Combined Uphill and Downhill Sprint Running Training Is More Efficacious Than Horizontal

Giorgos P. Paradisis, Athanassios Bissas, and Carlton B. Cooke

Paradisis is with Physical Education and Sport Science, University of Athens, Athens, Greece, and Bissas and Cooke are with Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.

Purpose: This study examined the effects of sprint running training on sloping surfaces (3°) on selected kinematic and physiological variables.

Methods: Fifty-four sport and physical education students were randomly allocated to one of two training groups (combined uphill–downhill [U+D] and horizontal (H)) and a control group (C). Pre- and posttraining tests were performed to examine the effects of 8 wk of training on the maximum running speed (MRS), step rate, step length, step time, contact time, eccentric and concentric phase of contact time (EP, CP), flight time, selected posture characteristics of the step cycle, and 6-s maximal cycle sprint test.

Results: MRS, step rate, contact time, and step time were improved significantly in a 35-m sprint test for the U+D group ($P < .01$) after training by 4.3%, 4.3%, −5.1%, and −3.9% respectively, whereas the H group showed smaller improvements, (1.7% ($P < .05$), 1.2% ($P < .01$), 1.7% ($P < .01$), and 1.2% ($P < .01$) respectively). There were no significant changes in the C group. The posture characteristics and the peak anaerobic power (AWT) performance did not change with training in any of the groups.

Conclusion: The U+D training method was significantly more effective in improving MRS and the kinematic characteristics of sprint running than a traditional horizontal training method.

Keywords: Kinematic sprinting characteristics, posture characteristics, 6-s maximal cycle sprint test

Many training methods have been used to improve maximal sprint running performance by effecting changes in step length and step rate. Running on sloping surfaces is widely used in training for sprint running.[1] Previous studies have examined kinematic changes of sprinting on a 3° slope and reported an 8.4% faster maximum running speed (MRS) for the downhill and 2.9% slower MRS for the uphill slope when compared with horizontal sprinting.[2,3] Kunz and Kaufmann4 examined sprinting on a 1.7° slope and reported similar results, whereas Slawinski et al[24] found decreases in MRS, step rate, and step length by 15.6%, 7.4%, and 14.2% respectively when sprinting in 4.9° uphill slope. Positive claims have been made for the effects of downhill and uphill training on the kinematic characteristics on horizontal running,[1,5] but only two studies have reported experimental data. Tziortzis[6] showed that after 12 wk of training on a downhill slope of 8° the MRS increased by 2.1% and the step length increased by 1.4%, whereas the step rate did not change. Paradisis and Cooke[7] have reported that after 6 wk of training on a downhill slope of 3° the MRS increased by 1.1% and the step rate increased by 2.3%, whereas the step length did not change. For uphill training, Tziortzis[6] reported that the MRS and step rate increased by 3.3% and 2.4% respectively, although the changes in step length were not statistically significant, whereas Paradisis and Cooke[7] reported no statistically significant changes after the uphill training.

There have also been positive claims for the benefits of training on combined uphill and downhill sloping surfaces, although again these claims have not been substantiated with published experimental data.[1,5] Only Paradisis and Cooke[7] have assessed the effects of 6 wk combined uphill–downhill sprinting training, on sloping surfaces of 3° and showed improvements on MRS and step rate by 3.5% and 3.4% respectively. In addition, the horizontal training and control groups did not produce any statistically significant changes.

The aim of this study was to evaluate further the effects of 8 wk of training on combined uphill and downhill sloping surfaces of 3° compared with both training on the horizontal and a control group in terms of the kinematic and posture characteristics of sprinting and performance in the 6-s maximal cycle sprint test (MCST). The current study will, therefore, either confirm or refute the findings of the previous preliminary study[7] using more appropriate group sizes and provide a comparison of training effects for 8 wk with those reported for 6 wk.

METHODS

Fifty-four male sport and physical education students participated in this study (age 24.1 ± 2.1 years, mass 75.3 ± 10.2 kg, height 1.75 ± 0.08 m). All subjects were active in different sports but none was a sprinter; their mean MRS was 8.20 ± 0.74 $m \cdot s^{-1}$. However, to participate in this study, all subjects were asked to terminate any other sport activity. Informed consent was obtained from each participant before data collection, where the study was granted with ethics approval by the appropriate board of the university. A wooden uphill–downhill platform was used and it was covered with synthetic track surface. The width of the platform was 1.20 m and the total distance covered was 80 m: 20 m horizontal, 20 m uphill at 3° slope, 10 m horizontal, 20 m downhill at 3° slope, and 10 m horizontal (Figure 1).

