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Effects of Resisted Sled Towing on Sprint Kinematics in Field-Sport Athletes

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ABSTRACT

Weighted sled towing is a common resisted sprint training technique even though relatively little is known about the effects that such practice has on sprint kinematics. The purpose of this study was to explore the effects of sled towing on acceleration sprint kinematics in field-sport athletes. Twenty men completed a series of sprints without resistance and with loads equating to 12.6 and 32.2% of body mass. Stride length was significantly reduced by ~10 and ~24% for each load, respectively. Stride frequency also decreased, but not to the extent of stride length. In addition, sled towing increased ground contact time, trunk lean, and hip flexion. Upper-body results showed an increase in shoulder range of motion with added resistance. The heavier load generally resulted in a greater disruption to normal acceleration kinematics compared with the lighter load. The lighter load is likely best for use in a training program.

Key Words: acceleration performance, resisted sprint training, team sports

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Introduction

Speed and acceleration are essential components of team sports, such as the various football codes, basketball, and field hockey (9, 16, 20). In addition, maximum-effort sprints are often too short to allow for the attainment of peak speed for athletes in these sports (33). As a result, the acceleration period of a sprint effort becomes an important focus for any training program for such athletes.

Resisted sprint towing has become a popular training method with many sports teams and athletes (28). This can involve an athlete towing a weighted sled, tyre, speed parachute, or some other device over a set distance (13). It has been said that such techniques will increase muscular force output, especially at the hip, knee, and ankle, leading to a potential increase in stride length over time (2, 8, 10, 13, 28). Sled towing is a common resisted sprint training technique and has the added benefits of being relatively unaffected by wind patterns. It has a design that easily allows weights to be secured to the sled for added resistance and consists of the metal sled training device, nylon rope, and harness. The popularity of this training device is reflected in its inclusion in a number of recent publications (6, 14). This form of training is often used with a view to enhancing acceleration performance, even though there is little in the way of scientific evidence to support such a practice.

In a cross-sectional study, Letzelter et al. (19) analyzed resisted sled towing effects on the kinematics of 16 trained female sprinters using loads of 2.5, 5, and 10 kg. The findings showed that a 2.5-kg load caused a 5.3% decrease in stride length and a 2.4% decrease in stride frequency. At 10 kg, stride length was reduced by 13.5% and stride frequency dropped by 6.2%. The 10-kg load increased ground contact time by more than 20%, and upper-body lean by approximately 20%. Additionally, an increase of the hip joint angle was found at the start of ground contact. The authors concluded that towing loads produced slower sprint times, changed the dynamics of the stride length/stride frequency relationship, increased support times, and induced changes in upper-body lean and the tendency of ''sitting'' strides. While this study provided a profile of female sprinters running at top speed, little or no research is available on the effects of resisted sled towing on the acceleration kinematics of field-sport athletes.

The purpose of this research was to determine the kinematic variables that are altered as a result of resisted sled towing in male field-sport athletes. It is hypothesized that sprinting while towing a resisted sled will cause changes in acceleration kinematics. In addition, it is hypothesized that the effect of different loads on kinematics will vary significantly. The results of this study will provide information that will help coaches ascertain the optimal use of this training protocol.

Methods

Experimental Approach to the Problem

In order to analyze the kinematics of acceleration while towing a sled, a cross-sectional analysis of field-sport athletes was to be conducted. It was decided to use loads that resulted in approximately 10 and 20% decreases in maximum velocity over 15 m. It has been suggested in the literature that, when towing resisted sleds, an athlete's horizontal velocity should fall to approximately 90% of their maximum speed (11, 15). Trials involving the greater (20%) velocity decrease will be used to determine the effects of a heavy load on an accelerating athlete. Unfortunately, a method for calculating the load/velocity relationship in human acceleration has not been established in the literature. Consequently, a pilot study was conducted prior to the commencement of the major study.

