Caloric Expenditure of Aerobic, Resistance, or Combined High-Intensity Interval Training Using a Hydraulic Resistance System in Healthy Men

Paul H. Falcone,[1] Chih-Yin Tai,[1] Laura R. Carson,[1] Jordan M. Joy,[1] Matt M. Mosman,[1] Tyler R. McCann,[2] Kevin P. Crona,[3] Michael P. Kim,[1] and Jordan R. Moon[1,4]

[1]MusclePharm Sports Science Institute, Denver, Colorado; [2]University of Colorado, Boulder, Colorado; [3]University of Colorado, Denver, Colorado; and [4]Department of Sports Exercise Science, United States Sports Academy, Daphne, Alabama

Abstract

Falcone, PH, Tai, C-Y, Carson, LR, Joy, JM, Mosman, MM, McCann, TR, Crona, KP, Kim, MP, and Moon, JR. Caloric expenditure of aerobic, resistance, or combined high-intensity interval training using a hydraulic resistance system in healthy men. *J Strength Cond Res* 29(3): 779–785, 2015—Although exercise regimens vary in content and duration, few studies have compared the caloric expenditure of multiple exercise modalities with the same duration. The purpose of this study was to compare the energy expenditure of single sessions of resistance, aerobic, and combined exercise with the same duration. Nine recreationally active men (age: 25 ± 7 years; height: 181.6 ± 7.6 cm; weight: 86.6 ± 7.5 kg) performed the following 4 exercises for 30 minutes: a resistance training session using 75% of their 1-repetition maximum (1RM), an endurance cycling session at 70% maximum heart rate (HRmax), an endurance treadmill session at 70% HRmax, and a high-intensity interval training (HIIT) session on a hydraulic resistance system (HRS) that included repeating intervals of 20 seconds at maximum effort followed by 40 seconds of rest. Total caloric expenditure, substrate use, heart rate (HR), and rating of perceived exertion (RPE) were recorded. Caloric expenditure was significantly ($p \leq 0.05$) greater when exercising with the HRS (12.62 ± 2.36 kcal·min^{-1}), compared with when exercising with weights (8.83 ± 1.55 kcal·min^{-1}), treadmill (9.48 ± 1.30 kcal·min^{-1}), and cycling (9.23 ± 1.25 kcal·min^{-1}). The average HR was significantly ($p \leq 0.05$) greater with the HRS (156 ± 9 b·min^{-1}), compared with that using weights (138 ± 16 b·min^{-1}), treadmill (137 ± 5 b·min^{-1}), and cycle (138 ± 6 b·min^{-1}). Similarly, the average RPE was significantly ($p \leq 0.05$) higher with the HRS (16 ± 2), compared with that using weights (13 ± 2), treadmill (10 ± 2), and cycle (11 ± 1). These data suggest that individuals can burn more calories performing an HIIT session with an HRS than spending the same amount of time performing a steady-state exercise session. This form of exercise intervention may be beneficial to individuals who want to gain the benefits of both resistance and cardiovascular training but have limited time to dedicate to exercise.

Key Words indirect calorimetry, strength training, endurance training, concentric

Introduction

Exercise is an essential component to the improvement of health. The American College of Sports Medicine (ACSM) recommends that individuals perform moderate exercise 5 d·wk^{-1}, vigorous exercise 3 times per week, or a combination of moderate and vigorous exercise 3–5 times per week (6). However, there is no simple answer to the question as to what type of exercise is the best for general health improvement. New machines and training methods are continually being developed and are often touted as being more effective than the present training methods; however, few of these devices or methods have been tested. It is important that new training systems are evaluated for efficacy to provide individuals with evidence on how various training systems may compare with one another. Caloric expenditure is a common measurement that can be used to compare different exercise systems.

Various studies have compared newer aerobic devices with traditional forms of aerobic exercise, such as walking, running, or cycling (3,12,22,23). Zeni et al. (23) compared the caloric expenditure of healthy men and women who exercised on 6 different aerobic machines at 3 ratings of perceived exertion (RPE) levels each. The results indicated

Address correspondence to Dr. Jordan R. Moon, jordan@musclepharm.com.

