Effect of Combined Uphill-Downhill Sprint Training on Kinematics and Maximum Running Speed in Experienced Sprinters

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ABSTRACT
This study examined the effects of sprint running training on sloping surfaces (3°) in experienced sprinters using selected kinematic variables. Twelve experienced sprinters were randomly allocated to two training groups (combined uphill–downhill and horizontal). Pre- and post-training tests were performed to examine the effects of six weeks of training on maximum running speed, step rate, step length, step time, contact time, braking and propulsive phase of contact time, flight time and selected postural characteristics during a step cycle in the final steps of a 35m sprint test. In the combined uphill–downhill training group, maximum running speed was substantially greater (from 9.08 ± 0.90 m s-1 to 9.51 ± 0.62 m s-1; p <0.05) after training by 4.8%; step rate, contact time, step time and concentric phase was not modified. There were no significant changes in maximal speed or sprint kinematics in the horizontal training group. Overall, the posture characteristics did not change with training. The combined uphill–downhill training method was substantially more effective in improving the maximum running speed in experienced sprinters than a traditional horizontal training method.

Key words: Cadence, Posture, Sprint Running Training, Stride Length

INTRODUCTION

Sprinting is essential to success in many sports and many different training methods have been used to improve sprinting performance. Running with maximum speed on sloping surfaces is a widely used training method aiming to create an additional stimulus for speed improvement. It has been demonstrated that maximum running speed (MRS) was 8.4% faster ($p < 0.05$) while sprinting on a 3° downhill slope and 2.9% slower ($p < 0.05$) while sprinting

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on a 3° uphill slope, when compared to horizontal sprinting [1]. Similar results have been reported while sprinting on 1.7° slopes [2], whereas sprinting on a 4.9° uphill slope decreased MRS by 15.6% [3].

Besides these acute effects of slopes on sprinting, training on downhill slopes (3°) for 6 weeks produced significant increases ($p < 0.05$) in MRS (1.1%) and step rate (2.3%) [1]. Under similar training conditions (duration, volume, and intensity) sprint training on a 3° uphill slope did not produce any significant changes in MRS for physical education (PE) students [1]. However, training for 6 to 8 weeks on the combined uphill-downhill (U+D) sloping surfaces (3°) produced superior improvements ($p < 0.05$) for both MRS (from 3.5% to 5.9%) and step rate (from 3.4% to 7.4%) when compared to any other training method on sloping surfaces [1, 4, 5]. These improvements in MRS and step rate were predominantly due to a 17% shorter concentric phase of the contact time [5]. Interestingly, these changes were linked to the observed improvements in the force generation properties of the leg flexor muscles. The U+D training improved the maximal bilateral isometric force by 7.1% and the relative and absolute time of force production by 24.7% [5]. These findings supported the emphasized role of the hamstring muscle group in the sprint action as the main energy supplier for the forward propulsion action during contact time [6-8].

Taken together, these results suggest that the U+D training method was more effective in improving the MRS and associated kinematic and kinetic characteristics of sprint running than an equivalent horizontal or downhill training method. However, having demonstrated the effects of the U+D method on PE students who were not engaged in specific speed training, it was important to examine the ecological validity of this training method and establish its efficacy with experienced sprinters. This is because it is important to establish the extent to which different training responses to stimuli are dependent on training status. Hence, the aim of this study was to evaluate the effects of the U+D (3°) training program, compared to the responses of training on the horizontal, on the kinematics of sprinting in experienced sprinters. This study will therefore either confirm or refute the findings of the previous uphill-downhill training studies in a sample of experienced sprinters. We hypothesized that training on U+D for 6 weeks would result in significant favourable changes in MRS and the associated kinematical variables, whereas training on the horizontal would not produce significant modifications in the kinematic characteristics of experienced sprinters.

METHOD

In order to test the hypothesis of the study and to establish the extent to which different training responses to stimuli were dependent on previous training status [1, 4, 5], an experienced sprint training specific group was selected (MRS, step length and rate were 8.98 ± 0.90 m s^{-1}, 2.09 ± 0.15 m and 4.31 ± 0.28 Hz respectively for the participants in the present study compared with 8.15 ± 0.65 m s^{-1}, 2.02 ± 0.09 m and 4.05 ± 0.22 Hz respectively for the participants in the previous studies).

