Physiological Responses to High-Intensity Interval Exercise Differing in Interval Duration

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ABSTRACT

Tucker, WJ, Sawyer, BJ, Jarrett, CL, Bhammar, DM, and Gaesser, GA. Physiological responses to high-intensity interval exercise differing in interval duration. J Strength Cond Res 29(12): 3326–3335, 2015—We determined the oxygen uptake (\(V_{\text{O}_2}\)), heart rate (HR), and blood lactate responses to 2 high-intensity interval exercise protocols differing in interval length. On separate days, 14 recreationally active males performed a \(4 \times 4\) (four 4-minute intervals at 90–95% HR peak, separated by 3-minute recovery at 50 W) and \(16 \times 1\) (sixteen 1-minute intervals at 90–95% HR peak separated by 1-minute recovery at 50 W) protocol on a cycle ergometer. The \(4 \times 4\) elicited a higher mean \(V_{\text{O}_2}\) (2.44 \(\pm 0.4\) vs. 2.36 \(\pm 0.4\) L.min\(^{-1}\)) and “peak” \(V_{\text{O}_2}\) (90–99% vs. 76–85% \(V_{\text{O}_2}\) peak) and HR (95–98% HR peak vs. 81–95% HR peak) during the high-intensity intervals. Average power maintained was higher for the \(16 \times 1\) (241 \(\pm 45\) vs. 204 \(\pm 37\) W), and recovery interval \(V_{\text{O}_2}\) and HR were higher during the \(16 \times 1\). No differences were observed for blood lactate concentrations at the midpoint (12.1 \(\pm 2.2\) vs. 10.8 \(\pm 3.1\) mmol.L\(^{-1}\)) and end (10.6 \(\pm 1.5\) vs. 10.6 \(\pm 2.4\) mmol.L\(^{-1}\)) of the protocols or ratings of perceived exertion (7.0 \(\pm 1.6\) vs. 7.0 \(\pm 1.4\)) and Physical Activity Enjoyment Scale scores (91 \(\pm 15\) vs. 93 \(\pm 12\)). Despite a 4-fold difference in interval duration that produced greater between-interval transitions in \(V_{\text{O}_2}\) and HR and slightly higher mean \(V_{\text{O}_2}\) during the \(4 \times 4\), mean HR during each protocol was the same, and both protocols were rated similarly for perceived exertion and enjoyment. The major difference was that power output had to be reduced during the \(4 \times 4\) protocol to maintain the desired HR.

KEY WORDS exercise training, \(V_{\text{O}_2}\), lactate, RPE, exercise prescription

INTRODUCTION

High-intensity interval exercise (HIE) is characterized by brief intermittent bursts of vigorous activity, interspersed with periods of rest or active recovery (11). This modality of exercise allows individuals to perform a greater volume of high-intensity exercise than continuous exercise (4). Furthermore, HIE protocols have been reported to yield cardiovascular, metabolic, and skeletal muscle adaptations that are similar, or superior, to traditional endurance training, despite having a lower exercise volume (11,19,23,27,31,34). For these reasons, HIE protocols have emerged as popular exercise training modalities to improve cardiorespiratory fitness and other cardiometabolic risk factors in both healthy and diseased populations (17,19,31,34), with protocols differing primarily by the durations of the active and recovery intervals.

One popular protocol is the \(4 \times 4\), or “Norwegian” HIE protocol (1,14,16,23,24,27,31,34), which consists of four 4-minute intervals at 90–95% of peak heart rate (HR peak), interspersed with 3 minutes of active recovery. This protocol has been shown to produce superior adaptations compared with continuous constant-load exercise training in several patient populations (1,14,16,23,24,27,31,34). Another protocol that has been used in a number of studies includes 8–12, 1-minute high-intensity intervals with 60–75 seconds of active recovery (9,12,15,17,19,20,29). This has recently been standardized as a \(10 \times 1\) protocol, including ten 1-minute intervals at 90–95% HR peak, interspersed with 1 minute of active recovery (11,12,19,29).