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that the treadmill induced the highest rate of energy expenditure compared to the other modes of exercise, and these findings were supported by those of a similar study (12). Many studies have also compared the caloric expenditure of modified forms of walking with that of regular walking (4,10,17,18). For example, Church et al. (5) compared Nordic walking (walking with poles) with regular walking, and Nordic walking induced significantly higher caloric expenditure and a higher heart rate (HR) than regular walking did. However, fewer studies compare the caloric expenditure of training regimes that involve resistance training (2).

Circuit training involves resistance training performed with short rest periods to maximize the aerobic benefits of the exercise session. Pichon et al. (16) compared the energy expenditure of circuit training with that in traditional resistance exercise and found that the circuit training induced higher energy expenditure. In another study, Monteiro et al. (14) compared the energy cost of circuit weight training (60 seconds for each set) with that of compounded circuit training, in which treadmill running is added in between sets (30 seconds of weights and 30 seconds of treadmill). The compounded circuit training induced higher energy expenditure than did the typical circuit training, suggesting that the energy cost of an exercise session can be increased by increasing the aerobic component.

Some exercise systems have been developed to combine resistance and aerobic exercise simultaneously. One example is a hydraulic resistance system (HRS) with which more resistance is provided as the user pushes or pulls harder. This type of system enables an individual to work against strong resistance in a rapid, frequent motion so that both muscular and cardiovascular training are engaged simultaneously. Additionally, the HRS involves only concentric motion, such that eccentric motion, and therefore muscle damage are minimized. No studies presently exist that have investigated a device that combines aerobic and resistance training using concentric motion only akin to the HRS.

Therefore, the purpose of this study was to compare the caloric expenditure, HR, and RPE of recreationally trained men as they performed 4 separate exercises at a moderate or vigorous intensity for approximately 30 minutes each: a typical weight training session, a treadmill session, a cycling session, and a high-intensity interval training (HIIT) session on the HRS. We hypothesized that caloric expenditure, HR, and RPE will significantly increase when using the hydraulic system, compared with when using typical training protocols such as running, biking, or lifting weights for a similar amount of time because of the increased intensity.

Methods

Experimental Approach to the Problem

This study was a descriptive study that investigated unique training methods with the same duration to compare caloric expenditure. In a repeated-measures design, subjects visited the laboratory on 4 separate occasions during which 4 unique exercise interventions were performed. Visits were separated by at least 72 hours to reduce the effects of physical fatigue. The order of exercise interventions was identical for all subjects, as a learning effect was not an issue because each exercise was unique. The order was treadmill, cycle, hydraulic system, and weights. All visits consisted of an exercise intervention with an 8- to 10-minute standard warm-up and cooldown before and after, respectively. Visit 1 also involved a familiarization session of equipment and protocols coupled with 1-repetition maximum (1RM) testing on all resistance equipment, which was used to determine the resistance for the weight training protocol.

Subjects

Nine men aged 18–35 volunteered to participate in the study. Subject characteristics are reported in Table 1. Subjects were all moderately active, engaging in physical activity 2 or more times per week. Individuals were initially recruited through flyers placed in fitness clubs and nutrition stores throughout the area. Screening occurred via telephone and email. Exclusion criteria included any physical condition that might be contraindicated to exercise, such as heart disease; high blood pressure; smoking; and orthopedic, muscular, cardiovascular, kidney, or liver complications. The study protocol was approved by an Institutional Review Board, and all subjects signed an informed consent before participation. All subjects were informed as to the possible risks of participation before written consent was given.

Pretesting and Posttesting Procedures

For 48 hours before arrival for visit 1, the subjects were asked to record dietary intake. The subjects were then asked to consume the same foods and drinks during the 48 hours before the next 3 visits, that is, to repeat their 48-hour intake so that diet or caffeine intake was not a confounding factor. They also refrained from performing exercise during these periods. Additionally, all testing sessions were performed at the same time of the day (±2 hours) to limit diurnal variations in performance.

