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ORIGINAL RESEARCH

Effects of different rest intervals in high intensity interval training programs on VO_{2max}, body composition, and isokinetic strength and power

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Abstract

The aim of this study was to evaluate the effect of 8 weeks of short and long rest running-based high-intensity training (HIIT) on body composition, isokinetic strength, and maximal oxygen uptake (VO_{2max}). Nineteen physically active men were recruited to voluntarily participate in the study. The participants were grouped using the closed-envelope randomized method as HIIT with a short rest (HIITS, n = 9; age: 19.60 ± 1.34 years) and HIIT with a long rest (HIITL, n = 10; age: 19.77 ± 0.97). Pre and post the 8-week running-based HIIT program, body mass index and body fat % were measured and all subjects performed isokinetic strength tests to determine their hamstring (H)/quadriceps (Q) peak torque ratio and the peak power and peak work for their H and Q muscles. The participants also underwent a graded exercise test to determine their VO_{2max}. Statistical analysis performed with One-Way Variance Analysis and Bonferroni correction *post hoc* tests. As a result of the study, there were no significant differences between the pre- and post-training isokinetic strength parameters for the H and Q of HIITL and HIITS at velocities of 60 and 240°s^{-1}. The VO_{2max} did not change for HIITS training but the VO_{2max} increased ($p <$ 0.05) for HIITL training. In conclusion, that HIITL and HIITS programs for 8 weeks did not change the relative and absolute strength, force production and the VO_{2max}, but the VO_{2max} increased ($p < 0.05$) for HIITL training.

Keywords

Peak torque; Peak power; Peak work; VO_{2max}; H/Q ratio

1. Introduction

Numerous training modalities are available to athletes seeking to optimize their athletic performance. One such modality is high-intensity interval training (HIIT), which entails brief, intermittent surges of vigorous physical exertion interspersed with intervals of rest or low-intensity activity [1]. HIIT stands as a widely favored training approach for enhancing athletic performance [2] including aspects such as aerobic performance, maximal exercise capacity [3], cardiorespiratory fitness, overall health, and the reduction of adipose tissue levels [4]. Several studies have substantiated HIIT as the foremost efficacious method for augmenting both aerobic and anaerobic capacities. Furthermore, its advantages typically materialize at a swifter rate in comparison to conventional training modalities [5, 6]. In addition, HIIT is specifically structured to enhance lactate and anaerobic thresholds through repetitive cycles of high intensity followed by rest [7]. Many athletes have incorporated HIIT into their training session to bolster their capacity for swift recovery during brief intermissions [8]. Research indicates that optimal results are achieved with HIIT programs during 8–12 weeks, though certain studies

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have demonstrated notable improvements even within shorter periods of 2–6 weeks [9, 10]. For example, after six sessions of HIIT exercise, Martinez Valdes *et al.* [11] found an increase in muscle torque in young adult males. Yan *et al.* [12] demonstrated training-related improvements in peak VO_{2max}, anaerobic threshold, anaerobic power, and muscle strength after 4 weeks of HIIT exercise sessions. Concurrently, Pritchard *et al.* [13] research indicated significant improvements in body fat, muscle strength, anaerobic capacity, fatigue, and muscular endurance amongst the isokinetic muscle functions of the HIIT team within only a 4-weeks period. This leads to the ascertain of how important is the HIIT in the development of athletes. It's noteworthy that this form of exercise session is recognized for its time-efficiency [14–16]. In this context, it is clearly seen that studies often focus on training sessions. In the literature, little attention has been paid to optimizing the recovery time between HIIT training sessions. Therefore, contrary to the researches [17–19], in our study, recovery times during HIIT training sessions were emphasized.

Moreover, HIIT protocols allow individuals to sustain maximal or near maximal oxygen uptake for extended durations due to the robust stimulus that triggers improvements in both central (oxygen transport) and peripheral (oxygen utilization) adaptations, ultimately enhancing VO_{2max} [20]. Aerobic capacity is measured as maximum volume of oxygen intake (VO_{2max}) [10]. An increasing number of systematic reviews and meta-analyses have been conducted to investigate the effectiveness of HIIT in improving VO_{2max}. In these studies, HIIT was found to be the best way to improve aerobic and anaerobic capacity [3, 21, 22]. In contrast to these studies, in our study, different changes in aerobic development were tried to be obtained by using different rest periods during HIIT training. In addition, since individual differences and genetic factors have an effect on VO_{2max} [23], it was decided to examine body composition in our study.

The principal allure of HIIT lies in its capacity to be accomplished within a significantly abbreviated time frame when contrasted with conventional aerobic training, while still yielding commensurate physiological adaptations [24]. Typically, HIIT involves the utilization of conventional exercise modalities such as running, rowing, and cycling [25]. During these activities, muscles participate in a continuous cycle of shortening and lengthening, known as concentric and eccentric muscle contractions, respectively [26]. Therefore, since pure concentric and pure eccentric muscle contractions can be measured using isokinetic dynamometers [27–29], it was thought that examining the effect of HIIT training on isokinetic strength would be more descriptive. Muscle strength, a crucial determinant of an athlete's overall performance, denotes an individual's capability to exert maximal muscular force, either in a static or dynamic [30]. Considering that muscle strength is one of the performance indicators of athletes, it will be useful for athlete development to know the effect of the training method we have applied on this variable. However, little is known about the effects of a running based HIIT program on isokinetic strength and power or about the optimal parameters (*i.e.*, intensity, duration and intrasession rest interval) for producing the greatest improvement in athletic performance in highly trained individuals [31, 32].

In light of the aforementioned associations, we postulated a model to elucidate the correlations between HIIT training with varying recovery durations and the parameters of body composition, isokinetic strength, and aerobic performance:

• H1: We hypothesized that a HIIT training protocol with short rest intervals would demonstrate efficacy in influencing body composition, isokinetic strength, and aerobic performance.

