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High-Intensity Interval Training in Different Slopes on Aerobic Performance: A Randomized Controlled Trial

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Abstract: This study investigated the impact of six high-intensity interval training (HIIT) running sessions at 1% or 10% slope on various physiological and performance parameters in 25 men. The participants underwent assessments of VO2max, time to exhaustion at 1% slope (TLim1%), and time to exhaustion at 10% slope (TLim10%) in the initial three visits. They were then randomly assigned to control (CON), HIIT at 1% slope (GT1%), or HIIT at 10% slope (GT10%) groups. Over three weeks, participants performed six HIIT sessions with equalized workload based on their individual maximal oxygen uptake (vVO2max). The sessions comprised 50% of TLim, with a 1:1 ratio of exercise to recovery at 50% vVO2max. Results indicated significant improvements in VO2max and peak velocity (VPeak) after HIIT at both slopes. Heart rate (HR) behavior differed between sessions for GT1%, while no significant differences were observed for GT10%. Rating of perceived exertion (RPE) significantly reduced for GT1% after the third session, with a similar trend for GT10%. In summary, six sessions of 1% or 10% slope HIIT effectively enhanced VO2max and VPeak, but there was no improvement in TLim performance, suggesting no adaptive transfer between training groups.

Keywords: anaerobic threshold; running speed; oxygen consumption; exercise test; physical endurance

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1. Introduction

Significant adaptations are observed in maximal oxygen uptake (VO2max) and aerobic performance after a few short sessions of high-intensity interval training (HIIT) performed at speeds close to VO2max (vVO2max) [1,2] and/or above maximum speed [3,4]. There is substantial evidence supporting the benefits of HIIT in competitive runners [5], highlighting that this high-intensity protocol, executed in brief periods, elicits physiological responses comparable to those achieved by continuous programs of prolonged exercise [6–8].

These adaptations establish a favorable relationship between training time and effectiveness [9–11] for the HIIT training model, regardless of the sport in focus, athlete's experience, and fitness level [4]. In addition to the intensification proposed by HIIT, the variation of training stimuli emerges as a potential strategy for metabolic and neuromuscular enhancements [12], beyond adaptations related to running performance.

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In the competitive running scenario, physiological and mechanical changes resulting from alterations in terrain (horizontal vs. inclined vs. declined) influence the dynamics of the stretch-shortening cycle and, consequently, the energy cost [13,14]. In this sense, uphill running, for example, demonstrates an increase in neuromuscular [15] and metabolic overload [16] compared to horizontal running, resulting in a higher perception of effort. Studies indicate an increase in muscle activation and a predominance of concentric overload during uphill running [17], possibly explaining the increase in energy cost and the reduction in acute performance [18].

Currently, there is substantial evidence supporting the effectiveness of different training programs for runners, aiming to minimize disparities caused by variations in inclination and optimize results [19]. Traditional approaches, such as continuous training at different intensities and resistance training regimens, have been widely studied and associated with improvements in endurance, metabolic efficiency, and aerobic performance in runners [20]. However, there is a current gap in specific evidence regarding the effects of HIIT in runners, especially concerning different inclinations. While HIIT is recognized for its general benefits, the specific application of these principles in varied uphill contexts in running may require further research to establish clear and direct evidence on its specific impacts in this athletic population [21].

Although previous studies have addressed the effects of HIIT in different sports contexts, there is a scarcity of research specifically focused on runners and their response to HIIT at different slope percentages [22,23]. In addition to methodological limitations, available studies have not adequately explored the complexity of the relationship between HIIT and uphill running; Furthermore, the lack of experimental research hinders a comprehensive understanding of adaptations over time [24]. This study aimed to investigate the impact of six sessions of HIIT in running at 1% and 10% slope, on key physiological parameters, including VO2max, peak velocity (VPeak), heart rate (HR), rate of perceived exertion (RPE) and time to exhaustion performance (TLim). Given the higher neuromuscular demand associated with a 10% slope, our hypotheses were as follows: a) running at 10% slope would result in more substantial adaptive improvements compared to a 1% (H1); b) the behavior of HR and RPE will show equal adaptation patterns over time; c) training at 10% slope would lead to significant performance gains for both TLim1% and TLim10% (H3 - adaptive transfer hypotheses), while training at 1% slope would generate specific improvements primarily in flat terrain performance.

2. Materials and Methods

2.1. Study Design and Registration

This study followed all the items proposed in the guidelines of CONSORT for reporting parallel group randomized trials. All procedures were performed in accordance with the Declaration of Helsinki and included in the clinical trial registration of the U.S. National Institutes of Health (ClinicalTrials.gov; NCT02511964). This research analyzed the effect of HIIT in different slope program (1% or Uphill running at 10% slope) on aerobic performance in healthy people, using a randomized, between-group design (experimental group [EG] and control group [CG], respectively). The primary outcomes of this study involve the dependent variables: VO2max, total time of protocol (TTotal); peak of velocity (VPeak); metabolic demands and absolute time values (min) of time to exhaustion at 1% and uphill running at 10% slope (TLim1% and TLim10%). As a secondary outcome, the behavior of HR and RPE were observed, as well as whether there was a possible transfer of adaptations between the training group, measured based on TLim performance. Flowchart 1 presents in the results section, the entry and exclusion flow of participants until the collection of primary and secondary outcomes.

2.2. Subjects

Twenty-five male college students, physically active and familiar with aerobic activities on a treadmill participated in this study. Individuals were invited from announcements made at the University and in a fitness center where the study was conducted over the course of six months. As

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inclusion criterion, participants must have a minimum of 2 years of aerobic training experience, who performed high intensity exercises a minimum of twice a week and executed at least 150 min.sem-1 moderate or vigorous aerobic activities. The study excluded those with a recent history of injury with potential interference on the running performance, low adherence to the exercise program (i.e., an interval of more than three days between sessions) or making use of any ergogenic substance that potentially interfere with the study results.