Pilot Study

The goal of the pilot study was to develop a formula, using regression analysis, that accurately described the relationship between towing loads and the resulting sprint velocity over 15 m. This was achieved by determining the sprint velocity that results from acceleration runs, i.e., with no external resistance and towing 5, 10, 15, and 20% of body mass. Two trials were completed for each load. Ten healthy men (age = 24.9 ± 4.5 years; mass = 83.7 ± 14 kg; height = 179.9 ± 7.9 cm) volunteered to participate in the pilot study. Active participation in a field sport (i.e., field hockey, rugby union, rugby league, Australian rules football, soccer) was a requirement.

The time taken for the sprints was measured through the use of a velocimeter. The velocimeter consisted of a nylon line, which was connected to a reel, which allowed the line to unwind unimpeded when the subject began their sprint. The line was attached to the back of the subject's shorts for the unloaded sprint trials and to the back of the harness for the resisted sprints. Time splits were recorded every 1 m via an attached stopwatch (Seiko, Japan). Resistance was provided for the loaded sprints through the use of a sled device. The load required on the sled was calculated using the equation

$$\text{load} = ([\text{body mass} \times \%\text{body mass}] - \text{sled weight}),$$

where %body mass was derived as a decimal (e.g., 5% body mass = 0.05), sled weight = 4 kg.

The resultant velocities that were produced from the loads were converted to a percentage of the maximum velocity over 15 m. These percentage values were then averaged for all subjects. These values were plotted against each other in order to produce the regression equation (Figure 1).

The regression equation was derived as

$$\%\text{body mass} = (-1.96 - \%\text{velocity}) + 188.99,$$

where %velocity = the required training velocity as a percentage of maximum velocity, e.g., 90% of maximum.

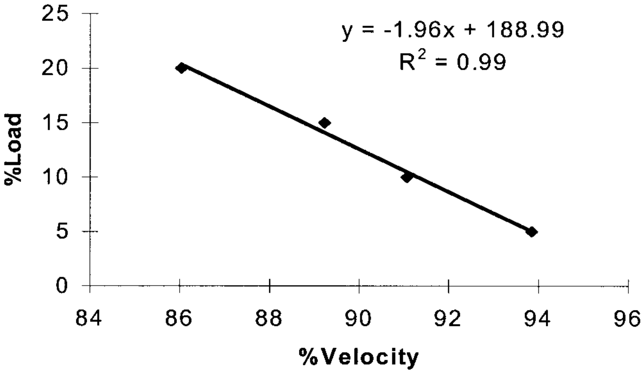

Figure 1. Regression analysis of the effect of increases in load (as a percentage of body mass) on velocity (as a percentage of maximum speed over 15 m).

The R^2 value for this equation was 0.99, which reflected the highly significant linear relationship that existed between these 2 variables. Due to this relationship, it was deemed that the formula could be confidently used in the major study to predict the speed/load relationship and allow us to control speed by using loads.

Subjects

Twenty healthy men (age = 23.1 ± 3.7 years; mass = 82.6 ± 13.1 kg; height = 179.1 ± 6.5 cm), who were currently active in field sports, volunteered to participate in this study. The same warm-up and sled from the pilot study were used for the major study. Subjects completed six sprint trials in total. These included 2 trials: (a) with no external resistance (unloaded); (b) towing 12.6% of body mass (90% of maximum 15-m velocity) (load 1); and, (c) towing 32.2% of body mass (80% of maximum 15-m velocity) (load 2).

Prior to data collection, the subject's age, height, and mass were recorded. In order to ensure consistent results, each subject was led through an identical warm-up routine, lasting approximately 15 minutes, which included sprints of increasing intensity. This study used a 15-m assessment distance for analysis, as sprint performances over this distance can be viewed as being representative of pure acceleration capabilities (23). Subjects were allowed to start in their own time. Rest periods of 1.5 minutes were allocated between unloaded trials, and for the load 1 trials. A 2-minute rest period was allocated between load 1 and load 2 trials.

The derivation of the correct load needed to reduce maximum velocity by a certain proportion was to be completed in 2 parts. The first part of the formula derived the load required as a percentage of body mass (from the pilot study) as

$$\%\text{body mass} = (-1.96 - \%\text{velocity}) + 188.99,$$

where %velocity = the required training velocity as a percentage of maximum velocity, i.e., 90 and 80% of maximum.

