benchmark Workout Karen. Eight trained men (28.4 ± 6.4 years; 1RM back squat 139.1 ± 26.0 kg) undertook the Karen protocol. The protocol consists of 150 Wall Balls (9 kg), aiming to hit a target 3 m high. Countermovement jump height (CMJ), creatine kinase (CK), and perceived recovery status scale (PRS) (general, lower and upper limbs) were assessed pre, post-0h, 24, 48 and 72 h after the session. The creatine kinase concentration 24 h after was higher than pre-exercise (338.4 U/L vs. 143.3 U/L; $p = 0.040$). At 48h and 72 h following exercise, CK concentration had returned to baseline levels ($p > 0.05$). The general, lower and upper limbs PRS scores were lower in the 24-h post-exercise compared to pre-exercise (general PRS: 4.7 ± 1.5 and 7.7 ± 1.7; $p = 0.013$; upper limbs PRS: 6.6 ± 1.3 and 7.5 ± 1.3; $p = 0.037$; lower limbs PRS: 3.9 ± 2.5 and 7.3 ± 0.1; $p = 0.046$). Our findings provide insights into the fatigue profile and recovery in acute CrossFit® and can be useful to coaches and practitioners when planning training programs. Moreover, recovery status can be useful to optimize training monitoring and to minimize the potential detrimental effects associated with the performance of repeated high-intensity sessions of CrossFit®.

Keywords: functional fitness, high intensity functional training, periodization, overreaching, muscle recovery

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INTRODUCTION

CrossFit® training programs are usually characterized by a high training intensity, with most of the sessions being performed at high intensities (Meyer et al., 2017). The training sessions contemplate the development of multiple physical abilities, through the use of different exercises such as weightlifting exercises (clean and jerk, snatch, and its variations), powerlifting (bench press, overhead press, deadlift, front, and back squat), and metabolic conditioning (Claudino et al., 2018; Martinez-Gomez et al., 2020). A recent systematic review identified that CrossFit® training sessions normally cause a substantial metabolic stress, leading to metabolite accumulation (e.g., lactate up to 18 mmol/L), and to high levels of fatigue, impairing the ability to repeat the initial performance in a countermovement jump, a potential indicator of neuromuscular fatigue, are also seen immediately after the sessions. These effects may last up to 48 h, depending on the characteristics of the session performed (Claudino et al., 2017; Cooper et al., 2020). In addition, the high number of repetitions performed, often to the point of muscular failure, increase markers of exercise-induced muscle damage (interleukin-6 - IL-6, and creatine kinase—CK), with these concentrations remaining elevated up to 24 h post-exercise (Claudino et al., 2018).

When comparing the perceptual responses and post-exercise physical disfunction between a CrossFit® session and a session based on the guidelines of the American College of Sports Medicine, Drum et al. (2017) found significant differences between sessions. CrossFit® participants reported a higher rating of perceived exertion (RPE) and a greater perceived number of hard training days per week. Also, feelings of excessive fatigue, muscle soreness, muscle swelling, shortness of breath, muscle pain to light touch, and limited movement in muscles used during exercise within 48-h post-exercise were also higher in CrossFit® participants. However, these responses were observed in a cross-sectional study, which limits the understanding of the cause-effect relationship (Wang and Cheng, 2020) that exists between a specific CrossFit® Workout session and physiological outcomes. Since adaptations caused by exercise training may result from the temporal summation of acute responses (Rockl et al., 2008), understanding the role of recovery status in a time-dependent manner is first to step to understand fatigue status. Comprehending the time-course of recovery following CrossFit® session is important for minimizing the risk of maladaptation due to insufficient recovery between each stimulus and might assist in ensuring optimal exercise monitoring.

The development of fatigue following the individual's physiological and perceptual responses to a stimulus, is a complex and multi-faceted phenomenon, that might arise due to a variety of different mechanisms (Halson, 2014). Recovery, therefore, is also a multifactorial process, and as such, the assessment of the recovery–fatigue continuum should be relative to the demands of the sport or activity performed (Kellmann et al., 2018). While performance measures represent the most sport-specific outcomes, other physiological and psychological measures provide integral information on an athlete's recovery (Kellmann et al., 2018). Stress markers such as creatine kinase (CK) counter movement jump (CMJ) and perceived recovery status (PRS) remain largely unknown in CrossFit® training programs, despite their potential to identify athletes' recovery status following exhaustive sessions (Tibana et al. 2019).

Despite the importance of performance and physiological markers, an athlete's perception of their "readiness to perform" can also be described as a critical determinant of recovery. In this context, Laurent et al. (2011) proposed a "Perceived Recovery Status" (PRS) scale, which is similar but opposite to a perceived exertion scale (RPE) (10–12). Both scales are based on the psychophysiological status of the athlete. However, while the rating of perceived exertion (RPE) is utilized during or after a session, the PRS scale is utilized prior to the session to identify the athletes' recovery status. The PRS scale has been shown to be a reliable tool to assess the perceived recovery state of individuals, demonstrating accuracy (>80%) in identifying changes in performance when the individuals reported feelings of being under-recovered (Laurent et al., 2011). A practical method of assessing athletes' recovery status prior to a session might allow coaches and practitioners to adjust the training session to match the individuals' current recovery status, potentially optimizing training outcomes (Laurent et al., 2011; Sikorski et al., 2013).

Thus, the purpose of this study is to describe the acute and delayed time course of recovery following the CrossFit® benchmark workout Karen in healthy trained subjects. The development of fatigue following the individual's physiological and perceptual responses to a stimulus, is a complex and multi-faceted phenomenon, that might arise due to a variety of different mechanisms it was hypothesized that the PRS scale would provide an accurate assessment of the participants' recovery status, and that this would be mirrored by the changes in CK and muscle performance, assessed via a countermovement jump (CMJ). This variety of tools to monitor recovery are practical for daily use due to low cost and time accompanied by simple interpretations.

MATERIALS AND METHODS

Participants

Eight male subjects (age 28.4 ± 6.4 years old; 1RM back squat: 139.1 ± 26.0 kg) were recruited. All participants were free of injury and known illnesses, were not using drugs to enhance performance, and had a minimum experience of 6 months with CrossFit® and were familiar with all exercises used in the study. The subjects trained five times a week, each training session consisting of approximately 10 min of warm-up, 40 min of strength and power training, and 20 min of metabolic conditioning. Indirect maximal aerobic capacity (VO_2 max), assessed via a maximal 2-km rowing test (Klusiewicz et al., 2016; Tibana et al., 2021) and strength (1RM) are described in **Table 1**, and were assessed 2 weeks before the participants completed the testing protocol. Participants performed one repetition maximum (1 RM) test for back squat according to procedures recommended by the National Strength and Conditioning Association (Lloyd et al., 2016). During this exercise period, standard instructions regarding the procedures of the test protocols and the appropriate execution of the exercise technique were supplied by an experienced investigator (Tibana et al., 2021). The participants were advised to refrain from ingesting alcohol in the 24 h before any of the tests, to avoid exercise in the 48 h before the protocol and in the 72 h after the workout of the day (WOD), and to maintain their normal daily diet and hydration during the study. All participants signed an informed consent document, and the study was approved by the University Research Ethics Committee for Human Use (2.698.225; 7 June 2018) and conformed to the Helsinki Declaration on the use of human participants for research.

TABLE 1 | Baseline sample demographics and performance characteristics (*n* = 8).

Variables	Mean ± SD
Age (years)	28.4 ± 6.4
Body mass (kg)	80.4 ± 4.9
Height (m)	1.8 ± 0.1
VO2 (ml/kg/min)	53.6 ± 3.5
Maximal Rowing test 2 km (sec)	447.3 ± 17.1
Back squat (kg)	139.1 ± 26.0
Back squat rel (kg/kg)	1.5 ± 0.7
Karen (sec)	613.8 ± 115.0

Note: Variables are expressed as mean and standard deviation (±). Rel: relative (back squat/body mass).

Experimental Design

This study was designed to analyze the time-course of recovery of physiological, psychological and performance responses in trained adult men, following the completion of the CrossFit® benchmark workout Karen. The protocol consists of 150 repetitions of wall balls, with athletes aiming to hit a target 3 m high, using a 9 kg medicine ball. All participants were experienced with the protocol, having previously performed it a minimum of 4 times as part of their own training. Each participant performed the session individually. In this study, the benchmark Karen was the independent variable, while the dependent variables consisted of changes in creatine kinase, countermovement jump and PRS scale (general, lower, and upper limbs) (**Figure 1**).

Karen Protocol

The CrossFit® WOD Karen corresponds to a timed protocol that utilizes one element (medicine ball throws; 9.07 kg for a height of 3 m). The aim is to complete the task of performing 150 medicine ball throws to a wall in the shortest time possible. Therefore, a better performance in this WOD is indicated by a shorter time to complete the protocol. The Karen protocol was chosen because it consists of only one exercise and because of the large number of repetitions performed as fast as possible. Also, Karen protocol is very popular and extremely usual among the WOD routines.

Creatine Kinase and Blood Lactate Analysis

Whole-blood creatine kinase activity was assessed from a single fingertip capillary sample with the subject in a seated position. After pre-warming the hand, a sample of blood (30 µL) was obtained and analyzed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, quality control (calibration) measurements were undertaken according to the manufacturer's recommendations. The "normal" reference range for creatine kinase activity, as provided by the manufacturer, is 24–195 U/L.

The blood lactate collection, management, and analysis were determined according to Falk Neto et al. (2020). Capillary blood samples were collected through a transcutaneous puncture on the medial side of the tip of the middle finger using a disposable hypodermic lancet (Falk Neto et al., 2020). Blood lactate concentration was determined by photometric reflectance on a validated Portable Accutrend Plus system (Roche, Sao Paulo, Brazil).

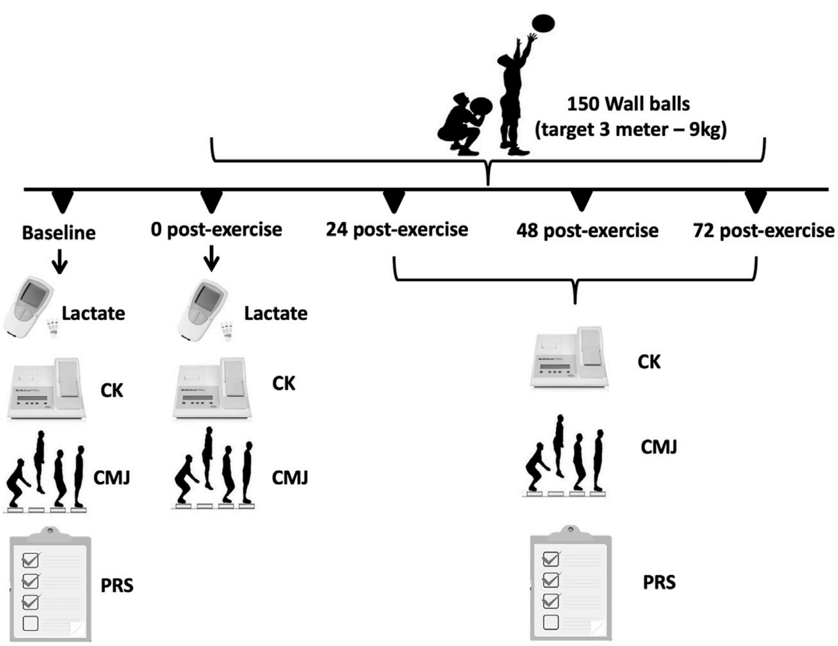

FIGURE 1 | Schematic study design and timeline used to examine the time-course effects of creatine kinase, countermovement jump performance and the PRS scale.