Training

The participants were randomly assigned to three groups:

• U+D was trained on the uphill-downhill platform (n = 18)

• H was trained on the horizontal (n = 18)

• C was the control group and did not train (n = 18)

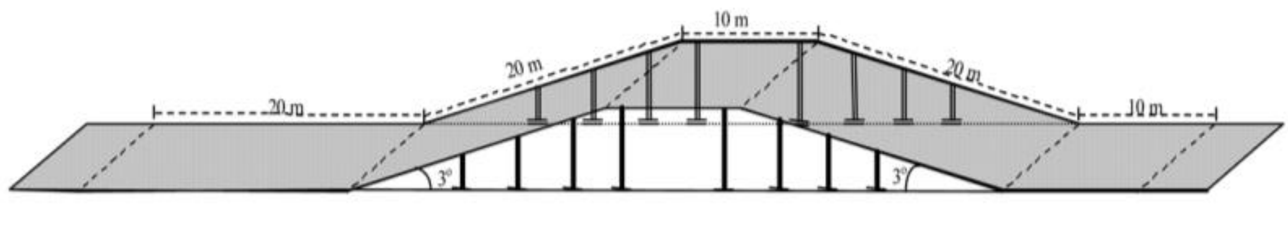

Figure 1 The uphill-downhill platform.

After completion of a 20-min warm-up, both training groups performed 6 x 80 m sprints at maximal intensity per session, three times a week, where the time between repetitions (10 min) was sufficient for the participants to recover fully.[8] This training program continued until the fourth week, after which one repetition was added for both training groups, for each of the remaining 4 wk (training sessions for the last week were 10 x 80 m). Group C maintained their normal physical activities throughout the experimental period without performing any kind of training.

Testing

Pre- and posttraining tests were employed to evaluate the effects of training on the kinematic and posture characteristics of sprinting and AWT performance. The sprints were performed in a corridor 60 m long and 2.5 m wide in the biomechanics laboratory, and the floor was covered with a synthetic track surface (tartan) 55 m long and 2.5 m wide. The corridor was well lit and the ambient temperature was 25o C. After completion of a 20-min warm-up, the participants performed three maximal sprint runs over a 35-m distance using a standing start. The time between the repetitions (10 min) was sufficient for the participants to recover fully.[8] The adoption of three trials for each participant was to establish the magnitude of variability associated with repeated trials.

A Kodak EktaPro 1000 high-speed video camera was used to collect recordings of the sagittal plane of a full stride (two consecutive steps) of all three maximal sprint runs, sampling at 250 Hz. Filming was performed with the camera placed at the 35-m distance (so it should be near to MRS as evidence from the literature has showed that MRS is achieved at about 30 m[9,10]) and 10 m from the performance plane such that its optical axis was approximately horizontal, forming an angle of 90° with the horizontal plane of running. For the digitization process, a metal calibration frame (2 x 2 m) was filmed such that the x-axis was parallel to the horizontal and the y-axis was perpendicular to the horizontal.

Analysis of the Video Data

The hardware of the digitizing system comprised a video projector Imager LCD 15E (General Electronic, USA), a TDS Graphic tablet and controller (x,y resolution, 0.025 mm; active area 1.20 x 0.90 m), interfaced with an IBM computer that ran the digitizing program DIGIT (Leeds Metropolitan University). A standard 17-point,11 14-segment model of the human performer based on the data of Dempster[12] was used to represent the human performer and to calculate the position of the center of mass. Reliability of the digitizing process was established in previous study[3] by repeated digitizing of one sprinting sequence at the same sampling frequency with an intervening period of 48 h. Contact time, flight time, step time, step length, flight distance, step rate, and MRS were calculated according to methods reported previously.[3] The comparison of left and right foot contact times was performed using the limits of agreement method (calculating the mean ± *s* of the differences between left and right feet, where the boundaries of agreement based on the expression $\delta \pm 1.96\sigma$).13 Additionally, the following were calculated according to methods reported previously3: the touchdown and take-off angles of the knee (α), hip (β), shank to running surface (γ), trunk to running surface (δ; trunk angle was determined by the line between the hip and glenohumeral joints of the right side of the body), and the distance parallel to the running surface between a line perpendicular to the running surface that passes through the center of mass and the contact point at touchdown (DCM TD) and at take-off (DCM TO; Figure 2).