The following formula was used to calculate the actual load that was required to be put onto the sled that would allow the subject to run at a certain velocity:

$$\text{load} = (\text{body mass} \times [\%\text{body mass}/100]) - \text{sled weight},$$

where %body mass = the answer from the previous equation; and sled weight = 4 kg.

Kinematic Analysis

Markers were placed on the right-hand side of the body. The landmarks were the acromion (shoulder), lateral epicondyle of the ulna (elbow), midpoint between the styloid processes of the radius and ulna (wrist), anterior superior iliac spine (hip_1), greater trochanter of the femur (hip_2), lateral condyle of the tibia (knee), lateral malleolus of the tibia (ankle), and fifth metatarsal (toe). Hip_1 was used to measure horizontal hip velocity, and this velocity was used to assess horizontal running speed, as a high horizontal hip velocity indicates a good sprint performance (25).

The sprints were recorded for examination on 2 different systems, each placed perpendicular to the athlete. A Qualysis (Qualysis, Sävedalen, Sweden) system provided digital imagery, which was obtained via 2 infrared cameras, with a frame rate set at 100 Hz. From these data, horizontal hip velocity at take-off into the second stride, trunk lean at touchdown of the first stride, and maximum extension and flexion, range of motion (ROM), and average angular velocity at the shoulder, elbow, hip, and knee joints, for the first and second strides, were measured. The first 2 strides were chosen because the initial acceleration will feature the greatest changes in speed. The measured joint angles are shown in Figure 2, and these allowed for the determination of the effects of sled load on acceleration kinematics.

In addition, a JVC-DV 9800 (JVC, Tokyo, Japan) high-speed video camera provided videographic information, with a sampling rate set at 100 Hz. The data collected by this camera were used to assess stride length, stride frequency, first- and second-step flight times, and the first- and second-step contact times. For the purpose of this study, step length was taken as the distance between the initial ground contact of one foot to the initial ground contact of the other foot. Stride length was calculated as the distance from successive contacts of the same foot.

Statistical Analyses

Following data collection and analysis, means and standard deviations were calculated for all results. The 2 trials for each load condition were averaged for an individual subject mean, and subject means for each load condition were averaged to provide a group mean. A repeated-measures ANOVA was used to determine whether there was a significant interaction between dependent variables under the various resisted conditions. Significant within-subjects effects were investigated with paired T-tests using a Bonferroni adjustment. An alpha level of $p \leq 0.05$ was chosen as the criterion for significance. All statistical analyses were computed using the Statistics Package for Social Sciences (Version 10.0).

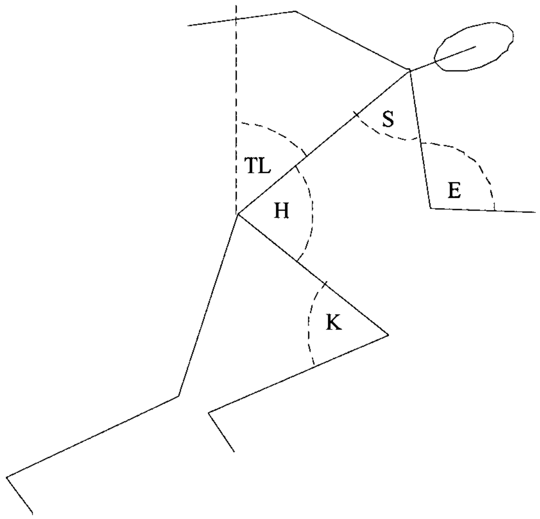

Figure 2. Joint angle conventions (TL = trunk lean; S = shoulder; E = elbow; H = hip; K = knee).

Results

Horizontal Hip Velocity

As expected, horizontal hip velocity decreased with increasing load. Loads 1 and 2 were both significantly different from the unloaded (i.e., free sprint) trial (Table 1). The load 1 and load 2 trials also significantly differed from each other. In addition, the resultant percentages of maximum speed over 15 m that were achieved during the resisted sprints related well to predicted speeds from the regression formula obtained from the pilot study (load 1 = 91% vs. 90%; load 2 = 76% vs. 80%).

