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PREDICTORS OF SPRINT START SPEED: THE EFFECTS OF RESISTIVE GROUND-BASED VS. INCLINED TREADMILL TRAINING

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ABSTRACT. Myer, G.D., K.R. Ford, J.L. Brent, J.G. Divine, and T.E. Hewett. Predictors of sprint start speed: The effects of resistive ground-based vs. inclined treadmill training. *J. Strength Cond. Res. 21(3):831–836. 2007.*—There is currently no consensus with regard to the most effective method to train for improved acceleration, or with regard to which kinematic variable provides the greatest opportunity for improvement in this important performance characteristic. The purpose of this study was to determine the effects of resistive ground-based speed training and incline treadmill speed training on speed-related kinematic measures and sprint start speed. The hypothesis tested was that incline treadmill training would improve sprint start time, while the ground-based resistive training would not. Corollary hypotheses were that treadmill training would increase stride frequency and ground-based training would not affect kinematics during the sprint start. Thirty-one high school female soccer players (15.7 ± 0.5 years) were assigned to either treadmill ($n = 17$) or ground-based ($n = 14$) training groups and trained 2 times a week for 6 weeks. The treadmill group utilized incline speed training on a treadmill, while the ground-based group utilized partner band resistance ground-based techniques. Three-dimensional motion analysis was used (4.5 m mark) before and after training to quantify kinematics during the fastest of 3 recorded sprint starts (9.1 m). Both groups decreased average sprint start time from 1.75 ± 0.12 to 1.68 ± 0.08 seconds ($p < 0.001$). Training increased stride frequency ($p = 0.030$) but not stride length. After training, total vertical pelvic displacement and stride length predicted 62% of the variance in sprint start time for the resistive ground-based group, while stride length and stride frequency accounted for 67% prediction of the variance in sprint start time for the treadmill group. The results of this study indicate that both incline treadmill and resistive ground-based training are effective at improving sprint start speed, although they potentially do so through differing mechanisms.

KEY WORDS. acceleration, sprint training, performance training, sprinting kinematics, stride frequency, stride length

INTRODUCTION

For running and cutting sports, short burst acceleration is one of the major discriminators between elite and subelite athletes (1, 8). Efficient and effective training methods to improve speed are often sought after by coaches and athletes in order to enhance this important performance characteristic. While most athletes desire improved acceleration and speed, the most effective training mode to obtain improvements in these measures is unclear (2–4, 6, 8–13, 15, 17, 19, 21). Two distinctly different speed training modes, both of which aim to improve acceleration and maximum sprint speed, are utilized for performance enhancement (12, 15–17, 21). Two of the most common speed training techniques are resistive ground-based training and speed training instituted on a treadmill. Both ground-based and treadmill-based speed training techniques provide mechanical load, which has the potential to initiate adaptations to stride frequency, stride length, and ultimately, acceleration and sprinting speed. However, to our knowledge no direct comparison of these techniques has been performed to determine their effects on sprinting mechanics.

In general terms, running speed is the product of stride length and stride frequency. Attempts to improve speed must induce neuromuscular adaptations that increase either stride length or stride frequency without significant detriment to the other. Speed training on a treadmill provides load resistance based on spatial position and gravitational pull during bouts performed on inclines with greater than 0% grade. Inclined treadmill sprinting creates adaptations in stride frequency by increasing lower extremity muscle activation and through increases in joint angular velocities (15). In contrast, ground-based speed training techniques provide load via horizontal resistance (i.e., weighted sled, parachute, partner bands). Ground-based resistive techniques during training may decrease stride frequency and stride length with concomitant disruptions in upper-extremity kinematics (12). Therefore, these undesirable kinematic adjustments made during resistive ground-based training may limit the potential for positive adaptations to acceleration.