All individuals were invited to have their questions clarified, subsequently to sign the consent form. The study was approved by the ethics committee of university (#045.2010). Using the statistical package G-Power (Free Version 3.0.5) for analysis "ANOVA Repeated Measures Between Factors" with two measures into three groups, the sample size considered an error to 5%, a statistic power of 80%, and an effect size of 0.60 (moderate) (19), resulting in 24 participants. Considering a sample loss and significant abandonment when conducting chronic experimental models, a greater number of participants were recruited, expecting a loss of around 20% to 30%. Table 1 contains the anthropometry, body composition, physiological and performance of the groups investigated.

Table 1. Average (SD) of the subject's characteristics, training sessions, physiological and performance.

Variables	**$GT_{1\%}$**	**$GT_{10\%}$**	**CON**
	(n = 9)	**(n = 8)**	**(n = 8)**
Age years (SD)	26 (5)	28 (3)	26 (3)
Anthropometry and Body Composition			
Body Mass kg (SD)	79.5 (9.8)	84.0 (13.6)	82.2 (10.5)
Height cm (SD)	178.0 (7.4)	175.1 (5.9)	177.3 (6.5)
BF % (SD)	13.5 (4.3)	14.7 (3.6)	12.5 (4.2)
Physiologic variables			
VO_{2max} $mL \cdot kg^{-1} \cdot min^{-1}$ (SD)	52.6 (4.4)	54.1 (4.1)	54.7 (5.6)
HR_{max} bpm (SD)	193 (7)	191 (10)	193 (10)

Subtitle: $GT_{1\%}$ - running group at 1% slope; $GT_{10\%}$ - running group at 10% slope; CON – control group; SD – standard deviation; HR_{max} – maximum heart rate; BF – body fat.

2.3. Withdrawal Criteria

Participants would automatically be removed from the study if they did not fully comply with the evaluation processes within a period of two weeks or did not complete the six training sessions exactly twice a week. Participants were also instructed to abandon the experiment and were free to withdraw, without harm, at any time.

2.4. Experimental Approach

The comparison between running programs was carried out using a randomized clinical trial composed of three groups (i.e., HIIT at 1% (GT1%) [n=9], HIIT at 10% (GT10%) [n=8] and control (CON) [n=8]). The allocation was given a random strategy conducted by a researcher not involved in the experiment (as described in specific session). Pre-treatment groups showed no significant differences in TLim1% performance (p = 0.632). The GT1% and GT10% groups were undergoing a training program with six sessions, while the control group not training. The pre- and post-training were performed in three visits as described in Figure 1. All training sessions were carried at the same time of day and temperature controlled between 21 and 23 and humidity ~60%. All participants were instructed not to eat the three hours preceding the tests, so as not to perform physical activity in the previous 24 h to evaluations. The protocol to evaluate VO2max and the time to exhaustion evaluation were performed in different days, with 48 hours between.

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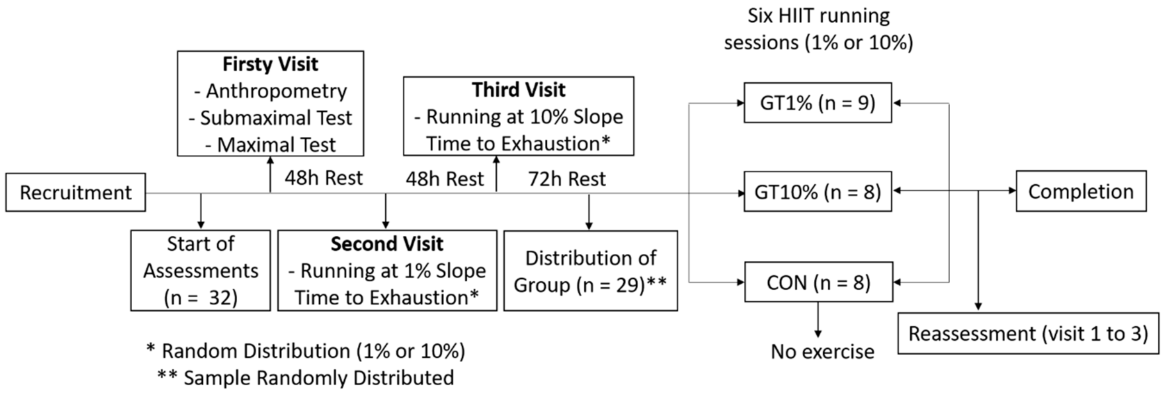

Figure 1. Experimental Approach.

2.5. Procedures

2.5.1. Anthropometry

It was used standard assessment established by the International Society for the Advancement of Kinanthropometry (ISAK) to determine the following anthropometric measures: body weight and height (Mechanic, Filizola, Brazil), and skinfold (Slim Guide, Rosscraft, Canada). We estimated the body fat percentage through Jackson & Pollock's equation [25].

2.5.2. VO2max Test

After a 6 to 10-minute rest in the supine position and subsequent assessment of HR and blood pressure, participants commenced walking on the treadmill at 5 km/h with a 1% inclination. The speed was incrementally increased by 1.0 km/h per minute until reaching 65% of heart rate reserve (HRRes), at which point the speed was maintained for 6 minutes. HR and RPE were recorded every minute. Subsequently, additional increments of 1.0 km/h were introduced every minute until participants could no longer sustain running, at which point the actual maximum HR (HRmaxR) and VPeak were recorded.

Verbal encouragement was given to participants to achieve maximum performance. The VO2max and vVO2max (velocity associated with VO2max) were predicted from the equations for running proposed by ACSM, and from the reserve method proposed by Swain et al. (2004). The reliability of the method using running provided a typical measurement error of 2.4 $mL^{-1}.kg^{-1}.min^{-1}$ (4.9%) and intraclass correlation coefficient of 0.864 [27].