One-Repetition Maximum Testing

After the subjects completed the treadmill protocol, they rested for 1 hour before the 1RM testing began. Subsequently, the subjects performed the 1RM testing on the 6 exercises that comprised the weight training protocol: squat, chest press, leg extension, shoulder press, seated row, and leg curl. All exercises were performed on air-compression resistance machines (Keiser, Fresno, CA, USA). The 1RM testing protocol has been previously described (1). Briefly, after a 5-repetition warm-up at 40–50% 1RM, the subjects were instructed to perform 1 repetition at a resistance near their 1RM. The subjects were required to successfully lift each weight before resistance was increased. Not >5 single attempts were allowed with

Table 1. Baseline characteristics.

	n	Age (y)	Height (cm)	Weight (kg)	Body mass index	Training ($d \cdot wk^{-1}$)	Training ($h \cdot d^{-1}$)
Men	9	25 ± 7	181.6 ± 7.6	86.6 ± 7.5	23.79 ± 2.92	6 ± 1	2 ± 1

each exercise. The subjects rested for 2 minutes between single attempts. The single highest weight that they could successfully lift was recorded as their 1RM. If the weight was too heavy, the subjects rested for 3–5 minutes, and the weight was decreased back to the previous attempt.

Testing Sessions

Aerobic exercises on a treadmill (Woodway Desmo, Waukesha, WI, USA) and cycle ergometer (Nordic Track, Logan, UT, USA) were performed for 30 minutes at 70% maximum heart rate (HRmax) as determined by the equation 220 − Age (15) (Moderate as described by ACSM) (6). Throughout the treadmill session, the HR was consistently monitored, and the treadmill velocity was adjusted accordingly if the subject's HR was $\pm 10\ b \cdot min^{-1}$. The protocol for the HRS (Surge Performance Training, Austin, TX, USA) was a standard HIIT regimen provided by the device company involving 8 exercises (Chest Press-Push/Pull, Circles inside, Circles outside, 360 Twist, 2-handed Flys, Bent over Shoulder Press/Pull, Torso Rotation, and Power X) at 4 sets each. Each exercise was performed for 20 seconds with 40 seconds of rest, thereby resulting in 32 exercises performed for a total of 32 minutes. The resistance training consisted of 6 exercises–squat, chest press, leg extension, shoulder press, leg curl, seated row–at 3 sets of 10 repetitions each at 75% 1RM (Vigorous as described by ACSM) (6). Rest periods between sets lasted for 60 seconds, resulting in a total time of approximately 30 minutes. The subjects were maximally encouraged verbally by a researcher throughout each exercise, to ensure consistency.

Metabolic Measurements

Respiratory gases were measured with a calibrated portable metabolic cart (k4B2; Cosmed, Rome, Italy). Calibrations were performed daily and consisted of room air, delay, flowmeter, and gas calibrations. Ventilated gases ($\dot{V}O_2$ and $\dot{V}CO_2$) and flow rate for each breath were collected and used to determine grams of fat and carbohydrate expended using the equations from Jeukendrup et al. (10). Calories were then determined using 4 $kcal \cdot g^{-1}$ for carbohydrates and 9 $kcal \cdot g^{-1}$ for fat. Heart rate was measured throughout each exercise session with an HR monitor (Polar USA, Lake Success, NY, USA). Perceived exertion was expressed verbally by the subject and recorded by a researcher every 5 minutes using a standard 6–20 Borg scale (4).

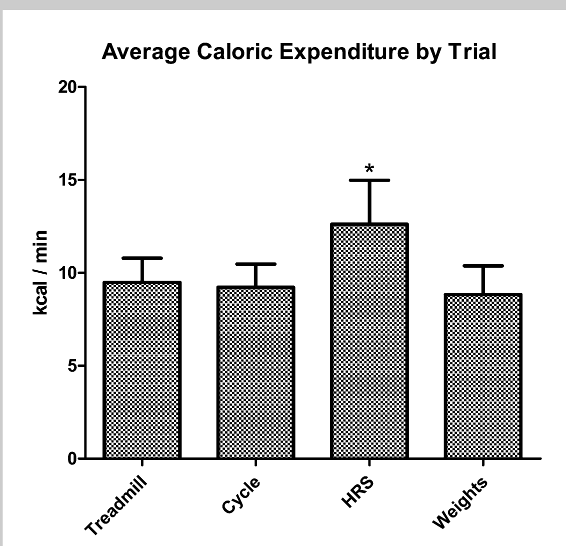

Figure 1. Average caloric expenditure by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights.