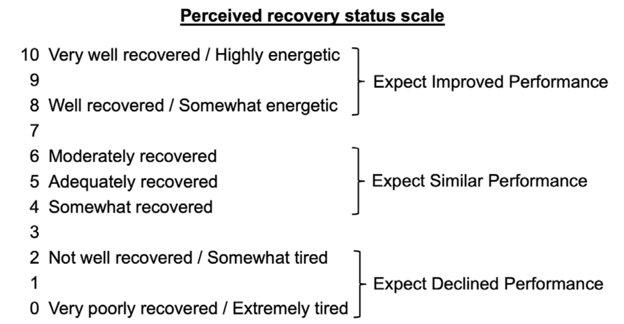

FIGURE 2 | The PRS Scale according to Laurent et al. (Laurent et al., 2011).

Perceived Recovery Scale

Immediately before the training sessions, the athletes were asked to rate their recovery status according to the PRS Scale. The scale (**Figure 2**) ranges from 0 to 10, with a score of "0" indicating that the athlete is "very poorly recovered/extremely tired" and a score of "10" indicating that the athlete is "very well recovered/highly energetic". A score of 0, 1, or 2, is associated with an expected reduction in performance, while a score of 8, 9, or 10, means an improvement in performance is expected. The range of values between three and seven indicate that no changes in performance are expected (Laurent et al., 2011).

Countermovement Jump Height

For the CMJ height, a jump platform (Jump System 1.0, Cefise Ltda.) was used. The athlete was positioned, barefoot, in the interior of the platform, with their hands fixed at their waist. The test consisted of performing a maximal vertical jump. The athletes were instructed to swing their arms back and aim to jump as high as possible while using the momentum created with their movement. Two jumps were performed with a 1-min interval between them. The participants' highest jump (in centimeters) was considered as the maximal CMJ height and utilized for subsequent analyses (Haugen et al., 2020). The CMJ was chosen because is a simple, practical, valid, and very reliable measure of lower-body power. The CMJ has been shown to be the most reliable measure of lower-body power compared to other jump tests (Petrigna et al., 2019).

Statistical Analysis

The data are expressed as mean value ±standard deviation (SD). Shapiro–Wilk test was used to check for normal distribution of study variables (all variables presented normal distribution). Paired sample *t*-test was used to compare blood lactate concentration and RPE pre- and post-exercise session. Cohen's *d* effect size (ES) was calculated to verify the magnitude of the difference between pre-test, and post-test. The ES are classified as: trivial (*d* lower than 0.10); small (*d* between 0.10 and 0.29); moderate (*d* between 0.30 and 0.49); large (*d* between 0.50 and 0.69); very large (*d* between 0.70 and 0.89), and perfect (*d* of 0.90 or greater). A repeated measures ANOVA was used to compare CK, PRS and CMJ between pre- and post-exercise session (24, 48, and 72 h after exercise session). Repeated measures ANOVA was also used to compare the score between general, upper and lower limbs of PRS scale. Compound sphericity was verified by the Mauchley test. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse–Geisser procedure. Tukey's post-hoc test with Bonferroni adjustment was applied in the event of significance. Cohen's *f* effect size (ES) for ANOVA was calculated to estimates the proportion of variance in the present sample. The Cohen's *f* effect size is classified as: small ($f = 0.10$); medium ($f = 0.25$); large ($f = 0.40$). The power of the sample size (1—ß) was determined using post hoc analysis on G*Power version 3.1.9 (Faul et al., 2007) and it is presented in the results section for each analysis. The Pearson correlation was used to evaluate correlations between PRS, CK and CMJ (pre-test, 24, 48, and 72 h post-session values grouped). The magnitude of the correlations was classified as: $r \leq 0.1$ trivial; $0.1 < r \leq 0.3$ small; $0.3 < r \leq 0.5$ moderate; $0.5 < r \leq 0.7$ large; $0.7 < r \leq 0.9$ very large; > 0.9 almost perfect (Hopkins et al., 2009). The level of significance was $p \leq 0.05$ and SPSS version 20.0 (Somers, NY, United States) software was used.

RESULTS

Completion Time

The average time to complete the 150 repetitions of wall ball was 597 ± 111.6 s. The fastest volunteer completed the exercise session in 495.6 s and the slowest in 795 s.

Physiological, Biochemical, and Neuromuscular Responses

The blood lactate concentration and RPE presented a statistically significant increase after the exercise session (blood lactate concentration, pre: 3.0 ± 0.7 mmol/L and post: 17.5 ± 3.0 mmol/L, $p \leq 0.005$; ES = 4.63; RPE, pre: 1.6 ± 0.5 and post: 9.0 ± 0.8 mmol/L, $p \leq 0.005$; ES = 10.59).

There was a statistically significant effect of time on CK, F (4, 24) = 8.31, $p < 0.0005$, ES = 0.58, observed power = 0.99. The CK concentration 24 h after the exercise session was statistically significant higher that pre-exercise concentration ($p = 0.040$; **Figure 3**). No statistically significant differences were observed between 0- ($p = 0.241$) 48- ($p = 0.608$) and 72-h ($p = 0.973$) after exercise and pre-exercise concentrations. The Karen protocol had a statistically significant effect on CMJ, F (4, 28) = 4.14, $p = 0.046$, ES = 0.37, observed power = 0.59. The height of CMJ post-exercise was statistically significantly lower than pre-exercise ($p = 0.043$; **Figure 4**). However, no statistically significant differences were observed in the height of CMJ between pre-exercise and 24- ($p = 0.108$), 48- ($p = 0.459$) and 72-h ($p = 0.827$) post-exercise.

Figure 5 shows the general, lower and upper limbs PRS of pre- and post-exercise session. There was a statistically significant effect of time on general PRS, F (3, 21) = 10.33, $p < 0.0005$, ES = 0.60, observed power = 0.98, lower limbs PRS, F (3, 21) = 739, $p = 0.002$, ES = 0.51, observed power = 0.96 and upper limbs PRS, F (3, 21) = 8.28, $p = 0.001$, ES = 0.54, observed power = 0.98. The

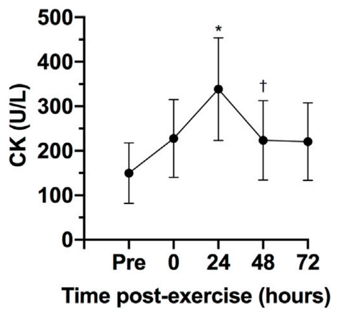

FIGURE 3 | Variables are expressed as mean and standard deviation (±). Creatine kinase concentration (CK) during pre-test, post-test, 24, 48 and 72 h post-test. *$p \le 0.05$ for pre-exercise; †$p \le 0.05$ for 24-h post-exercise.

scores of general, lower, and upper limbs PRS were statistically significant lower 24-h post-exercise session than pre-exercise (p = 0.013 for general, p = 0.037 for lower and 0.046 for upper limbs). No differences in the scores of PRS were observed between 48- (p = 0.647 for general, p = 0.244 for lower and p = 1.000 for upper limbs) and pre-exercise scores or between 72-h post-exercise (p = 1.000 for general, p = 1.000 for lower and p = 0.190 for upper limbs) and pre-exercise scores.

The comparison between the scores of general, lower, and upper limbs of PRS was presented in **Figure 6**. No statistically significant differences were observed between PRS scales pre- (p = 1.000 between general and upper PRS scores; p = 0.262 between general and upper PRS scores; p = 1.000 between lower and upper PRS scores) and 72 h post-exercise (p = 0.107 between general and upper PRS scores; p = 0.332 between general and upper PRS scores; p = 0.093 between lower and upper PRS scores). However, 24- and 48-h post-exercise, the PRS of upper limbs was statistically significantly higher than general PRS (p = 0.015 for 24-h and p = 0.030 for 48-h) and PRS of lower limbs (p = 0.041 for 24-h and p = 0.014 for 48-h). Finally, 48-h post-exercise, the PRS of lower limbs was statistically significantly lower than general PRS (p = 0.037).

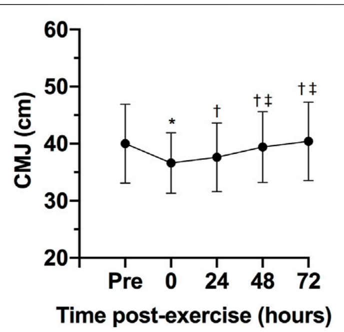

FIGURE 4 | Variables are expressed as mean and standard deviation (±). Height of counter movement jump (CMJ) during pre-test, post-test, 24, 48 and 72 h post-test; *$p \le 0.05$ for pre-exercise; †$p \le 0.05$ for 0-h post-exercise; ‡$p \le 0.05$ for 24-h post-exercise.

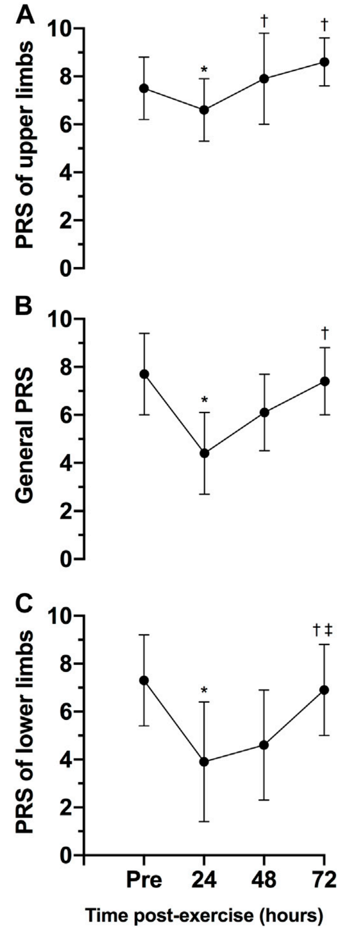

FIGURE 5 | Variables are expressed as mean and standard deviation (±). Perceived recovery scale (PRS) of the upper limbs **(A)** general **(B)** and lower limbs **(C)** during pre-test, 24, 48 and 72 h posttest. *$p \le 0.05$ for pre-exercise; †$p \le 0.05$ for 24-h post-exercise; ‡$p \le 0.05$ for 48-h post-exercise.

Correlations

Table 2 shows the correlations between the PRS scales, CK concentration and height of the CMJ. It was observed only a statistically significant correlation between PRS of upper limbs and height of the CMJ ($p < 0.0005$; r = 0.533; large).

DISCUSSION

The aim of this study was to analyze the physiological, biochemical, and neuromuscular responses following a CrossFit® benchmark session and to assess if the PRS scale could be a practical tool to determine the athletes' readiness to train status. The main findings partially confirm the initial hypothesis, revealing 1) significant increases in blood lactate post-exercise; 2) an increase of CK concentration 24 h post-exercise, returning to baseline levels 48 h post-exercise; 3) a significant change in the participants' perceived recovery status PRS for upper and lower limbs 24 h post-exercise

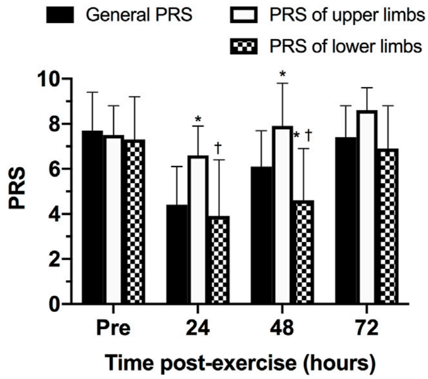

FIGURE 6 | Comparison between scores of general, lower and upper limbs of perceived recovery scale (PRS) at different time points. *$p \leq 0.05$ for general PRS; †$p \leq 0.05$ for PRS of upper limbs.