2.5.3. Time to Exhaustion (TLim)

After a 6-minute warm-up at 50% of vVO2max, participants underwent a time-to-exhaustion test on a treadmill with inclinations of 1% and 10%, randomly determined. The test aimed to determine the maximum duration achievable at vVO2max. HR and RPE were closely monitored at 15-second intervals. In the post-training test, a new vVO2max was established based on the achieved VO2max. Given the variations in speed between pre- and post-training, we utilized the metabolic demand (mL.kg-1.min-1) estimated at the training speed (pre and post) for each gradient, multiplied by the duration in minutes achieved in the time-to-exhaustion test (TLim), as the primary outcome under investigation.

2.5.4. Training Program

Participants performed a total of six training sessions for three weeks (two sessions per week), with three days between each session. The running sessions began with a 6 min warm-up to 60% vVO2max. The stimuli were administered in vVO2max, with equalized workload by the ACSM running equation to the two slope percentages investigated (1% or 10%). The stimulus volume was

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represented by 50% of TLim, with an equal percentage of recovery at 50% vVO2max (i.e., a 1:1 ratio). Participants began each stimulus after the speed of the treadmill was reached. Likewise, the end of each stimulus occurred with a sudden movement to the side of the treadmill, with the speed quickly reduced to the stipulated recovery intensity. Two evaluators, positioned on each side of the treadmill, carried out process safety. Both HR (Polar FT1 cardiac monitor - USA) and RPE were monitored continuously throughout the training session. The criteria for interruption of the protocol of interval training were achieved six stimuli or maximum voluntary exhaustion.

2.5.5. Analysis of Rate of Perceived Exertion (RPE)

The assessment of subjective perception of exertion was carried out for both experimental groups using the category ratio scale for perceived exertion from 0 to 10 (CR-10). A dimension scale (60 x 30 cm) was positioned on the mirror in front of the treadmill, and each participant was encouraged to verbally indicate an effort score every 30 s and at the end of the stimulus.

2.5.6. Randomization

Eligible subjects gave written informed consent, and after initial screening, were randomly distributed for TLim assessments up to 1% or 10% slope. After this moment, participants were again randomized to blind allocation within the three different experimental groups. At end, a new randomization was performed to determine the TLim retest at 1% or 10% slope. A simple randomization was applied. The randomization process was made by lot from a paper stored in sealed opaque envelopes. The allocation of participants was concealed from the blinded assessor. Participants were reminded not to disclose their group allocation during follow-up assessment.

2.5.7. Blinding and Data Analysis and Treatment

To avoid possible analysis biases, the data were collected by two different researchers associated with the project and the research group (A.S. and E.P.) and analyzed by a third researcher (group leader T.M.S). The researcher responsible for data analysis remained blind throughout the data collection process. The names of all participants remained confidential, being excluded from the data sheet and replaced with numbers. Participants did not have access to the results until the study ended. Afterwards, everyone received a report of their performances via email.

2.6. Statistical Analysis

The results were shown by average and standard deviation (SD). After assumptions testing, the comparison of the TTotal between GT1% and GT10% was performed by independent t-test. A two-way variance analysis (ANOVA) (group x time) with repeated measures was used to test differences between the VO2max and VPeak averages for the three groups investigated (CON, GT1%, GT10%). The differences between the metabolic demands and absolute time values (min) of TLim1% and TLim10%, and the effect of training specificity was determined by a three-way ANOVA (group vs. test vs. time) with repeated measurements only for factors test and time. The post hoc Tukey was applied to identify differences between groups. The effect size (ES) was calculated using Cohen "d" index with the following threshold values: <0.2: trivial; 0.2-0.6: small; 0.6-1.2: moderate; >1.2: large. The analysis was performed in the SPSS program (v. 17, SPSS Inc., Chicago, USA), considering a significance level of $p \leq 0.05$.

3. Results

Flowchart 1 presents the timeline for entry and exclusion of participants.

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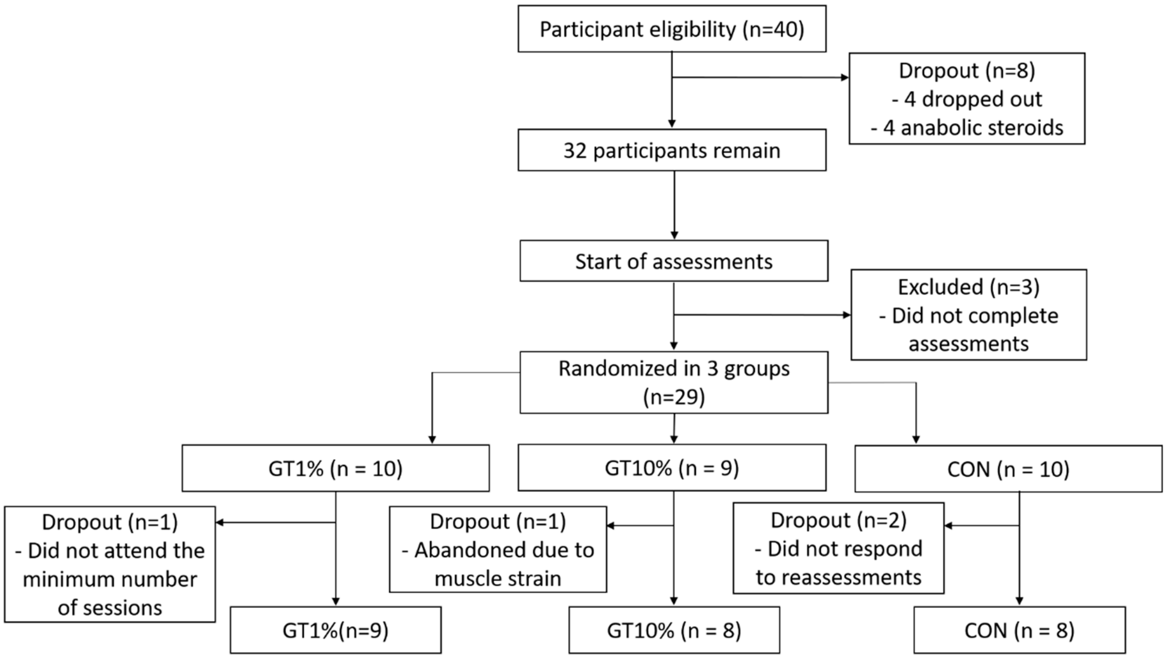

Flowchart 1. Entry flow and exclusion of participants.