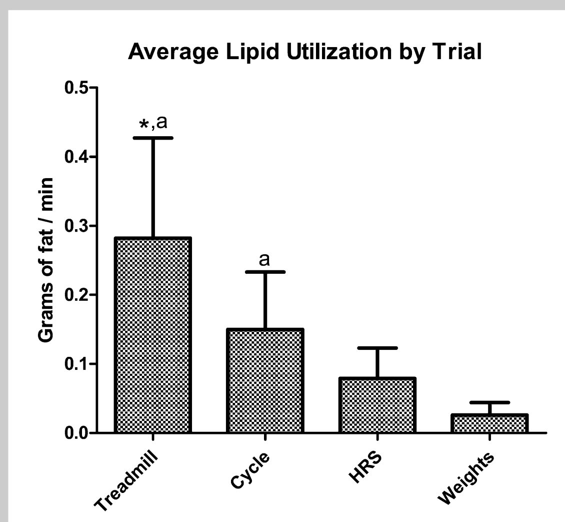

Figure 2. Average lipid use by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from HRS; a, significantly different from weights.

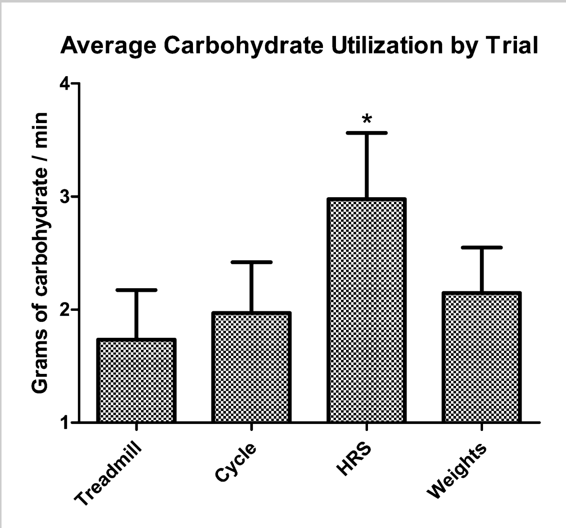

Figure 3. Average carbohydrate use by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights.

Statistical Analyses

All variables were analyzed using a repeated-measures analysis of variance (ANOVA) with a significant p value of ≤ 0.05. When a significant main effect was found, Tukey's post hoc analysis was used. The following power values were observed for the ANOVAs: calories $\beta = 0.9957$; fat $\beta = 0.9998$; carbohydrate $\beta = 0.9995$; HR $\beta = 0.9972$; and RPE $\beta = 1.0000$. Reliability testing on the metabolic cart using a 30-minute protocol in 6 subjects resulted in an intraclass correlation (ICC) > 0.98 and $SEM = 97.08\ \text{ml}\cdot\text{min}^{-1}$ for $\dot{V}O_2$, an ICC > 0.98 and $SEM = 102.5\ \text{ml}\cdot\text{min}^{-1}$ for $\dot{V}CO_2$, and an ICC > 0.77 and $SEM = 2.28$ for HR (beats per minute).

