The Effects of Uphill Vs. Level-Grade High-Intensity Interval Training on $\dot{V}O_2max$, V_{MAX}, V_{LT}, and T_{MAX} in Well-Trained Distance Runners

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Abstract

Ferley, DD, Osborn, RW, and Vukovich, MD. The effects of uphill vs. level-grade high-intensity interval training on $\dot{V}O_2max$, V_{max}, V_{LT}, and T_{max} in well-trained distance runners. *J Strength Cond Res* 27(6): 1549–1559, 2013—Uphill running represents a frequently used and often prescribed training tactic in the development of competitive distance runners but remains largely uninvestigated and unsubstantiated as a training modality. The purpose of this investigation included documenting the effects of uphill interval training compared with level-grade interval training on maximal oxygen consumption ($\dot{V}O_2max$), the running speed associated with $\dot{V}O_2max$ (V_{max}), the running speed associated with lactate threshold (V_{LT}), and the duration for which V_{max} can be sustained (T_{max}) in well-trained distance runners. Thirty-two well-trained distance runners (age, 27.4 ± 3.8 years; body mass, 64.8 ± 8.9 kg; height, 173.6 ± 6.4 cm; and $\dot{V}O_2max$, 60.9 ± 8.5 ml·min^{-1}·kg^{-1}) received assignment to an uphill interval training group (G_{Hill} = 12), level-grade interval training group (G_{Flat} = 12), or control group (G_{Con} = 8). G_{Hill} and G_{Flat} completed 12 interval and 12 continuous running sessions over 6 weeks, whereas G_{Con} maintained their normal training routine. Pre- and posttest measures of $\dot{V}O_2max$, V_{max}, V_{LT}, and T_{max} were used to assess performance. A 3 × 2 repeated measures analysis of variance was performed for each dependent variable and revealed a significant difference in T_{max} in both G_{Hill} and G_{Flat} ($p < 0.05$). With regard to running performance, the results indicate that both uphill and level-grade interval training can induce significant improvements in a run-to-exhaustion test in well-trained runners at the speed associated with $\dot{V}O_2max$ but that traditional level-grade training produces greater gains.

Key Words hill running, incline running, sprinting, treadmill running

Introduction

Uphill running represents a frequently prescribed and often used form of high-intensity interval training in the development of competitive distance runners. For example, a survey of teams competing in the 1996 National Collegiate Athletic Association Division I national cross-country meet verified its widespread use as a training method and revealed that uphill training correlated with faster team times (29). Moreover, references to its potential effectiveness as a high-velocity resistance-to-movement exercise have appeared in scholarly reviews (2,36). Although widely touted by coaches, athletes, and industry lay journals as a means to increase lower-body power output and running speed–and ultimately race performance–interestingly, a review of the literature produced just one study examining the physiological responses to uphill training for distance runners (24).

With the physiological effects of uphill training on distance running performance remaining essentially unproven, its purported mechanisms of action for improving running performance have been proposed to be similar to other high-intensity resistance-to-movement training tactics such as explosive strength training, heavy strength training, and plyometric training. Recent investigations suggest that these types of training methods improve distance running performance by enhancing muscular and neuromuscular characteristics, which ultimately lead to improved economy of movement (28,42,47,51). However, as opposed to other high-intensity resistance-to-movement exercises, uphill running can be seen to represent a much more sport-specific training tactic and may therefore prove more effective at improving distance running performance than other high-intensity

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resistance-to-movement exercises. In comparison, traditional level-grade high-intensity interval training using at or near maximum intensities has long been recognized for its potent and robust effects on improving physiological indices such as $\dot{V}O_2max$, blood lactate kinetics, and muscle buffer capacity in already well-trained distance runners (6,8,31). As a result, improvements in indices such as those just mentioned may manifest themselves during actual training and racing as both a greater time spent at or near $\dot{V}O_2max$ and a greater amount of work being completed at a high intensity (7). Improving through training the time spent at or near $\dot{V}O_2max$ or the amount of work completed at a high intensity appears crucial as the ability to sustain near maximum efforts in distance running correlates strongly with running performance in events ranging from 800 m to 10 km (3,6,39).

Earlier research has revealed that when seeking to improve the running performance of well-trained distance runners, training velocities that elicit at least 90% $\dot{V}O_2max$ must be used (37,45). Whereas explosive strength training, heavy strength training, and plyometric training incorporate resistance-to-movement exercises such as weighted squat jumps, knee extensions, and single leg bounds that involve a percentage of 1 repetition maximum or body weight, at present, no recommendations exist for prescribing training intensities when performing uphill running. One possible training intensity to use in uphill running may be the running velocity associated with $\dot{V}O_2max$, which in terms of level-grade interval running represents a training intensity that has been the focus of many investigations. Termed V_{max}, this training intensity can be determined in an incremental running test and may lead to greater improvements in $\dot{V}O_2max$ through a variety of means, including increased mitochondrial density and enhanced lactate removal (2,6,16).