There is currently no consensus with regard to the most effective method (resistive ground-based vs. incline treadmill-based method) to train for improved acceleration, nor is there consensus with regard to which kinematic (stride length or stride frequency) variable provides the greatest opportunity for improvement in this measure. The purpose of this study was to determine the effects of resistive ground-based and incline treadmill-based speed training on sprint start time (9.1 m) and speed-related kinematic measures (4.5 m). The primary hypotheses were that the treadmill training protocol would improve sprint start time while the ground-based resistive training protocol would not affect sprint start time. The corollary hypotheses were that treadmill training would increase stride frequency without decrement to stride length and that ground-based training would not affect those kinematic variables measured during the acceleration phase of a sprint start.

METHODS

Experimental Approach to the Problem

A controlled cohort repeated-measures experimental design was employed to quantify the relative effects of 2 types of sprint training techniques. Study subjects were pretested 1 week before the initial training session. Posttesting was performed approximately 7 weeks after the pretest on subjects (4 days after the final training session). Parents or guardians and all subjects signed the informed consent approved by the Institutional Review Board before the subjects participated in the study.

Subjects

Thirty-one female soccer players (incline treadmill, *n* = 17; resistive ground based, *n* = 14) from an area high school participated in this study. The mean (±1 *SD*) age of the participants was 15.7 ± 0.5 years, with a range of 14–17 years. Prior to training both height (incline treadmill = 167.5 ± 5.3 cm; resistive ground based = 167.9 ± 6.4 cm) and body mass (incline treadmill = 61.0 ± 5.4 kg; resistive ground based = 60.4 ± 11.5 kg) were assessed and recorded for each athlete. All subjects were selected from the same school teams; each listed her primary sport as soccer and had greater than 3 years of experience participating in the sport.

Testing

Sprint Start Speed. Sprint time was measured by a photoelectric timing system (Speed Trap II; Brower Timing Systems, Draper, UT). The distance from start to finish was 9.1 m and the time was measured with an accuracy of 0.01 second. Each subject was instructed to begin in an upright stance with her self-selected toe in a forward position on the start transmitter. A self-selected start was used once the timing system was zeroed and athletes were given the "ready" signal. Timing began when toe pressure was removed and ended when the subject interrupted the infrared beam. The time for each of the 3 test trials was recorded pre- and posttraining.

Kinematics. Each subject was instrumented with 19 retro-reflective markers placed bilaterally on the greater trochanter, mid-thigh, medial and lateral knee (joint line), mid-shank, medial and lateral ankle (malleolus), posteriorly on the calcaneous, and superiorly on the dorsal aspect of the foot (between second and third metatarsals). An additional marker, placed on the left posterior superior iliac spine, was also applied to offset the right and left side to aid in the real-time identification of markers during data collection. The motion analysis system consisted of 8 digital cameras (Eagle cameras; Motion Analysis Corporation, Santa Rosa, CA) connected through an Ethernet hub to the data collection computer (Dell Computer Corporation, Round Rock, TX) and sampled at 300 Hz. Data were collected with EvaRT (Version 3.21; Motion Analysis Corporation) and imported into KinTrak (Version 6.2; Motion Analysis Corporation) for data reduction and analysis. Prior to each data collection session, the motion analysis system was calibrated to manufacturer recommendations.

Three-dimensional marker trajectories were estimated using the direct linear transformation method and filtered through a low-pass Butterworth digital filter at a cutoff frequency of 12 Hz (20). Total pelvic vertical displacement, stride length, and stride frequency captured at the 4.5-m mark during the sprint start were calculated. Three trials were recorded for each subject, and the trial with the fastest sprint acceleration time for both pre- and posttest was analyzed for kinematics.

TABLE 1. Example training protocol for weeks 1, 3, and 6 for the incline treadmill speed training group.