6-s Maximal Cycle Sprint Test

A 6-s maximal cycle sprint test (MCST) was used to determine the peak anaerobic power and consisted of a 6-s maximal sprint on a modified cycle ergometer (Monark 814E) against a braking force of 0.075 $kg \cdot kg^{-1}$ of body mass. This test was included to establish whether any adaptations to training transferred to a different mode of exercise than that used in sprint running training. These data will be useful in characterizing the specific and general responses to sprint training using running on sloping surfaces. Initially, the participants were instructed to perform a warm-up activity for 5 min by cycling at 60 rpm with 1.5 kg of load. After a 5-min rest period, each participant performed three all-out trials and the best of the three trials was analyzed. The participants were instructed to attain an initial pedaling frequency of 80 rpm with 0.5 kg of resistance. When this pedal rate was achieved, the load was applied and the participants accelerated, pedaling maximally for 6 s. The time between repetitions (10 min) was sufficient for the participants to recover fully.[8]

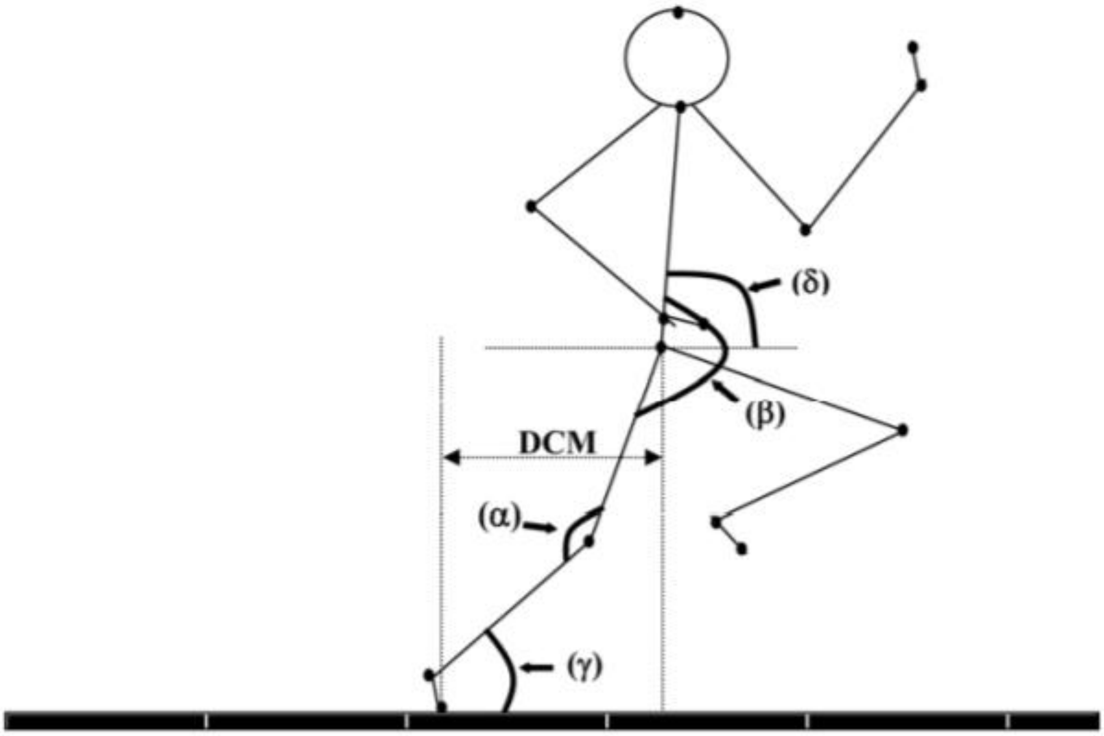

Figure 2 Location of the body landmarks and visualization of the angles: knee (α), hip (β), shank to running surface (γ), trunk to running surface (δ), and the distance parallel to the running surface between a line perpendicular to the running surface that passes through the center of mass and the contact point at touchdown and takeoff. Note that in terms of simplicity the ipsilateral and contralateral hip/glenohumeral joints appeared to be in the same position; however, this was not the case.

Statistical Analysis

A three-way ANOVA with repeated measures on two factors (trial and test) was used to establish if there were any significant differences between the trials, the tests (pre and post) and the groups (training groups) and any interaction effects. Each dependent variable was analyzed using a separate ANOVA. A multivariate analysis of variance, used to analyze all dependent variables, was not completed as there were insufficient participants for the required degrees of freedom. In the event of significant main effects, a post hoc Tukey test was used to locate the differences. The significance level for the tests was set at $P < .05$.

RESULTS

Comparison of the Three Trials

To assess the consistency between the three trials, a comparison was performed across the groups. Factors that could affect the consistency include fatigue, lack of familiarization, boredom, natural variation, insufficient warm-up, and lack of motivation. There was no significant difference in all the analyzed variables between the three trials for all the groups.