TABLE 2 | Correlation of creatine kinase (CK) concentration, height of counter movement jump (CMJ) and perceived recovery scales (PRS).

	CK Concentration (U/L)	Height of CMJ (cm)
General PRS	r = -0.228	r = 0.184
	p = 0.242	p = 0.314
PRS of upper limbs	r = 0.075	r = 0.533*
	p = 0.705	p < 0.0005
PRS of lower limbs	r = -0.149	r = 0.007
	p = 0.450	p = 0.968

*Note: Pearson correlation test. The magnitude of the correlations was classified as: r ≤ 0.1 trivial; 0.1 < r ≤ 0.3 small; 0.3 < r ≤ 0.5 moderate; 0.5 < r ≤ 0.7 large; 0.7 < r ≤ 0.9 very large; > 0.9 almost perfect. *p ≤ 0.05 for relationship between PRS, of upper limbs and height of CMJ.*

when compared to baseline, with PRS values for the lower and upper limbs showing different rates of recovery at 24- and 48-h post exercise (with the lower limbs' PRS recovering slower than the PRS for the upper limbs). The findings corroborate previous studies that demonstrate the significant physiological, biochemical, and neuromuscular changes following a CrossFit® session (Mate-Munoz et al., 2017; Gomes et al., 2020; Martinez-Gomez et al., 2022). Importantly, this study highlights the potential of the PRS scale to be used as a marker of recovery status following a Crossfit® session.

CrossFit® training sessions are often performed with near-maximal or maximal efforts, leading to a significant metabolic stimulus (Tibana et al., 2016; Claudino et al., 2018). In this context, blood lactate concentration has been utilized as a reliable marker to assess the intensity of different sessions of CrossFit® (Falk Neto et al., 2020). While changes in blood lactate concentrations will be dependent on the duration and intensity of the sessions performed (Özsu et al., 2018), previous research has shown that different CrossFit® sessions incur high blood lactate levels (Toledo et al., 2021). Timon et al. (2019) analyzed the blood lactate responses of two different protocols (Protocol 1: AMRAP of Burpees and Toes to Bar increasing repetitions (1–1, 2–2, 3–3 . . .) in 5 minutes; Protocol 2: three rounds of 20 repetitions of wall ball (9 kg) and 20 repetitions of power clean (40% 1RM) in the shortest possible time), with protocol two showing a similar lactate response as the one seen in this study (18.38 ± 2.02 mmol/L vs. 17.5 mmol/L ±3.0 mmol/L). Despite a similar perception of effort, it seems that protocols that do not use an external load (protocol 1) have a smaller lactate response (Timon et al., 2019). Still, the metabolic response in these sessions is considered high, even in the absence of an external load. For example, a session requiring participants to complete as many rounds as possible (AMRAP) of two exercises (burpees and toes to bar) still elicited a high blood lactate response (13.3 ± 1.87 mmol/L). Tibana et al. (2016), analyzing a session that involved AMRAP of double under and rowing, and Maté-Muñoz et al. (2017) with a session that consisted of performing a single exercise (double unders), also reported a high lactate response (9.05 ± 2.56 vs. 10.37 ± 2.91 mmol/L), respectively. In addition, even when the intensity of a CrossFit® session was manipulated to be performed at a lower perception of effort (6 out of 10, utilizing the Borg CR-10 scale), the lactate responses were still quite high (12.8 ± 3.2 mmol/L) (Alsamir Tibana et al., 2019). Previous studies have demonstrated that the metabolic responses induced by a training session are related to the required time to recover from this stimulus (Özsu et al., 2018). Considering the high physiological stress induced by CrossFit® sessions, even when there is no external load, or when the intensity is controlled, understanding the time-course of recovery from these sessions is essential to ensure athletes can optimize their training.

The serum CK is often utilized to understand the recovery status of participants following a training session given its easy of collection and analysis (Halson, 2014). The CK concentrations can be raised due to exercise induced muscle damage as a consequence of intense and prolonged training. The peak of serum CK normally occurs about 12–24 h after a strength training session, and values can remain elevated for up to 96 h when the exercise is focused on the eccentric phase of the movement (Baird et al., 2012). Importantly, CK values have been associated with muscle injury (Hyatt and Clarkson, 1998; Halson, 2014). Studies involving CrossFit® showed significant increases in CK that could be pathological due the extremely high values (Tibana et al., 2018b; Meyer et al., 2018). The present study found increases in CK 24 h post-exercise, with the values returning to baseline 48 h post-exercise. These results are in agreement with Timon et al. (2019) that evaluated the time course of recovery of CK in response to two different CrossFit® WODs. Both sessions induced a significant increase in CK levels 24 h post-exercise, with the values decreasing and returning to baseline 48 h post-exercise. Similarly, Tibana et al. (2019) showed that after five workouts over three consecutive days of competition the peak CK concentration occurred 24 h post-exercise (~698.7 U/L). Thus, it seems that when the CrossFit® session does not elicit increases in CK concentration that could be considered pathological, the concentrations might return to baseline levels within 48 h.

In addition to changes in CK concentrations, CMJ height alterations might also be utilized as a potential marker of fatigue (Claudino et al., 2017). A recent study analyzed CMJ height as a measure to assess neuromuscular status following a CrossFit® competition (Tibana et al., 2019). The CMJ jump height was significantly reduced 24-h post competition, with the values collected at 48- and 72-h post competition showing no differences from baseline. However, Tibana et al. (2016) demonstrated that consecutive days of CrossFit® training, despite eliciting significant metabolic changes, did not lead to impairments in muscle power. Considering that CrossFit® sessions vary often in the exercises performed and consequently, muscle groups utilized, and their duration, it is possible that CMJ height might have limited application as a measure to monitor the athletes' neuromuscular status, particularly after single bouts of exercise.

The novel finding of this study is that while objective measures (CK and CMJ height) indicate that the participants might be fully recovered from a session within 24–48 h, the psychobiological monitoring of the athlete's perceived recovery state indicates that 48–72 h might be needed for the athletes to return a point where performance is expected to be the similar or improved, based on the PRS. Psychobiological monitoring of training status is a non-invasive and non-exhaustive measure of assessing fitness (e. g. stress, fatigue), and also presents an effective and inexpensive measure to assess individual responses to training and competition. Despite its possibility as a tool to monitor current training status, Bishop et al. (2008) reported that there is still a limited knowledge by trainers and athletes about how to utilize such tools to optimize training intensity and recovery within a microcycle. Nevertheless, the large effect sizes reported indicate that further studies are required to assess the efficacy of the general PRS scale to determine the athletes' recovery status. The different time course of recovery for the upper and lower limbs, with the perception of recovery for the lower limbs taking a longer time to return to baseline levels, has practical significance in CrossFit®. Coaches and practitioners can potentially use this information to prescribe the next training bout in a way that respects the recovery time required following the previous session. In this scenario, prescribing a training session that focuses on the upper or lower body, or controlling the intensity of the subsequent session might assist coaches in reducing the intensity of the subsequent session, when required, or to reduce the level of physiologic stress, consequently, properly managing the athlete's training load (Tibana et al., 2018a; Falk Neto et al., 2020). While these would be important outcomes to ensure improved training prescription in the modality, further studies are required in this topic.

Despite a range of instruments to monitor recovery have been established, many are impractical for daily use due to cost, time, and challenges with interpretation (Lee et al., 2017; Seshadri et al., 2019). The results in this study demonstrate that a practical, non-invasive and expeditious approach to monitoring the participant's recovery following an acute CrossFit® session might provide important information for coaches and practitioners. In particular, the time-course of recovery according to the PRS is similar to that of the CK responses, with both measures reaching its most extreme values 24 h after the training session. However, while CK responses recover faster in the subsequent 24 h, the athletes' perceived recovery might show a slower improvement, particularly for the lower limbs based on the protocol used in this study. Therefore, this study demonstrates that the PRS may be useful in allowing appropriate adjustments in training intensity or volume in CrossFit® based on the athletes' recovery status. Considering the potentially detrimental effects of performing numerous maximal or near-maximal CrossFit® sessions in a short period of time, the use of the subsets of the PRS scale (upper and lower limbs) might assist in optimizing training prescription, providing important information about when the next stimulus should be provided, according to the athletes recovery status. Future studies should investigate if the use of the PRS scale might, in fact, optimize training prescription while helping to reduce the incidence of muscle injuries and the onset of non-functional overreaching.

Some limitations of the present study must be emphasized. Particularly, the reduced numbers of participants, the lack of control over the participants' diet prior to the test must be acknowledged. In addition, other factors that could influence the participants' recovery such as sleep, and stress have not been assessed during this study. Caution is advised when extrapolating the results of the current study to other populations or individuals of different training experience, as only healthy, experienced and male participants were recruited in this study. Our findings should not be generalized for other WOD and exercises. Moreover, our results cannot be used to infer the effects of combining these sessions within a larger training week, including a match stimulus and other modes of training (i.e., gymnastics, strength, power, and cardiorespiratory training). Future studies of a similar nature should include other critical biomarkers and an upper limb power measures to elucidate the time course of recovery and whether a state of fatigue truly occurred. Further longitudinal studies analyzing fatigue status and recovery in response to CrossFit® training over several days using similar methods can be relevant to further our understanding of the performance changes, and fatigue and recovery markers in different subjects.

CONCLUSION

In summary, a single CrossFit® session using repeated wall-ball movements elicited a significant level of metabolic stress, along with an increase in CK levels in the 24-h after the exercise session. More importantly, the results showed the potential utility of the PRS scale as noninvasive tool for accurately monitoring recovery status in CrossFit® practitioners. Particularly, the subscales of the PRS (upper and lower limb) seemed to be more effective at assessing changes in the athletes' perceptions of recovery following an acute session. Coaches, sport scientists, and practitioners could implement the use of these scales PRS to obtain important insights into the recovery status of the participants. While this information can be useful to coaches to optimize training monitoring and to minimize the potential detrimental effects associated with the performance of repeated high-intensity sessions of CrossFit®, further studies are required to test this hypothesis.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the studies involving human participants were reviewed and approved by Local Ethics Committee (2.698.225; 7 June 2018). The participants provided their written informed consent to participate in this study. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

RT: conceptualization and formal analysis. IN, NS, FN, JF, and RT: methodology and investigation. IN, NS, FN, JF, and RA: data curation, writing, review, and editing. All authors contributed to the article and approved the submitted version.

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Psychophysiological Responses of Exercise Distribution During High Intensity Interval Training Using Whole Body Exercise

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The time-efficient nature of HIIT using bodyweight exercises can facilitate the application of exercise programs at home by encouraging more people to perform regular physical exercise. However, there are no studies investigating the influence of the distribution/order of exercises during HIIT training sessions using this method. The aim of the present study was to evaluate the effects of different exercise orders on training load indicators during HIIT sessions using body weight. Twenty male participants performed three 20-min sessions of HIIT using whole body exercise, consisting of 20 sets with 30 s of activity performed at maximal intensity, followed by 30 s of passive recovery. Three designs of exercise protocols were randomly performed according to the following exercise distribution: A: jumping jack, burpee, mountain climb and squat jump); B: jumping jack, mountain climb, burpee, and squat jump) and C: burpee, squat jump, jumping jack and mountain climb. No differences were found between protocols for relative heart rate, perceived exertion, and lactate concentrations. Significant differences ($p < 0.001$) were found for the number of movements (A:712 ± 59, B:524 ± 49, C:452 ± 65). No differences were observed for the area under curve when examining perceived exertion between protocols. However, the values for perceived recovery significantly differed ($p < 0.001$) between protocols (A:64 ± 19; B:52 ± 11; C:17 ± 13). Interestingly, protocol B and C induced a displeasure perception compared to protocol A. Our findings suggest that exercise distribution/order using HIIT whole body exercise promotes alterations in psychophysiological responses in HIIT using whole body exercises.