	Grade (%)	Time*	Sets	Speed
Treadmill training (wk 1)				
Run (6 mph)	0	10	3	
Run (7 mph)	0	45	1	
Run (6–9 mph)	10	20	3	
Run (6–8 mph)	15	20	2	
Run (6–8 mph)	20	20	1	
Hold (8–10 mph)	15	10	4	
Run (10 mph)	10	10	2	
Run (10–12 mph)	0	8	3	
Treadmill training (wk 3)				
Run (8 mph)	0	30	1	
Run/off/run (9/off/ + mph)	0	10	1	
Run (10–14 mph)	10	12	3	
Hold (10–12 mph)	15	8	3	
Run (10 mph)	20	12	3	
Run (9 mph)	25	10	3	
Run (8 mph)	30	8	3	
Run (8 mph)	35	6	3	
Run (10–12 mph)	0	20	3	
Retrograde (3–5 mph)	5	15	3	
Treadmill training (wk 6)				
Run/off/run (9/off/+ mph)	0	10	1	
Run (12–14 mph)	10	10	2	
Run (12–14 mph)	15	10	2	
Run (10–13 mph)	20	10	2	
Run (12–14 mph)	20	6	2	
Run (12–16 mph)	10	6	2	
Run (14–20 mph)	0	6	3	
Retrograde (5–9 mph)	5	10	2	
Retrograde (6–12 mph)	0	6	3	

* Time measured in seconds.

Training

Each of the 2 groups trained twice a week, for 6 weeks, with 1 of the 2 training protocols (Tables 1 and 2). All athletes participated in a minimum of 9 speed training sessions. In order to normalize the volume of training between the 2 groups, both groups performed runs that were identical in length of time. Normalization of the training run intensity was attempted by matching treadmill incline percent grade to a directed to relative resistance applied during the band-resisted runs. The intensity relationship between percent grade and directed band resistance was maintained throughout the duration of the training study. The protocol transitioned from initial training sessions with higher volume and lower intensity, progressing to later sessions with lower volume and increased intensity. For example, to lower the volume, the average length of each run fell from 16 seconds in the initial training session to 8 seconds in the final training session. Accordingly, the treadmill group utilized runs with increased inclines later in training, while the resistive ground-based group employed increased band resistance during their later training sessions.

TABLE 2. Example training protocol for weeks 1, 3, and 6 for the ground-based speed training group.

	Resistance	Time*	Sets
Ground-based training (wk 1)			
Run	None	10	3
Run	None	45	1
Run	Light	20	2
Run	Light	20	1
Run	Medium	20	1
Drum majors	Light	10	2
Run	Light	10	1
Run	None	8	1
Ground-based training (wk 3)			
Run	None	30	1
Jog to sprint	None	10	1
Run	Light	12	2
Drum majors	Light	8	1
Run	Medium	12	1
Run	Medium	10	2
Run	Heavy	8	2
Run	Heavy	6	1
Run	None	20	2
Backwards	None	15	1
Ground-based training (wk 6)			
Jog to sprint	None	10	1
Run	Light	10	1
Run	Light	10	1
Run	Medium	10	1
Run	Medium	6	1
Run	Light	6	1
Run	None	6	2
Backwards	None	10	1
Backwards	None	6	1

* Time measured in seconds.

The resistive ground-based training group used 2 conjoined medium-strength (green) rubber bands (Jump Stretch Inc., Youngstown, OH) to create resistance. The athletes were secured together, with one athlete inside each band, to provide resistance to each other (Figure 1). The athletes were instructed to give light, medium, or heavy resistance depending on the protocol. When the protocol called for no resistance, the athletes sprinted without the use of the bands. To standardize the resistance between athletes a goal distance was set for them to obtain in the prescribed time frame. For example, a light resistance required the athlete to achieve approximately 60 yd in 15 seconds, whereas the heavy resistance run required the athlete to achieve approximately 20 yd in 15 seconds. Certified strength and conditioning specialists counted seconds down during each run and gave feedback to the spotter to help standardize the resistance given to each athlete.