PARTICIPANTS

Twelve experienced 100m – 200m sprinters (three females with MRS ranging from 7.56 to 8.25 m s^{-1} and 100 m best times ranging from 13.35 to 12.66 s and nine males with MRS ranging from 8.39 to 10.37 m s^{-1} and 100 m best times ranging from 12.53 to 10.59 s) participated in this study (age 25.3 ± 2.9 years; mass 71.2 ± 9.4 kg; height 1.75 ± 0.06 m). Participants have 8.6 ± 12 years of training experience in sprinting, and have been engaged in regional and national level competitions. Before the commencement of the study, participants were informed of the risks involved and gave written consent, as well as agreeing to refrain from any other sport activity during the period of the study. All procedures involved in this study conformed to the Declaration of Helsinki, and were reviewed and approved by the University's research ethics committee before initiation of the research.

PROCEDURES

A 80 m wooden uphill-downhill platform was used, which consisted of: a 10 m horizontal, 20 m uphill at 3° slope, 10 m horizontal, 20 m downhill at 3° slope and 20 m horizontal (Figure 1). The uphill-downhill platform was 1.20 m wide and covered with synthetic track surface. The participants were randomly assigned to the U+D group, which was trained on the uphill-downhill platform (n = 6) or the control group, which was trained on the horizontal (n = 6). Both training groups performed 6 × 80 m sprints per session at maximal intensity, after completion of a 20-minute warm-up, three times a week for six weeks. The time between repetitions (10 min) was deemed to be sufficient for the participants to fully recover [9]. This training program continued until the fourth week after which one repetition was added for each of the remaining weeks.

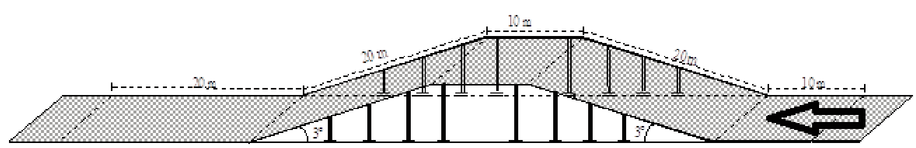

Figure 1. The uphill-downhill platform

PRE- AND POST- TESTING

Pre- and post-training tests were conducted to quantify the effects of training on the kinematic characteristics of sprint running. Participants performed three maximal horizontal sprint runs over a 35 m distance using a standing start in an indoor runway covered with a synthetic tartan track surface after completion of a 20-minute warm-up. The time between repetitions (10 minutes) was sufficient for the participants to recover fully [9]. The best of the three trials, based on MRS values, was selected for further analysis. Participants attended 3 familiarization sessions in which they were familiarized with testing procedures, and on the last day, the participant's age, height and mass were recorded.

KINEMATIC ANALYSIS

A Kodak EktaPro 1000 high speed video camera (512 × 384 resolution, Hamburg, Germany), sampling at 250 Hz, was used to collect recordings of the sagittal plane for a full stride (two consecutive steps). Filming was performed with the camera placed at the end of the 35 m runway and 10 m from the performance plane such that its optical axis was horizontal, with an angle of 90° to the horizontal plane of running. Running speed should be near to its maximum at 35 m after the start, as it has been shown that MRS for non-elite sprinters is achieved between 30-40 m [10]. For the digitization process, a 2 x 2 m metal calibration frame was filmed such that the x-axis was parallel to the horizontal, and the y-axis was perpendicular to the horizontal.

A digitizing system (a video projector Imager LCD 15E; LG, Berkshire, UK), a TDS Graphic tablet (London, UK) and controller (x,y resolution, 0.025 mm; active area 1.20 x

0.90 m) and a digitizing program DIGIT (Leeds, UK) was used to analyse the video data. A standard 17-point, 14-segment model based on the data of Dempster [11] was used to represent the human performer and to calculate the position of the centre of mass. Reliability of the digitising process has been established [1] by repeated digitising of one sprinting sequence at the same sampling frequency with an intervening period of 48 hours. Contact, flight and step time, step length, step rate, MRS, touchdown and take-off angles of the knee, hip, shank and trunk to running surface, and the distances between the centre of mass, the foot's contact points at touchdown (DCM TD) and at take-off (DCM TO) (Figure 2) were calculated according to methods reported previously [1]. The braking phase was defined by the downward movement of the centre of mass, with a decreasing knee and ankle angle and the propulsive phase by the upward movement of the centre of mass and increasing angles at the knee and ankle.