Keywords: bodyweight, exercise, exercise order, psychophysiological, HIIT body work, training

1 INTRODUCTION

High intensity interval (HIIT) training has been considered as an effective method to increase maximum oxygen uptake (VO_2), time to exercise exhaustion, maximal activity of cytochrome c oxidase (COX) and total protein content of peroxisome proliferator-activated receptor coactivator one alpha (PGC-1α). These increases contribute to improvements in cardiometabolic parameters (Gibala and McGee, 2008; Nogueira et al., 2012), decrease body fat (Alves et al., 2017; Khammassi et al., 2018) and promote increases in the functional capacity of practitioners (Gibala et al., 2012).

A potential alternative complementary training regime using HIIT is bodyweight training, currently ranked in seventh position in the American College of Sports Medicine (ACSM's) Fitness Trends (Thompson, 2019). Although traditionally HIIT is performed using exercise protocols with cyclical characteristics, recent studies have investigated different approaches, including HIIT using body weight (McRae et al., 2012; Evangelista et al., 2017; Machado et al., 2017; Machado et al., 2018a; Machado et al., 2018b; Rica et al., 2018; Schaun et al., 2018; Evangelista et al., 2019; Schaun et al., 2019).

Additionally, the time-efficient nature of HIIT (Gibala and McGee, 2008) and its association with bodyweight exercises (McRae et al., 2012) can facilitate the application of the exercise program at home and therefore encourage more people to perform regular physical exercise. This method is appealing, as practitioners do not need to purchase expensive equipment and the exercises can be performed anywhere and at any time. Few studies (Williams, 2008; McRae et al., 2012; Evangelista et al., 2017; Schaun and Alberton, 2020) are available in the literature that have investigated psychophysiological responses associated with HIIT using whole body exercise. In this context, Evangelista et al. (2017) shows that HIIT using whole body exercise reduced sensation of anger, depression, tension, confusion, and vigor according to the mood scale (Evangelista et al., 2017). Long term, HIIT using whole body exercise was able to increase the perception of pleasure and adherence to this exercise (McRae et al., 2012; Schaun and Alberton, 2020). However, these studies presented only one order of exercise, and the effect of exercise distribution on exercise-induced psychophysiological responses is unclear. Additionally, significant improvements have been demonstrated in cardiorespiratory fitness and neuromuscular conditioning following training programs using HIIT and body weight (Machado et al., 2018a; Schaun et al., 2019).

Interestingly, a study by Machado et al. (2018a) demonstrated that during training sessions, differences in the total number of movements and differences in heart rate were observed for exercises performed during the exercise program. The manipulation of the distribution of exercises in training sessions is not new idea, and different studies have been reported in the literature investigating different training modalities (Simão et al., 2005; Skidmore et al., 2012; Aniceto et al., 2013), however, special attention has been applied to this methodology during resistance training studies. Research has demonstrated that the number of repetitions used during exercise, and the perceived effort and energy cost of the session can be affected when the training order is changed regarding exercise distribution (Schaun and Alberton, 2020). Klika and Jordan (2013) proposed an organization of training sessions using body weight, promoting exercise using four body areas. These included total body, lower body, upper body, and core. To our knowledge, there are no studies that have investigated the influence of the distribution/order of exercise during HIIT training sessions using body weight. Therefore, the aim of the present study was to evaluate the effects of the order of exercise on training load indicators during HIIT sessions using body weight. Thus, we hypothesized that exercise distribution order will promote smaller psychophysiological responses in healthy adult men.

2 MATERIAL AND METHODS

2.1 Participants

Following approval from the research ethics committee of the Federal University of Espirito Santo (N°3.733.252/2019), 20 healthy cross fit practitioner men for at lest 2 year (Age: 26 ± 5 years old, body mass: 74.13 ± 12.80 kg; height: 1.71 ± 0,07 m and body mass index: 25.07 ± 2.99 kg/m^2) voluntarily participated in the study. All procedures used followed the ethical standards of the committee on human experimentation (institutional or regional) and used guidelines outlined in the Helsinki Declaration. Signed informed consent was obtained from all participants prior to data collection. The following parameters were used as exclusion criteria: positive clinical diagnosis of diabetes mellitus, smoking, musculoskeletal complications, or cardiovascular alterations confirmed by medical evaluation and lower than 150 min of physical active per week. The Adapted International Physical Activity Questionnaire—short form (IPAQ) was used to determine the physical activity level of subjects (Matsudo et al., 2012). All participants were assigned to an exercise condition routine using a computerized random-number generator. The randomization process was completed with six subjects being assigned to different exercise blocks. Each block resulted in the allocation of two subjects to each protocol, ensuring a recruitment balance of 1:1 throughout the study. Sample size was calculated by *a priori* analysis G * Power software (v. 3.1.9.4), using a power (1—β) of 0.95, and an alpha level of 0.05.

2.2 Anthropometric

Height was measured using a calibrated Cardiomed (WCS model) stadiometer, with an accuracy of 115/220 cm. Measurements were performed with the cursor at an angle of 90°, with the subject maintaining a standing position with feet together in contact with the Stadiometer. Total body mass was measured by a calibrated Filizola electronic scale (Personal Line Model 150) with a 100 g scale and a maximum capacity of 150 kg. Body mass index (BMI, kg/m^2) was calculated using the equation BMI = body mass (kg)/height^2 (m).

2.3 Protocols

All participants performed three protocols each comprising of a single HIIT bodywork session, which differed regarding exercise order. The HIIT bodywork session consisted of 20 sets with 30 s of activity (TE) using "all-out" effort, followed by 30 s of passive recovery (TR). Five cycles were performed for each of the four exercises and were performed in different orders. The exercises used included jumping jack, burpee, mountain climber and squat jump.

Therefore, three designs of exercise session protocols were randomly performed according to following exercise distribution: A: jumping jack, burpee, mountain climb and squat jump); B: jumping jack, mountain climb, burpee, and squat jump) and C: burpee, squat jump, jumping jack and mountain climb.

The participants were advised not to exercise or consume any stimulants for 24 h prior to each exercise session. Each participant was instructed to consume 500 ml of water every hour in the 2 h prior to the exercise sessions. They were also advised not to consume any type of food during that period.

2.4 Number of Movements

The number of movements for each exercise (repetitions) performed in each set was quantified as suggested by Machado et al. (2018a).

2.5 Heart Rate

Heart rate (HR) was recorded continuously throughout the training session using HR monitors (Polar Electro Oy S810i, Kempele, Finland). HR data were recorded every 5 s. To reduce HR recording error during training, all subjects were asked to check their HR monitors before the session and after each set (~ 3 and 10 min). Maximal heart rate was estimated using the Tanaka equation (Tanaka et al., 2001).

2.6 Blood Lactate Measurement

Capillary blood samples were taken from a sterile fingertip using a sterile lancet immediately following training sessions. The first drop of blood was discarded, and free flow blood was collected in glass capillary tubes. All blood samples used for lactate analysis were evaluated using an Accutrend® (Roche—Basel, Switzerland) as described previously (Machado et al., 2018a; Rica et al., 2018).

2.7 Rate of Perceived Exertion and Recovery

Subjects reported their rating of perceived exertion (RPE, scale 1–10) as described by Borg (0–10) (Foster et al., 2017), immediately at the end, and prior to each exercise set as previously outlined (Machado et al., 2018a; Machado et al., 2018b; Rica et al., 2018). Recovery was measured using a scale adapted by Laurent et al. (2011) and has been used previously in exercise studies (Machado et al., 2018a). Values on the scale ranged from 0 to 10. The closer the value 10, the greater the recovery perception of the practitioner.

2.8 Feeling Scale

The psychological responses to the exercise sessions were evaluated using a feeling scale instrument (Hardy and Rejeski, 1989; Frazão et al., 2016). To measure the feeling scale (FS) a 11-point bipolar scale ranging from −5 to +5 and has been used to measure affective response (pleasure/displeasure) during exercise. However, in this study the parameters were evaluated prior to and following 5 min of exercise completion. The scale range includes the following outcome measures: −5 = very bad; −3 = bad; −1 = fairly bad; 0 = neutral; +1 fairly good; +3 = good; and +5 = very good.

2.9 Statistical Analysis

The D'Agostino–Pearson test was applied to Gaussian distribution analysis. Two-way repeated measures ANOVA followed by Bonferroni's post hoc test was performed considering time points and protocols as main factors to analyze responses of selected variables (heart rate, lactate, feeling scale). In addition, the comparison among exercise protocols and area under the curve was performed using a one-way repeated measures ANOVA followed by Bonferroni post hoc test for selected variables (perceived exertion, number of movements). The effect sizes (ES) based on Cohen's d were evaluated and qualitatively interpreted using the following thresholds: < 0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large and; >4.0, extremely large. An alpha of 0.05 was used to determine statistical significance. All data values were expressed as mean ± standard deviation (SD). All analyses were performed using GraphPad Prism version 6.00 for Windows (GraphPad Software, La Jolla California, United States).

3 RESULTS

There were no injuries or musculoskeletal problems reported for any of the exercise sessions. All subjects completed the three training protocols. As shown in **Table 1**, the absolute values for heart rate and lactate concentrations significantly increased following exercise without any differences between protocols. No differences ($F = 1.912$, $p = 0.1650$) were found for relative heart rate between protocols (A: 93.67 ± 4.74, B: 92.70 ± 4.13, C: 94.79 ± 2.87; %).

The values for feeling scale (**Table 1**) revealed a significant time ($F = 438.3$, $p < 0.0001$) and protocol interaction ($F = 28.79$, $p < 0.0001$) indicating a significant reduction in this outcome measure for all protocols. However, the values observed following the sessions were significantly different between protocols. A greater reduction was observed for the B and C protocols compared to protocol A, for mean values which indicates a displeasure perception compared to protocol A.

Perceived exertion did not differ (A: 9.3 ± 0.73; B: 9.1 ± 1.21; C: 9.15 ± 1.31; $F = 0.3139$, $p = 0.7062$) between protocols, however, the number of movements (A: 712 ± 59, B: 524 ± 49, C: 452 ± 65; $F = 107.9$, $p < 0.0001$) were significantly different between all protocols, with higher values for protocol A, followed by B and C.

TABLE 1 | Absolute values of heart rate and lactate concentration according to exercise protocol.