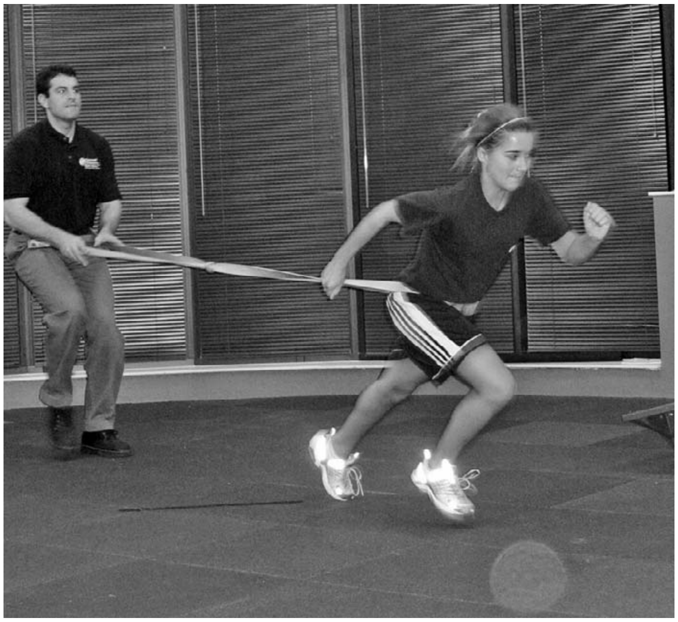

FIGURE 1. Example of partner ground-based resistive training.

FIGURE 2. Example of incline treadmill training.

The incline treadmill training group used an oversized treadmill capable of reaching speeds of up to 25 mph and inclines up to 40% in grade. The athletes ran sprints from a full speed start at inclines varying from 0° to 40° (Figure 2). The incline was matched with the level of resistance in the ground-based group by asking subjects to run at inclines that corresponded as follows: 0–5% = no band resistance, 10–15% = light band resistance, 20–25% = medium band resistance, and 30%+ = heavy band resistance.

Athletes were also given feedback regarding their biomechanical technique, specifically as it related to arm swing, stride length, foot strike, and trunk posture during training (Figure 3). This feedback was given to both groups in an attempt to optimize running gait biomechanics and to obtain consistency in technique between groups throughout the training. In addition to either the resistive ground-based or incline treadmill speed training protocols, both groups participated in identical preseason neuromuscular training, which consisted of resistance strength, plyometric, and core stability training.

Statistical Analyses

A 2-way, mixed-design multivariate analysis of variance (MANOVA) was utilized to determine the effects of training (pretest and posttest) and group (ground-based resistive and incline treadmill methods) on each dependent variable ($p \leq 0.05$). A post-hoc univariate analysis was then performed to determine which dependent variables were significantly different after training. Stepwise mul-