Despite the significant number of publications documenting the efficacy of these 2 HIE protocols (1,9,11,12,14–17,19,20,23,24,27,33,34), there has been no characterization of these 2 protocols with regard to the physiological responses. The intensity and duration of the active and recovery intervals can influence the oxygen uptake (\(V_{\text{O}_2}\)), heart rate (HR), and blood lactate profiles (2,13,21,28,32). For fitness professionals and coaches to safely, accurately, and effectively prescribe HIE, it is imperative that the
physiological responses to various protocols are characterized and understood (32).

Therefore, the purpose of this study was to compare $\dot{V}O_2$, HR, and blood lactate responses during these 2 commonly used protocols. To equate the 2 protocols for total amount of active interval duration, we used a 16 × 1 protocol to compare with the 4 × 4 protocol. Secondly, we also assessed ratings of perceived exertion (RPE) and enjoyment of each protocol with the Physical Activity Enjoyment Scale (PACES). Because we used the same target HR range (90–95% $HR_{peak}$) for each protocol and adjusted power output continuously to maintain HR in the desired range, we hypothesized that the 2 protocols would elicit similar $\dot{V}O_2$ and blood lactate responses and similar values for RPE and PACES.

**METHODS**

**Experimental Approach to the Problem**

A randomized repeated-measures design was used for this study. Each subject performed both HIE protocols in random order with at least 72 hours between trials to avoid carryover effects. This design strengthened internal validity and allowed us to test our hypothesis and ensure practical application of the results. During each session, $\dot{V}O_2$, HR, blood lactate concentration, and RPE were measured. Physical activity enjoyment was assessed at the end of each protocol. Subjects were instructed to not exercise or consume caffeine or alcohol >48 hours before each visit. Trial order of the 2 exercise protocols was randomized for all subjects using a random number generator. Sample size ($n = 14$) was determined based on previous studies that have assessed physiological/metabolic differences between HIE protocols (13,35).

**Subjects**

Fourteen ($n = 14$) recreationally active nonsmoking young males (age, 18–35 years) volunteered to participate in the study. Subject characteristics are listed in Table 1. Exclusion criteria were use of dietary supplements, current participation in an exercise training program, and any "yes" answers on the Physical Activity Readiness Questionnaire (PAR-Q) (30). All subjects provided informed written consent and passed the PAR-Q before starting the study. This study was approved by the Arizona State University Institutional Review Board (IRB #: 1203007568).

**Procedures**

All experimental conditions were conducted in a climate-controlled laboratory (22° C) at Arizona State University. During the initial visit, body composition was assessed using air-displacement plethysmography (Bod Pod, COSMED, Concord, CA, USA). Standing height (in centimeters) was measured against a wall-mounted stadiometer (Seca, Hamburg, Germany). Body weight (in kilograms) was measured using a calibrated electronic scale (Life Measurement Instruments).

**Assessment of Peak Oxygen Uptake**

During the initial visit, subjects were equipped with an oronasal mask fitted with a standard nonrebreathing valve (Hans Rudolph, Shawnee, KS, USA) and Polar heart rate monitor (Polar Electro OY, Kempele, Finland). Ventilation, gas exchange, and HR were monitored continuously with a Parvo Medics TrueMax 2400 computerized metabolic measurement system (Parvo Medics, Sandy, UT, USA). This system has been previously validated against the Douglas bag method with high levels of accuracy and precision for gas-exchange measurement over a wide range of exercise intensities (8). We performed the standard 3-point calibration before each test.

After 2 minutes of seated rest, subjects pedaled on an electronically braked cycle ergometer (Viasprint 150P; Ergoline, Bitz, Germany) at a cadence of their choice (50–80 rpm) for 5 minutes at 50 W. After this warm-up, power was increased in ramp fashion by 30 W min$^{-1}$ until each subject reached volitional fatigue despite strong verbal encouragement. After a 5- to 10-minute cool-down period of cycling at 50 W, participants performed a verification phase at a constant power of 100% of the peak power reached during the incremental ramp test until they reached volitional exhaustion (22). Participants were asked to keep their cadence above 50 rpm and pedal for as long as possible during the verification phase.

$\dot{V}O_2peak$ was defined as the average of the 2 highest consecutive 15-second averages achieved for $\dot{V}O_2$ during either the ramp or verification phase of the maximal exercise test. $HR_{peak}$ was determined using the highest HR achieved during either the ramp or the verification phase.