• H2: We posited that a HIIT training protocol incorporating long rest intervals would prove effective in impacting body composition, isokinetic strength, and aerobic performance.

• H3: We conjectured that HIIT training with short rest intervals would exhibit a superior influence on body composition, isokinetic strength, and aerobic performance in comparison to HIIT training with long rest intervals.

• H4: Conversely, we postulated that HIIT training with long rest intervals would yield a more pronounced effect on body composition, isokinetic strength, and aerobic performance when juxtaposed with HIIT training featuring short rest intervals.

Currently, much information is available regarding the optimal training load to be used during HIIT training programmes. However, intrasession rest intervals are a component that has not been extensively studied [33–36]. Sufficient rest intervals between exercises are crucial to counteract the negative impacts of fatigue and support muscle recovery. Nonetheless, proponents suggest that deliberately inducing fatigue through the reduction or exclusion of rest intervals may potentially augment strength development. Moreover, it is widely recognized that intense exercise induces peripheral muscle fatigue, reducing the ability of skeletal muscles to generate active tension. The recovery of neuromuscular activation, active muscle tension, and metabolic equilibrium is a time dependent process, emphasizing the importance of a noncontractile rest period subsequent to exercise. Although the available evidence seems limited and contradictory, it can be argued that the effect of intrasession rest intervals varying over the duration of training plays an important role in strength development. The purpose of this study was to examine the effects of different intrasession rest intervals with 8 weeks of an HIIT program on isokinetic strength (peak torque, PT), peak power (PP), hamstrings to quadriceps (H/Q) ratio, peak work (PW) for hamstring (H) and quadriceps (Q) muscles, and VO_{2max}. It was hypothesized that short and long rest intervals during 8 weeks running-based HIIT would positively affect body composition, isokinetic strength and aerobic performance (maximum oxygen uptake), and this effect would be more distinct during HIIT with a long rest interval.

2. Materials and methods

2.1 Participants

For this study, 19 physically active men with at least two years of athletic history and who regularly participate in sports two or three days a week participated voluntarily. Participants were grouped as follows: running based HIIT intrasession short rest (120–130 heart rate rest) (HIITS, n = 9; age: 19.77 ± 0.97 years; height: 176.55 ± 6.94 cm) and running based HIIT intrasession long rest (100–110 heart rate rest) (HIITL, n = 10; age: 19.60 ± 1.34 years; height: 178.40 ± 6.23 cm).

In our study, the closed envelope randomization method was used to determine the HIITS and HIITL groups [37]. The closed envelope randomization method is the most used type of randomization. Each envelope contained a number representing the groups (1 for HIITS, 2 for HIITL), known only to the research writer. Subsequently, the envelopes were distributed randomly to participants by another researcher who was not involved in the implementation or evaluation, thus forming the aforementioned groups. The inclusion criteria for participation in the current study included: (1) regularly engaging in exercise or being physically active, (2) active and consistent participation in exercise sessions in both programs, and (3) the absence of any medical conditions or injuries that could affect the results. Participants who did not regularly attend exercise sessions and those who had any injuries throughout the study were excluded from the study.

2.2 Study design

The current investigation was designed to examine the impact of two distinct intrasession rest intervals (short and long) over the course of an 8-week running-based HIIT sessions on isokinetic strength and VO_{2max}. Participants underwent isokinetic strength tests to assess their H/Q PT ratio, PP and PW for H and Q muscles. Additionally, an incremental treadmill test was performed to estimate their VO_{2max}. These assessments were conducted both before and after the training program. The intrasession rest to work intervals were determined based on participants' heart rate percentages. Distinct rest interval heart rates were established for each group. Specifically, participants in the HIITS group received short rest intervals between HIIT sets, corresponding to a 45:85% recovery to running ratio. Conversely, participants in the HIITL group received long rest intervals between HIIT sets, corresponding to a 30:85% recovery to running ratio [38, 39].

Throughout the training phase, the HIITS and HIITL groups engaged in separate and individualized exercise sessions for a duration of 8 weeks, three days per week. Both groups adhered to identical training volumes and loads. The core component was divided into five segments: 2 sets of 200 meters, 2 sets of 300 meters, 2 sets of 400 meters, 2 sets of 300 meters, and 2 sets of 200 meters, with a target heart rate of 85% of the heart rate reserve (HRR). The exercise session lasted from 50 to 90 minutes for both groups. The duration of the training session for the HIITS group was shorter in comparison to that of the HIITL group due to the differential intrasession rest intervals. Upon the participants in the HIITS group reaching an intrasession rest heart rate equivalent to 45% of the heart rate reserve, they proceeded to the subsequent exercise segment. Similarly, participants in the HIITL group commenced the next exercise when their intrasession rest heart rates returned to the targeted 30% of the HRR. Additionally, HR was recorded for each player every 5 s using a wireless heart rate monitor worn around the chest (System—Polar Team Pro.2, Kempele, Finland).

2.3 Procedure

Each participant was provided with comprehensive information regarding the study's objectives and methodology, with specific emphasis on the nature of the tests and the high intensity exercises involved. Furthermore, we obtained informed consent from all study participants. Before each test, the participants performed 10 minutes warmup with low intensity exercises on the leg curl and leg extension machine (Strength Machine, Body-Solid Corporation, Chicago, IL, USA). None of the participants received any medication or illegal nutritional supplements and they obtained a minimum of eight hours of sleep before the pre–post-test and during intervention program [40]. Moreover, participants were required not to engaged in any high intensity related activities for 24 hours prior to the assessments.