TTotal performed in GT1% was significantly higher compared to GT10% (30.4 ± 9.4 min vs. 22.3 ± 5.1 min, respectively; p = 0.035) despite the same number of stimuli received by GT1% and GT10% (4.7 ± 1.3; 4.8 ± 1.3 stimuli, respectively; p = 0.920). The CON group did not differ after the training period for all dependent variables. Nevertheless, significant increases were found after six interval running sessions for VO2max (p = 0.002) and for VPeak (p = 0.001) in both GT1% e GT10% groups, with no significant interaction for groups. Training showed ES of 0.67 (GT1%), 0.70 (GT10%), 0.03 (CON) of the VO2max, and 0.67 (GT1%), 0.70 (GT10%), 0.01 (CON) of the VPeak. The results are presented in Table 2.

Table 2. Average (SD) of training effect on the dependent variables.

Characteristics	**Pre Training**			**Post Training**			
	$GT_{1\%}$	**$GT_{10\%}$**	**CON**	**$GT_{1\%}$**	**$GT_{10\%}$**	**CON**	***P value***
VO_{2max} (mL.kg.$^{-1}$min^{-1})	52.6 (4.4)	54.1 (4.1)	54.7 (5.6)	56.0 (4.6)	57.1 (5.5)	54.0 (5.2)	0.002
V_{Peak} (km.h^{-1})	15.8 (1.5)	16.3 (1.9)	16.9 (1.3)	16.8 (1.6)	17.7 (1.9)	16.9 (1.1)	0.001
$T_{Lim1\%}$							
Time (min)	6.1 (1.2)	6.2 (2.1)	6.6 (2.6)	5.8 (1.6)	6.0 (3.2)	6.0 (2.3)	0.001
Velocity (km.h^{-1})	14.1 (1.3)	14.5 (1.2)	14.7 (1.6)	15.1 (1.3)	15.4 (1.6)	14.5 (1.5)	0.001
VO_2 Demand (mL.kg^{-1})	324 (75)	329 (122)	368 (172)	329 (109)	333 (176)	324 (121)	0.680
$T_{Lim10\%}$							
Time (min)	3.6 (0.5)	4.5 (1.4)	4.3 (1.2)	3.6 (0.7)	4.0 (1.9)	3.7 (1.1)	0.001
Velocity (km.h^{-1})	9.9 (1.0)	10.0 (1.0)	10.1 (1.2)	10.9 (1.0)	11.1 (1.1)	10.4 (1.1)	0.001
VO_2 Demand (mL.kg^{-1})	192 (40)	235 (82)	237 (65)	200 (50)	223 (106)	198 (57)	0.680

Subtitle: $GT_{1\%}$ - running group to 1% slope; $GT_{10\%}$ - running group to 10% slope; CON – control group; SD – standard deviation; V_{Peak} - peak velocity in maximum incremental test; VO_2 demand (mL.kg^{-1}) - product of metabolic demand by the total exercise time to 1% and 10% slope.

Significant differences were observed when compared the metabolic demands of TLim1% vs. TLim10% and absolute values performed in both conditions. Although, the significant improvement in VPeak after training, there were no changes in metabolic demand after training for TLim1% and TLim10% and, consequently, it was not found an influence of specificity in running test performed

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on two slope percentages investigated (interaction vs test vs time, p = 0.680). The TLim performance in two inclinations showed trivial ES.

HR behavior differs significantly between session 1 (S1) and session 6 (S6) for the group that trained at 1% slope (p < 0.001), presenting lower HR values for the same workload. However, there were no significant differences between S1 and S6 for the GT10% group (p > 0.05). The results are presented in Figure 2A. RPE suffered significant reductions from the third training session (S3) for the GT1% group (p < 0.001), compared to S1, suggesting an adaptive response on effort modulation. A similar pattern was observed for the GT10% group, however, with a smaller magnitude. The adaptive RPE responses can be observed in Figure 2B. Figure 3A,B illustrate the behavior of intrasession HR and RPE, comparing S1 vs. S6.