Bout duration represents the other main facet to interval training, and, similar to training intensity, at present, no recommendations exist for prescribing bout durations when performing uphill running. In contrast, previous investigations into level-grade interval training show both short bouts ranging 10 to 30 seconds and long bouts lasting up to 5 minutes can be effective for enhancing the physiological determinants associated with distance running performance (31,35). Regardless, similar to V_{max}, 2 key considerations for interval length selection must include attempts to maximize both the time spent at $\dot{V}O_2max$ and the total work completed at a high intensity (7). Hence, pursuits to optimize these 2 criteria and to individualize interval training protocols have led to recent investigations examining the time to exhaustion while running at the velocity associated with $\dot{V}O_2max$ (21–23,49,50). This duration, defined previously as T_{max}, has been shown to be highly variable among runners with the same V_{max} (21) and therefore provides a physiological rationale for prescribing individualized bout durations when performing interval work. In attempts to maximize both the time spent at $\dot{V}O_2max$ and the total work completed at $\dot{V}O_2max$, previous findings suggest that bout durations of 60% T_{max} appear most effective (21,22,49,50).

Because many coaches, distance runners, and industry pundits advocate uphill training as part of a comprehensive distance running training routine despite a lack of proven recommendations for training intensity, bout duration, hill grade, and evidence as to its overall physiological effectiveness, we sought to conduct an investigation comparing this mode of training with traditional level-grade high-intensity interval training. Therefore, the purpose of this study included documenting, in well-trained athletes, the physiological effects associated with high-intensity interval training performed during uphill running on a 10% grade compared with level-grade running while using previously established training prescriptors for running intensity and bout duration. We hypothesized that both uphill high-intensity interval training at a 10% grade and high-intensity interval training performed on a level-grade would result in significantly improved $\dot{V}O_2max$, velocity at lactate threshold (V_{LT}), velocity at $\dot{V}O_2max$ (V_{max}), and time to exhaustion (T_{max}) compared with a group of controls but that physiological gains from level-grade running would be more pronounced.

Methods

Experimental Approach to the Problem

A parallel, 3-group, longitudinal (pretraining, posttraining) study approach was used. Before the start of the study, the investigator asked each participant his or her willingness to be randomly assigned to 1 of 3 groups: hill interval training, G_{Hill}; level-grade interval training, G_{Flat}; or control group in which each participant maintained his or her normal training routine, G_{Con}. Those participants unwilling to participate in G_{Hill} or G_{Flat} training methods received assignment to the control group ($G_{Con} = 8$) while all other participants were matched according to $\dot{V}O_2max$ and then randomly assigned by the investigator to the hill interval training group ($G_{Hill} = 12$) or the level-grade interval training group ($G_{Flat} = 12$). The study took place at Avera Sports Institute (Sioux Falls, SD) from January to August 2011 and consisted of (a) familiarization training, (b) pretraining testing, (c) a 6-week training intervention, and (d) posttraining testing.

Subjects

In addition to contacting members of a local running club, the principal investigator also recruited potential participants through social media. Thirty-two well-trained participants (14 men and 18 women) voluntarily enrolled and gave their written consent to participate in this study after being fully informed of the risks and discomforts associated with the experimental procedures. Inclusion criteria for male and female participants required having completed a 5 km run under 21:00 minutes and 24:00 minutes, respectively, within the previous 12 months. Female participants also completed a questionnaire regarding menstrual cycle status at the initial visit. The investigator excluded those individuals who had experienced a lower-body injury in the previous 3 months. The participants had the following characteristics (mean ± *SD*): age, 27.4 ± 3.8 years; body mass, 64.8 ± 8.9 kg; and height, 173.6 ± 6.4 cm. The Avera McKennan Hospital and University Health Center's Institutional Review Board approved this study, and it conformed to the recommendations of the Declaration of Helsinki.

Procedures

Familiarization Testing. In the week before the start of the testing and training program, participants reported to Avera Sports Institute to become familiarized with a warm-up routine and $\dot{V}O_2$max test. After the $\dot{V}O_2$max test, the investigator explained the concepts of V_{max}, V_{LT}, and T_{max}. The participants completed the same warm-up routine before every testing and training session throughout the 6-week program. For all performance testing, the investigator instructed the participants to arrive in a rested and hydrated state and to avoid caffeine, alcohol, and strenuous exercise in the 2 days preceding a test session. Participants were also shown how to complete a food diary for the 3 days before baseline testing and asked to replicate this diet before the posttraining session. Additionally, attempts were made to ensure all participants completed pre- and posttesting procedures at approximately the same time of day. All testing days were separated by ≥48 hours.