**High-Intensity Interval Exercise Protocols**

Subjects consumed the same standardized breakfast (whole grain bagel, cream cheese, and orange juice; 500 kcal, 94 g carbohydrate, 16 g protein, 16 g fat) between 08:00 and 09:00 on the day of each treatment. Thereafter, subjects reported to the exercise laboratory at ~12:45, and exercise sessions...
started between 13:00 and 13:30. Consequently, time of day, nutrition, and hydration status were all held constant between the 2 exercise trials. Subjects were fitted with the same oronasal mask, nonrebreathing valve, HR monitor, and metabolic measurement system, as they were for the maximal exercise test. After 2 minutes of seated rest, subjects pedaled for 5 minutes on the same electronically braked cycle ergometer to obtain \( \dot{V}O_2 \) peak at a cadence of their choice (50–80 rpm) at a power output that elicited approximately 60–65% \( \dot{V}O_2 \) peak for the warm-up. After the warm-up, subjects performed one of the following HIE protocols: (a) 4\( \times \)4 HIE, which consisted of four 4-minute intervals designed to elicit 90–95% HR peak, interspersed with 3-minute recovery periods at 50 W, (b) 16\( \times \)1 HIE,
which consisted of sixteen 1-minute intervals designed to elicit 90–95% $HR_{peak}$, interspersed with 1-minute recovery periods at 50 W (Figure 1). Having the subjects perform 16 intervals of 1-minute duration ensured that the 2 protocols were matched with regard to cumulative duration of the active intervals. Subjects were instructed to maintain the same cadence during the high-intensity intervals as the warm-up and not drop below 50 rpm. Power output was adjusted in an effort to maintain HR within the target heart range of 90–95% $HR_{peak}$ during the active intervals. After the interval protocol was completed, participants completed a 5-minute cool-down at 50 W. Energy expenditure (EE) (in kilocalories per minute) was computed by multiplying the oxygen uptake (in liters per minute) by the caloric equivalent based on respiratory exchange ratio.

Assessment of Blood Lactate and Ratings of Perceived Exertion
Blood was obtained using the finger-stick method. Capillary blood lactate concentration was determined by a Lactate Plus portable blood lactate meter (Nova Biomedical, Waltham, MA, USA). Samples were taken at rest and immediately after the incremental ramp test. During the HIE protocols, samples were taken at rest, after 50% of the intervals had been completed, and after the last interval had been completed (Figure 1). The end-exercise sample was taken within 20 seconds after completion of the last interval for each protocol. Ratings of perceived exertion were obtained each minute for the duration of each protocol using Borg’s 10-point RPE scale (25).

Physical Activity Enjoyment Scale
To assess whether there were differences in perceived enjoyment between the 2 HIE protocols, each subject completed the PACES (3,18). This scale has been shown to be a valid measure to quantify perceived enjoyment of exercise (3,18). Each item on the PACES is rated on a 7-point bipolar scale, with 4 representing a neutral point in terms of how much the respondent enjoyed the exercise. Subjects completed the PACES within 20 minutes of completing each HIE protocol.
Statistical Analyses
All data were analyzed using SPSS Software (SPSS 21.0; IBM Corporation, Armonk, NY, USA). All data in text, tables, and figures are presented as mean ± SD, and significance was set at \( p \leq 0.05 \). To compare the physiological responses between the HIE protocols, we averaged \( \text{VO}_2 \) for the entire protocol and split the data by interval to compare the active high-intensity intervals and between-interval recovery periods. This process was repeated for HR, power output, and RPE. All data were initially assessed for normality using the Shapiro-Wilk test. Once normality was verified, a comparison of the mean physiological responses was assessed using a repeated-measures analysis of variance (ANOVA) to determine whether there were any significant differences between HIE protocols for \( \text{VO}_2 \), HR, power output, blood lactate concentration, EE, RPE, and PACES. Furthermore, a repeated-measures ANOVA was conducted to examine whether there were differences in \( \text{VO}_2 \) and power output across intervals within each HIE protocol. If the sphericity assumption was violated (Greenhouse-Geisser \( \epsilon \), 0.75), the Greenhouse-Geisser adjustment was used to interpret main effects. In the event of a significant main effect, Bonferroni’s adjustments were used to determine physiological differences across intervals within each HIE protocol.