Stride Length and Stride Frequency

Stride length during both loaded trials was significantly different from the unloaded trial (Table 1). In addition, mean stride lengths during load 2 trials were significantly different from the load 1 trials. Mean stride length dropped by approximately 10% for the load 1 trials and 24% for the load 2 trials. As such, it can be said that increases in towing resistance will significantly reduce stride length.

Significant differences were found between the stride frequencies for the unloaded condition and the

Table 1. Mean horizontal hip velocities, stride length, stride frequency, first (1) and second (2) step flight times, and first (1) and second (2) contact times ($N = 20$).

	Unloaded (mean ± *SD*)	Load 1 (12.6% BM)† (mean ± *SD*)	Load 2 (32.2% BM) (mean ± *SD*)
Velocity ($m \cdot s^{-1}$)	5.7 ± (0.4)	5.2 ± (0.4)*	4.4 ± (0.4)*,**
Stride length (m)	2.1 ± (0.1)	1.9 ± (0.2)*	1.6 ± (0.2)*,**
Stride frequency (Hz)	1.8 ± (0.2)	1.7 ± (0.2)*	1.7 ± (0.2)*
Flight time 1 (s)	0.05 ± (0.02)	0.04 ± (0.03)	0.03 ± (0.03)*
Flight time 2 (s)	0.06 ± (0.02)	0.05 ± (0.02)	0.03 ± (0.02)*,**
Contact time 1 (s)	0.21 ± (0.03)	0.23 ± (0.03)*	0.25 ± (0.04)*,**
Contact time 2 (s)	0.18 ± (0.02)	0.20 ± (0.02)*	0.22 ± (0.03)*,**

† BM = body mass.
* Significantly ($p < 0.05$) different from unloaded condition.
** Significant ($p < 0.05$) differences between load 1 and load 2.

load 1 and load 2 trials (Table 1). No significant changes were found between load 1 and load 2. These data suggest that increases in towing resistance (i.e., from load 1 to load 2), will lead to greater reductions in stride length compared with stride frequency.

Flight Time and Contact Time

Interestingly, for the first-step flight time, only load 2 significantly differed from the unloaded trials, decreasing by approximately 40% (Table 1). The same was true for second-step flight time, as load 2 significantly lowered this variable by approximately 50% (Table 1). It appears that a greater resistance than load 1 is needed to significantly reduce flight time.

The first-step contact times for loads 1 and 2 were both significantly different from the unloaded trial (Table 1). The same was true for second-step contact times. Load 1 led to an approximate 10% increase in the first- and second-step contacts. Load 2 increased the first contact by approximately 19% and the second contact by approximately 22%. Therefore, as resistance is increased, contact with the ground is lengthened considerably.

Upper-Body Kinematics

The effect of towing different loads on shoulder and elbow joint kinematics is shown in Table 2. Two variables at the shoulder joint and one at the elbow joint showed significant changes between the sprint trials at different loads. Second-stride shoulder extension and ROM were found to have significantly increased between the unloaded condition and load 2. That both variables are from the same cycle is no surprise because the amount of shoulder extension will directly affect the ROM about that joint.

Angular velocity during the first stride was the only variable at the elbow joint found to have any significant change with load. The load 2 condition was significantly lower compared with both the unloaded and load 1 conditions. That said, there was a wide variation between subjects for the angular velocities recorded for both cycles, as evidenced by the very large standard deviations (Table 2). While the data displays few significant changes with increases in load, trends suggest a greater use of the shoulder (and arms) during resisted sprinting (Table 2).

Significant differences existed between the trunk-lean angle obtained without resistance and the trunk-lean angles obtained under both of the resisted conditions. Average trunk lean during unimpeded acceleration was 39.1 ± 5.0°. Under added resistance, this figure increased to 42.4 ± 6.5° (load 1) and to 45.0 ± 6.6° (load 2). However, there was no difference between loads 1 and 2. The increased trunk-lean data indicates that, when sprinting with a sled of increased resistance, subjects were forced into a body position of increased forward lean (Figure 3).