Performance Testing. Within 7 days of completing the $\dot{V}O_2$max test familiarization trial, participants undertook their performance tests. These performance tests took place on 2 separate days, with day 1 consisting of an incremental running test to determine $\dot{V}O_2$max, V_{max}, and V_{LT} and day 2 testing involving a T_{max} test. The $\dot{V}O_2$max test consisted of using a Physio-Dyne MAX-II Metabolic Cart (AEI Technologies, Inc., Bastrop, TX, USA), which the investigator calibrated before each test, and having the participants complete 2-minute stages on a Super Treadmill (Standard Industries, Fargo, ND, USA) set to a 1% grade (7). The investigator modified the initial treadmill speed for each individual to determine a comfortable starting speed. At the completion of each 2-minute stage, a 30-second pause occurred at which time the investigator collected a fingertip blood sample by using a 2.0 × 1.5 mm BD Microtainer single-use contact-activated lancet (Becton, Dickinson and Co., Franklin Lakes, NJ, USA) and Lactate Plus portable lactate analyzer (Nova Biomedical, Waltham, MA, USA) (7). During each blood sample collection, the investigator prepared the fingertip by cleaning it with alcohol and drying it with a gauze pad using a sterile technique.

With each subsequent stage of the $\dot{V}O_2$max running test, the investigator increased the treadmill speed by 0.8 km per hour. The investigator used the following criteria to determine the participant's $\dot{V}O_2$max: (a) a respiratory exchange ratio > 1.10, (b) an ending heart rate within ± 10 $b \cdot min^{-1}$ of age-predicted HRmax (220 − age) (18), (c) no further increase in O_2 consumption despite an increased work rate, and (d) volitional exhaustion. In determining V_{max}, the investigator required the participant to complete at least 90 seconds of the 2-minute stage; if the participant completed less than 90 seconds of the 2-minute stage, then V_{max} was defined as the treadmill speed from the previous stage. Regarding blood lactate measurements, the investigator defined the participant's lactate threshold as that speed which elicited a 1 $mmol \cdot L^{-1}$ rise above baseline (12).

The assessment of T_{max} took place on day 2 of performance testing, and after arriving at the training facility, the participants performed the same warm-up routine described above. After a 5-minute pause, the investigator set the Super Treadmill to a 1% grade and the participant's previously determined V_{max} and the participant then mounted the Super Treadmill and ran as long as possible. During the T_{max} test, each participant received verbal encouragement to run to volitional exhaustion. For both the $\dot{V}O_2$max and T_{max} tests, the investigator had the participants wear a heart rate monitor (Polar RS400 Heart Rate Monitor; Polar Electro Oy, Kempele, Finland). Heart rate data were collected in 5-second increments and downloaded to a personal computer after each testing session. Additionally, heart rate data were collected in a similar manner for G_{Hill} and G_{Flat} during each of the 4 weekly training sessions and downloaded to the same personal computer after each training session. Within 48–72 hours of the last training session, each participant repeated the day 1 testing procedures. After an additional 48–72 hours of rest, each participant repeated day 2 testing procedures.

Training Protocol. Before beginning the investigation, all participants regularly engaged in moderate-intensity run training 3–4 times per week; however, none routinely performed high-intensity interval training in the 3 months preceding the training intervention. During the training intervention, G_{Hill} performed 2 high-intensity interval sessions and 2 continuous running sessions per week. G_{Hill} high-intensity interval sessions consisted of completing 10–14 bouts for 30 seconds on a treadmill set to a 10% grade while running at 100% V_{max}. Additionally, rest durations between interval bouts lasted for the time it took heart rate to return to 65% of the individual's age-predicted maximum (65% HRmax). For the days on which continuous run training took place, G_{Hill} participants ran on a treadmill set at 1% grade (to more closely replicate overground running) (27) and 75% V_{max} for 45–60 minutes. G_{Flat} also completed 2 high-intensity interval sessions and 2 continuous running sessions per week. G_{Flat} high-intensity interval running sessions consisted of completing 4–6 bouts for a duration equal to 60% T_{max} on a treadmill set to a 1% grade and 100% V_{max}. G_{Flat} participants also used rest durations between interval bouts that lasted for the time it took heart rate to return to 65% HRmax. During each of the continuous running sessions, G_{Flat} participants also ran for 45–60 minutes at a treadmill velocity and grade set to 75% V_{max} and 1% grade,

Table 1. The 6-week training protocol for the 2 high-intensity interval training groups (G_{Hill} and G_{Flat}) and the control group (G_{Con}).