RESULTS
Oxygen Uptake and Energy Expenditure
The \( 4 \times 4 \) HIE protocol elicited a higher (~3%) overall mean \( \text{VO}_2 \) than the \( 16 \times 1 \) HIE (\( p = 0.04 \); Table 2). Furthermore, mean \( \text{VO}_2 \) and HR during the high-intensity intervals were also significantly higher with the \( 4 \times 4 \) HIE compared with the \( 16 \times 1 \) HIE (\( p < 0.001 \)). Conversely, mean \( \text{VO}_2 \) and HR during the recovery periods were significantly higher in the \( 16 \times 1 \) HIE than \( 4 \times 4 \) HIE (\( p < 0.001 \)). The highest \( \text{VO}_2 \) attained during the \( 4 \times 4 \) protocol ranged between 90 and 99% of \( \text{VO}_2 \)peak, with significantly lower peak \( \text{VO}_2 \) attained during the third (3.24 ± 0.5 L·min\(^{-1}\)) and fourth (3.15 ± 0.5 L·min\(^{-1}\)) intervals compared with the first 2 intervals (3.44 ± 0.5 L·min\(^{-1}\) and 3.46 ± 0.6 L·min\(^{-1}\); Figure 2). By contrast, the highest \( \text{VO}_2 \) attained during the \( 16 \times 1 \) ranged between 76 and 85% of \( \text{VO}_2 \)peak, with no statistically significant difference in the highest \( \text{VO}_2 \) attained across the 16 intervals.

Mean EE (in kilocalories per minute) was higher during the \( 4 \times 4 \) protocol when compared with the \( 16 \times 1 \) protocol (\( p = 0.01 \)). In contrast, total EE during the \( 16 \times 1 \) protocol was 19% greater than the \( 4 \times 4 \) protocol (363 ± 54 kcal vs. 305 ± 47 kcal; Table 2) because of the 6-minute longer duration of the \( 16 \times 1 \) protocol.

![Figure 3. Mean heart rate (in beats per minute) during 4 x 4 (upper image) and 16 x 1 (lower image) high-intensity interval exercise protocols.](image-url)
Heart Rate
Heart rate was higher during the high-intensity intervals of the 4 × 4 protocol, whereas HR during the recovery intervals was higher for the 16 × 1 protocol (Table 2; Figure 3). Consequently, the mean HR during the entire exercise session was not different between the 2 protocols (Table 2). The highest HR achieved during the high-intensity intervals ranged from 95 to 98% of HR\(_{\text{peak}}\) during the 4 × 4 protocol and 81 to 95% of HR\(_{\text{peak}}\) during the 16 × 1 protocol (Figure 3). It was not until the fifth interval in the 16 × 1 protocol that the minimum target HR of 90% of HR\(_{\text{peak}}\) was attained. Thereafter, HR reached 90–95% of HR\(_{\text{peak}}\) in intervals 6 through 16.

Power Output
The mean power output sustained during the 16 high-intensity intervals in the 16 × 1 protocol was 18% higher than during the 4 × 4 protocol (\(p < 0.001\); Table 2). During the 4 × 4 protocol, power output decreased during the course of the protocol, with significantly lower mean power output maintained during the second interval (205 ± 48 W) compared with the first interval (226 ± 51 W) (\(p = 0.02\)) and significantly lower mean power output maintained during the third (187 ± 42 W) and fourth (179 ± 37 W) intervals compared with the first and second intervals (\(p < 0.001\)) (Figure 4). Thus, the mean power output during the 4 × 4 protocol decreased by 20% between the first and fourth intervals. The decrease in power output during each interval was necessary to prevent HR from increasing to HR\(_{\text{peak}}\). By contrast, power output was well maintained during the 16 × 1 protocol, with no statistically significant difference in power output across the 16 intervals (Figure 4).

Blood Lactate
There were no significant differences between the 4 × 4 and 16 × 1 protocols for mid-protocol and end-protocol blood lactate concentrations, which reached 80–90% of the value attained in the VO\(_{2}\)\(_{\text{peak}}\) test (Tables 1 and 2).

Subjective Responses
Ratings of perceived exertion during the high-intensity intervals and during the recovery intervals did not differ between protocols (Table 2). During the 4 × 4 protocol,
RPE increased from 5–6 during the first minute of each interval to 7–8 during the fourth minute of each interval, whereas during the 16 × 1 interval, RPE increased from 5 during the first interval to 8 during the last few intervals (Figure 5). Ratings of perceived exertion during the recovery intervals ranged between 3 and 4 for all intervals in each protocol. Physical activity enjoyment (PACES) was not different between protocols (Table 2).