Results

Average calories expended per minute are presented in Figure 1. Caloric expenditure was significantly ($p \leq 0.05$) greater when exercising with the hydraulic system ($12.62 \pm 2.36\ \text{kcal}\cdot\text{min}^{-1}$), compared with when using weights ($8.83 \pm 1.55\ \text{kcal}\cdot\text{min}^{-1}$), treadmill ($9.48 \pm 1.30\ \text{kcal}\cdot\text{min}^{-1}$), and cycle ($9.23 \pm 1.25\ \text{kcal}\cdot\text{min}^{-1}$). When comparing grams of fat used during the exercises, the subjects displayed significantly ($p \leq 0.05$) greater fat expenditure on the treadmill ($0.282 \pm 0.145\ \text{g}\cdot\text{min}^{-1}$) compared with when using weights ($0.026 \pm 0.018\ \text{g}\cdot\text{min}^{-1}$) and HRS ($0.079 \pm 0.044\ \text{g}\cdot\text{min}^{-1}$), and on the cycle ($0.150 \pm 0.083\ \text{g}\cdot\text{min}^{-1}$) compared with when using weights (Figure 2). Regarding carbohydrates, the subjects displayed a significantly ($p \leq 0.05$) greater carbohydrate expenditure when exercising with the HRS ($2.98 \pm 0.59\ \text{g}\cdot\text{min}^{-1}$), compared with when using weights ($2.15 \pm 0.40\ \text{g}\cdot\text{min}^{-1}$), treadmill ($1.74 \pm 0.44\ \text{g}\cdot\text{min}^{-1}$), and cycle ($1.97 \pm 0.45\ \text{g}\cdot\text{min}^{-1}$) (Figure 3). Regarding HR, the subjects displayed a significantly higher HR when exercising with the hydraulic system ($156 \pm 9\ \text{b}\cdot\text{min}^{-1}$), compared with when using weights ($138 \pm 16\ \text{b}\cdot\text{min}^{-1}$), treadmill ($137 \pm 5\ \text{b}\cdot\text{min}^{-1}$), and cycle ($138 \pm 6\ \text{b}\cdot\text{min}^{-1}$) (Figure 4). Similarly, the RPE was

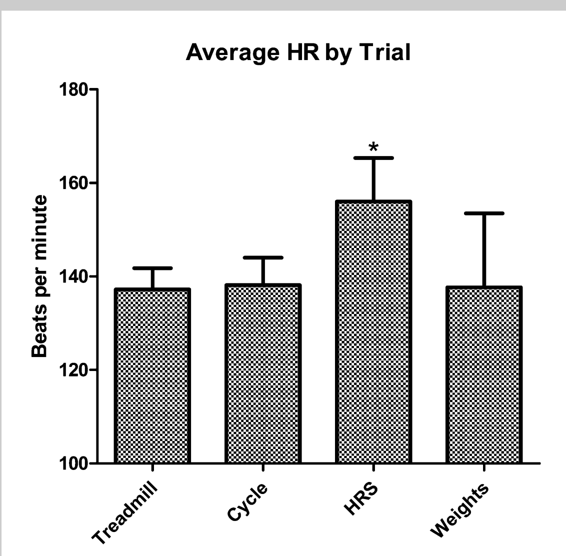

Figure 4. Average heart rate (HR) by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights.

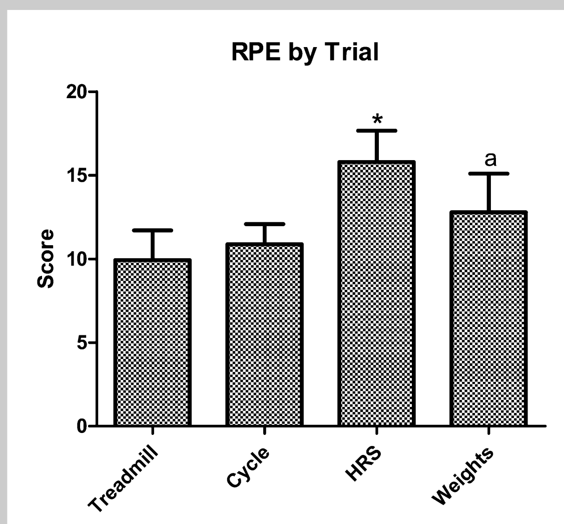

Figure 5. Rating of perceived exertion by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights; a, significantly different from treadmill and cycle.

significantly higher when exercising with the hydraulic system (16 ± 2), compared with when using weights (13 ± 2), treadmill (10 ± 2), and cycle (11 ± 1) and was significantly higher with weights compared with when using a treadmill or cycle (Figure 5).