Lower-Body Kinematics

Table 3 highlights the kinematics of the hip and knee joints during acceleration with different resistance. Significant differences were found for the hip flexion and ROM variables. Mean first-stride hip flexion during load 1 was significantly lower than the unloaded first-stride hip flexion. Second-stride hip flexion elicited significant changes at both loads 1 and 2 compared with the unloaded condition. This, in turn, led to significant increases in second-stride hip ROM, such that hip ROM increased by 9.4% for load 1 and by 15.2% for load 2. These data suggest that, as load and resistance are increased upon the accelerating subject, an increase in hip flexion (decreased hip joint angle) is produced upon take-off after the first stride.

Few knee-joint variables showed significant changes over the 3 sprint acceleration velocities (Table 3). Second-stride knee extension for load 2 was significantly increased compared with both the unloaded and load 1 conditions. This increased extension, however, did not lead to a significant change in the knee's

Table 2. Upper-body kinematic variables for the first (1) and second (2) stride ($N = 20$).†

	Unloaded (mean ± *SD*)	Load 1 (12.6% BM) (mean ± *SD*)	Load 2 (32.2% BM) (mean ± *SD*)
Shoulder			
Flexion 1 (°)	69.1 ± (19.5)	76.4 ± (11.3)	78.5 ± (11.1)
Flexion 2 (°)	69.9 ± (10.1)	73.1 ± (8.7)	72.5 ± (10.7)
Extension 1 (°)	72.7 ± (10.0)	71.7 ± (11.0)	71.2 ± (11.8)
Extension 2 (°)	68.2 ± (9.5)	70.0 ± (11.2)	72.9 ± (9.4)*
ROM 1 (°)	141.8 ± (22.8)	148.1 ± (14.2)	149.7 ± (12.8)
ROM 2 (°)	138.1 ± (10.1)	143.1 ± (10.7)	145.4 ± (9.6)*
Ang Vel 1 ($°\cdot s^{-1}$)	518.5 ± (123.5)	531.6 ± (59.1)	506.2 ± (69.4)
Ang Vel 2 ($°\cdot s^{-1}$)	546.7 ± (55.6)	539.0 ± (41.8)	543.9 ± (62.8)
Elbow			
Flexion 1 (°)	65.1 ± (20.9)	68.9 ± (16.9)	71.9 ± (18.1)
Flexion 2 (°)	60.1 ± (19.8)	61.7 ± (20.5)	64.8 ± (20.8)
Extension 1 (°)	134.6 ± (14.8)	133.5 ± (13.6)	132.9 ± (14.1)
Extension 2 (°)	135.3 ± (19.0)	132.4 ± (18.4)	133.1 ± (14.7)
ROM 1 (°)	69.5 ± (25.7)	64.7 ± (18.1)	61.0 ± (20.4)
ROM 2 (°)	75.1 ± (30.4)	70.7 ± (26.5)	68.3 ± (26.8)
Ang Vel 1 ($°\cdot s^{-1}$)	420.4 ± (193.1)	412.8 ± (207.7)	299.2 ± (130.7)*,**
Ang Vel 2 ($°\cdot s^{-1}$)	527.8 ± (370.3)	463.9 ± (299.9)	438.9 ± (317.9)

† BM = body mass; ROM = range of motion; Ang Vel = angular velocity.
* Significantly ($p < 0.05$) different from unloaded condition.
** Significant ($p < 0.05$) differences between load 1 and load 2.

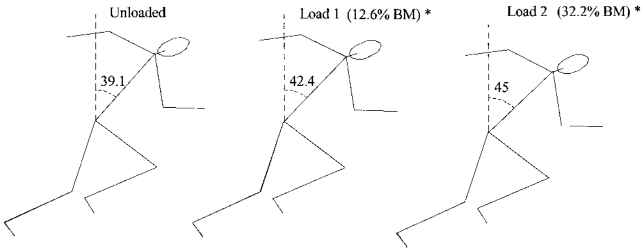

Figure 3. Increase in mean trunk lean over the 3 different load conditions (measurements in degrees). * Significantly ($p < 0.05$) different from unloaded condition.