2.4 Measurements

All measurements were conducted both pre- and post-training. Prior to body weight and body fat assessments, participants received detailed instructions in adherence to the criteria recommended by the World Health Organization to minimize measurement inaccuracies, which they duly followed [41]. Participant height and body weight were measured using an electronic scale (708 Seca, Hamburg, Germany). Body Mass Index (BMI) and body fat percentage were assessed with a BC-418 Tanita Body Composition Analyzer (Body Composition Analyzer, Tanita Corporation, Tokyo, Japan) employing the electrical bio-impedance method. Participants refrained from eating or drinking for a minimum of four hours prior to both pre- and post-training body composition measurements. All measurements were conducted in the laboratory under consistent temporal conditions. The estimation of VO_{2max} was determined through a graded exercise test (Bruce protocol) utilizing a Fitmate Pro device (Respirator Mask, Cosmed, Rome, Italy). The IsoMed 2000 isokinetic dynamometer (Isokinetic Dynamometer, D&R Ferstl, Hemnau, Germany) was employed for the evaluation of PT, PP, H/Q ratio and PW. Additionally, we computed the relative strength of the H and Q muscles by dividing certain measurements by body weight (PT/weight and PP/weight).

2.4.1 Bruce protocol treadmill test

The Bruce treadmill test protocol, an incremental treadmill test, was employed to estimate the participants' VO_{2max} values. This test involved multiple stages of exercise, commencing with a walking speed of 1.7 mph (2.7 km) on a treadmill inclined at 10%. Subsequently, both speed and incline were incrementally elevated every 3 minutes. Participants were instructed to continue running until fatigue hindered their ability to maintain pace with the treadmill. Throughout the test, the Fitmate Pro device from Cosmed, Italy, was used to record peak and mean data for gas exchange and heart rate. Fitmate Pro designates peak VO_{2max} as the highest attainable rate of oxygen consumption [42]. Valid peak VO_{2max} values were established when three or more of the following criteria were met:

1. A plateau in VO_2 despite escalating running speed.
2. A respiratory exchange ratio exceeding 1.1.

3. A peak heart rate equal to or surpassing 90% of the age predicted maximum.

4. Observable signs of participant fatigue [43].

2.4.2 Isokinetic strength measurement

The knee strength of the participants was assessed utilizing the Iso Med 2000 isokinetic machine. Each participant executed ten maximal concentric contractions at both $60°s^{-1}$ and $240°s^{-1}$ for each leg, as detailed in [44]. The ensuing testing procedure was adhered to:

1. Participants assumed a seated position in a 90 degree testing chair.

2. A cuff was applied above the knee to stabilize the pelvis and thigh of the assessed leg.

3. The upper body was secured with a shoulder pad, aligning the rotational axis of the instrument with that of the knee joint.

4. Individual seat and knee positions were adjusted for optimal positioning.

5. A static gravity correction was implemented.

6. A 3-minute interval was observed between test speeds, and a 5-minute intermission was enforced between the assessment of each limb.

7. Data from the initial and tenth repetitions were used from analysis.

2.4.3 Hamstring/quadriceps ratio

The conventional H/Q muscle ratio was calculated by dividing the peak isokinetic strength of the H (knee flexors) by the peak strength of the Q (knee extensors) at a specific mode of contraction and joint angular velocity, in accordance with its established formula [45].

2.5 Statistical analysis

The G-power (version: 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) software [46] was used to determine the minimum sample size required. A priori power analysis was performed according to the study's design, using *t*-tests and differences between two dependent means (matched pairs): α error probability (α err prob) = 0.05, power ($1-\beta$ error probability) = 0.80, estimated effect size of 0.60. A sample of at least 19 participants was determined based on a priori analyzes based on the research of Buckley *et al.* [25].

Data analysis was performed using SPSS (version/statistics) 26.0 software (SPSS, Inc., Chicago, IL, USA). To assess the normality of the data, the results of the Shapiro-Wilk test, skewness and kurtosis values were examined. It was determined that the values obtained based on Tabachnick and Fidell fit the normal distribution (±1.5). To compare the pre- and post-test results of body composition, isokinetic strength, and aerobic performance parameters in the HIITS and HIITL groups, the paired sample *t*-test was employed. Statistical significance was set at $p < 0.05$ and $p < 0.01$.

3. Results

The physiological findings are displayed in Table 1. No significant differences were found for weight, body mass index and body fat at pre- and post-training between the two groups. There was a significant difference in VO_{2max} between pre- and post-training for HIITL ($p < 0.05$). However, there was no discernible difference between the average VO_{2max} pre and post HIITS training. As indicated Tables 2 and 3, no significant differences were found between pre and post training for all variables (PT, PW and PP) at velocities of 60 and $240°s^{-1}$ for both legs, in both groups. Based on the data presented in Figs. 1,2 , no significant differences in the mean ratios of PT H/weight, PT Q/weight, PP H/weight, and PP Q/weight were observed between the pre-training and post-training measurements for both legs in both the HIITL and HIITS conditions at velocities of 60 and 240°/s.

4. Discussion

The primary objective of this investigation was to examine the ramifications of differing rest durations (short and long) within an 8-week, running based high intensity interval training program on various physiological parameters, specifically encompassing body composition metrics (comprising body weight, body mass index, and body fat percentage), isokinetic muscular strength attributes (including PT, PP, H/Q and PW for both H and Q muscles), as well as VO_{2max} levels.

The central discovery emanating from this study suggests that no statistically significant disparities were evident in isokinetic strength parameters when comparing pre-training to post-training assessments for both HIIT Long (HIITL) and HIIT

TABLE 1. Pre-post test comparison of weight, body mass index, body fat and VO_{2max} values of HIITL and HIITS groups.