Comparison of Left and Right Leg

In the analysis of the pre- and posttraining tests, contact time was measured from the left foot throughout. This was justified through a comparison of left and right foot contact times using the limits of agreement method.[13] The mean ± *s* of the differences between left and right feet was 0.001 ± 0.003 s and the boundaries of agreement were −0.008 and 0.005 s (heteroscedasticity correlation was close to zero). Given these results it was concluded that there were no significant differences between the contact times for the left and right foot.

Effects of Different Training Methods

Kinematic Characteristics. MRS increased significantly after 8 weeks of training for the U+D group by 4.3% and for the H group by 1.7%, whereas for the control group did not change significantly (Table 1). In the U+D group, all participants produced increases in the MRS (0.35 ± 0.21 $m \cdot s^{-1}$, ranged from 0.10 $m \cdot s^{-1}$ to 0.89 $m \cdot s^{-1}$), whereas in the H group thirteen participants increased their MRS (0.21 ± 0.15 $m \cdot s^{-1}$, ranged from 0.05 m·s−1 to 0.53 $m \cdot s^{-1}$). Finally, the repeated-measures ANOVA showed no significant differences between the groups for all the pretraining tests.

Similarly, step rate increased significantly for U+D group (4.3%) and H group (1.2%), whereas it did not change significantly for the C group (Table 1). Fifteen participants increased their step rate for the U+D (0.23 ± 0.10 Hz, ranged from 0.04 Hz to 0.39 Hz), whereas in the H group 14 participants increased their step rate (0.06 ± 0.05 Hz, ranged from 0.01 Hz to 0.15 Hz).

Table 1 Mean ± SD of the three trials (post- to pretraining values) of the kinematic characteristics of all groups

		MRS ($m \cdot s^{-1}$)	SR (Hz)	SL (m)	CT (ms)	FT (ms)	ST (ms)
U+D	Pre	8.25 ± 0.69	3.98 ± 0.32	2.07 ± 0.11	128 ± 18	125 ± 11	253 ± 20
	Post	8.60 ± 0.68	4.15 ± 0.38	2.08 ± 0.15	121 ± 15	121 ± 12	243 ± 22
	P	0.001	0.001	0.763	0.001	0.052	0.001
	CI	0.28 to 0.43	0.11 to 0.24	-0.037 to 0.028	4.3 to 8.6	0.9 to 7.5	6.1 to 13.8
H	Pre	8.12 ± 0.40	3.91 ± 0.14	2.02 ± 0.08	128 ± 11	128 ± 10	256 ± 10
	Post	8.26 ± 0.42	3.96 ± 0.17	2.03 ± 0.07	125 ± 11	127 ± 10	253 ± 11
	P	0.010	0.001	0.396	0.001	0.175	0.001
	CI	0.03 to 0.23	0.02 to 0.07	-0.032 to 0.013	1.0 to 3.3	-0.4 to 2.3	1.5 to 4.6
C	Pre	8.20 ± 0.86	4.05 ± 0.20	1.99 ± 0.18	125 ± 6	122 ± 9	247 ± 13
	Post	8.16 ± 0.81	4.04 ± 0.20	1.98 ± 0.18	126 ± 5	123 ± 9	248 ± 13
	P	0.180	0.200	0.887	0.508	0.439	0.058
	CI	-0.019 to 0.096	-0.009 to 0.041	-0.012 to 0.013	-1.4 to 0.7	-2.2 to 1.0	0.2 to 6.0

Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, C = control group, CI = confidence interval, MRS = maximum running speed, SR = step rate, SL = step length, CT = contact time, FT = flight time and ST = step.

The contact time decreased significantly for U+D group (5.1%) and H group (1.7%) after the 8 weeks of training, whereas it did not change significantly for the C group (Table 1). Sixteen participants reduced their flight time in the U+D group (8 ± 5 ms, range = 1 to 19 ms), whereas 15 participants reduced it in the H group (5 ± 4 ms, range = 1 to 15 ms).

Step time decreased significantly for U+D group by 3.9% and for H group by 1.2%, whereas for the C group it was not significantly different (Table 1). Fifteen participants shortened their step time for the U+D group (14 ± 6 ms, range = 3 to 23 ms), whereas 14 participants shortened it for the H group (4 ± 3 ms, range = 1 to 9 ms).

Finally, step length remained unaltered for U+D, H and C groups (Table 1), the flight time showed a trend toward a decrease by 3.1% for the U+D group after the 8 weeks of training but this was not statistically significant. The step length for the H and C groups remained unaltered (Table 1).

Concentric and Eccentric Phases of Contact. The concentric phase of the contact time decreased significantly for the U+D group after the 8 weeks of training (11.5%), whereas for the H and C groups it did not change significantly (Table 2). There were no significant changes in the eccentric phase of the contact time for all groups, after the 8 weeks of training (Table 2).