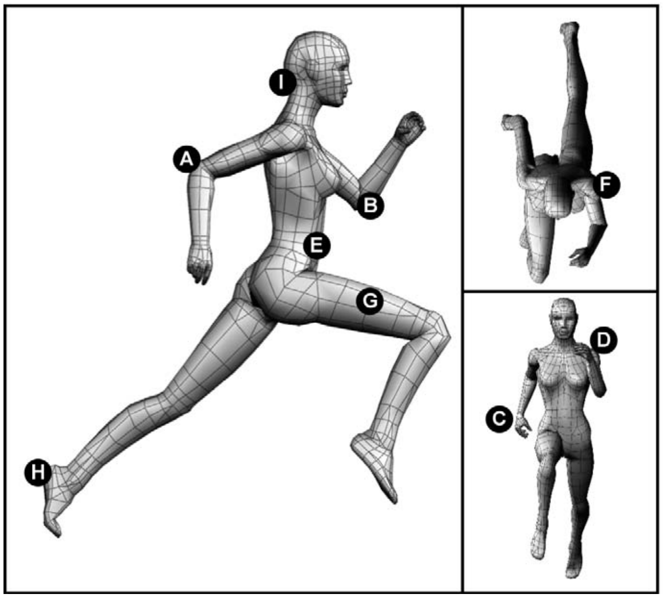

FIGURE 3. Biomechanical representation of technique guidelines provided to the study subjects during training. A) The athlete was instructed to flex her elbow to 90° and maintain this position (though slightly increased elbow extension was acceptable at the endpoint range of motion) during the back swing. B) The athlete was instructed to maintain 90° position of elbow (though slightly increased elbow flexion was acceptable at the endpoint range of motion) during the forward arm swing. C) The athlete was instructed to extend her shoulder to a point at which her wrist would swing past her hip. In addition, during the back swing the athlete was encouraged to minimize shoulder horizontal abduction by keeping her elbows in and was instructed to "brush your hip pocket with your wrist." D) During the forward arm swing the athlete was told to continue to keep her elbows close to her body but not to horizontally adduct or flex her shoulder to a point that her wrist crossed the midline of her torso; the athlete was also advised not to "take your wrist higher than your chin." E) The athlete was instructed to "maintain upright position of your torso" during sprint training. Both the inclined treadmill training and resistive ground-based training can influence forward trunk flexion beyond optimal positions. The teaching cue for torso positions was cued often for both sprint groups during training. F) The athlete was encouraged to "keep your shoulders square to the direction of travel" in order to limit torso rotation during training. G) The athlete was encouraged to "drive your thigh through" and attempt to get your thigh parallel to the ground" (90° hip flexion) during the forward leg swing. H) The athlete was instructed to initiate foot strike "on the balls of your feet" and "push off with full ankle extension." I) The athlete was encouraged to be relaxed and to avoid trying to "strain" through her sprint training bouts. The athlete was also instructed to "relax your upper torso" and to "avoid clinching or straining your jaw and neck" during training bouts.

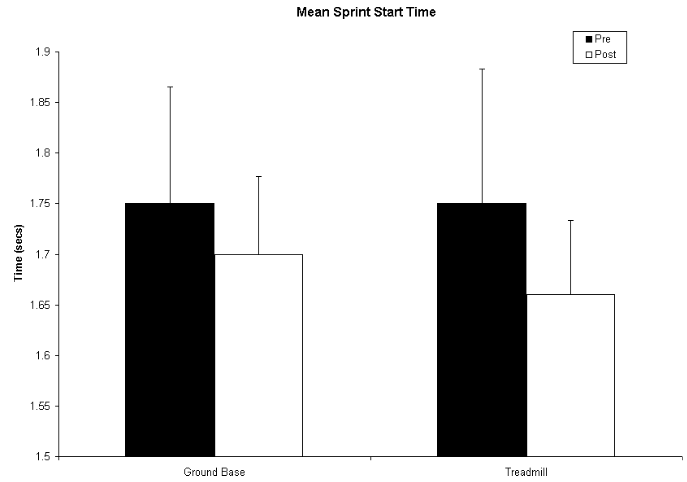

FIGURE 4. Mean (±1 *SD*) pre- and posttest times for 9.1-m sprint start for both resistive ground-based and incline treadmill training groups.

tiple linear regression was used to determine the relationships between sprint time and kinematic variables measured during the test trial (criteria $F < 0.100$). Statistical analyses were conducted in SPSS (version 12.0; SPSS, Inc., Chicago, IL).

RESULTS

A significant difference between pre- and posttraining results was found for the entire subject pool when all the dependent variables within the MANOVA were examined ($F_{4,26} = 5.91$; $p = 0.002$). Statistically significant training effects were observed in 9.1-m sprint time and kinematics for both groups; however, there were no training × group interactions. When the data from all subjects were combined, the ground-based and treadmill training decreased average sprint start time from 1.75 ± 0.12 seconds to 1.68 ± 0.08 seconds ($F_{1,29} = 16.68$; $p < 0.001$). The mean pre- vs. posttest group sprint start times are detailed in Figure 4. Training also affected total pelvic vertical displacement during the sprint start test. The mean total pelvic vertical displacement for both groups decreased from 86.94 ± 26.59 mm to 77.01 ± 18.00 mm ($F_{1,29} = 5.72$; $p = 0.024$) after training. Training also significantly increased stride frequency from 1.87 ± 0.14 Hz to 1.91 ± 0.12 Hz ($F_{1,29} = 5.93$; $p = 0.030$) with no significant effects on stride length (2.89 ± 0.19 m to 2.86 ± 0.18 m; $p = 0.234$). There were no significant effects of group ($F_{4,26} = 2.05$; $p = 0.116$) or interaction (group × training) on any of the measured variables ($F_{4,26} = 1.02$; $p = 0.415$).