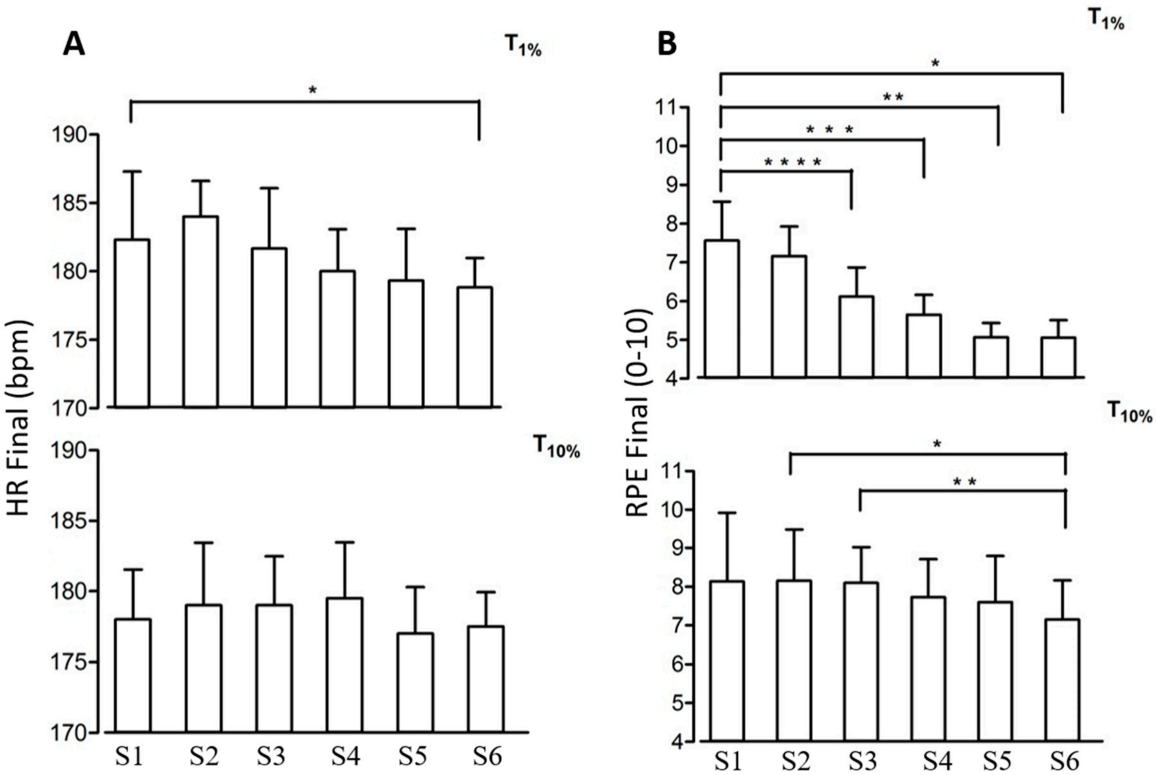

Figure 2. HR and RPE behavior during the six training sessions. Subtitle: * - significant differences between sessions; Figure 2A - represents the adaptive behavior of the HR; Figure 2B - represents the adaptive behavior of the RPE.

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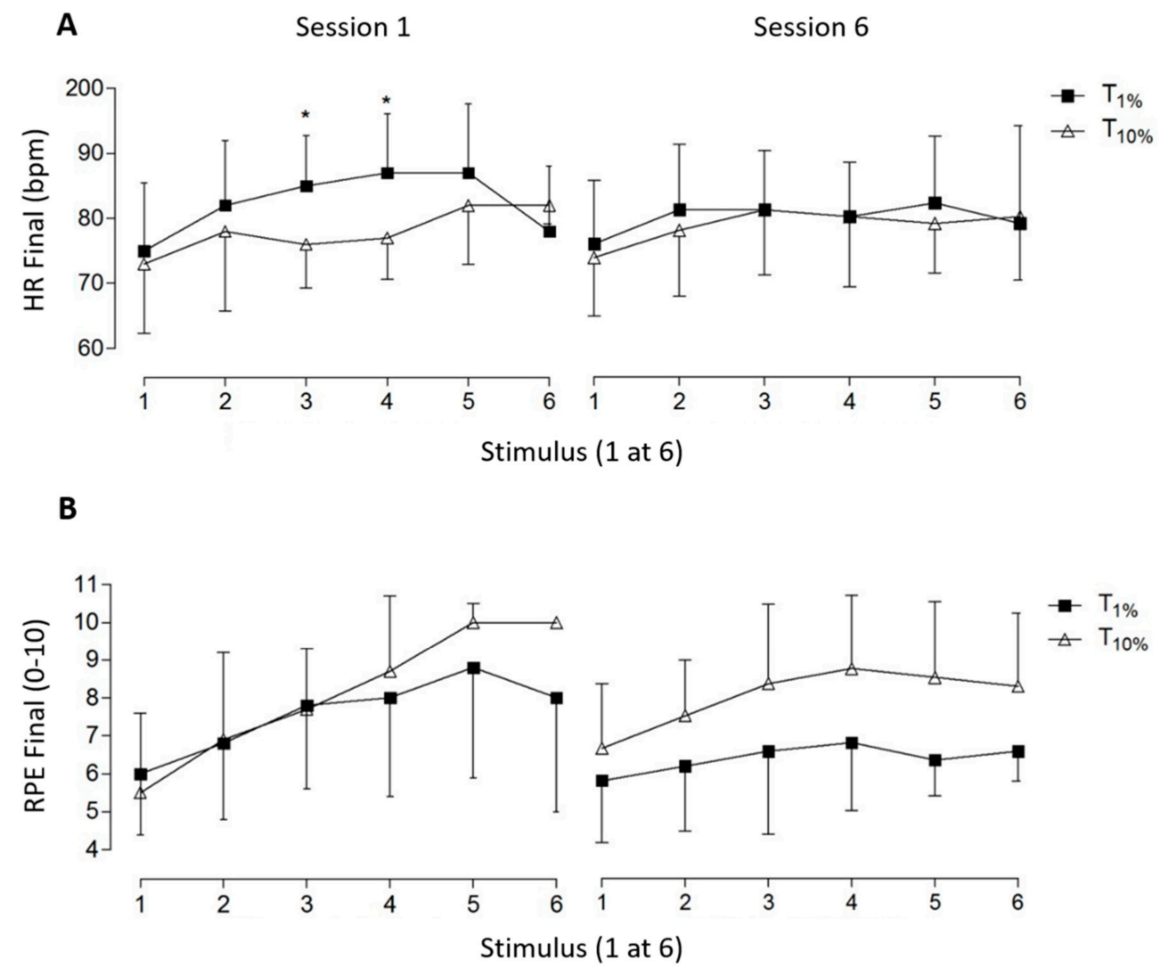

Figure 3. Behavior of HR and RPE in the face of stimuli in the first vs. in the last session. Subtitle: * - significant differences between stimulus; Figure 3A - represents the adaptive behavior of the HR; Figure 3B - represents the adaptive behavior of the RPE.