	HIITS (n = 9)			HIITS (n = 10)		
	Pre-training	Post-training	*p* value	Pre-training	Post-raining	*p* value
Body weight (kg)	63.62 ± 8.12	64.04 ± 8.25	0.91	68.23 ± 7.23	68.11 ± 6.91	0.97
Body Mass Index (kg/m^2)	20.36 ± 1.60	20.26 ± 1.95	0.91	21.40 ± 1.55	21.35 ± 1.59	0.94
Body Fat %	7.40 ± 3.74	7.34 ± 3.41	0.94	7.23 ± 4.47	6.29 ± 3.87	0.62
VO_{2max} (mL/kg^1/min^{-1})	59.28 ± 4.90	60.94 ± 3.69	0.43	55.31 ± 5.21	58.68 ± 4.74*	0.05*

*Significant differences: *$p < 0.05$; n: Test subject; kg: Kilogram; kg/m^2: Kilogram/square meter; %: Percent; mL/kg^1/min^{-1}: Milliliter/kilogram/minute.*
HIITS: short rest high-intensity interval training; HIITL: long rest high-intensity interval training; VO_{2max}: maximal oxygen uptake.

TABLE 2. Isokinetic PT, work and power values for HIITS at velocities of 60 and 240°s^{-1} Values are means ± SD.

	Left Leg (n = 9)			Right Leg (n = 9)		
	Pre-training	Post-training	*p* value	Pre-training	Post-training	*p* value
60°s^{-1}						
PT H (Nm)	118.00 ± 18.87	110.56 ± 27.15	0.51	131.78 ± 17.42	129.78 ± 23.96	0.84
PT Q (Nm)	212.22 ± 29.62	203.67 ± 40.14	0.61	222.67 ± 37.63	192.33 ± 39.43	0.11
PT H/Q (%)	55.87 ± 3.96	54.38 ± 7.81	0.62	60.33 ± 4.18	65.11 ± 8.51	0.15
PW H (J)	126.33 ± 17.41	115.44 ± 29.33	0.36	137.56 ± 13.31	138.11 ± 29.52	0.96
PW Q (J)	184.67 ± 21.86	177.89 ± 36.10	0.64	188.11 ± 23.63	175.00 ± 35.98	0.37
PW H/Q (%)	68.74 ± 6.38	64.82 ± 12.12	0.40	73.51 ± 4.20	78.94 ± 9.79	0.15
PP H (W)	90.22 ± 14.96	92.67 ± 17.63	0.76	101.44 ± 13.10	112.00 ± 21.99	0.23
PP Q (W)	137.11 ± 21.31	148.22 ± 45.40	0.52	144.11 ± 30.14	154.00 ± 45.60	0.60
240°s^{-1}						
PT H (Nm)	90.22 ± 14.63	90.11 ± 19.41	0.99	100.44 ± 14.70	109.78 ± 23.07	0.32
PT Q (Nm)	137.11 ± 14.19	146.56 ± 43.40	0.54	129.67 ± 22.29	147.44 ± 4.27	0.26
PT H/Q (%)	65.92 ± 8.48	63.67 ± 14.68	0.70	78.54 ± 9.73	76.34 ± 13.18	0.69
PW H (J)	67.00 ± 10.92	84.67 ± 4.32	0.24	75.78 ± 11.23	87.33 ± 25.07	0.23
PW Q (J)	109.67 ± 8.67	126.11 ± 41.56	0.26	108.22 ± 11.95	124.22 ± 36.71	0.23
PW H/Q (%)	61.01 ± 8.02	59.03 ± 11.22	0.67	63.40 ± 23.35	71.42 ± 11.86	0.37
PP H (W)	143.33 ± 26.51	118.98 ± 56.20	0.26	162.56 ± 22.64	169.44 ± 32.74	0.61
PP Q (W)	241.67 ± 27.27	245.00 ± 46.54	0.86	248.33 ± 33.44	255.56 ± 56.37	0.75

Nm: Newton meter; J: Joule; W: Watt; PT: Peak torque; PW: Peak work; PP: Peak power; H: Hamstring; Q: Quadriceps; N: Test subject.

TABLE 3. Isokinetic PT, work and power values for HIITL at velocities of 60 and 240°s^{-1} Values are the mean ± SD.

	Left Leg (n = 10)			Right Leg (n = 10)		
	Pre-training	Post-training	*p* value	Pre-training	Post-training	*p* value
60°s^{-1}						
PT H (Nm)	113.00 ± 18.74	125.10 ± 18.50	0.16	126.50 ± 28.72	127.90 ± 19.78	0.90
PT Q (Nm)	222.20 ± 21.84	216.90 ± 29.86	0.66	229.50 ± 40.16	233.40 ± 37.12	0.82
PT H/Q (%)	51.16 ± 8.24	58.62 ± 10.68	0.10	55.29 ± 7.57	55.26 ± 5.89	0.99
PW H (J)	119.50 ± 20.62	128.90 ± 25.07	0.37	119.50 ± 29.86	131.20 ± 20.54	0.32
PW Q (J)	181.10 ± 19.51	179.80 ± 32.85	0.92	193.10 ± 33.68	202.60 ± 37.60	0.56
PW H/Q (%)	66.29 ± 10.31	72.46 ± 12.68	0.25	61.55 ± 9.12	65.56 ± 8.81	0.33
PP H (W)	89.30 ± 13.27	95.20 ± 15.18	0.37	97.40 ± 22.39	98.40 ± 14.84	0.91
PP Q (W)	142.00 ± 23.02	137.70 ± 22.90	0.68	162.10 ± 29.11	159.20 ± 28.55	0.83
240°s^{-1}						
PT H (Nm)	87.90 ± 14.07	101.60 ± 20.17	0.10	96.60 ± 20.57	106.90 ± 26.40	0.34
PT Q (Nm)	142.90 ± 20.40	142.30 ± 23.56	0.95	134.10 ± 24.18	145.00 ± 27.18	0.36
PT H/Q (%)	62.47 ± 10.46	73.57 ± 19.33	0.13	73.58 ± 17.73	75.33 ± 17.98	0.83
PW H (J)	64.50 ± 14.23	75.40 ± 17.91	0.15	75.60 ± 15.37	78.10 ± 14.24	0.71
PW Q (J)	111.40 ± 18.06	110.60 ± 16.43	0.92	111.90 ± 22.97	121.80 ± 20.01	0.32
PW H/Q (%)	58.70 ± 13.80	69.20 ± 18.21	0.16	70.88 ± 26.85	64.87 ± 10.70	0.52
PP H (W)	143.50 ± 30.14	165.50 ± 37.61	0.17	171.50 ± 37.29	171.80 ± 36.14	0.99
PP Q (W)	250.80 ± 46.00	250.80 ± 41.46	1.00	257.50 ± 53.81	281.20 ± 48.76	0.32