A multiple regression analysis was performed to determine the potential associations between the measured kinematic variables and sprint start time. Prior to training there were no significant predictors of sprint time identified from the dependent variables in the multiple regression model. However, posttraining regression models demonstrated significant predictors of sprint start time, which were different for the 2 training groups. For the ground-based training group, as the total pelvic vertical displacement decreased the sprint start time decreased ($R = 0.69$; $SEE = 0.06$). In addition, when combined with total pelvic vertical displacement stride length, which was negatively correlated with sprint time, predicted ($R = -0.79$; $SEE = 0.05$) sprint start time in the ground-based training group. Therefore, total pelvic vertical displacement and stride length predicted 62% of the variance in sprint time in the resistive ground-based groups after 6 weeks of training. For the treadmill training group, stride length also negatively correlated to sprint time ($R = -0.56$; $SEE = 0.06$). The addition of stride frequency, which also negatively correlated with sprint start time, increased the association between variables in the regression model ($R = 0.82$; $SEE = 0.04$). In the treadmill training group, stride length and frequency accounted for 67% prediction of the variance in sprint start time.

DISCUSSION

For running and cutting sports, short burst acceleration is one of the primary discriminators between elite and subelite athletes. Coaches and athletes seek training methods to improve acceleration in order to enhance this important performance variable. While there is evidence that both modes may induce positive neuromuscular adaptations that improve sprint speed, there is currently no consensus as to the most effective method (ground-based resistive or incline treadmill method) to train for improved short burst acceleration. Likewise, it is unclear which variable, stride length or stride frequency, provides the greatest adaptation and improvement during neuromuscular training. The purpose of the current study was to evaluate 2 popular modes of speed training in order to determine their effects on speed-related kinematic measures and sprint start speed. We hypothesized that the incline treadmill training protocol would improve sprint start time, while the ground-based resistive training would not affect sprint start time. We also speculated that treadmill training would increase stride frequency without decrement to stride length and that the ground-based training would not affect kinematic variables, when measured during the acceleration phase of a sprint start. Our initial hypothesis was partially supported by the results, as the treadmill training decreased 9.1-m sprint start time and associated stride frequency. However, statistical analysis demonstrated that these improvements were not an effect of training group, as the resistive ground-based group also demonstrated improvements in the same measures.

The improvements in stride frequency were also not expected in the resistive ground-based training group, as Lockie et al. (12) reported that acute bouts of resistive sled pulling induced the undesirable effects of decreased stride length and stride frequency. These acute effects were not evident in the ground-based study group after 6 weeks of training. The improved acceleration and stride frequency agree with a recent study by Zafeiridis and colleagues (21), who utilized a similar, ground-based, resistive sled training protocol to increase acceleration performance and stride frequency.

Differences between the current study and those of the study of Lockie et al. (12) may be related to the resistance magnitude utilized. The Lockie et al. study utilized resistances of approximately 10 and 25 kg, compared to the Zafeirdis et al. study, which utilized 5-kg resistance in its training protocol (12, 21). While not quantified in the current study, the similarities between our results and those of Zafeiridis et al., with regard to increased acceleration and stride frequency, suggest that the partner band resistance used in the current study may have been of relatively lower magnitude (12, 21). Cumulatively, these data agree with the conclusion of Lockie et al., who recommended utilization of lighter resistance to maximize the training effects of resistive ground-based training (12, 21).

As was the case with the ground-based group, the incline treadmill training group also decreased average sprint start time and stride frequency after training. Several authors have contended that treadmill training is not as effective as other speed training methods based on the theory of specificity. Because high-speed incline treadmill training does not have identical kinematics or kinetics to over-ground sprinting, it may be argued that increases in performance on the treadmill may not correlate to performance while sprinting on the ground or during sports activities (5, 7, 14, 18). However, in more recent work by Swanson and Caldwell (15), high-intensity incline treadmill training similar to the training utilized in the current study induced several effects related to increased joint power and muscle activation. The improved sprint start time and stride frequency demonstrated by the incline treadmill training group in the current study support the positive effects of 6 weeks of incline treadmill training on ground-based speed measures.