Parameters	Before	After	95% IC of diff	ES	ANOVA		
					Effect		
					Time effect	Time*protocol	
						F	p
Heart rate (bpm)							
Protocol A	81.90 ± 14.13	178.05 ± 9.36*	−104.2 to −88.12	6.59	<0.0001		
Protocol B	76.95 ± 9.69	176.20 ± 8.36*	−107.3 to −91.22	7.19	<0.0001	0.67	= 0.5117
Protocol C	78.70 ± 8.71	180.20 ± 7.06*	−109.5 to −93.47	12.26	<0.0001		
Lactate (mMol.L-1)							
Protocol A	1.38 ± 0.70	13.99 ± 3.16*	−14.41 to −10.80	5.50	<0.0001		
Protocol B	1.42 ± 0.66	13.84 ± 2.99*	−14.23 to −10.62	5.74	<0.0001	0.016	= 0.9797
Protocol C	1.41 ± 0.46	13.95 ± 3.64*	−14.35 to −10.74	4.83	<0.9839		
Feeling scale							
Protocol A	4.35 ± 0.58	0.20 ± 2.07*†‡	3.11 to 5.18	2.73	<0.0001		
Protocol B	4.30 ± 0.73	−1.50 ± 2.28*‡	4.76 to 6.83	3.43	<0.0001	23.84	<0.0001
Protocol C	4.30 ± 0.80	−3.95 ± 0.88*	7.21 to 9.28	9.81	<0.0001		

*Values expressed in mean ± DP, for heart rate (bpm), lactate (mMol.L-1) and feeling scale for protocol A (jumping jack, burpee, mountain climb and squat jump), protocol B (jumping jack, mountain climb, burpee, and squat jump) and protocol C (burpee, squat jump, jumping jack and mountain climb). *p < 0.0001 vs. before. †p < 0.0001 vs. Protocol B. ‡p < 0.0001 vs. Protocol C.*

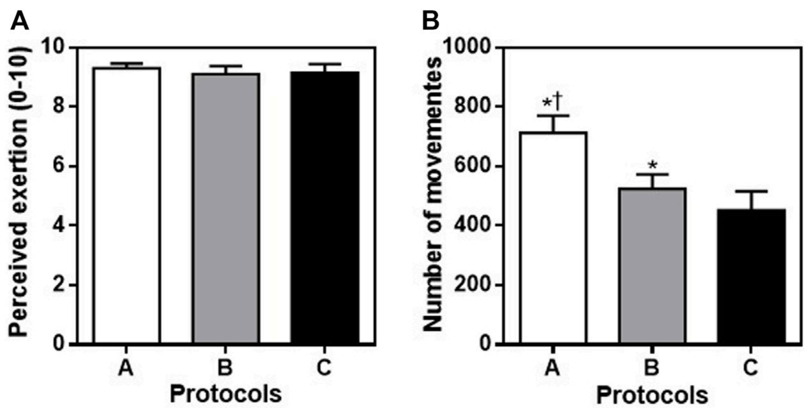

FIGURE 1 | Values expressed at mean ± DP for perceived exertion [Panel **(A)**] and number of movements [Panel **(B)**] for protocol A (jumping jack, burpee, mountain climb and squat jump), protocol B (jumping jack, mountain climb, burpee, and squat jump) and protocol C (burpee, squat jump, jumping jack and mountain climb). *p < 0.001 vs. protocol C †p < 0.001 vs. protocol B.

Perceived exertion and recovery values are presented in **Figure 2**. As shown in Panel B no differences (F = 0.0074; p = 0.9926) were found for the area under curve for perceived exertion between protocols (A: 184 ± 6, B: 184 ± 5, C: 184 ± 5). The values for perceived recovery (Panel C) significantly differed (p < 0.001) from the third set compared to protocol A and B. Protocol C differed from the second set compared to first set (p < 0.001). Statistical differences (F = 49.42; p < 0.00010) were found for the area under curve (A: 64 ± 19 > B: 52 ± 11 > C: 17 ± 13) for perceived recovery (Panel D) between protocols.

4 DISCUSSION

The main findings from this study demonstrated that, although there were no differences in HR, Lactate and RPE, the number of movements, the perception of recovery and pleasure were modified between protocols. To our knowledge, studies investigating the influence of exercise distribution using HIIT sessions in conjunction with body weight are few in the scientific literature. The results presented here are original and innovative and demonstrate physiological differences using variations in exercise order.

In the present study, HR did not differ between protocols. This suggests that the use of different exercise orders induced similar physiological stress and could be considered as a HIIT session. This is particularly true when values recorded during exercise were above 85% of the HR as recommended by Karvonen and Vuorimaa (1988). This has also been observed in other HIIT sessions (Maclnnis and Gibala, 2017) when subjects exercised with or without equipment (McRae et al., 2012; Gist et al., 2015). Considering HR, Machado et al. (2018a) demonstrated that

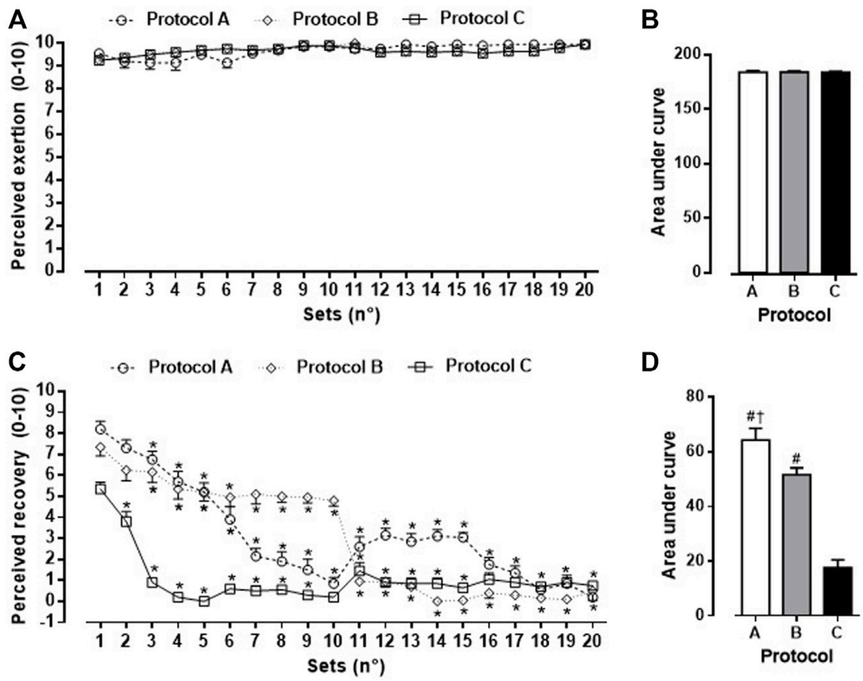

FIGURE 2 | Values expressed as mean ± DP for perceived exertion around set [Panel **(A)**], area under curve for perceived exertion [Panel **(B)**], perceived recovery around set [Panel **(C)**] and area under curve for perceived exertion [Panel **(D)**] for protocol A (jumping jack, burpee, mountain climb and squat jump), protocol B (jumping jack, mountain climb, burpee, and squat jump) and protocol C (burpee, squat jump, jumping jack and mountain climb). $^{*}p < 0.001$ vs. First set. $^{\#}p < 0.001$ vs. protocol C $^{\dagger}p < 0.001$ vs. protocol B.

exercise type induced modifications in HR for the same session. It is worth noting here, that in the present study, the same exercises were used for all sessions, varying only in temporal order. Additionally, even if performed using different exercise distributions (protocols A, B, and C) the HR values remained similar regardless of the protocol used.

In relation to blood lactate concentrations and perceived exertion, our findings agree with previous studies (Machado et al., 2018a; Machado et al., 2018b). As outlined in **Table 1** (lactate) and shown in **Figure 1A** (perceived exertion) all protocols induced increases in these parameters following HIIT using whole body exercise. In conjunction with the HR data, it is possible to consider that the physiological stress was similar between protocols performed in this study. However, it is worth mentioning that studies using HIIT and bodyweight use maximal intensities of exercise as protocol standards (Machado et al., 2018a). As a result, it is possible that the perceived effort of programs using these characteristics are considered as severe exercise intensities.

Although there are no studies dedicated to investigating different effects of exercise distribution on programs using HIIT using bodyweight, some studies (Skidmore et al., 2012; Aniceto et al., 2013) have investigated the effects of different exercise session formats. Skidmore et al. (2012) evaluated the responses of HR and lactate concentrations to three exercise programs using different orders in the distribution of exercises. The research group varied circuit training with collective gymnastics, cycle ergometer and sprints using maximal intensities. The findings of the study demonstrated that HR, lactate concentrations and perceived exertion were higher during circuit training sessions followed by sprints. These findings agree with Aniceto et al. (2013) that training session organization can promote different physiological responses, and that the exercises have different physiological characteristics, including motor and/ or metabolic differences.

One of the parameters that can influence physiological responses to high-intensity exercise sessions is the interval between series (Buchheit et al., 2009; Driller et al., 2009; Germano et al., 2022). In our study, we did not evaluate the influence of the intervals, but we did investigate the impact that the different exercise protocols had on the perception of recovery. This parameter can be interesting, especially when the purpose is to evaluate the repercussions of both the training session and the series regardless of the type/modality of HIIT. The findings of the present study were different from the findings of Machado et al. (2018a), who demonstrated a continuous reduction in the perception of recovery.

In this study, the distribution of the exercises influenced the perception of recovery, with alternating protocols inducing a greater perception of recovery throughout the training sessions. This may be explained by the greater fatiguing effect that the burpee and squat jump exercises induce regardless of when they are performed.

The exercise order may explain the differences in the total number of movements observed between protocols, especially the influence of exercises on the perception of recovery. The evaluation of different training program strategies and external load parameters is not new (Sforzo and Touey, 1996; Simão et al., 2005; Schaun et al., 2019). Our results, using body weight exercise, present similar results compared to traditional strength training, indicating that the exercise sequence or training modalities can promote alterations in exercise performance in one session. This effect of exercise order during training sessions needs consideration and is an important factor when designing programs. Training session design needs to consider if the order of the exercises used are specific to meet the training goals of a program.

Considering the perception of pleasure, studies have shown favorable (Oliveira et al., 2018; Olney et al., 2018) or unfavorable (Frazão et al., 2016; Evangelista et al., 2017; Follador et al., 2018) outcomes when using high intensity exercise. It has been proposed that the intermittent nature of interval training induces a "rebound effect" that generates a better feeling of pleasure (Jung et al., 2014). Frazão et al. (2016) demonstrated a reduction in the perception of pleasure throughout a training series in active individuals and displeasure in insufficiently active individuals performing 10 sets of exercise from 60 s to 90% of vVO2max with intervals of 60 s to 30% vVO2max. Using body weight, Evangelista et al. (2017) studied twenty-six healthy recreationally active adult men performing 8 sets of 20 s of maximal intensity exercise with 10 s of passive recovery using HIIT whole body weight. The results of the study found a reduction in the perception of pleasure until the sixth series and displeasure in the seventh and eighth grades. To our knowledge, the information on the perception of pleasure in HIIT exercise programs using body weight is still inconclusive. The findings of the present study agree with the findings of Evangelista et al. (2017) and show a reduction in the sensation of pleasure following completion of the protocol. Additionally, Schaun and Alberton (2020) suggest that whole-body interval training can be used as an enjoyable low-cost alternative to traditional treadmill-based sprint interval training (SIT) and moderate-intensity continuous training (MICT).

It is worth mentioning that the parameters related to protocols B and C exhibited displeasure after the exercise sessions. An explanation for this finding may be related to the possibility of reduced or insufficient recovery time for protocols B and C induced by the exercise distribution order. In support of this suggestion, studies have (Nogueira et al., 2012; Dalamitros et al., 2016) observed that short periods of recovery during high intensity exercise, generate residual fatigue, which contributes to the decrease in the sensation of pleasure. The perception of pleasure is crucial in adhering to physical activity programs, since the feelings experienced during exercise are reliable predictors for future participation in structured exercise. Our findings indicate that the selection of exercises during HIIT sessions using body weight can affect the perception of pleasure and therefore the possibility of adhering to the practice of HIIT.