Posture Characteristics. There was generally a small effect on the posture characteristics for touchdown and take-off after the 8 weeks of training. The U+D group showed significant changes in the knee (3°) and shank (3°) angles for the contact phase and the hip angle (6°) for takeoff after the 8 weeks of training, whereas the H group showed significant changes in the hip angle during the contact phase by 3° and during the takeoff phase by 2°. The C group did not show any significant changes (Table 3 and Table 4).

Table 2 Mean ± SD (post- to pretraining values) of the eccentric and concentric phases of all groups

		U+D	H	C
EP (ms)	Pre	53 ± 9	56 ± 7	57 ± 8
	Post	53 ± 9	55 ± 6	56 ± 9
	P	0.954	0.745	0.456
	CI	-4.1 to 3.9	-4.4 to 6.0	-1.9 to 4.1
CP (ms)	Pre	75 ± 19	70 ± 12	67 ± 10
	Post	67 ± 17	69 ± 14	69 ± 10
	P	0.003	0.614	0.069
	CI	3.5 to 14.0	-3.4 to 5.5	-3.6 to 0.1

Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, C = control group, CI = confidence interval, EP = eccentric phase of contact time, CP = concentric phase of contact time.

Table 3 Mean ± SD (post- to pretraining values) of the posture characteristics at contact

		Knee (o)	Hip (o)	Shank (o)	Trunk (o)	DCM (m)
U+D	Pre	144 ± 7.4	135 ± 7.0	91 ± 5.4	82 ± 4.8	0.30 ± 0.06
	Post	147 ± 7.2	132 ± 5.7	94 ± 4.7	80 ± 4.9	0.32 ± 0.04
	P	0.001	0.091	0.001	0.183	0.069
	CI	1.56 to 4.27	-0.44 to 5.47	1.24 to 4.85	-1.02 to 4.95	-0.048 to 0.002
H	Pre	151 ± 6.2	134 ± 5.5	92 ± 3.9	78 ± 3.3	0.30 ± 0.03
	Post	149 ± 5.1	137 ± 3.8	92 ± 4.6	78 ± 3.8	0.29 ± 0.02
	P	0.244	0.0012	0.479	0.663	0.836
	CI	-1.36 to 4.93	1.08 to 5.78	-2.23 to 1.10	-3.49 to 2.29	-0.06 to 0.07
C	Pre	146 ± 2.0	133 ± 3.7	92 ± 3.5	77 ± 2.7	0.30 ± 0.03
	Post	147 ± 3.1	134 ± 4.0	93 ± 4.0	78 ± 3.8	0.30 ± 0.04
	P	0.078	0.101	0.055	0.096	0.678
	CI	-1.77 to 0.11	-1.60 to 0.16	-1.71 to 0.02	-1.53 to 0.14	-0.01 to 0.02

Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, C = control group, CI = confidence interval, DCM = the distance parallel to the running surface between a line perpendicular to the running surface that passes through the center of mass and the contact point.

Table 4 Mean ± SD (post- to pretraining values) of the posture characteristics at takeoff

		Knee (o)	Hip (o)	Shank (o)	Trunk (o)	DCM (m)
U+D	Pre	164 ± 6.5	207 ± 7.8	42 ± 4.7	84 ± 5.4	0.60 ± 0.06
	Post	162 ± 8.6	201 ± 6.6	42 ± 5.1	82 ± 5.4	0.61 ± 0.06
	P	0.194	0.001	0.705	0.087	0.486
	CI	-1.03 to 4.72	1.97 to 8.52	-0.96 to 1.38	-0.46 to 6.23	-0.03 to 0.01
H	Pre	164 ± 5.5	203 ± 5.1	43 ± 3.2	84 ± 2.0	0.60 ± 0.04
	Post	163 ± 7.1	205 ± 2.9	43 ± 3.3	84 ± 2.2	0.60 ± 0.03
	P	0.162	0.002	0.811	0.832	0.250
	CI	-0.68 to 3.68	0.27 to 3.48	-1.58 to 1.99	-1.34 to 1.10	-0.01 to 0.02
C	Pre	164 ± 4.1	204 ± 4.3	42 ± 1.2	83 ± 0.9	0.60 ± 0.05
	Post	165 ± 5.3	203 ± 3.4	42 ± 1.2	83 ± 1.6	0.58 ± 0.05
	P	0.411	0.245	0.053	0.347	0.056
	CI	-2.91 to 1.26	-0.39 to 1.39	-1.26 to 0.01	-0.35 to 0.94	-0.01 to 0.02

Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, C = control group, CI = confidence interval, DCM = the distance parallel to the running surface between a line perpendicular to the running surface that passes through the center of mass and the contact point.