Another variable that significantly changed after training was decreased vertical pelvic displacement. The decreased vertical motion of the relative center of mass, demonstrated by both groups, may be considered a beneficial adaptation to improved sprint performance; however, the exact mechanism of this change is not clear. Lockie et al. (12) reported that resistive ground-based training decreased flight time relative to unresisted sprint trials. Similarly, Nelson et al. (14) reported that running on a treadmill caused decreased vertical velocity when compared to unresisted ground running. Thus, the decreased vertical component observed in the current study may be a result of decreased flight time during resistive ground-based training or of decreased vertical displacement observed in treadmill sprint training. However, further investigation is required to evaluate whether these potential mechanisms are actually related to reduced vertical center of mass displacement following training similar to that employed during the current study. In addition, it is not clear whether the measured kinematic effects in both groups are the result of acute neurologic changes in running technique or of the initial phases of neuromuscular adaptation to the load applied during the 6 weeks of training. Future investigations of study protocols with longer durations (>6 weeks) may help to further quantify the potential for adaptation using either resistive ground-based or inclined treadmill training modes.

A multiple regression analysis was performed to determine the potential relationships of kinematics with regard to sprint start time. Prior to training there were no significant predictors of sprint time identified from the dependent variables utilized in the multiple regression model for either training group. However, posttraining regression models revealed significant predictors of sprint start time that were different for each training group. For the ground-based training group, total pelvic vertical displacement and stride length predicted 62% of the variance in sprint time. The positive correlation ($R = 0.69$) between total pelvic vertical displacement and sprint start time increased with the addition of stride length to the stepwise multiple regression model ($R = 0.79$). In other words, decreased pelvic vertical displacement and increased stride length were predicted to account for 62% of the decrease in sprint time after training with resistive ground-based training. Considering that the group as a whole increased their stride frequency, it appears that reduced interindividual variability, as evidenced by decreased standard deviation in this measure, may have allowed stride length and pelvic vertical motion to predict faster sprint times in the resistive ground-based group after training.

The incline treadmill training group also demonstrated significant predictors of sprint start time following training; however, the significant variables utilized and their order in the stepwise regression differed from those of the ground-based training group. For the treadmill training group, stride length negatively correlated to sprint start time ($R = 0.56$). The inclusion of stride frequency increased the coefficient of the regression model ($R = 0.82$), which accounted for 67% prediction of the variance in sprint start time in the incline treadmill training group. This predictive value demonstrates that increased stride length and increased stride time account for 67% percent of the cases after training for 6 weeks with incline treadmill training. Thus, the incline treadmill training group demonstrated expected predictors of speed. Interestingly, these predictors were not evident in either group of athletes prior to training.

PRACTICAL APPLICATIONS

The results of this study indicate that both treadmill and ground-based training are effective at improving sprint start speed, though potentially through differing mechanisms. Both training groups improved their sprint start time, likely through the similar mechanisms of increased stride frequency and decreased vertical pelvic displacement. However, after observing that training outcome in the resistive ground-based group was not as closely related to improvement in stride time as it was with the incline treadmill training group, it appears that the combination of decreased pelvic vertical motion and stride length dictated the posttest sprint start time in this group. Conversely, the treadmill training group relied on the more conventional improvements in stride frequency with maintained stride length to enhance sprint performance after training. Cumulatively, these data may indicate that increased potential for sprint start improvements may be achieved through a combination of these training techniques. Future study designs may include the determination of the potential combined effects of ground-based resistive and incline treadmill speed training and may quantify the effects of these training techniques on sprint measures determined at other sprint stages. Specifically, investigation of sprint mechanics beyond the acceleration phase is warranted, as is quantification of the effects of speed adaptations with training protocols of various volumes and durations. In addition, further investigation is justified to determine if the effects assessed in the female athlete population can be generalized to other athletic populations.

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