Nm: Newton meter; J: Joule; W: Watt; PT: Peak torque; PW: Peak work; PP: Peak power; H: Hamstring; Q: Quadriceps; N: Test subject.

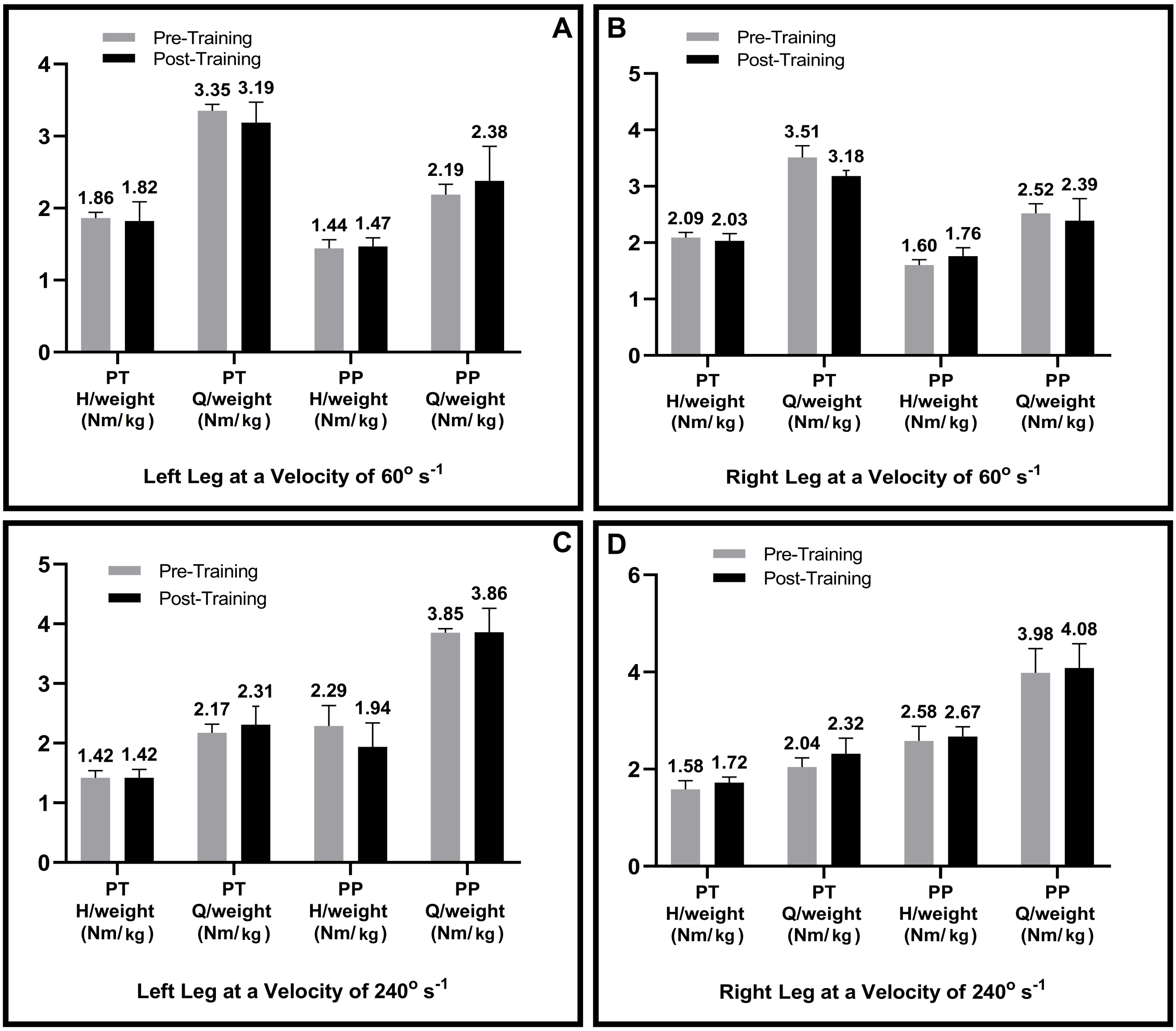

FIGURE 1. The mean and SD values of the PT and power of the muscle (H and Q)/weight ratio for HIITS. PT and PP were divided by the weight of subjects to obtain the relative strength of the H and Q muscles for HIITS (for A–D). Nm: Newton meter; W: Watt; kg: Kilogram; S: Second; H: Hamstring; Q: Quadriceps; PT: Peak torque; PP: Peak power.