Peak Anaerobic Power. The results of the best trial of the 6-s MCST showed no significant differences between the pre- and posttraining tests for the MCST for any group (from 1207.7 ± 172.9 to 1219.3 ± 187.3 W for U+D, from 1085.4 ± 188.9 to 1098.3 ± 198.8 W for H group and 1067.3 ±1076.7 ± 291.9 W for the C group). These findings suggested that the training had not increased the ability to generate a higher peak anaerobic power output in an alternative mode of exercise.

DISCUSSION

The methodological procedures used for digitization and calculation of kinematic and posture variables, for the comparison of repeated trials and for the comparison of the left and right step shown to be consistent enough for the effective comparison of adaptations to various sprint training methods against a control group. There were no significant differences between the pre- and posttraining tests for all the analyzed variables in the C group, where other studies[6,14,15] reported similar results. The results of the current study were not influenced by a learning effect, which means that the familiarization of the subjects before the pretraining test was sufficient. Therefore, it can be argued that if any pre- to posttesting changes occurred, these could be attributed as the effect of the training.

The H training method produced significant increases in MRS (1.7%) and step rate (1.2%), whereas contact time decreased (1.7%) as did step time (1.2%) after training, with only minor changes in posture characteristics. Dintiman[16] after 8 wk of horizontal training, observed an improvement of 5.2% in performance for 50 m, whereas Suellentrop[17] found a 2.5% improvement in 100-m performance after 6 wk of training, but there are no experimental data regarding changes in step rate, step length, contact time, and flight time, in the literature. However, as the correlation between MRS and performance is very high (r = .90)[18,19] it can be concluded that the current study has produced findings that are consistent with those predicted by the limited literature for subjects of similar level of expertise. The results of this study showed that traditional horizontal training produced small improvements in step rate, contact and step time, variables that influence MRS.

The U+D training produced an increase in MRS of 4.3%, which were accompanied by an increase in step rate by 4.3%, whereas the step length did not change. The increase in step rate was mainly due to a shorter step time (−3.9%), which was affected by the shorter contact time (−5.1%). The U+D training produced an 11.5% decrease in the concentric phase of contact time after training, whereas the eccentric phase did not show any significant changes. This is arguably the most important adaptation to training, which may account for the improvement in running speed. In addition, the shortening of the concentric (propulsive) phase and effectively the shortening of contact time could be interpreted as an improvement of muscle power.[1,21,25] However, in the context of this study the suggestion of improvements in the force-time (power) muscle's characteristics is hypothetical, as no measurement of power was conducted. In addition, the lack of changes in the eccentric phase is rather surprising, as a reduction of this phase was expected. Slawinski et al showed the vastus lateralis was less active but for a longer time during the concentric phase in uphill sprinting of ~3° (MRS 6.28 ± 0.38 $m \cdot s^{-1}$), whereas no differences occurred during the eccentric phase.[24] However, Gottschall and Kram showed a decrease in eccentric impulse and an increase in the concentric impulse during similar uphill sprinting.[29] The role of eccentric and concentric phases in the improvement of MRS as well as the changes of the muscles activation during uphill and downhill sprinting needs move evaluation.

Despite the significant changes that occurred in almost all the kinematic variables after the training period, U+D training did not produce significant changes in the posture characteristics. The only exception was an increase in the shank angle of 3° at contact, which can be explained by the increase of the knee angle (3°) and a decrease in the hip angle at take off by 6°, all of which can be explained by the decrease of the concentric phase. It can therefore be concluded that the combined uphill–downhill training method did not significantly alter the subject's running technique.

Overall, the superiority of the U+D training method was clear from the results, with statistical analysis demonstrating that the improvements produced were significantly greater than for the H training method. There are few reports in the literature concerning the effects of U+D training methods, suggesting that a combination of training methods (uphill and downhill) should produce better results than any other training method[1] and indicating that a combination of uphill and downhill training would produce significant improvements in all the kinematic characteristics of sprint running.[20–22] These suggestions are supported by the findings of the current study, which showed that the combined method of training on the uphill, horizontal, and downhill produced significant improvements in almost all the kinematic variable analyzed. In contrary, the results indicated that the training employed did not improve performance in the 6-s maximal cycle sprint test. It seems that the generation of forces to produce peak power in the 6-s test is based on a different adaptation to that seen in the sprint running groups, which was not stimulated with the specific sprint running training regimen used in the current study.