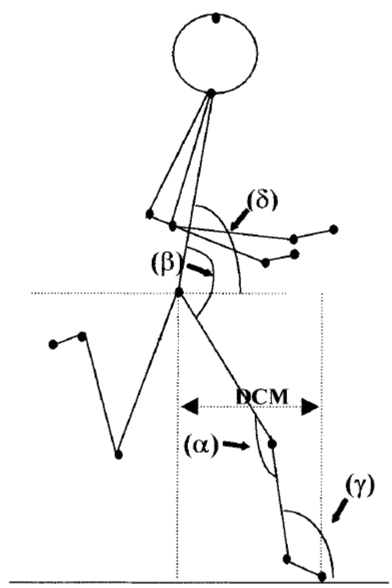

Figure 2. Location of the body landmarks and visualization of the angles DCM = the distance parallel to the running surface between a line perpendicular to the running surface which passes through the centre of mass and the contact point; α = angle of the knee; β = angle of the hip; γ = angle of shank to running surface; δ = angle of trunk to running surface.

STATISTICAL ANALYSIS

A two-way repeated-measures ANOVA was used to establish if there were any significant differences between the pre and post training tests, the training groups and any interaction effects for each variable. Data normality was tested with the Kolmogorov-Smirnov test, and for all the repeated-measures ANOVAs the assumption of sphericity was tested. Given that this assumption was not violated, no adjustments to significance values were required. In the event of significant main effects or interactions, Tukey post-hoc tests were used to identify the differences. The significance level for all tests was set at $p < 0.05$. In addition, effect sizes using Cohen' s [14] criterion (d) (effect sizes defined as "small, d = 0.2," "medium, d

= 0.5," and "large, d = 0.8"), the magnitude of the mean ± SD of pretest to posttest differences (MΔ) and the 95% confidence limits (95%CL) and power estimation were used for data interpretation.

RESULTS

Statistical analysis revealed no significant differences between the groups for all the pre-training tests. This suggested that the randomization process produced groups that are similar at baseline, and therefore provides a sound basis to compare U+D against horizontal training. Additionally, as there were no significant differences between the contact times for the left and right foot, contact time were reported from the left foot throughout the study.

There was a significant interaction between groups and pre-post tests for MRS ($F = 7.142$; $P = 0.023$, $\eta p^2 = 0.417$, power = 0.674). Post hoc analysis showed that MRS increased after 6 weeks of training only for the U+D group by 4.8% (U+D: P = 0.002, d = 0.56, MΔ = 0.43 $m \cdot s^{-1}$, 95% CL ± 0.24 $m \cdot s^{-1}$; horizontal: P = 0.774, d = 0.03 $m \cdot s^{-1}$) with all U+D participants producing increases in their MRS (range from 0.08 to 1.02 $m \cdot s^{-1}$). There were no other significant interactions between groups and pre-post training tests or any other main effects for the remaining kinematic variables, even though all variables for U+D training group showed trends towards improvement (Table 1).

There was no significant interaction effect between the groups and pre-post test data for the braking and propulsive phases of contact time after the 6 weeks of training. Although the change was not significant, there was a 6.9% trend towards an improvement in the propulsive phase for the U+D group, which is a large effect size (d = 0.89, Table 1).

There was a significant 4% increase for the shank angle during touchdown in the U+D group ($F = 10.810$; $P = 0.008$, $\eta p^2 = 0.519$, power = 0.841; post hoc test for U+D: p = 0.003, d = 1.10, MΔ = 4.00 degrees, 95% CL ± 4.35 degrees). However, there was no modification in the remaining body posture characteristics for touchdown and take-off after the 6 weeks of training (Table 2).

DISCUSSION

The purpose of this study was to examine the ecological validity of the U+D training method for experienced trained sprinters. The results of this study support a positive effect of this training method on MRS in experienced sprinters. In all the similar previous studies, there were no significant differences between the pre- and post-training tests for all the analysed variables in the control group [1, 4, 5]. This was partly due to the adequate familiarization of the participants before the pre training tests were completed, which ensured that the results were not influenced by a learning effect. Also, even though the participants were not specialist sprinters they were regularly training for sprinting for their respective sports, so the standardized horizontal control sprint training would be expected to maintain their sprint performance. Given the fact that the present study used the same methods and familiarization procedures and the groups were similar at baseline, any significant pre- to post-training changes can be confidently attributed to the effects of the training.