Discussion

In agreement with our hypothesis, the results of this study indicated that caloric expenditure, HR, and RPE increased when using a concentric-only hydraulic-based HIIT exercise protocol, compared with when running, biking, or lifting weights for a similar amount of time (~30 minutes). This is the first study to directly compare the caloric expenditure of a concentric-only hydraulic-based exercise device that involves both resistance and cardiovascular training to running, biking, and resistance training with the same duration within subjects. This is a novel finding in that most studies comparing acute sessions with exercise devices with traditional aerobic exercise sessions have shown that treadmill results in the highest caloric expenditures (12,22,23). In a study by Zeni et al. (23), caloric expenditure was compared at 3 RPE levels using 6 exercise machines: treadmill, cross-country skiing simulator, cycle ergometer, rowing ergometer, stair stepper, and aerobic cycle (Airdyne, Schwinn Inc., Vancouver, WA, USA). The treadmill induced a higher caloric expenditure than did all other exercise machines at all RPE values: 11 (light), 13 (medium), and 15 (hard). However, all previous studies comparing exercise machines to other aerobic exercise modalities have involved steady-state exercises at similar intensities (12,22,23).

In this study, we wanted to compare traditional exercise modalities of the same duration; therefore, not all the exercise sessions involved steady-state exercise or the same intensities. Weight training is typically performed at high intensity for short periods with longer periods of rest in between. The protocol that was used with the HRS in this study was similar to circuit training protocols (14), though the timing was modified. In a study by Monteiro et al. (14), circuit training induced greater caloric expenditure than did resistance exercise, which is supported by the findings of this study. However, no studies have compared circuit resistance training with exercising on treadmill or cycle. Skelly et al. (20) compared single sessions of 2 cycling protocols: HIIT training and steady-state moderate endurance training. The caloric expenditure of the steady-state protocol (547 ± 65 kcal) was higher than that of the HIIT protocol (352 ± 34); however, the steady-state protocol was much longer in duration (50 vs. 20 minutes) Therefore, one could surmise that if the 2 sessions were equal in duration, the HIIT protocol would induce higher caloric expenditure, but because that was not tested, it remains unclear.

Fat expenditure was significantly greater during the treadmill session compared with that in all other exercises. These results are supported in the literature, which demonstrate that exercise intensity and fat metabolism are inversely correlated (6). Similarly, the HRS induced significantly higher carbohydrate expenditure than did the treadmill, cycle, or weights. These findings are supported by those of previous studies, which have shown that carbohydrate expenditure increases as exercise intensity increases (19).

In this study, caloric expenditure from a typical weight training session was slightly lower but not significantly different from caloric expenditure from running or cycling. This finding is divergent from results found in the literature. In a study by Bloomer (2), subjects performed cycling for 30 minutes at 70% $\dot{V}O_2$max and a resistance training protocol that consisted of squatting for 30 minutes at 70% 1RM. When the caloric expenditure of the 2 exercises was compared, the subjects expended significantly more calories while cycling than while squatting. It is possible that study design differences may explain the discrepancy between the results of Bloomer's study and of this study. First, HRmax or $\dot{V}O_2$max are not the same, and using the same percentage of each (70%) may result in different outcomes. This seems to be the case here, considering that the average HR during the cycling trial in Bloomer's study (160.12 ± 4.82 $b \cdot min^{-1}$) and the average HR in this study (138.136 ± 5.882 $b \cdot min^{-1}$) were so different. Also, squatting for 30 minutes is not identical to a total body resistance exercise regimen for 30 minutes. Because the same muscle group was used throughout the exercise, fatigue may have contributed to the lower caloric expenditure measured in Bloomer's study.