It can be argued that a faster sprinting speed could be attained by shortening the step time while the step length remained the same. The step time could be shortened by reducing the contact time and keeping the flight time the same, as was the case for the U+D group. However, if the contact time was shortened and the muscle force remained the same, the impulse produced by the muscles would decrease ($I = F \times t$). In such a scenario, the gain from a shortened contact time should be lost by producing a smaller step length, but step length did not change in the U+D group. So, as the impulse would be the same and the contact time shortened, the muscle force must be increased to produce a higher step velocity. As the MRS was increased, the contact time was shortened and the step length remained the same in the U+D group, it could be hypothesized that muscle force was improved. This hypothesis is partially supported by Wood's[23] conclusion that to increase MRS, athletes should increase the muscle force of the hamstring. Studies have demonstrated enhanced muscular loading applied to the hip, knee and ankle extensors[25–28] during uphill running (in lower range of speed ~4.5 $m \cdot s^{-1}$), whereas Slawinski[24] showed a decreased activation of the hamstrings muscles during contact time (running at 6.28 $m \cdot s^{-1}$) in ~3° uphill running; however, no data are available regarding muscle activation during downhill running. It seems that there may be a link between the force-time characteristics of the muscles and the production of shorter contact time and eventually the production of greater MRS, but this needs further evaluation, since in the context of this study no measurement of muscle force was conducted.

A comparison of the findings from the current study with those previously published7 showed a greater magnitude of training response in the current study, in similar subject expertise (the MRS, step rate, contact time, and step time were improved for the U+D group by 4.3%, 4.3%, 5.1%, and 3.9% respectively, whereas in the previous study[7] the MRS, step rate, and step time were increased by 3.5%, 3.4%, and 3.3% respectively, but the contact time did not change significantly). It is possible that the greater magnitude of change in the current study might be partly due to the longer training period, as the subjects' level of expertise was similar (8 wk vs. 6 wk in the previous study[7]). This suggests that the specific training adaptations associated with the combined uphill–downhill methods continue while the training stimulus is applied. However, this particular interpretation must be made with caution, since the only way such a claim can be objectively evaluated is to monitor the training adaptations longitudinally throughout the training program. Further work is therefore required to substantiate this suggestion, but the magnitude of training response for the U+D method is certainly encouraging in comparison with horizontal sprint training.

During running on the platform, subjects experience a 20-m resistive stimulus (uphill), followed by a 10-m normal stimulus (horizontal) and after that a 20-m facilitative stimulus (downhill). During the resistive stimulus the neuromuscular system will be overloaded owing to extra resistance (5% of the body weight because of the 3° slope).[7] By repetitive application for a certain time, the body will adapt to that extra load and as a result some trends of change in the MRS and kinematic characteristics of horizontal running occur. However, in downhill, an extra propulsive force (5% of the body weight because of the 3° slope) produces a supramaximal speed.[7] During the uphill part of the platform, the MRS would be reduced by 2.9% whereas during the downhill part the MRS would be increased by 8.4%, producing a net increased in the average running speed, over the whole distance (80 m), compared with maximum horizontal running.[2] With training, the body adapts to this stimulus and increases MRS by improving some of the kinematic characteristics. The results of both the previous[7] and present studies suggest that this quick transition from the first stimulus to the second, from one form of overload to another, benefited the neuromuscular system. The immediate transition from the overload status to the facilitated status seems to be a key factor in enhancing the training adaptation. However, to investigate some of the possible mechanisms that produce this adaptation further work is needed. It is important to identify the effects of training on the maximum force and the force-time characteristics from the dominant muscles during sprinting, to have some information on possible cause and effect.

PRACTICAL APPLICATIONS

The U+D training method was significantly more effective in improving the maximum sprinting speed and the associated kinematic characteristics of sprint running in active sports subjects than an equivalent horizontal training method, with little change in running posture. The correlation coefficient between MRS and resulting performance in the 100 m was reported as 0.90 and 0.96 for male and female sprinters respectively, indicating the importance of the maximum speed for high-level performance.[30,31] Similarly, Tziortzis[6] found a correlation 0.88 between MRS and resulting performance. Susanka et al,[31] interpreting these results, reported that MRS seems to be the most important factor in male sprinters in the 100-m race. So, it could be speculated that the combined uphill–downhill training method is more effective in improving performance in short distance sprinting events. This study therefore provides further objective evidence substantiating the efficacy of the combined U+D training method for improving maximum horizontal sprinting speed, which is important in a range of sports, including athletics and a variety of major team games.

REFERENCES

1. Dintiman G. Sprinting: *What research tells the coach about*. Washington DC: AAHPER publications; 1974.

2. Paradisis G, Cooke CB, Bissas A. Sloping surface sprinting kinematics and running posture. *J Sports Sci*. 1988;16:13–14.