	Sessions per week	Bouts per session	Intensity	Work duration	Rest duration
G_{Hill}	2	10–14	100% V_{max}	30 s	65% HRmax
	2	1	75% V_{max}	45–60 min	NA
G_{Flat}	2	4–6	100% V_{max}	60% T_{max}	65% HRmax
	2	1	75% V_{max}	45–60 min	NA
G_{Con}	NA	NA	NA	NA	NA

respectively. Participants in G_{Con} continued their normal weekly training programs (4.9 ± 0.07 days per week, 270.4 ± 81.6 minutes per week) away from the training facility. During the 6-week training intervention, G_{Con} completed daily training diaries, which the investigator analyzed at the end of the intervention.

All testing and high-intensity interval training sessions involved use of a Super Treadmill, which raises and lowers hydraulically, offers a running belt area measuring 51 × 183 cm, and has elevation and speed capacities ranging from −10 to 40% and 0 to 48 km per hour, respectively. On days the participants completed a continuous running session, they used a Precor, Inc. 932i treadmill (Woodinville, WA). The specifications of the Precor, Inc. 932i treadmill include a running belt area measuring 56 × 142 cm and elevation and speed capacities ranging from 0 to 15.0% and 0 to 19.3 km per hour, respectively. Calibration of all treadmills for speed and incline occurred weekly. The principal investigator administered and monitored all G_{Hill} and G_{Flat} high-intensity interval training sessions on the Super Treadmill and gave "spotting" assistance as a safety precaution when needed. Additionally, on days during which the testing and training sessions involved using the Super Treadmill, participants gathered real-time visual feedback on running form via a 91 × 183-cm wall-mounted mirror in front of the Super Treadmill. The 6-week group-assigned training protocol appears in Table 1.

Statistical Analyses

For all data analyses, the investigator used the statistical analysis program JMP (v.8.0.2; SAS Institute, Cary, NC, USA). Descriptive statistics of each outcome variable, including mean, standard deviations, and tests of normality were determined. All dependent variables ($\dot{V}O_2max$, V_{max}, V_{LT}, and T_{max}) were assessed for percent change and analyzed with a 1-way analysis of variance to determine differences between groups. A mixed design repeated measures analysis of variance (3 × 2) was used to test for the effect of training and training group on $\dot{V}O_2max$, V_{max}, V_{LT}, and T_{max}. A significance level of $p \leq 0.05$ was set for all statistical analyses and, where significance was found, a Tukey post hoc test was performed.

Results

Body Mass and $\dot{V}O_2max$

Table 2 highlights the training investigation's effect on body mass and $\dot{V}O_2max$. Both before and after the intervention, a significant difference existed in body mass between G_{Con} and the 2 high-intensity training groups; however, no significant changes in body mass occurred in any of the groups or between groups in response to the training. Concerning $\dot{V}O_2max$, no significant differences existed between groups before or after training and no alteration in $\dot{V}O_2max$ occurred in any of the groups over the course of the 6-week investigation.

Total Weekly Exercise Dynamics

Table 3 highlights the differences among the 3 groups in total weekly exercise time. During each 2-week microcycle of the 6-week training intervention, G_{Con} spent considerably more time exercising compared with G_{Hill} and G_{Flat} and this difference proved significant. In brief, G_{Con} spent more than double the time exercising during each 2-week microcycle.

High-Intensity Interval and Continuous Run Dynamics

Table 4 shows a comparison of the high-intensity interval

Table 2. Pre- vs. posttraining values for body mass and maximal oxygen uptake ($\dot{V}O_2max$).†

	G_{Hill}	G_{Flat}	G_{Con}
Body mass (kg)			
Pre	65.8 ± 12.2	66.0 ± 7.1	62.6 ± 7.5*
Post	65.3 ± 12.5	66.0 ± 6.9	62.3 ± 6.9*
% Δ	−0.1 ± 2.2	0.0 ± 1.3	−0.6 ± 2.1
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)			
Pre	63.3 ± 8.0	59.4 ± 8.9	59.9 ± 8.6
Post	62.7 ± 7.0	59.6 ± 7.6	58.3 ± 7.9
% Δ	−0.4 ± 8.1	0.8 ± 5.5	−2.6 ± 3.9

*Significantly different from G_{Hill} and G_{Flat} both pre- and posttraining ($p < 0.05$).
†Data are mean (±*SD*).