Short (HIITS) protocols, particularly at angular velocities of 60 and 240°s^{-1}. Moreover, it is noteworthy that the relative strength and force production remained largely unaltered following 8 weeks of HIITL and HIITS training session, as indicated by the lack of discernible changes in isokinetic strength parameters before and after training. In our analysis, we normed the isokinetic strength data (comprising PT, PW and PP) with respect to the participants' body weights, thereby facilitating the computation of relative strength for the H and Q. Notably, the outcomes yielded consistent results, demonstrating that mean relative strengths pertaining to isokinetic PT H/weight, PT Q/weight, PW H/weight, PW Q/weight, PP H/weight and PP Q/weight for the H and Q muscles did not change between pre- and post-training for HIITL and HIITS for both H and Q muscles exhibited negligible fluctuations between pre-training and post-training assessments for both HIITL and HIITS session. However, it is important to underscore that the cardiovascular aspect of our study revealed a significant augmentation in VO_{2max} levels for the HIITL group when comparing pre-training and post-training measurements, whereas VO_{2max} remained relatively constant for the HIITS group. This divergence suggests that HIITL engendered a more pronounced enhancement in VO_{2max} as compared to HIITS. Furthermore, with regard to body composition variables, no statistically significant deviations were observed in body weight, BMI or body fat percentage between the pre-training and post-training evaluations for either the HIITS or HIITL protocols.

In the existing literature, numerous studies have been noticed that exhibit similar experimental designs [47–52]. For instance, Sporer and Wenger [48] conducted a study demonstrating that the type and intensity of aerobic training can influence subsequent performance in a strength training session, depending on the recovery period. They observed that the

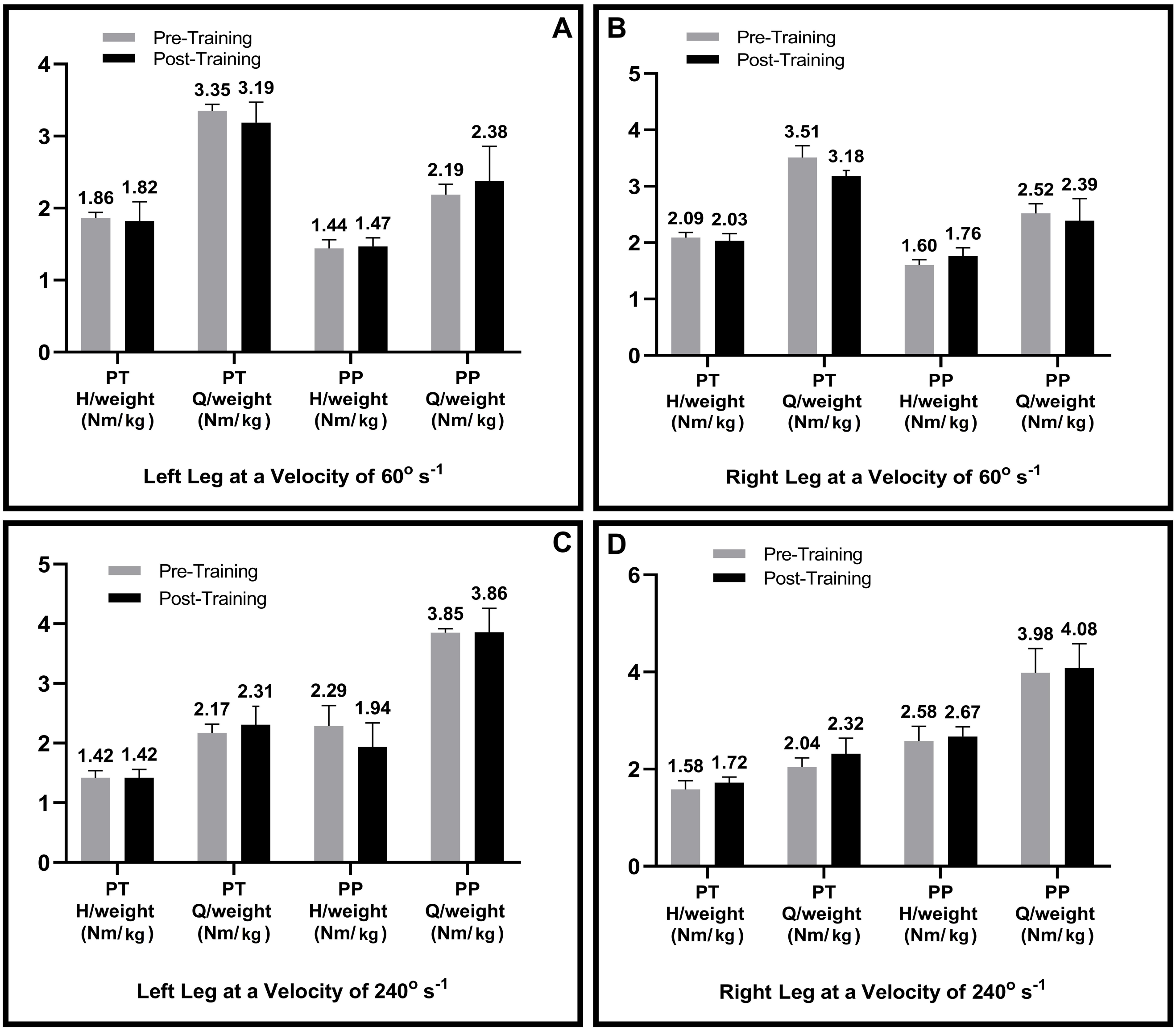

FIGURE 2. The mean and SD values of the PT and power of the muscle (H and Q)/weight ratio for the HIITL. PT and PP were each divided by the weight of the subjects to determine the relative strength of the H and Q muscles for HIITL (for A–D). Nm: Newton meter; W: Watt; kg: Kilogram; S: Second; H: Hamstring; Q: Quadriceps; PT: Peak torque; PP: Peak power.