ROM for the second stride. Additionally, the first-stride knee ROM for load 1 was significantly different from the unloaded condition.

Discussion

Resisted sprinting is a training protocol often used by field-sport athletes attempting to improve acceleration and sprinting performance. Sled towing is one form of resisted sprinting. While an increase in strength is a potential output from this training technique, conclusive documentation on the acute effects of resisted sled towing on sprint kinematics cannot be found in the research literature. Therefore, the aim of this study was to investigate the effects of resisted sled towing on acceleration kinematics in field-sport athletes.

The results of this study showed that horizontal speed will be reduced with increases in load (Table 1). Letzelter et al. (19) also reported similar results in trained female sprinters at top speed. Several authors have suggested that, when towing resisted sleds, an athlete's horizontal velocity should only fall to approximately 90% of their maximum (11, 15). Load 1 for this study achieved an average velocity drop of approximately 9% (i.e., 90% of maximum). This shows that the regression formula developed in the pilot study accurately describes the relationship between maximum velocity and resistance, and as such, can be used by coaches and trainers wishing to designate a set resisted training velocity for their athletes.

The decrease in horizontal velocity with increased load could be a function of reductions in stride length and stride frequency (Table 1). In the current study, stride length was affected by increases in resistance to a greater degree. Stride length decreased by 10% from the unloaded condition to load 1 and by 24% from the unloaded condition to load 2. In addition, loads 1 and 2 were significantly different. Conversely, there was no difference between stride frequencies for loads 1 and 2, even though stride frequency did decrease by approximately 6% between the unloaded and both loaded trials. Letzelter et al. (19) also reported this phenomenon in experienced female sprinters. The authors believed that sprinters were attempting to compensate for the large decline in stride length by overemphasizing stride frequency. This will lead to a much smaller reduction in stride frequency when compared with stride length.

Table 3. Lower-body kinematic variables for the first (1) and second (2) stride ($N = 20$).†

	Unloaded (mean ± *SD*)	Load 1 (12.6% BM) (mean ± *SD*)	Load 2 (32.2% BM) (mean ± *SD*)
Hip			
Extension 1 (°)	142.1 ± (7.3)	140.4 ± (7.7)	140.4 ± (8.9)
Extension 2 (°)	144.4 ± (5.7)	143.1 ± (6.4)	144.0 ± (7.1)
Flexion 1 (°)	87.8 ± (7.1)	83.8 ± (9.0)*	84.2 ± (9.7)
Flexion 2 (°)	96.5 ± (7.2)	90.7 ± (8.9)	90.7 ± (7.9)*
ROM 1 (°)	54.3 ± (8.3)	56.6 ± (9.0)	56.2 ± (7.9)
ROM 2 (°)	47.9 ± (6.8)	52.4 ± (8.3)*	55.2 ± (7.9)*
Ang Vel 1 (°·s^{-1})	232.8 ± (36.9)	237.5 ± (38.0)	241.1 ± (45.3)
Ang Vel 2 (°·s^{-1})	235.6 ± (53.3)	241.5 ± (31.3)	242.6 ± (35.5)
Knee			
Extension 1 (°)	151.9 ± (10.3)	155.8 ± (9.0)	154.5 ± (10.8)
Extension 2 (°)	148.0 ± (10.6)	151.6 ± (11.8)	156.4 ± (9.9)*,**
Flexion 1 (°)	68.1 ± (9.8)	66.5 ± (12.7)	67.1 ± (15.9)
Flexion 2 (°)	61.5 ± (9.3)	65.1 ± (11.8)	67.1 ± (16.6)
ROM 1 (°)	83.9 ± (14.2)	91.5 ± (16.1)*	87.4 ± (15.5)
ROM 2 (°)	86.5 ± (12.8)	86.4 ± (15.4)	89.3 ± (16.9)
Ang Vel 1 (°·s^{-1})	469.2 ± (57.7)	499.5 ± (104.6)	450.6 ± (70.9)
Ang Vel 2 (°·s^{-1})	515.0 ± (77.0)	501.6 ± (79.9)	502.3 ± (81.5)

† BM = body mass.