**DISCUSSION**

High-intensity interval exercise protocols like the 2 we examined have been used extensively to study training adaptations in a variety of populations. The 4 × 4 protocol has been used the most (1,14,16,23,24,27,31,34). Variants of the 16 × 1 protocol include studies that have used interval numbers ranging from 8 to 12, with 60- to 75-second recovery intervals (9,12,15,17,19,20,29). However, to our knowledge, specific details on physiological responses during these protocols have not been reported. Our study shows for the first time continuous V\textsubscript{\text{\text{\textsuperscript{\text{\text{\textsubscript{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{
and third intervals, in which power output had to be reduced by 11–16 W from the first to the fourth minute (Figure 4). Although mean power output was reduced by 20% from the first to the fourth interval, power output was reduced by 22% when comparing the first minute of the first interval to the fourth minute of the fourth interval. Despite this reduction in power output, HR still reached 97–98% of HRpeak during the last 3 intervals of the 4 × 4 protocol. Power output adjustments during the 16 × 1 protocol were much more subtle. The initial power output during the first interval was 242 ± 43 W, which increased slightly to 255 ± 47 W by the fifth interval and was 236 ± 50 W by the last interval. These changes were not significantly different. In contrast to the 4 × 4 protocol, HR during the 16 × 1 protocol did not reach 90% of HRpeak until the fifth interval, despite a power output (~250 W) that was higher than the 4 × 4 protocol.

Because VO2 is both power and time dependent (10), the higher VO2 attained during the 4 × 4 protocol is expected, similar to results previously reported (2,7). During the high-intensity intervals of the 4 × 4 protocol, VO2 reached 90–99% of VO2peak, whereas during the high-intensity intervals of the 16 × 1 protocol, VO2 reached only 76–85% of VO2peak. However, VO2 during the recovery intervals was significantly higher during the 16 × 1 protocol, which resulted in an overall rate of EE that was only 4% higher for the 4 × 4 protocol (Table 2). The reduction in VO2 during subsequent intervals in the 4 × 4 protocol can be explained by the significant reduction in power output necessary during the protocol to maintain HR within the desired intensity range (10).

Despite the continual lowering of power output during the 4 × 4 (Figure 4), HR still reached 97–98% of HRpeak during the last 3 intervals (Figure 3). This highlights the necessity for continual reductions in power output during HIE, in which interval length is several minutes in duration, to maintain the desired target HR range. In contrast, during the 16 × 1 protocol, HR was maintained within the desired 90–95% range with only minor adjustments in power output (Figure 3). This is in agreement with previous studies that have used 1-minute intervals as part of a 10 × 1 (15,19) or 8–12 interval protocol (9,17,20), which maintained a constant power output across all intervals. It is important to note that because of the short interval length of the 16 × 1, it was not until the fifth interval that HR reached 90% of HR (Figure 3). Similar results have been reported previously for a 10 × 1 protocol (19). As shown in Figure 3, for individuals with HRpeak of ~184 b·min⁻¹ (our subjects), 1-minute intervals may not be long enough to allow HR to reach 90% HRpeak when the starting HR is below ~75% of HRpeak (~140 b·min⁻¹).

In this study, we found no significant differences in blood lactate concentrations between protocols. There was a trend (p = 0.09) toward higher blood lactate concentration with the 4 × 4 HIE at the midpoint of exercise protocols, but this trend was no longer evident at the end of exercise protocols with identical mean blood lactate concentrations immediately after the last interval. Blood lactate concentrations during high-intensity exercise are dependent on both relative power output and time (10). Prior work by Astrand et al. (2) and Christensen et al. (7) showed that longer intervals (2 to 3 minutes) yielded higher blood lactate concentrations than shorter intervals (30 seconds to 1 minute) when intervals were performed at the same peak and mean power. In our study, longer intervals of the 4 × 4 protocol are offset by the reduced power output during this protocol, especially the power reduction during the last 2 intervals. Additionally, the longer active recovery intervals during the 4 × 4 protocol would have facilitated oxidative lactate removal (6). These offsetting effects likely explain the similar blood lactate concentrations observed at the midpoint and end of the 2 exercise protocols.