The comparison of the pre and post training tests showed that MRS was improved by 4.8% after the six weeks of training for the U+D group of experienced sprinters. The correlation coefficient between MRS and resulting performance in the 100 metres has been reported as 0. 900 [12] and 0.934 [13], indicating the importance of MRS for sprint race performance. The findings from the present study are comparable with those of previous studies [1, 4, 5] in which PE and sports science students improved MRS from 3.5% to 5.9%. These results indicate that the effects of the U+D training method were similar for both the

Table 1. Mean ± *s* and % differences (post-pre training values) of the kinematic characteristics of all groups

		MRS (m s^{-1})	SR (Hz)	SL (m)	CT (ms)	FT (ms)	ST (ms)	BP (ms)	PP (ms)
U+D	Pre	9.08 ± 0.90	4.44 ± 0.27	2.05 ± 0.18	107 ± 8	119 ± 9	226 ± 14	49 ± 8	58 ± 6
	Post	9.51 ± 0.62*	4.51 ± 0.29	2.12 ± 0.20	106 ± 7	117 ± 15	223 ± 14	51 ± 9	54 ± 2
	MΔ	0.43 ± 0.36	0.07 ± 0.34	0.07 ± 0.15	-1 ± 7	-2 ± 14	-3 ± 18	3 ± 7	-1 ± 5
	d	0.56	0.25	0.37	0.13	0.16	0.21	0.24	0.89
H	Pre	8.87 ± 0.97	4.18 ± 0.29	2.12 ± 0.12	108 ± 11	132 ± 11	240 ± 17	56 ± 8	52 ± 11
	Post	8.90 ± 0.94	4.17 ± 0.28	2.13 ± 0.12	106 ± 9	134 ± 12	241 ± 11	55 ± 9	51 ± 9
	MΔ	0.03 ± 0.13	-0.01 ± 0.07	0.01 ± 0.03	-2 ± 3	3 ± 4	1 ± 4	-1 ± 4	-4 ± 6
	d	0.03	0.04	0.08	0.20	0.20	0.07	0.12	0.10

* Significantly different from pre-training ($p < 0.05$) as determined by repeated-measures analysis of variance and post-hoc Tukey tests. Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, MΔ = the magnitude of the mean difference of pretest to posttest ± the 95% confidence limits, d = Cohen's criterion effect size, MRS = maximum running speed, SR = step rate, SL = step length, CT = contact time, FT = flight time and ST = step time BP = braking phase of contact time, PP = propulsive phase of contact time

Table 2. Mean ± *s* and % differences (post-pre training values) of the posture characteristics at contact and take off

		MRS (m s-1)	SR (Hz)	SL (m)	CT (ms)	FT (ms)	ST (ms)	BP (ms)	PP (ms)
U+D	Pre	9.08 ± 0.90	4.44 ± 0.27	2.05 ± 0.18	107 ± 8	119 ± 9	226 ± 14	49 ± 8	58 ± 6
	Post	9.51 ± 0.62*	4.51 ± 0.29	2.12 ± 0.20	106 ± 7	117 ± 15	223 ± 14	51 ± 9	54 ± 2
	MΔ	0.43 ± 0.36	0.07 ± 0.34	0.07 ± 0.15	-1 ± 7	-2 ± 14	-3 ± 18	3 ± 7	-1 ± 5
	d	0.56	0.25	0.37	0.13	0.16	0.21	0.24	0.89
H	Pre	8.87 ± 0.97	4.18 ± 0.29	2.12 ± 0.12	108 ± 11	132 ± 11	240 ± 17	56 ± 8	52 ± 11
	Post	8.90 ± 0.94	4.17 ± 0.28	2.13 ± 0.12	106 ± 9	134 ± 12	241 ± 11	55 ± 9	51 ± 9
	MΔ	0.03 ± 0.13	-0.01 ± 0.07	0.01 ± 0.03	-2 ± 3	3 ± 4	1 ± 4	-1 ± 4	-4 ± 6
	d	0.03	0.04	0.08	0.20	0.20	0.07	0.12	0.10