3.1. Unintentional Harm

Risks, small damages are inherent in physical training. Two evaluators experienced in applying physical training followed the procedures appropriately, in accordance with ethical and safety precepts. However, the rate of delayed muscle soreness was frequently reported by at least 50% of participants in the GT10% group after the first session (adapting later), since such a performance format was not routine. Furthermore, one of the participants was forced to abandon the study due to a muscle strain in the gastrocnemius region. Adequate guidance was provided to the participant and contact was maintained for appropriate follow-up.

4. Discussion

This study aimed to determine the effect of six running sessions of HIIT at 1% or 10% slope on VO2max, VPeak, HR, RPE and TLim performance, as well as the influence of the specificity of training on performance in the different slope percentages. The main effects observed were significant increases in VO2max and VPeak without any effects of training on the TLim1% and TLim10% performance, regardless of the specificity of the slope used. To the best of our knowledge, this was the first study to compare the effects of interval training on different slope in a short training period and to observe the increase in VO2max and VPeak.

The significant difference between the TLim1% and TLim10% is also an important finding, as it interferes directly on impulse training (i.e., TRIMP, volume x intensity) applied between groups. Nevertheless, ES of interventions at 1% and 10% slope showed moderate clinical significance, similar to the previously observed in the literature for VO2max and vVO2max [28]. Additionally, it is worth highlighting that the six sessions were sufficient to generate chronotropic adaptations, at least for GT1%. The RPE responses were also significantly modified for both experimental protocols, suggesting that the different modulation of effort observed is the result of interoceptive (metabolic) or cognitive changes (there is no way to distinguish).

Several studies have shown the effects of HIIT on physiological, biochemical markers and performance in six sessions of cycling [3,4] or running in the horizontal plane [29,30]. In contrast, little chronic evidence has been published on uphill running [15]. This study supports the evidence that only a small number of sessions with reduced exercise duration leads to physiological and performance adaptations from the administration of stimulus in vVO2max. Considering the TLim1% and TLim10% performances, even after metabolic equalization between running protocols (377 ± 119 s; 246 ± 68 s; at 1% and 10% slope, respectively), lower impulse training was generated by the protocol at 10% slope. This is an important finding and demonstrates that with smaller impulse training, the results after six interval running sessions were similar to VO2max and VPeak between GT1% and GT10%. Moderate ES in GT1% and GT10% groups for these variables support these findings and further suggest that the uphill running may be established as a strategy for greater efficiency and time savings compared to TTotal observed in GT1%.

The improvement in VO2max seems to be primarily affected by the power developed during running (intensity-dependent), together with the time spent in VO2max [31]. The use of only 50% of TLim to construct the training protocol duration, even though does not lead participants to maximum efforts and shows a lower TTotal in running at 10% slope, it was not an attenuator factor to adaptive VO2max responses. The reduction in HR throughout the sessions is an attribute that would explain intrinsic changes in VO2max, since they are collinear variables. Therefore, we can infer that the reduced HR response for the same workload comes from an adaptation related to the volume of blood ejected, which in turn, would alter the capacity to perform work. However, this theoretical rationale would be valid exclusively for the GT1% group and would not explain the effects of training in GT10%, suggesting that other adaptive factors may be linked to the effects at 10% slope.

The TTotal administered to each stimulus was probably sufficient to achieve VO2max (~ 2 min) in both training protocols (GT1% and GT10%). Although we do not propose to directly address the topic, due to the indirect instruments used, the HR of both groups will be able to reflect this until the first three sessions. So, it is speculated that permanence in VO2max seems crucial for the improvement of this variable [31]. In cases that the intensity exceeds the severe exercise domain (approximately 136% of vVO2max), fatigue may be established before VO2max being reached [32].

Despite the significant training effect for vVO2max on aerobic performance demonstrated in the literature regarding running in the horizontal plane [28,30], and maximum sprint running [15], TLim was not sensitive enough to demonstrate these differences after six interval sessions, regardless of the difference in impulse training (36% lower at 10% slope). The increase in intervention time may enable effective improvement in the TLim1% and TLim10% performance, as noted in the studies of Paradisis et al. [15]. In addition, the great inter-subject variability of TLim test (CV = 25-30%) may also have contributed to reducing the statistical power and the ability to observe significant effect of training [33].

Finally, HIIT with six sessions at 1% and 10% slope was efficacy in improvement of VO2max and VPeak. The smallest impulse training at uphill running intervention suggests additional importance to this strategy for greater time saving and even adaptive effect on VO2max and its associated speed. In addition, the intervention time is not enough to improve the performance TLim and therefore no crossed effect was developed.

4.1. Limitations

The lack of an instrument for direct analysis of gas exchange is the main limitation of our study. Despite this, the indirect measure used presents significant validity, as well as appropriate predictive validity, as well as reliability (typical measurement error of 2.4 mL-1.kg-1.min, suggesting consistency in the results. Furthermore, the lack of a biochemistry, such as lactate, could help us respond to certain events that occurred in this study.

5. Conclusions

The study results suggest the use of stimulus HIIT in two different slope (1% or 10%) for diversification of training and improvement of VO2max and VPeak. However, the exercise volume at 10% slope was 36% lower than the administered in the running at 1% slope. This strategy then, sets as time economic to generate significant improvements in VO2max and the same evolution on VPeak, an important variable able to predict performance.