main effect was not attributed to the specific type of aerobic training. However, when aerobic training was performed before strength training, the researchers found that the volume of work that could be accomplished was reduced for a duration of up to 8 hours. Performing aerobic training before strength training can indeed have an impact on the subsequent volume of work that can be accomplished during strength training sessions [48]. Contrary to our research, the above studies have shown that endurance training has many effects on strength. The reason why such effects were not observed in our study may be due to the fact that the training protocol we applied did not provide full strength gains. In addition, the fact that aerobic exercise primarily activates slow-twitch muscle fibers and increases cardiovascular endurance, while strength training targets fast-twitch muscle fibers, may lead to different results in strength and power gains [49, 50]. The underlying mechanisms responsible for this effect are not fully understood, but several hypotheses have been proposed. One possible explanation is related to the physiological adaptations that occur in response to aerobic exercise, such as increased Adenosine Monophosphate (AMP) activated protein kinase (AMPK) activity and the subsequent inhibition of protein synthesis pathways that are crucial for muscle hypertrophy. Additionally, aerobic exercise can lead to temporary fatigue and depletion of energy stores, which can impair subsequent strength training performance [51, 52]. In summary, within the scholarly literature, upon a comprehensive evaluation of the referenced studies [15, 49–52], it becomes evident that aerobic exercises executed with varying rest intervals elicit disparate effects on a range of physical performance attributes. However, our research concluded that HIIT exercises with long and short rest intervals have no effect on strength. Moreover, it is imperative to acknowledge that various aspects of training, including strength, speed, endurance, and coordination, are

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influenced by distinct intrasession rest intervals [53, 54]. The preservation and enhancement of muscular power in athletes represent a significant undertaking for trainers. Consequently, the quantification of isokinetic strength holds the potential to furnish coaches with valuable insights for optimizing the training sessions tailored to the specific demands of a given sport. In this regard, it is thought that the reason for the different results in our research and in the literature should be fully determined.

Based upon the results mentioned above, the present study showed that the athletes who performed HIIT with a long intrasession rest interval and a short intrasession rest interval did not experience any changes in their mean isokinetic strength parameters. The absence of changes in mean isokinetic strength parameters should not discount the potential benefits of HIIT in other aspects of physical fitness. These findings suggest that athletes, who do not perform strength or resistance training, do not improve or change the isokinetic strength with HIIT and with rest to work interval time of HIIT. In contrast to our results, Panissa *et al.* [35] analyzed the effect of the time interval after high-intensity aerobic exercise on strength performance in individuals with different training backgrounds. The researchers reported a drop in performance that was related to the strength exercise activity with the same magnitude and time interval. Similarly, Denadai *et al.* [55] conducted a study to investigate the impact of high-intensity exhaustive running exercise on the muscular torque capacity of knee extensors in well-trained runners. The researchers found that there was a significant reduction in concentric contraction at 60°/s and a decrease in the isokinetic PT of the knee extensors following a session of high-intensity exhaustive running exercise, specifically when blood lactate accumulation began, and this effect was dependent on the angular velocity being tested. Another study performed by Hill Haas *et al.* [54] noted that the improvement in the repeated-sprint capacity after high-repetition resistance training with 20-s rest intervals was greater than that after training with 80-s rest intervals, but the strength for the latter improved more than for the former. In our study, HIIT did not lead to a significant improvement in isokinetic strength performance parameters, there are several physiological factors that may be at play. First, the lack of a significant effect of HIIT on isokinetic strength performance parameters in our study may be related to neuromuscular adaptations. While HIIT can lead to improvements in various aspects of fitness, such as cardiovascular endurance and metabolic adaptations, it may not directly stimulate the same neuromuscular adaptations necessary for isokinetic strength gains. Isokinetic strength often relies on specific motor patterns, muscle recruitment, and muscular control, which may not be significantly targeted by HIIT protocols. Secondly, different types of exercise training can have varying effects on muscle fiber types. If the HIIT protocol primarily targeted fast-twitch muscle fibers, which are more involved in explosive movements, it may not have translated to improvements in the specific parameters measured in isokinetic testing. Third, isokinetic testing often involves a specific range of motion and resistance. If the HIIT protocol did not closely match these conditions, it may not have provided the stimulus needed for improvements in isokinetic strength. Lastly, different individuals may respond differently to various training stimuli. It's possible that the participants in the study had varying baseline levels of isokinetic strength or different responsiveness to the HIIT protocol [53, 56]. Therefore, coaches and practitioners should perform strength or resistance training to increase their isokinetic performance. Moreover, it is essential to carefully consider these factors when interpreting the results and to conduct further research to understand the specific interactions between HIIT and isokinetic strength performance. Additionally, adjusting the HIIT protocol or incorporating complementary training methods may be avenues for future investigation.

Furthermore, our study, HIIT with a long intrasession rest interval affected the mean VO_{2max}. This implies that the observed augmentation in VO_{2max} among participants engaged in HIITL the corresponding increase observed in participants undergoing HIITs. HIIT, especially with extended rest, may allow for better recovery between intervals. Coaches develop VO_{2max} with HIITL training instead of HIITS training. Indeed, the physiological mechanisms underlying the effect of HIIT with extended rest intervals on mean VO_{2max} involve a combination of factors: HIIT with extended rest intervals allows for better oxygen delivery to working muscles. During rest intervals, oxygen levels can replenish, enabling higher oxygen availability during subsequent high-intensity intervals. This supports increased oxygen uptake and utilization. Moreover, HIIT, with its intermittent high-intensity efforts, can trigger a significant excess post-exercise oxygen consumption (EPOC) effect. During this post-exercise period, the body continues to consume oxygen at an elevated rate to restore physiological processes, clear metabolic byproducts, and return the body to a resting state. This increased post-exercise oxygen consumption can contribute to the overall increase in mean VO_{2max}. Additionally, HIIT engages a broad spectrum of muscle fibers, including both slow-twitch (Type I) and fast-twitch (Type II) fibers. This recruitment pattern can lead to muscle fiber hypertrophy and improved endurance, further contributing to the increase in mean VO_{2max}. Lastly, extended rest intervals provide more time for mitochondrial recovery and adaptation. Mitochondria play a crucial role in aerobic energy production. HIIT can stimulate mitochondrial biogenesis, increasing the number and efficiency of these organelles, which enhances the body's ability to generate adenozin trifosfat (ATP) aerobically [22, 57, 58]. These mechanisms collectively lead to improved aerobic fitness and higher VO_{2max} levels. HIIT with extended rest intervals can be an effective training strategy to induce these physiological adaptations, ultimately enhancing an individual's ability to perform high-intensity aerobic exercise and improving overall cardiovascular fitness.