This study also demonstrated that the average HR and RPE were greater after the HIIT compared with those for resistance exercise, treadmill, and cycle. However, the HR data cannot be considered significant because we controlled the HR in 2 of the exercise modalities. Regarding RPE, Gosselin et al. (8) found that an HIIT protocol resulted in a higher RPE than did a moderate endurance protocol of a similar duration. These findings are not surprising because the intensity with HIIT is much higher. Although rest periods are involved, the data suggest that the body does not have enough time to recover and remains in an activated state while resting. Additionally, resistance training resulted in higher average RPE scores than did running or cycling. Other studies have corroborated this finding (15), perhaps because resistance training is also an exercise modality that requires maximal effort with rest periods. Although the average HRs are similar, data from this study suggest that individuals feel as if they are working harder when performing resistance training, compared with when performing steady-state endurance training, such as running or cycling. Another possibility is because of the difference in intensities used among these 3 exercise modalities. The resistance exercise was performed at 75% 1RM, which is considered vigorous by ACSM standards (6). However, the running and cycling were performed at 70% HRmax, which is considered moderate by ACSM standards. Therefore, this discrepancy could account for the significant difference in RPE values. The intensities for the various exercises for this study were chosen to reflect "real-world" exercise regimens. By adhering to a moderate pace for the aerobic exercises, the protocol reflects what may be considered a traditional exercise session for an individual. However, because our subjects were able to perform the required 3 sets of 10 repetitions at 75% 1RM, it is possible that 75% 1RM, though considered vigorous by ACSM standards, may represent the intensity of a typical resistance exercise session. Another consideration is that our subjects were training 6 times per week for 2 hours per session on average, so perhaps ACSM guidelines were not the ideal method for determining intensity in such a highly trained group.

One possible limitation of this study was that RPE was not used to standardize the various protocols. Some other researchers that have compared exercise regimens have used the RPE to set the intensity level (9,21). However, we used percentages of HRmax and 1RM that resulted in moderate to vigorous exercise, as defined by the ACSM guidelines. In this way, we sought to compare exercise protocols that were practical, in both design and intensity, so that the results might reflect the caloric expenditure of an average person performing typical workouts. Also, the RPE may not be a good standardizing tool when HIIT is involved, because of the intervals and the high intensity. Even though the RPE while using the hydraulic system was high, individuals were resting for most of the exercise period, which would help them to get through the entire exercise period. It is possible that recreationally active individuals may not be able to perform a steady-state exercise at that high RPE for the entire 30-minute period. Possible future studies could compare HIIT protocols with steady-state exercise at the same RPE in recreationally trained or untrained individuals to determine the feasibility of performing various exercises at such a high level. Another area for future research could be the effect of these various exercise protocols on excess post-exercise oxygen consumption. Other studies have demonstrated elevated caloric expenditure after certain types of exercise for as long as 9 hours (13), which could certainly impact individuals performing typical workouts to benefit body composition or overall health. Also, longitudinal studies should be pursued in the future to determine effects on performance and body composition over time. The greater caloric expenditure induced by the HRS may translate into improved body composition over other traditional exercise modalities, which could be ascertained by a longitudinal study.

In conclusion, the results of this study suggest that a single bout of high-intensity training that combines concentric resistance training along with aerobic conditioning can increase caloric expenditure, HR, and RPE to a greater extent than running, cycling, or resistance exercise at typical intensities for the same duration in healthy men.

Practical Applications

These findings have implications for individuals at many athletic levels. For untrained men who want to improve their health and body composition, the HRS provides a workout that combines the benefits of aerobic and resistance training. An individual can burn more calories performing HRS compared with other typical exercise modalities and intensities. Also, individuals can effectively burn calories performing a typical weightlifting protocol. Finally, if burning fat is desired during exercise, running on the treadmill seems to be a better option than cycling at the same intensity or lifting weights or performing hydraulic-based HIIT training.

These findings may also have implications for professional athletes. The maintenance of muscle mass is important as the season progresses, though training in-season is difficult because of time and energy constraints. The HRS could be used in place of 30 minutes of aerobic training, which would give the athlete additional resistance training. Because the HRS involves only concentric motion, recovery may be faster because of less muscle damage, which would also be helpful for in-season training. Also, perhaps resistance training could replace some aerobic training, if the purpose is for maintenance of body composition because the caloric expenditures were similar. Certainly, other factors would have to be taken into consideration, such as the intensity level of the program to avoid overtraining and muscle fatigue that may occur posttraining. Future research should compare the training methods and durations used in the current investigation over multiple weeks of regular training to determine their impact on strength, athletic performance, and body composition.

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