3. Paradisis G, Cooke CB. Kinematic and postural characteristics of sprint running of sloping surfaces. *J Sports Sci*. 2001;19:149–159.

4. Kunz H, Kaufmann D. Biomechanics of hill sprinting. *Track Technique*. 1981;82:2603– 2605.

5. Costello F. Resisted and assisted training to improve speed. *Track Field Q Rev*. 1976;81:27.

6. Tziortzis S. Effects of training methods in sprinting performance. Doctoral Dissertation. University of Athens, Dept. of Physical Education and Sport Science, Athens, Greece. 1991.

7. Paradisis G, Cooke CB. The effects of sprint running training on sloping surfaces. *J Strength Cond Res*. 2006;20(4):767–777.

8. McArdle W, Katch F, Katch V. *Exercise Physiology: Energy, Nutrition and Human Performance*. London: Lea & Febiger; 1991.

9. Murase Y, Hoshikawa T, Yasuda N, Ikegami Y, Matsui H. Analysis of the changes in progressive speed during 100 meter dash. In: Komi PV, ed. *Biomechanics V-A*. Baltimore: University Park Press; 1976:200–207.

10. Moravec P, Ruzicka J, Susanka P, Dostal E, Kodejs V, Nosek M. The 1987 International Athletic Foundation / IAAF Scientific Project Report: time analysis of the 100 metres events at the 2nd World Championships in Athletics. *New Stud Athletics*. 1988;3:61–96.

11. Plagenhoef S. *Patterns of Human Motion: a cinematographic analysis*. New Jersey: Prentice Hall, Inc; 1971.

12. Dempster WT. *Space requirements of the seated operator. WADC Technical Report*. Dayton, OH: Wright-Patterson Air Force Base; 1955.

13. Bland JM, Altman G. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;i:307–308.

14. Gutoski FP. Effects of force treadmill sprint training on selected physiological parameters. Doctoral Dissertation. University of Edmonton, Alberta; 1974.

15. Irwin D. A study of stride length and stride rate changes after high speed treadmill and sprint training. Master Dissertation. University of Alberta; 1974.

16. Dintiman G. Effects of various training programs on running speed. *Res Q Exerc Sport*. 1964;35:456–463.

17. Suellentrop JM. A variation of Russian Downhill sprint training for selected College students. Master Dissertation. Southern Illinois University at Carbondale; 1979.

18. Komi PV. Stretch-shortening cycle. In: Komi PV, ed. *Strength and Power in Sport*. London: Blackwell; 1992:169–179.

19. Pauletto, B. Speed-power training. *Scholastic coach*. 1993;63:54-55.

20. Milakov M, Cox V. Improving speed by training on sloping surfaces. *Track Technique*. 1962;8:254–255.

21. Mero A, Komi PV. Effects of supramaximal velocity on biomechanical variables in sprinting. *Int J Sport Biomech*. 1985;1:240–252.

22. Verkhoshanky YV. Speed training for high level athletes. *New Stud Athletics*. 1996;11:39–49.

23. Wood GA. Biomechanical limitations to sprint running. *Med Sport Sci*. 1987;25:58– 71.

24. Slawinski J, Dorel S, Hug F, et al. Elite long sprint running: A comparison between incline and level training sessions. *Med Sci Sports Exerc*. 2008;40:1155–1162.

25. Delecluse C, Van Coppenolle H, Willems E, Van Leemputte M, Diels R, Goris M. Influence of high-resistance and high-velocity training on sprint performance. *Med Sci Sports Exerc*. 1995;27:1203–1209.

26. Roberts TJ, Belliveau RA. Sources of mechanical power for uphill running in humans. *J Exp Biol*. 2005;208:1963–1970.

27. Sloniger MA, Cureton KJ, Prior BM, Evans EM. Anaerobic capacity and muscle activation during horizontal and uphill running. *J Appl Physiol*. 1997;83:262–269.

28. Sloniger MA, Cureton KJ, Prior BM, Evans EM. Lower extremity muscle activation during horizontal and uphill running. *J Appl Physiol*. 1997;83:2073–2079.

29. Gottschall JS, Kram R. Ground reaction forces during downhill and uphill running. *J Biomech*. 2005;38:445–452.

30. Baumann W, Schwirtz A, Gross V. Biomechanik des Kurzstreckenlaufs. In: Ballreich A, Kuhlow A, eds. *Biomeckanik der Leichtathletik*. Stuttgart: Enke Verlag; 1986:1– 15.

31. Susanka P, Moravec P, Dostal E, et al. *Fundamental motor abilities and selected biomechanical variables related to performance in 100 m OG Seoul 1988*. Monaco: IAF; 1988.