There are some important limitations in this study. The sample size was limited to healthy and cross fit practitioner men who had experience using whole body in exercise sessions. As a result, our findings cannot be applied to overweight/obese or untrained individuals. A maximal test may also be needed to confirm the % HR kinetics during the exercise sessions. In general, HR is presented as HRminimum, HRmaximal, HRmean %HRpeak during the session. This method of presentation makes it difficult to quantify the training load by HR. Additionally, there is a large variety of HIIT applications and exercise regimes, and the results from this study cannot be applied to other forms of exercise designs and taken together, these observations limit the generalization of the results.

Although some limitations are present in this study, some positive practical applications can be observed. The organization of exercises alternately promoted improvements in the perception of recovery and pleasure in relation to other models of exercise selection. This can contribute to the development of different training strategies. The results of the present study demonstrate that protocol A produced a greater number of movements and better perception of recovery compared to protocols B and C. Additionally, protocol A induced just reduction of feeling of pleasure, differently of B and C protocol that induced displeasure. This is concerning given that these responses may promote negative exercise experiences, which may impact on exercise adherence (Williams, 2008). In this context, the use of exercise distributed alternately during HIIT-body work with "all out" efforts might favor a better performance in addition to more positive affective responses. This suggestion seems to promote a more favorable exercise experience. However, the different exercise orders used during the HIIT sessions using body weight did not alter the classical parameters of physiological responses, and the corresponding measures of HR, lactate concentrations and perceived exertion.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Federal University of Espirito Santo (N°3.733.252/2019). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AM, PZ, and DB contributed to the data collection and the intellectual concept of the study, carried out bibliographic research, evaluated the data from the statistical analysis and jointly wrote the manuscript. RR, JM, and AE contributed to the data collection, carried out bibliographic research, jointly wrote and reviewed the manuscript. CA, VB, SG, MB, and JB reviewed the manuscript, contributed to the intellectual concept of the study and jointly wrote the manuscript. DB evaluated the data from the statistical analysis and jointly wrote the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Functional and Traditional Resistance Training Are Equally Effective in Increasing Upper and Lower Limb Muscular Endurance and Performance Variables in Untrained Young Men

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Background: Functional resistance training (FRT) has been proposed as a safe alternative to traditional resistance training (TRT) for developing neuromuscular adaptation capacity and improving muscular strength and competitive performance. This study sought to compare the effects of 6 weeks of FRT and TRT on upper and lower limb muscular endurance and performance variables in untrained young men.

Methods: Twenty-nine untrained healthy young males aged 18–29 years were randomly given 6 weeks of FRT [40% of 1repetition maximum (RM), 4,5 sets of 20 repetitions, 3 times/week] or TRT (70% of 1RM, 4,5 sets of 12 repetitions, 3 times/week). All participants underwent numerous tests before and after the 6-week training, such as muscular endurance (reps of bench press and leg flexion) and physical performance tests (sprint performance, pull-ups, throwing ability, and jumping ability).

Results: After the 6 weeks of training, the TRT and FRT groups showed an equally significant increase in muscular endurance ($p < 0.01$), while the throwing and jumping abilities, 30-m sprint, and pull-ups performances in both the groups ($p < 0.01$) also improved significantly. However, no differences were observed between the groups ($p > 0.05$).

Conclusion: These findings indicate that both functional resistance training and traditional resistance training are effective training methods for improving the upper and lower limb muscular endurance and performance in untrained young men.

Keywords: functional resistance training, traditional resistance training, physical performance, muscle strength, muscular endurance

BACKGROUND

Previously used for treating functional and partial deterioration in old adults as well as stroke patients (Scholtes et al., 2012; Lee et al., 2013) and postoperative rehabilitation patients (Ageberg et al., 2008), functional resistance training (FRT) on unstable surfaces (e.g., BOSU ball, Swiss ball, and balance disc), is now employed as a new training technique for improving sports performances (Thompson, 2021). Conceptually, FRT is a set of exercises performed to enhance performance in daily functions (Fowles, 2010) or develop the ability to perform activities of daily living (Thompson, 2016). It features several dynamic exercises containing synchronized, multidimensional, and numerous joint movements conducted on unstable surfaces for developing different physical conditioning (e.g., muscle strength) and performance variables (e.g., power and speed) for increased core stability (La Scala Teixeira et al., 2017; Feito et al., 2018). It is suggested that FRT should focus more on improving movement patterns rather than concentrating on specific muscular adaptations, as done in another fitness-enhancing exercise, traditional resistance training (TRT). It was reported that regular resistance training imparted more attention to specific muscles for enhancing strength and physical performance by gradually increasing the training load in either fixed or stable positions (Tomljanović et al., 2011; Feito et al., 2018).

Previous studies have reported the effects of FRT were generally observed in athletes, older adults, and diseased patients and seldom covered healthy untrained young individuals. For example, a systematic review (Xiao et al., 2021) concluded that although FRT significantly improved athletes' muscular strength, power, speed, and agility, no significant effects were found in muscular endurance and anthropometric variables. Another study by (Bale and Strand, 2008) reported that a 4-week FRT of the lower limbs gave better results than TRT in promoting functional performance and muscular strength in 18 post-stroke patients in the subacute phase. Similarly (Abbaspoor et al., 2020), also indicated that an 8-week combined FRT might be an effective training model for increasing the walking speed, quadriceps, and handgrip strength in women with multiple sclerosis (MS). Tomljanović et al. (2011) studied healthy young kinesiology students during a 5-weeks program and demonstrated that while FRT improved postural control and coordination, TRT augmented the energetic potential of trained musculature; thus, increasing the strength. Several studies conducted on inexperienced healthy individuals suggested that instability resistance training that engages lower forces can improve maximal strength (Milovan et al., 2012), power (Mate-Munoz et al., 2014), movement velocity, and jumping ability (Sparkes and Behm, 2010) similar to TRT held under stable conditions along with heavier loads. However, these studies only involved the effects of local exercise on physical capacities. There are no studies to date that have compared the instability resistance training with TRT programs in untrained young men in terms of muscular endurance and performance for several weeks. This might be significant in cases of two training programs having a similar training volume; however, there is little empirical data to suggest that FRT can greatly improve muscular endurance.

Several studies have reported that similar exercises, when performed under unstable parameters as compared to stable conditions (e.g., muscular strength, power, and speed), display increased physical capacities (Tomljanović et al., 2011; Yildiz et al., 2019; Xiao et al., 2021), as physical capacities play a crucial role in determining players' competitiveness. However, Behm et al. (2010) stated that unstable devices are not always effective in meeting the specific demands (e.g., strength and balance) of the athletes. For example, if an athlete needs to develop optimal strength and power, then training under unstable surfaces that require reduced external load and force is not very efficacious for trained athletes (Behm and Colado, 2012; Behm et al., 2015; La Scala Teixeira et al., 2017). On the contrary, unstable resistance training can also be employed by an untrained population to improve strength and power and promote functional health benefits. It is reported that resistance training under unstable conditions might impart instability in the performance of daily activities, occupations, and sports, thus, providing more beneficial training adaptions and transfer (Tomljanović et al., 2011). Another study by Behm and Colado (2012) reported that a 30% force deficit induced by unstable resistance training can be beneficial, as the lower load and torque might reduce the risk of training injuries or improve the functional restoration after injury. However, a meta-analysis suggested that balance training is highly task-specific in trained and untrained individuals (Kummel et al., 2016). Furthermore, the effects of resistance training on unstable surfaces are inconsistent and unfavorable for developing muscular fitness, especially muscular strength, when compared with stable conditions (Behm et al., 2015). Thus, to our knowledge, no study to date has compared the effects of two types of equal-volume resistance training schedules (functional vs. traditional) on upper and lower limb muscular endurance and performance in untrained young men.

Therefore, this study aimed to compare the distinct effects of FRT and TRT protocols, having equal training volume, on upper and lower limb muscular endurance and certain specific performance variables (e.g., sprint performance, pull-up, throwing ability, and jumping ability) in untrained men for over 6 weeks. Our hypothesis suggests that both groups would show a significant increase in all performance indicators, although the FRT group might display greater muscular endurance enhancements.

MATERIALS AND METHODS

General Design

This study was designed as a randomized controlled trial and was prospectively registered at the http://www.chictr.org.cn/as ChiCTR2100048485, with ethical approval granted by the Capital University of Physical Education and Sports ethical committee. Before study initiation, all the participants were informed of the risks and requirements of the training program, and voluntary consent was obtained from all of them. This paper followed the CONSORT statement (Schulz et al., 2010).

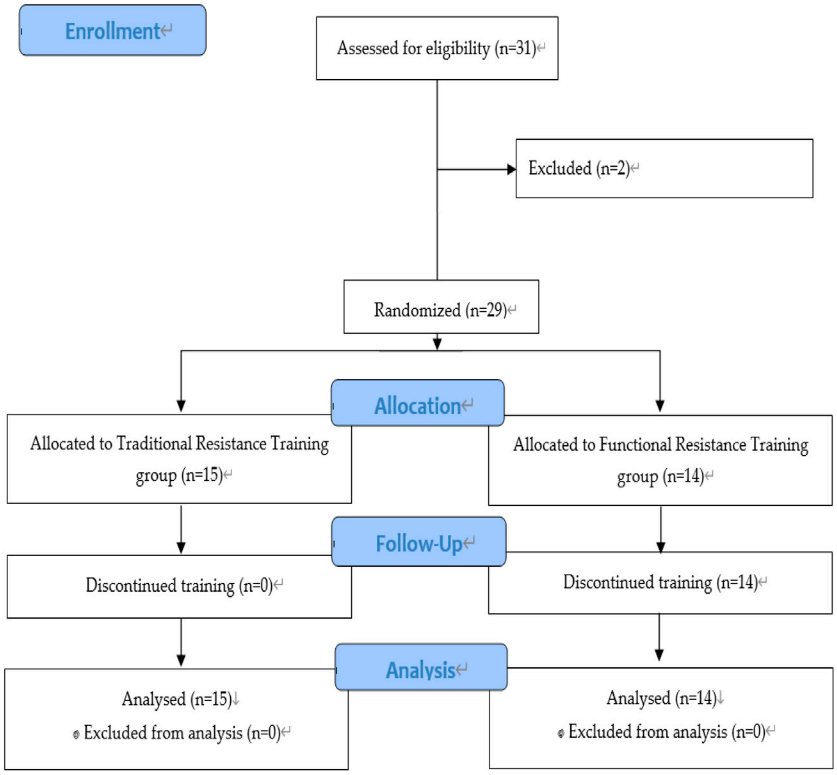

FIGURE 1 | Study Flow chart (Schulz et al., 2010).

Participants

A total of 31 untrained individuals were initially screened at the Capital University of Physical Education and Sports in Haidian District, Beijing, China (**Figure 1**). All the participants were recruited through print and word-of-mouth advertising. The inclusion criteria were as follows: 1) participants ≥18 years old, 2) they did not undergo any regular resistance-type training for 6 months before the study commenced, and 3) patients did not regularly smoke, drink alcohol, or consume any medications, 4) patients without overt chronic diseases and sports injury. Consequently, 29 participants met the inclusion criteria, while two were dropped out because of personal reasons. All the participants were randomly assigned to either the TRT (n = 15) or the FRT groups (n = 14) and were instructed not to attend any extra training and to maintain normal eating habits throughout the 6-week training period.

Anthropometric Measurements

The height and weight were measured using a portable stadiometer and an electronic scale before and after a 6-week regular resistance training intervention. Then, the body mass index (BMI) was calculated according to the following formula: BMI = weight (kg)/height $(m)^2$. Anthropometric measurements of the participants who fasted overnight (>8 h) were simultaneously assessed before and after the resistance training intervention.