The development of a training protocol per TLim response provides individualization of time and workloads. When different inclinations percentages are used for training prescription, specific tests are suggested for the development of these protocols because of the differences in TLim1% and TLim10%. Further studies using different types of training (e.g., continuous aerobic exercise) in inclination should be tested to assess the possible advantages of different training strategies.

The adaptive HR response at 1% slope was superior to the 10% running protocol. HIIT at 1% slope produced greater impacts on RPE after the six exercise sessions. Even though both running protocols significantly benefited.

Author Contributions: Conceptualization: Tony Meireles, Alberto Sá Filho, Marcelo Sales; Methodology: Júlio Brugnara, Iransé Silva and Patricia Martins; Document validation and statistical analysis: Alberto Sá Filho, Gaspar Chiappa; Data collection and preliminary writing: Roberto Bittar, Pedro Inacio; Supervision: Alberto Sá Filho, Tony Meireles; Different review steps: Rodrigo Martins. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the Evangelical University of Goiás (approval number: #045.2010) and ClinicalTrials.gov; NCT02511964.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Gillen, J.B.; Little, J.P.; Punthakee, Z.; Tarnopolsky, M.A.; Riddell, M.C.; Gibala, M.J. Acute High-intensity Interval Exercise Reduces the Postprandial Glucose Response and Prevalence of Hyperglycaemia in Patients with Type 2 Diabetes. Diabetes Obes Metab 2012, 14, 575–577. https://doi.org/10.1111/j.1463-1326.2012.01564.x.
2. Gibala, M.J.; McGee, S.L. Metabolic Adaptations to Short-Term High-Intensity Interval Training. Exerc Sport Sci Rev 2008, 36, 58–63. https://doi.org/10.1097/JES.0b013e318168ec1f.
3. Burgomaster, K.A.; Heigenhauser, G.J.F.; Gibala, M.J. Effect of Short-Term Sprint Interval Training on Human Skeletal Muscle Carbohydrate Metabolism during Exercise and Time-Trial Performance. J Appl Physiol 2006, 100, 2041–2047. https://doi.org/10.1152/japplphysiol.01220.2005.
4. Burgomaster, K.A.; Hughes, S.C.; Heigenhauser, G.J.F.; Bradwell, S.N.; Gibala, M.J. Six Sessions of Sprint Interval Training Increases Muscle Oxidative Potential and Cycle Endurance Capacity in Humans. J Appl Physiol 2005, 98, 1985–1990. https://doi.org/10.1152/japplphysiol.01095.2004.
5. García-Pinillos, F.; Soto-Hermoso, V.M.; Latorre-Román, P.A. How Does High-Intensity Intermittent Training Affect Recreational Endurance Runners? Acute and Chronic Adaptations: A Systematic Review. J Sport Health Sci 2017, 6, 54–67. https://doi.org/10.1016/j.jshs.2016.08.010.