* Significantly ($p < 0.05$) different from unloaded condition.

** Significant ($p < 0.05$) differences between load 1 and load 2.

It has been suggested that a training effect of resisted sled towing is an eventual increase in stride length, due to increases in the propulsive force generated by the leg musculature when pushing off from the ground (2, 8, 10, 13, 28). The results in the current study certainly indicate that stride length is significantly reduced under resisted sprint conditions. However, whether these acute reductions in stride length will eventually lead to increased stride length during free sprinting needs to be investigated by further study.

Stride frequency is not commonly thought of as a variable that can be improved by resisted training mechanisms, although Artingstall (2) has suggested it is a possibility. Stride frequency did not change from load 1 to load 2 and only dropped by 6% between the unloaded and loaded trials. Thus, it can be theorized that, with increases in load, an athlete will attempt to maintain stride frequency in order to compensate for large reductions in stride length (Table 1). Indeed, the reduction in stride length will make it easier for the athlete to maintain stride frequency. These increased efforts to maintain stride frequency may, over time, result in an increase in free sprinting speed via an improved rate of striding. However, this is only speculation at this stage and further study is required.

Flight time was shortened with increases in load, while contact time was lengthened (Table 1). The decrease in flight time appears to be synonymous with the decrease in stride length. The athlete will spend less time in the air, as the length of each step, and thus the stride, are shortened. The results from this study show that acceleration contact times will be augmented with increases in load. Letzelter et al. (19) also found that contact time during maximum velocity sprinting was larger with increases in resistance. This increase in ground contact time seems to be a result of the athlete requiring more time to produce greater muscular power, in order to overcome the higher resistance, and would conceivably be appropriate for the development of hip extension power.

When coaching sprint acceleration, a great deal of technical emphasis is placed on the actions of the upper limbs. During the sprint start, it has been suggested that a vigorous arm action will assist forward drive (7, 12, 29). Bhowmick and Bhattacharyya (5) hypothesize that the horizontal acceleration of the arm swing may help to increase stride length and regulate the leg movement, while the vertical component of the arm swing creates a condition for enhanced leg drive during ground contact.

The results of this study seem to indicate that, while there were few significant changes, there is a trend toward increased arm action with increases in resisted load (Table 2). In particular, movement about the shoulder joint increased with added resistance. Thus, for coaches wishing to increase arm drive during acceleration, it appears that relatively heavy loads (i.e., load 2) may be more effective at eliciting changes in upper-body kinematics.

Trunk lean at touchdown of the first stride was greater in the loaded compared with the unloaded conditions (Figure 3). Letzelter et al. (19) also reported that trunk lean increased during maximum speed sprinting with increases in resistance. When compared with the trunk leans of an athlete leaving starting blocks, the mean trunk lean for an unloaded condition in the current study (39.1 ± 5.0°) is not as great as those measured by Atwater (4) (step 2 = 60°). However, increases in load forced the subject closer to the trunk lean shown by Atwater (4) (load 1 = 42.4 ± 6.5°, load 2 = 45.0 ± 6.6°). This body positioning could be more efficient for acceleration purposes and allow greater application of horizontal force to the ground. It must also be recognized that this body position could restrict flight time and thus lead to a shortened stride but a maintained stride frequency. Research has suggested that short strides during acceleration could in fact be beneficial (7, 22, 29, 30). It is unknown whether this position is maintained as a training effect over time.

Any reduction in the hip flexion angle means that the thigh is being brought closer to the trunk and thus flexion is actually being increased. It has been suggested that the thigh should make an angle of approximately 90° with the trunk during acceleration/sprinting (24). In the unloaded condition, first-stride mean hip flexion was 87.8 ± 7.1°, while second-stride mean hip flexion was 96.5 ± 7.2°. With increases in load, first-stride mean hip flexion decreased to 83.8 ± 9.0° (load 1) and 84.2 ± 9.7° (load 2). Second-stride hip flexion fell to 90.7 ± 8.9° (load 1) and 90.7 ± 7.9° (load 2) (Table 3).