Test Procedures

All participants performed the assessment process before, during, and after the 6-week intervention. The test procedure involved two separate phases with a gap of 24 h. The first testing day included anthropometric measurements and a 1RM test, including barbell squat, bench press, deadlift, and right leg flexion. The second phase incorporated throwing and jumping abilities, sprint achievement, pull-ups, and muscular endurance tests. In order to avoid the influence of the muscular endurance test on other test results, the upper and lower limb muscular endurance measurements were arranged as the last measurement of all assessments. Participants were asked not to undergo any physical exercise a day before and avoid taking food, caffeine, and alcohol 12 h before the measurement.

Maximal Strength Measurements

Each participant completed the 1RM test before the 6 weeks training program in the same order, i.e., barbell squat, bench press, deadlift, and seated leg flexion. The 1RM tests conformed to the prescribed guidelines of the American College of Sports Medicine (American College of Sports Medicine et al., 2018). Measurements were taken by gradually increasing the weight lifted by the participants until they failed to lift the current weight throughout the exercise. Initially, the participants performed a 5 min warm-up on a paddle ergometer at a perceived exertion level of 3 (on the CR 10 Borg scale), followed by two warm-up sets of 5–10 repetitions at 40–60% 1RM. For the last set, participants performed three to five repetitions at approximately 60–80% 1RM, while a 1–2 min rest period was allowed between the warm-up sets. After the last set, a 3 min rest was taken before the actual 1RM test. Participants completed the test in five trials, with a rest period between each trial set of approximately 3 min, and the highest load achieved was recorded as the 1RM load. Before each strength test, participants were instructed to understand each test movement pattern, especially the bench press, which required the participants to lower the bar to the chest without touching as well as keeping the upper arms parallel to the ground followed by returning the bar upward and successfully straightening the elbow at "press" command. Barbell squats were performed while the participants held a bar on the back and core fully stretched perpendicularly to the knee. All participants were further asked to keep their feet shoulder-width apart at a 45° angle throughout the test. As the participants were in a seated position, the hip angle was approximately 110° in the leg flexion test. With verbal encouragement, the participants attempted to perform a concentric dominant leg flexion starting from the extended position at 180° to reach an approximate flexion of 70° against the resistance loads (kg).

Muscular Endurance Measurements

Upper and lower limb muscular endurance were assessed by bench press and leg flexion tests; participants were instructed to complete the maximum number of repetitions (reps) of bench press and leg flexion, respectively. The same load (70% of 1RM) was used for pre-and post-intervention measurements as suggested by a previous study (Hackett et al., 2021). According to the 1RM test, participants were asked to achieve a full range of motions and proper techniques. The repetition cadence was performed in 1 s eccentric and concentric contractions. The maximum number of reps and the volume load for each exercise were recorded for statistical analysis.

Physical Performance Measurements

Physical performance measurements consisted of throwing ability, jumping ability, 30-m sprint, and pull-ups. To assess the throwing ability, a medicine ball throw (MBT) test was used in which participants were kept behind a line marked on the floor in a seated position and were instructed to sit on the floor with their head, shoulder, and back against the wall. Their legs were straight apart and facing the direction in which the ball was thrown. A 2 kg medicine ball was held in their hands with arms at 90° to the shoulder abduction, similar to a chest pass in basketball, and they were told to throw the ball horizontally. Additionally, participants were also further instructed not to use their lower body for exerting force with their head, shoulder, and back pressed against the wall. Participants completed three practice trials with a 1-min rest between each trial. The average of these multiple readings was used for analysis.

The Quattro Jump System (Kistler 9290AD, Switzerland) was used to evaluate the jumping ability. All participants performed a countermovement jump (CMJ) test without swinging their arms from the portable force plate. For the starting position, the participants stood straight on the force plate with their hands on the hips, but after the instructor's cue, they squatted down rapidly to a 90° knee angle position and jumped straight up as high as possible, with their hands on the hips. During the ascending phase, the participants left the force plate with the fully stretched lower limbs and landed on both feet on the force plate with straight knees to measure the airtime. As suggested by a previous study (Sattler et al., 2012), the best of three consecutive trials, with appropriate rest allowed between each trial, was used as the final test result.

In the 30-m sprint test, participants were asked to sprint a distance of 30 m while passing through a photocell (Brower Timing System, United States). The participants started on the sound signal, which activated the timer system. Two sets of photocells were placed at the 30-m gates. The timing results from individual gates were recorded as the result of a 30-m sprint. The best of two consecutive tests was selected as the final result for the statistical analysis.

The pull-up test was performed starting from a dead hang position with the arms fully stretched and locked and feet off the floor. The bar was clasped with hands in pronation, set apart by a distance wider than the shoulders. From this position, the entire body was lifted until the chin was higher than the bar. On the way down, the body was kept straight, hanging down from the bar with fully stretched arms. This procedure was repeated until they could not finish a pull-up, and the number of pull-ups was recorded.

Exercise Interventions

TRT Protocol

Table 1 presents the summary of the TRT and FRT protocols. The participants in both groups were trained for 18 sessions (of 60 min each) thrice a week for six consecutive weeks. Each session time contained a 5–10 min warm-up on a wind ergometer before every workout, while the remaining 50 min of the session was spent in the whole-body workout. The TRT program comprised five exercises, namely barbell squat for the lower limb, horizontal bench press for chest muscles, deadlift for back and leg muscles, reverse arm curl for biceps, and seated leg flexions for quadriceps in stable conditions (70% of 1RM, and 4,5 sets of 12 repetitions), with 1,2 min of rest between the sets.

FRT Protocol

The FRT group performed the same training exercises as the TRT group on unstable devices (e.g., BOSU ball, Swiss balls, and balance discs). Moreover, an unstable training schedule may not provide the same intensity of muscle overload as TRT under stable conditions while considering safety factors (Kibele and Behm, 2009). The horizontal bench press, deadlift, and barbell squat were performed on the Swiss ball, balance disc, and BOSU ball, while kettlebell swings and Bulgarian split squats were performed on the BOSU ball, respectively. The equivalents of the total training volume were coordinated between the two groups. The repetition in the FRT group was calculated using the following formula: 70% 1RM lifting weight (kg) × reps (TRT group)/40%1RM to volition fatigue, with 1,2 min of rest between sets. Thus, the FRT group performed 4,5 sets of 20 repetitions at 40% 1RM with 1,2 min of rest between sets. The strength assessment for all participants was done again after 3 weeks of

TABLE 1 | Resistance training protocols.

Group	Exercises	Sets	Repetitions	Training Intensity	Rest
TRT	Barbell Squat	4,5	12	70%1RM	1,2 min
	Bench Press	4,5	12	70%1RM	1,2 min
	Deadlift	4,5	12	70%1RM	1,2 min
	Reverse Arm Curl	4,5	15	10 kg	1,2 min
	Leg Flexion	4,5	15	70%1RM	1,2 min
FRT	Barbell Squat & BOSU	4,5	20	40%1RM	1,2 min
	Bench Press & Swiss ball	4,5	20	40%%1RM	1,2 min
	Deadlift & BOSU	4,5	20	40%1RM	1,2 min
	Kettlebell Swing & BOSU	4,5	15	20 kg	1,2 min
	Bulgarian Split Squats & BOSU	4,5	15	16 kg	1,2 min

TABLE 2 | Anthropometric characteristics of the participants at baseline.

Test	TRT (*n* = 15)	FRT (*n* = 14)	*p*-value
Age (y)	22.1 ± 2.9	20.9 ± 2.7	0.262
Height (cm)	176.6 ± 5.4	176.7 ± 6.0	0.957
Body mass (kg)	77.9 ± 11.6	73.4 ± 10.2	0.270
BMI (kg/m^2)	24.9 ± 3.1	23.4 ± 2.6	0.168
BP (kg)	75.0 ± 9.8	71.4 ± 10.3	0.348
BS (kg)	116.0 ± 19.9	114.3 ± 16.0	0.801
DL (kg)	118.7 ± 21.3	110.0 ± 25.4	0.310
R-LF (kg)	43 ± 6.5	39.3 ± 6.8	0.143

BMI body mass index, BP bench press, BS barbell squat, DL deadlift, R-LF right leg flexion, TRT traditional resistance trainings, FRT functional resistance training.

intervention to ensure that the participants had readjusted training intensities based on their strength gains. All the participants were asked to maintain normal dietary habits and avoid overeating to minimize any potential diet-induced variability in muscle strength and body composition measurements.

Statistical Analysis

Statistical analyses were performed using SPSS version 22.0 Windows (SPSS, Inc. Chicago, IL, United States). The sample size was estimated based on a similar experimental design (Unhjem et al., 2016). Moreover, with an effect size $f^2 = 0.30$, a power of 0.80, and a significance level of 0.05 (Cohen, 1992), the minimum sample size of 24 (12 per group) was found to be adequate using repeated measurements analysis of variance (ANOVA, G*Power 3.1; Heinrich Heine, Dusseldorf, Germany). All baseline and post-intervention data were normally distributed utilizing the Shapiro-Wilk's W test, which indicated appropriate normality in the distribution for all variables. All pre- and post-intervention data were expressed as mean ± standard deviation (SD). An independent sample *t*-test was used to test the pre-intervention measurement difference between the two groups. Training effects were analyzed using a mixed two-way repeated-measures ANOVA ([time (pre-and post-training)] — training group (TRT and FRT)] to verify differences in muscular endurance and physical performance between the groups. Post-hoc tests were applied using the Bonferroni corrections. The mean difference of changes in muscular endurance and physical performance for each group was presented. Furthermore, the effect sizes were calculated as partial eta square and converted to Cohen d, being classified as small (0–0.2), medium (0.2–0.8), and large (>0.8). A p-value < 0.05 was considered statistically significant.

RESULTS

Participants

Table 2 presents the main characteristics of all the participants at baseline. No significant differences between the groups were observed in terms of age, height, body weight, body mass index, and 1RM tests. Additionally, all the participants in the groups adhered to the scheduled 18 training sessions during the intervention period. No training-related injuries, as well as participant withdrawal, were observed.

Muscular Endurance

Table 3 presents the results of muscular endurance tests. Both training protocols displayed increased bench press (repetitions) for the upper limb muscular endurance (TRT +10.1reps, p = 0.000, FTR +12.4reps, p = 0.000, Cohen d = 0.43), right leg flexion (repetitions) for the lower limb muscular endurance (TRT +8.1, p = 0.000, FTR +7.9, p = 0.000, Cohen d = -0.03), with a main effect of time ($p < 0.001$) and no difference between groups. Additionally, muscular endurance expressed as volume-load also significantly increased in both the groups for the bench press (TRT +508.7 kg, p = 0.000, FRT +587.9 kg, p = 0.000, Cohen d = 0.23) and the right leg flexion tests (TRT +251.3 kg, p = 0.000, FRT +214.8 kg, p = 0.000, Cohen d = -0.13) without any significant difference between the training groups.

Physical Performance

As shown in **Table 4**, a significant difference in throwing and jumping abilities was observed. The MBT performance increased by 0.4 and 0.3 m in TRT and FRT groups, while the CMJ performance increased by 6.7 and 5.0 cm in TRT and FRT groups, respectively, with no significant difference between the groups; the effect sizes indicated small effects (Cohen d = –0.18 for MBT and –0.17 for CMJ).

An improvement in 30-m sprint and pull-up performance tests was observed in both the groups; however, all the analyzed measurements were significantly different from

TABLE 3 | Change in upper and lower limbs muscular endurance as mean difference, a statistical test of group difference and effect sizes as Cohen d.