 doi:10.20944/preprints202409.0848.v1

6. Gibala, M.J.; Little, J.P.; Van Essen, M.; Wilkin, G.P.; Burgomaster, K.A.; Safdar, A.; Raha, S.; Tarnopolsky, M.A. Short-term Sprint Interval versus Traditional Endurance Training: Similar Initial Adaptations in Human Skeletal Muscle and Exercise Performance. J Physiol 2006, 575, 901–911. https://doi.org/10.1113/jphysiol.2006.112094.
7. Gibala, M.J.; Little, J.P.; MacDonald, M.J.; Hawley, J.A. Physiological Adaptations to Low-volume, High-intensity Interval Training in Health and Disease. J Physiol 2012, 590, 1077–1084. https://doi.org/10.1113/jphysiol.2011.224725.
8. Burgomaster, K.A.; Howarth, K.R.; Phillips, S.M.; Rakobowchuk, M.; MacDonald, M.J.; McGee, S.L.; Gibala, M.J. Similar Metabolic Adaptations during Exercise after Low Volume Sprint Interval and Traditional Endurance Training in Humans. J Physiol 2008, 586, 151–160. https://doi.org/10.1113/jphysiol.2007.142109.
9. Gillen, J.B.; Percival, M.E.; Skelly, L.E.; Martin, B.J.; Tan, R.B.; Tarnopolsky, M.A.; Gibala, M.J. Three Minutes of All-Out Intermittent Exercise per Week Increases Skeletal Muscle Oxidative Capacity and Improves Cardiometabolic Health. PLoS One 2014, 9, e111489. https://doi.org/10.1371/journal.pone.0111489.
10. Gillen, J.B.; Gibala, M.J. Is High-Intensity Interval Training a Time-Efficient Exercise Strategy to Improve Health and Fitness? Applied Physiology, Nutrition, and Metabolism 2014, 39, 409–412. https://doi.org/10.1139/apnm-2013-0187.
11. Gibala, M.J.; Little, J.P. Just HIT It! A Time-Efficient Exercise Strategy to Improve Muscle Insulin Sensitivity. J Physiol 2010, 588, 3341–3342. https://doi.org/10.1113/jphysiol.2010.196303.
12. Paavolainen, L.; Häkkinen, K.; Hämäläinen, I.; Nummela, A.; Rusko, H. Explosive-Strength Training Improves 5-Km Running Time by Improving Running Economy and Muscle Power. J Appl Physiol 1999, 86, 1527–1533. https://doi.org/10.1152/jappl.1999.86.5.1527.
13. Silva, R.; Damasceno, M.; Cruz, R.; Silva-Cavalcante, M.D.; Lima-Silva, A.E.; Bishop, D.J.; Bertuzzi, R. Effects of a 4-Week High-Intensity Interval Training on Pacing during 5-Km Running Trial. Brazilian Journal of Medical and Biological Research 2017, 50. https://doi.org/10.1590/1414-431x20176335.
14. Pringle, J.; Carter, H.; Doust, J.; Jones, A. Oxygen Uptake Kinetics during Horizontal and Uphill Treadmill Running in Humans. Eur J Appl Physiol 2002, 88, 163–169. https://doi.org/10.1007/s00421-002-0687-0.
15. Paradisis, G.P.; Bissas, A.; Cooke, C.B. Combined Uphill and Downhill Sprint Running Training Is More Efficacious Than Horizontal. Int J Sports Physiol Perform 2009, 4, 229–243. https://doi.org/10.1123/ijspp.4.2.229.
16. TOWNSHEND, A.D.; WORRINGHAM, C.J.; STEWART, I.B. Spontaneous Pacing during Overground Hill Running. Med Sci Sports Exerc 2010, 42, 160–169. https://doi.org/10.1249/MSS.0b013e3181af21e2.
17. Touron, J.; Costes, F.; Coudeyre, E.; Perrault, H.; Richard, R. Aerobic Metabolic Adaptations in Endurance Eccentric Exercise and Training: From Whole Body to Mitochondria. Front Physiol 2021, 11. https://doi.org/10.3389/fphys.2020.596351.
18. Gottschall, J.S.; Kram, R. Ground Reaction Forces during Downhill and Uphill Running. J Biomech 2005, 38, 445–452. https://doi.org/10.1016/j.jbiomech.2004.04.023.
19. Prieto-González, P.; Sedlacek, J. Effects of Running-Specific Strength Training, Endurance Training, and Concurrent Training on Recreational Endurance Athletes' Performance and Selected Anthropometric Parameters. Int J Environ Res Public Health 2022, 19, 10773. https://doi.org/10.3390/ijerph191710773.
20. Hottenrott, K.; Ludyga, S.; Schulze, S. Effects of High Intensity Training and Continuous Endurance Training on Aerobic Capacity and Body Composition in Recreationally Active Runners. J Sports Sci Med 2012, 11, 483–488.
21. Atakan, M.M.; Li, Y.; Koşar, Ş.N.; Turnagöl, H.H.; Yan, X. Evidence-Based Effects of High-Intensity Interval Training on Exercise Capacity and Health: A Review with Historical Perspective. Int J Environ Res Public Health 2021, 18, 7201. https://doi.org/10.3390/ijerph18137201.
22. Stankovic, M.; Djordjevic, D.; Trajkovic, N.; Milanovic, Z. Effects of High-Intensity Interval Training (HIIT) on Physical Performance in Female Team Sports: A Systematic Review. Sports Med Open 2023, 9, 78. https://doi.org/10.1186/s40798-023-00623-2.
23. Liu, Y.; Abdullah, B. Bin; Abu Saad, H. Bin Effects of High-Intensity Interval Training on Strength, Speed, and Endurance Performance among Racket Sports Players: A Systematic Review. PLoS One 2024, 19, e0295362. https://doi.org/10.1371/journal.pone.0295362.
24. Ferley, D.D.; Osborn, R.W.; Vukovich, M.D. The Effects of Uphill Vs. Level-Grade High-Intensity Interval Training on V[Combining Dot Above]O2max, Vmax, VLT, and Tmax in Well-Trained Distance Runners. J Strength Cond Res 2013, 27, 1549–1559. https://doi.org/10.1519/JSC.0b013e3182736923.
25. Jackson, A.S.; Pollock, M.L. Generalized Equations for Predicting Body Density of Men. British Journal of Nutrition 1978, 40, 497–504. https://doi.org/10.1079/BJN19780152.
26. SWAIN, D.P.; PARROTT, J.A.; BENNETT, A.R.; BRANCH, J.D.; DOWLING, E.A. Validation of a New Method for Estimating &OV0312;O2max Based on &OV0312;O2 Reserve. Med Sci Sports Exerc 2004, 36, 1421–1426. https://doi.org/10.1249/01.MSS.0000135774.28494.19.

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27. Santos, T.M.; Viana, B.F.; Sá Filho, A.S. Reprodutibilidade Do VO2Máx Estimado Na Corrida Pela Frequência Cardíaca e Consumo de Oxigênio de Reserva. Revista Brasileira de Educação Física e Esporte 2012, 26, 29–36. https://doi.org/10.1590/S1807-55092012000100004.
28. BILLAT, V.L.; FLECHET, B.; PETIT, B.; MURIAUX, G.; KORALSZTEIN, J.-P. Interval Training at V??O2max: Effects on Aerobic Performance and Overtraining Markers. Med Sci Sports Exerc 1999, 31, 156–163. https://doi.org/10.1097/00005768-199901000-00024.
29. Bacon, A.P.; Carter, R.E.; Ogle, E.A.; Joyner, M.J. VO2max Trainability and High Intensity Interval Training in Humans: A Meta-Analysis. PLoS One 2013, 8, e73182. https://doi.org/10.1371/journal.pone.0073182.
30. Smith, T.P.; McNaughton, L.R.; Marshall, K.J. Effects of 4-Wk Training Using Vmax/Tmax on VO2max and Performance in Athletes. Med Sci Sports Exerc 1999, 31, 892–896. https://doi.org/10.1097/00005768-199906000-00019.
31. HILL, D.W.; ROWELL, A.L. Responses to Exercise at the Velocity Associated with ??VO2max. Medicine &amp Science in Sports &amp Exercise 1997, 29, 113–116. https://doi.org/10.1097/00005768-199701000-00016.
32. HILL, D.W.; POOLE, D.C.; SMITH, J.C. The Relationship between Power and the Time to Achieve &OV0312;O2max. Med Sci Sports Exerc 2002, 34, 709–714. https://doi.org/10.1097/00005768-200204000-00023.
33. Renoux, J.C.; Petit, B.; Billat, V.; Koralsztein, J.P. Calculation of Times to Exhaustion at 100 and 120% Maximal Aerobic Speed. Ergonomics 2000, 43, 160–166. https://doi.org/10.1080/001401300184530.