Letzelter et al. (19) suggested that incomplete extension of the hip joint might arise when load is increased on a runner. However, in the current study, there were no significant changes in maximum hip extension for the first 2 strides during acceleration with increased loads (Table 3). In fact, all the hip extension values for both the first and second strides for all load conditions appear to relate well to hip extension values recorded by Merni et al. (25) during acceleration (144 ± 11.6°). As a vigorous extension of the lower limbs is believed to be a precursor to good acceleration performance (1, 17, 32), the fact that hip extension is not significantly reduced under resistance is a positive outcome for the current training protocol. This was possibly a result of the tight control that was placed on the relative load towed by the subjects and the use of a relatively upright starting position for the sprint tests.

As can be seen by these hip flexion data, significant changes occur when a load of approximately 13% of body mass is added to the subject. However, subsequent increases in this load do not appear to alter the hip flexion angle. This increase in hip flexion seems to signify an increase in activity of the hip flexors as they attempt to drive the leg forward during recovery, which is reduced in time (Table 1). This potential increase in hip muscle activity may lead to the development of increased strength and power. Mann et al. (21) state that the main muscle group that appears to increase gait speed is that of the hip flexors. Therefore, if hip flexion strength and power improved, this would be of benefit not only to acceleration, but potentially also to maximum velocity technique. Because of the specificity of resisted sprint training, this can then lead to higher force recruitment during free sprinting. Thus, in training, it is recommended that loads equivalent to approximately 12–13% of body mass be used. This load will encourage greater hip flexion than unloaded sprints while not negatively affecting hip extension.

Second-stride knee extension for load 2 was significantly increased compared with both the unloaded and load 1 trials (Table 3). As stated previously, it has been suggested that a vigorous and full extension of the lower limbs and thus the knee is important during acceleration (1, 17, 32). Knee extension during the second stride reached a mean value of 156.4 ± 9.9° (load 2) compared with 148.0 ± 10.6° (unloaded) and 151.6 ± 11.8° (load 1). Consequently, it can be suggested that this increase in knee extension at take off into the second stride may indicate that the athlete is attempting to gain an increase in propulsive force through a more vigorous extension of the shank segment. Thus, resisted sleds in training may be useful for a coach wishing to encourage full extension of the leg. Whether this knee action will benefit acceleration with training requires further research.

Practical Applications

Several authors have suggested that resisted sled towing will not benefit sprint performance because it will cause deterioration in sprint technique (18, 28, 31), and this will negatively alter the athlete's sprint mechanics (15, 27, 28, 31). While this study indicates that the acute effects of resisted sled towing will change some of an athlete's acceleration mechanics, this training protocol may be very useful in order to overload an athlete's sprint technique and develop the specific recruitment of fast-twitch muscle fibers, particularly compared with traditional weight training. Further research is needed to examine the longer term effects of sled towing on sprint kinematics.

The regression formula, %body mass = (−1.96 − %velocity) + 188.99, accurately describes the relationship between sled towing loads and velocity that will result from a sprint trial. The formula can be used to predict the load that is needed to cause an athlete to run at a certain velocity and could be useful for the progression of overload in a sprint training program. Load 1 (12.6% of body mass) is likely a better guide for use as a training load if a coach wishes there to be minimal disruption to sprint kinematics while still overloading key aspects of sprint kinematics such as stride length, stride frequency, and hip flexion. Load 2 (32.2% of body mass) appears to be specifically good for developing the upper-body action during acceleration. While the heavy load does cause significantly slower acceleration runs and could contravene specific high-speed muscular adaptation (3), there are still few significant changes in joint angular velocities. However, caution should be exercised when determining the volume of heavy load used during weighted sled training. Extended periods of heavy loaded sprint training may lead to lower speed, high type muscular adaptation, which would be detrimental to sprint performance. As such, it is suggested that sled training be appropriately periodized in an athlete's training program, with specific consideration given to the transfer of any muscular adaptations back to high-speed movement patterns.

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