* Significantly different from pre-training ($p < 0.05$) as determined by repeated-measures analysis of variance and post-hoc Tukey tests. Abbreviations: U+D = combined uphill and downhill training group, H = horizontal training group, MΔ = the magnitude of the mean difference of pretest to posttest ± the 95% confidence limits, d = Cohen's criterion effect size, MRS = maximum running speed, SR = step rate, SL = step length, CT = contact time, FT = flight time and ST = step time BP = braking phase of contact time, PP = propulsive phase of contact time

experienced sprinters (MRS before training was 8.98 ± 0.90 m·s^{-1}) and non-specialist track and field participants (MRS before training was 8.15 ± 0.65 m·s^{-1}). Evaluating the results of the present study together with the results of the previous studies, it can be concluded that the effects of the U+D training method are independent of the pre-training status of the participants as a similar pattern and magnitude of adaptations were observed in both non-specialist track and field athletes and experienced track and field sprinters in terms of MRS.

However, it would be very interesting if we could examine the effects of U+D training method on higher level sprinters with MRS above 10 m s^{-1}. Examining the response of one high performance participant from the U+D group, with initial MRS of 10.37 m·s^{-1} and 100 m best time of 10.58 s, it can be revealed that he increased his MRS after training by 1.1%. While in relative terms this improvement is less than the mean improvement for the group, this is to be expected for higher performing athletes with long training histories as they should already be performing closer to their potential. In absolute terms, small improvements are important in higher level sprinters, as the MRS increment for this participant would be predicted to improve 100 m sprint performance by 0.11 s. Any positive changes for such high level performers would be of ecological value to improving their performance given the margin of difference in many national and international sprint events. However, further research is needed in order to clarify the effects of U+D training in high performing sprinters with an MRS greater than 10m·s^{-1}.

Statistical analysis did not reveal any other significant change for the rest of the kinematic variables. However, looking at the pattern of the trends towards significant change, findings were similar to those that have been reported previously [1, 4, 5]. For example, the increases in MRS were accompanied by trends to increase step rate (1.5%), which was mainly due to a trend towards a shorter contact time (1.2%), the main reason for which was a trend to reduce (6.9%) the concentric phase of contact time.

Despite the significant change that occurred in MRS after the training period, U+D training did not alter the body posture characteristics, except for the shank angle at contact. Shank angle was increased by 4°, and this probably reflects the summation of the small but not significant changes that occurred in the related angles of the leg, resulting in the shank angle producing a small but significant correlation with MRS ($r = 0.34$, $p > 0.05$). Indeed, the improvement of the shank angle is accounted for by the sum of the effects of the 6° reduction of Hip angle, the 1° increase of knee angle and the 0.02 m increase of the DCM (Figure 2). It can therefore be concluded that the U+D training method did not dramatically alter the sprinters' running posture, suggesting that the changes observed were most probably due to adaptations in the neuromuscular system. The current findings are comparable with those previously published [1, 4, 5], even though participants in those studies were PE and sport science students and supported the conclusion of the previous studies regarding the negligible effects of the U+D training method on body posture when subsequently sprinting on horizontal surfaces.

The results of this study indicated that horizontal training method did not produce any significant changes in kinematics or posture, even though there were some small trends towards change in contact time (-1.8%) and flight time (2.0%), which also were similar to previous studies [1, 4, 5]. However, coaches believe that continuous horizontal sprint training could produce a plateau in athletes' MRS, due to the repetitive stimulus experienced during the training sessions [15]. It is suggested that incorporation of alternative training methods like a combination of resisted, assisted and horizontal runs may benefit the athletes [15]. The differentiated stimulus provided by the U+D training resulted in improvements of MRS and shank angle at touchdown and also the transfer of these qualities to horizontal sprint running after training on sloped surfaces.

The findings of the present study indicated that the combination of uphill, downhill and horizontal runs improved MRS. During running on the platform, participants 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 would be overloaded by the 5% extra resistance of the body weight because of the 3° slope, whereas in downhill sprinting, a 5% extra propulsive force, as a result of the 3° slope, produces a supramaximal speed [1]. Based on previous research, during uphill sprinting the MRS would be reduced by around 3% whereas during downhill sprinting the MRS would be increased by approximately 8%, producing a net increase in the average running speed, over the whole distance (80 m), compared with maximum horizontal running [16]. With training on the U+D, by repetitive application for a certain time, the body would adapt to that stimuli and increase MRS by improving some of the kinematic characteristics compared to horizontal training. The results of previous research [1, 4, 5] also suggest that the quick transition from the first stimulus (uphill) to the second (downhill), 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 when using combined uphill and downhill training. While the significant improvements in MRS are consistent with previous research, these changes were not accompanied by other significant improvements in the kinematic variables of stride length and stride frequency, the product of which defines running speed. Furthermore, there are no other significant changes in lower order kinematic variables that feature in a model of sprint running [16]. This suggests that combinations of different small but insignificant adaptations to training occurred in the U+D group that resulted in a significant group improvement in MRS.