Test	Group	Pre	Mid	Post	Md	Es a	Es b	p^G
BP Rep	TRT	19.5 ± 5.5	26.7 ± 5.0##	29.7 ± 6.3**	10.1	1.84	0.43	0.374
	FRT	17.6 ± 5.3	25.1 ± 6.8##	30.0 ± 7.1**	12.4	2.34		
BP VL (kg)	TRT	1,033.2 ± 341.4	1,394.4 ± 289.0##	1,541.9 ± 330.2	508.7	1.49	0.23	0.510
	FRT	897.1 ± 361.1	1,256.9 ± 426.6##	1,484.9 ± 375.5**	587.9	1.63		
R-LF Rep	TRT	21.6 ± 5.2	25.7 ± 7.0##	29.7 ± 8.3**	8.1	1.56	–0.03	0.907
	FRT	23.3 ± 9.2	25.6 ± 6.0##	31.1 ± 7.8**	7.9	0.86		
R-LF VL (kg)	TRT	661.0 ± 207.8	787.5 ± 274.6##	912.2 ± 327.8**	251.3	1.21	–0.13	0.570
	FRT	679.0 ± 357.4	731.5 ± 232.8##	893.8 ± 304.9**	214.8	0.60		

BP bench press, R-LF right leg flexion, Rep repetition, VL volume-load, TRT traditional resistance training group, FRT functional resistance training group, MD mean difference Post-Pre, ES a effect sizes within the group as Cohens d, ES b effect sizes between groups as Cohens d, p G *value of the difference between groups, Mid-Pre ##*p *< 0.01, Post-Pre ***p *< 0.01.*

TABLE 4 | Change in physical performances as mean difference, statistical test of group difference and effect sizes as Cohen d.

Test	Group	Pre	Mid	Post	Md	Es a	Es b	p^G
MBT (m)	TRT	5.9 ± 0.4	6.0 ± 0.4##	6.2 ± 0.4**	0.4	1.00	–0.18	0.513
	FRT	5.9 ± 0.7	6.1 ± 0.6##	6.3 ± 0.6**	0.3	0.43		
CMJ (cm)	TRT	59.1 ± 9.1	65.1 ± 5.0#	65.9 ± 5.2**	6.7	0.74	–0.17	0.483
	FRT	61.3 ± 10.7	66.2 ± 10.9##	66.3 ± 10.3**	5.0	0.47		
CMJ power	TRT	20.7 ± 2.9	22.4 ± 2.6##	23.4 ± 2.8**	2.7	0.93	0.04	0.753
	FRT	20.1 ± 3.8	21.9 ± 3.3#	23.1 ± 3.0**	3.0	0.79		
30 m sprint(s)	TRT	4.1 ± 0.3	3.8 ± 0.3##	3.8 ± 0.3**	–0.3	–1.0	0.00	0.343
	FRT	4.1 ± 0.2	3.7 ± 0.2##	3.7 ± 0.2**	–0.3	–1.5		
Pull-ups (reps)	TRT	8.1 ± 3.5	10.1 ± 3.7##	12.5 ± 3.7**	4.5	1.29	–0.07	0.303
	FRT	8.9 ± 4.0	11.1 ± 4.5##	12.9 ± 4.2**	4.0	1.0		

MBT medicine ball throw, CMJ countermovement jump, TRT traditional resistance training group, FRT functional resistance training group, MD mean difference Post-Pre, ES a effect sizes within the group as Cohens d, ES b effect sizes between groups as Cohens d, p G *value of the difference between groups, Mid-Pre #*p *< 0.05 ##*p *< 0.01, Post-Pre ***p *< 0.01.*

the baseline. 30-m sprint increased by 0.3s in TRT ($p = 0.002$) and FRT groups ($p = 0.000$), respectively. Similarly, for pull-ups performance, the TRT group improved by 4.5 as compared to 4.0 in the FRT group. However, these results did not differ between the training protocols. The effect sizes indicated small effects for the 30-m sprint test (Cohen d = 0.00) and pull-ups (Cohen d = –0.07), respectively.

DISCUSSION

The present study was designed to compare the effects of the 6-week supervised TRT and FRT protocols with equal volume on upper and lower limb muscular endurance and physical performance in untrained healthy men. Our results suggested that both resistance training modalities (functional and traditional resistance training) produced similar training effects in untrained healthy young men over a 6-week intervention period. No pre-to post-test significant differences were detected in the training-induced improvements in parameters such as repetitions and volume-load in the bench press, leg flexion, MBT distance, CMJ height, 30-m sprint time, and pull-ups. In a study, Sparkes and Behm (2010) reported that unstable resistance training had a tendency for a smaller instability-induced force deficit in comparison with the force produced with the stable training. However, no difference between TRT and FRT groups was found during the muscular endurance and performance assessment in our study. Therefore, it is stated that unstable resistance training is also an effective method for developing force during a brief training period (Sparkes and Behm, 2010).

However, contrary to our hypothesis, the muscular endurance enhancement in the FRT group was not significantly greater than in the TRT group. It was discovered that an increase was seen in the repetition of bench press and leg flexion, which was similar between the groups, whereas enhanced volume load was observed in both the groups after 6 weeks of training. Our results indicate that high-intensity resistance training elicited greater metabolic stress than lower-intensity resistance training; the specific stimuli provided by a traditional protocol did not translate into enhanced muscular endurance. The evidence suggests that high repetitions (≥20RM) with lighter loads are efficient in enhancing muscular endurance under equal training volume. Additionally, Campos et al. (2002) reported that no difference was observed between low, moderate, and high repetition groups with equal volume despite excellent muscular endurance observed in the high repetition group, which was in accordance with our study. Therefore, it is suggested that traditional high-intensity/instability and low-intensity resistance training might induce muscle capillarization and mitochondrial adaptation, while the enhanced muscular endurance provided by instability resistance training could also be a cumulative result of better tolerance in unstable conditions.

Our study is the first preliminary study that has investigated the FRT effects on the CMJ, as well as compared the effects of

6-week TRT and FRT protocols in untrained young men; our results indicated that both were equally beneficial in promoting the jumping height. Recent evidence states that TRT improves the jumping ability (Fatouros et al., 2000; Tomljanović et al., 2011; Yildiz et al., 2019). However, a few studies focusing on the FRT effects on vertical jumping ability demonstrated that although vertical CMJ increased after long-term FRT (Yildiz et al., 2019; Keiner et al., 2020), FRT did not have a great advantage in improving explosive force, which was contrary to a study done on non-athletes (Liu et al., 2014). By contrast, the results of another two studies showed that FRT protocol did not improve jumping abilities (Cressey et al., 2007; Tomljanovic et al., 2011), which was inconsistent with our study. Additionally, two main reasons explaining the inability of Cressey's and Tomljanović's protocols to improve participants' jumping abilities were elucidated. Firstly, their FRT protocol mainly performed upper limb/lower limb exercise, whereas there were five exercises covering the main muscle groups of the whole body in our protocol design, which is the biggest difference from their exercise protocols design. Secondly, since their participants were trained men, the training stimulation might not have affected them to the same degree as the untrained young men. For the reasons mentioned above, our study results were inconsistent with findings from the previous studies. In addition, we speculated that TRT and FRT protocols seem to increase the force generated by joints, which might lead to some improvement in the measured jumping ability.

Explosive strength or performance was influenced by several dominant factors, that included force generated by joints, muscle force development rate/muscle power, and neural coordination of movement (Tomljanović et al., 2011). Considering that the FRT protocol of this study covered main muscle groups of body, the FRT group obtained enough training stimulation for explosive strength performance, which significantly improved their throwing ability. Moreover, we deduced that the improvement in throwing is mainly connected with neuromuscular coordination. It is due to the fact that the training imparted using unstable devices in which most emphasis is placed on trunk region control and muscular coordination. It was found that multiple joints participated in movements during the MBT test, either in eccentric-concentric contractions of the shoulders and trunk regions, or to ensure stability of the non-active parts of the hip and lower body regions (Tomljanović et al., 2011), the significant improvement in throwing ability by our FRT protocol seemed to be logical.

Regarding other physical performance tests, we observed a significant improvement in 30-m sprint and pull-ups from baseline, and no difference was noted between the groups; therefore, both the TRT and FRT protocols were effective training methods in improving the performance of 30-m sprint and pull-ups in untrained young men. Previous studies have shown that functional resistance training yielded a significant positive impact on athletes' straight-line sprint ability (Yildiz et al., 2019; Keiner et al., 2020). However, inconsistent study findings were also found in trained individuals. For example, Cressey et al. (2007) reported that elite athletes could improve more significantly by performing stable training rather than unstable surface training in 40-yard sprint time, and they can produce better results for other indicators of athletic performance. Given the fact that the present study target is untrained young men, we should exercise caution when interpreting the treatment outcomes. It is noteworthy that untrained individuals adapt more readily, to a great magnitude, and with less need for specificity when performing training under stable or unstable conditions. Gruber and Gollhofer (2004) found that instability resistance training enhanced neuromuscular activation in untrained individuals in the early training phase of muscular action. Similarly, Kibele and Behm (2009) also reported that greater instability could challenge the neuromuscular system to a greater extent than the stable environment in the early stages of resistance training, possibly enhancing strength gains attributed to neuromuscular adaption. However, according to the specificity-of-training principle, training must fit the demands of the task or activity as much as possible, especially for the athletes training in unstable environments (e.g., BOSU ball, Swiss ball or wobble boards) which are not specific to their sporting tasks. More importantly, the effects of early phase training (increased rate of strength development) observed in untrained individuals might not be applicable in cases of trained athletes. Therefore, recent evidence showed that both, stable or unstable training proved valuable in health promotion and physical capacities in untrained individuals, while caution should be duly exercised in applying unstable training to well-trained athletes' performance and general exercise scenarios.

Some limitations in this study should also be noted. First, this study involved a limited number of performance variables, and it would be imperative to include other additional motor ability tests such as static and dynamic balance, agility tests, and cardiopulmonary fitness in future research, especially in FRT protocol. Secondly, the study participants were limited to young men; thus, the outcomes could not be generalized due to the absence of women or experienced individuals such as athletes. Moreover, the intervention duration was relatively short (6 weeks), which was not enough to cause a significant difference in muscular fitness and physical performance between the two groups. Future studies with large sample sizes and a variety of participants along with longer study periods are required to determine the excellent resistance training pattern for health promotion.

CONCLUSION

In summary, there were no differences between 6 weeks of functional resistance training compared to traditional resistance training on upper and lower limbs muscular endurance and performance. Hence, both training patterns were effective methods for strengthening the physique of untrained young men. Nevertheless, given the limitations summarized in this study, it is necessary to be cautious about the study outcome. Furthermore, training on an unstable surface with external load and purposefully challenging the participants' balance is inherently unsafe. Hence, the coaches, athletes, or amateurs must select appropriate training methods to suit their core strengths for better training results.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Approved by the Capital University of Physical Education and Sports in Haidian District, Beijing, China after institutional ethics clearance. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

CZ contributed to the conceptualization and design of the study. CZ, TW, and WZ contributed to the data collection. CZ conducted the formal analysis and wrote the first draft of the manuscript. CZ and YY reviewed the manuscript. YY made an important contribution to the revision of the manuscript. All authors have read and agreed to the published version of the manuscript.

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The first author from the Capital University of Physical Education and Sports designed this study, as a sub-study. The first author had full access to all the data of this study and had final responsibility for the decision to submit it for publication. The first author would like to thank all the patients who were willing to join the study.

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