To our knowledge, blood lactate responses to protocols similar to our 16 × 1 protocol (9,12,15,17,19,20,29) have not been reported, and only 1 study using the 4 × 4 protocol has reported blood lactate responses (33). In that study, triathletes achieved a peak blood lactate concentration of only 6.6 mmol·L⁻¹, which was only 52% of that achieved during a Wingate sprint protocol consisting of four 30-second all-out sprints. The much lower blood lactate concentration observed in the 4 × 4 protocol in that study may be due in large part to the fact that postprotocol blood samples were obtained after a 10-minute active cool-down, and there was no blood lactate measurement during the protocol. Our study shows that both 4 × 4 and 16 × 1 protocols yield similar blood lactate concentrations that are not different from values reached during an incremental protocol for determination of VO2peak.

In this study, subjective measures of exercise difficulty (RPE) and enjoyment (PACES) did not differ between protocols. The RPE scores are similar to previous studies that have assessed RPE differences between interval exercise protocols differing in interval and recovery lengths (28,35). Our RPE scores for the 16 × 1 protocol are very similar to the 10 × 1 protocol used by Little et al. (19), increasing from ~5 during the first interval to ~8 by the end of the protocol. Prior studies that have assessed RPE during the 4 × 4 protocol have used the Borg’s 6-20 RPE scale (5) as opposed to the Borg’s 10-point scale used in this study. The mean RPE of 17 during the 4 × 4 protocol used by Wisloff et al. (34) translates roughly to an exercise intensity of “very hard,” which is similar to what we found during the intervals for both our 4 × 4 and 16 × 1 HIE protocols. Our PACES scores (4 × 4: 91 ± 15; 16 × 1: 93 ± 12) are similar to that reported previously for HIE (3,26). Bartlett et al. (3) found that young men enjoyed performing high-intensity interval running (PACES 88 ± 6) more than traditional moderate-intensity continuous running (PACES 61 ± 12) (p ≤ 0.05). In contrast, Oliveira et al. (26) found no difference in PACES scores when comparing high-intensity interval running (98 ± 17) or continuous moderate-intensity running (96 ± 17).

To our knowledge, this study is the first to compare exercise enjoyment for 2 HIE protocols using the PACES. The
similar RPE and PACES responses to the 4 × 4 and 16 × 1 protocols are consistent with the similar overall physiological responses to the 2 protocols.

Our study included only young recreationally active males. However, there are a number of studies showing that the 4 × 4 and 10 × 1 protocols are safe and well-tolerated in patients with cardiovascular disease, heart failure, metabolic syndrome, and diabetes (19,27,31,34). Also, the majority of prior studies that have used the 4 × 4 protocol have used a treadmill, whereas most studies that have included the 10 × 1 protocol used a cycle ergometer. It is unclear whether speed and inclination would have to be titrated as much as power on the cycle ergometer to maintain HR within the desired range with the 4 × 4 protocol.

**Practical Applications**

The results of our investigation provide practical insights for fitness professionals and coaches prescribing HIE such as the protocols used in this study. First, when using HR to control exercise intensity, power output must be adjusted (decreased) to a greater extent during the 4 × 4 protocol compared with the 16 × 1 protocol. Otherwise, HR could very easily reach maximum during the latter intervals of the 4 × 4 protocol, and it may not be feasible for subjects to maintain the entire 4 minutes of effort without attenuation of the absolute power output. Also, the rate of EE is modestly higher in the 4 × 4 protocol, owing to higher VO₂ reached during the longer active interval stages of this protocol. Second, in using the 16 × 1 (or similar variant, i.e., 8–12 × 1) protocol, it is important to note that 90% of HRpeak may not be attained until at least the fifth interval, despite a higher power output maintained during the 16 × 1 protocol. If a high-power output is the desired feature of the exercise session, the 16 × 1 protocol would be preferred. Conversely, blood lactate concentrations, perceived exertion, and enjoyment did not differ between the 2 protocols, suggesting that although power output and EE differ between the 2 protocols, the clients and athletes may perceive the 2 protocols in a very similar manner. This is a positive finding because it gives fitness professionals and coaches more options when prescribing HIE.

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