The mechanisms outlined in a previous study regarding the link between the kinetic and kinematic characteristics in terms of training adaptation can be suggested to explain the results of this study. The most reasonable explanation for the changes in the kinematic and force production characteristics, after 8 weeks of U+D training, was the occurrence of neural adaptations. Similar adaptations have been demonstrated in strength training [9, 17, 18] and explosive training studies [19-21] which include powerful anisometric single or multi joint contractions, as in the current study. These neural adaptations could be either improvement in neural drive to the muscle, by increasing the recruited number of motor units during contractions and/or by increasing the "firing" (excitation) rate of the motor units of the trained muscles, or/and changes in the muscular coordination, by redefying the recruiting strategy between motor units of the same muscle, or a group of synergist muscles [22, 23].

Specific low or high velocity training could differentiate the organization and central command of slow and the most rapid ballistic muscle actions [24]. It has been suggested that specific high-velocity training could increase the maximal muscle shortening velocity [25] and/or the rate of onset of motor unit activation [26, 27]. Interestingly, Mero and Komi [28] suggested that supramaximal sprint training might increase the motor nerve conduction velocity which could attenuate improvements in the force generation during contact and the attainment of higher stride rates. These neural adaptations, caused by the U+D training, could predominantly occur in the type II motor units as there is a strong relationship between MRS, type II fibres and sprinting performance characteristics [29, 30]. However, the possibility of this adaptation in the current training study was not tested and therefore it is not known if this accounts for the improvement in MRS.

Step rate, contact time and concentric phase did not statistically change after U+D training, even though they produced similar patterns of trends towards change with those reported previously [1, 4, 5]. This could be either the small number in the training groups (n = 6), or the background of the trained sprinters. Indeed, as the participants in the present study were trained sprinters, the dose response of training might have been different compared to untrained participants. There is evidence that trained sprinters have developed more efficient kinematic movement patterns than untrained participants [28]. It was found that when relatively untrained participants were towed to supra-maximal running velocities they were unable to increase step rate above their normal maximum and responded to the increased speed with inefficient increases in step length. In contrast, experienced sprinters responded to such stimuli by increasing both step rate and step length, similar to the trends observed in the present study [28]. However, as no differences were found at maximum speeds (aside from the trained being faster than untrained), it was concluded that well-trained sprinters incorporated superior neural adaptations to high intensity sprint exercise. Additionally, it has been demonstrated that trained sprinters might have a significantly greater ability to selectively recruit fast twitch motor units compared with untrained individuals [31]. Indeed, it has been reported that sprint-trained athletes' motor unit pool requires greater stimulation from the Ia afferents in order to elicit a reflex [32]. Cross-sectional differences in neurological parameters such as nerve conduction velocity, maximum electromyogram, motor unit recruitment strategy and Hoffman reflex, are evident between sprint trained and untrained trained groups [32-35]. There is therefore some evidence to suggest a difference in muscle response between trained and untrained sprinters and this difference might be associated with the higher sensitivity of muscle receptors and the central nervous system of high performance athletes to additional stimulation [36]. However, further work is required to elucidate the role of training stimuli and the mechanisms of response in non-specialists and highly trained sprint runners.

CONCLUSION

According to the results of the present study, it can be concluded that the significantly greater improvement in MRS could be attributed to the U+D training method in experienced sprinters, when compared to the control condition of horizontal training. These results supported the conclusions of the previous studies regarding the beneficial effects of the U+D training method. The U+D training method was significantly more effective in improving the MRS at 35 m of sprint running than an equivalent horizontal training method, with little change in running posture in trained sprinters. Therefore, this study provides further objective evidence substantiating the efficacy of the combined uphill-downhill training method for improving MRS in short distance sprinting events, which is an important performance requirement in a large range of sports, such as athletics and a variety of team games.

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