Another finding of our study was that HIIT with short and long rest intervals had no effect on physical parameters. When the research in the literature is examined, it is stated that high-intensity interval training is an effective, time-efficient form of exercise for fat loss in practice. Additionally, most studies have shown that high-volume HIIT is effective in improving body composition [59, 60]. Additionally, Mandrup *et al.* [61] and Mandrup *et al.* [62] have suggested that low-volume HIIT produces an improvement in lean body mass

[61, 62]. In another study, Batacan *et al.* [21] and Wewege *et al.* [63] HIIT was recognized and frequently discussed as a time-efficient and safe form of exercise to achieve superior health benefits over traditional training in athletic, healthy, and clinical populations. Additionally, Keating *et al.* [64] and Wewege *et al.* [63] reported that HIIT interventions produced similar levels of fat loss, although a subanalysis suggested that HIIT protocols involving lower energy expenditure tended to show less effectiveness for reductions in total body fat percentage. Unlike the literature, Sultana *et al.* [65] stated that the HIIT protocol they implemented did not have any effect on body composition, similar to our research.

Therefore, based on the literature, it can be said that both low and high volume HIIT training are effective methods on body composition. However, in our research, unlike the literature, it appears that HIIT training with short and long rest intervals has no effect on body composition. It is thought that this may be due to the fact that the athletes in our study have less fat mass to lose. It is thought that the protocol in our research will produce different results on body composition in different groups. In addition, it is thought that these results may be different in HIIT protocols such as cycling and rowing in the laboratory environment, where the running-based HIIT protocol is also effective on these results.

The present investigation encompasses several acknowledged limitations. Firstly, the constrained sample size within both experimental cohorts poses a challenge in terms of the generalizability of the findings. Second, the study did not entail systematic monitoring of participants' alimentary intake and hydration status throughout the 8-week interventions of HIITS and HIITL. To mitigate this limitation, a 24-hour retrospective dietary record could have been implemented, capturing the participants' dietary habits over two week-days and one weekend day, thus aggregating data across three days. This methodological enhancement would have facilitated the computation of their caloric intake. Furthermore, an additional limitation arises from the exclusively male composition of the participant pool. This singular demographic focus engenders challenges in extending the results, particularly visàvis the female demographic. Subsequent research endeavors should endeavor to encompass both male and female participants to engender a more inclusive comprehension of the findings and their transferability to a wider population. Lastly, the absence of a control group in the research design constitutes a conspicuous limitation. Future investigations should endeavor to incorporate control groups, thereby fortifying the methodological integrity and augmenting the overall scholarly rigor within this domain of inquiry.

5. Conclusions

The HIIT sessions, characterized by varying rest-to-work interval durations over an 8-week period, demonstrated a noteworthy impact on VO_{2max} levels, particularly in the context of HIITL training. Conversely, this experimental paradigm yielded no discernible effects on isokinetic strength measures, encompassing both relative and absolute strength, as well as parameters pertaining to body composition. Consequently, meticulous attention should be afforded to the calibration of rest-to-work interval durations, particularly in endeavors aimed at augmenting VO_{2max} levels among physically active male individuals. The findings of this present study underscore the imperative nature of judiciously planned and personalized training sessions, supplemented by the integration of sound recovery protocols. These strategies collectively serve to optimize overall performance outcomes while concurrently mitigating potential adverse repercussions associated with the execution of high-intensity aerobic training protocols. Coaches can design periodized training programs over an 8-week period, incorporating varying rest-to-work intervals. This approach can help athletes systematically progress in their cardiovascular fitness and optimize performance for specific events. Moreover, While the HIIT session may not directly impact isokinetic strength measures, it can be effectively combined with separate strength training routines. Coaches can combine both HIIT and strength training for athletes and individuals seeking a balanced fitness session to achieve comprehensive physical fitness goals.

ABBREVIATIONS

HIIT, high-intensity interval training; HIITS, short rest high-intensity interval training; HIITL, long rest high-intensity interval training; VO_{2max}, maximal oxygen uptake; H/Q Ratio, hamstring/quadriceps ratio.

AVAILABILITY OF DATA AND MATERIALS

Data are available for research purposes upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

RFK and SB—conceived this study. HİC—undertook the statistical analysis. GB, ÖE—interpreted the data, GB, LPA—developed the manuscript. RFK, SB, HİC, ÖE, YB, GB, SBA-M, RSE and LPA—critically revised the manuscript and approved the final manuscript for publication. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Our study received approval from the Ethics Committee of Gumushane University Clinical Research Institute (Approval no: 2023/03) and was conducted in compliance with the ethical guidelines outlined in the Helsinki Declaration. Written informed consent to participate in this study was provided by the participant's legal guardian/next of kin. Informed consent was obtained from all individual participants included in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Georgian Badicu is serving as one of the Editorial Board members of this journal. We declare that Georgian Badicu had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DM.

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