7-1-2009

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INFLUENCE OF TOWING FORCE MAGNITUDE ON THE KINEMATICS OF SUPRAMAXIMAL SPRINTING

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ABSTRACT

The purpose of this study was to determine the influence of towing force magnitude on the kinematics of supramaximal sprinting. Ten high school and collegiate aged track and field athletes ran 60m maximal sprints under 5 different conditions: non-towed (NT), Tow A (2.0% body weight), Tow B (2.8%BW), Tow C (3.8%BW), and Tow D (4.7%BW). Three-dimensional kinematics of a 4-segment model of the right side of the body were collected starting at the 35m point of the trial. Significant differences were observed in stride length (SL) and horizontal velocity of the center of mass (V_H) during Tow C and Tow D. For Tow D, a significant increase in the distance from the center of mass to the foot at touchdown (D_H) was also observed. Contact time (CT) decreased significantly in all towing conditions, while stride rate (SR) increased slightly (< 2.0%) under towed conditions. There were no significant changes in joint or segment angles at touchdown, with the exception of a significant decrease in the flexion/extension angle at the hip during the Tow D condition. We concluded that towing force magnitude does influence the kinematics of supramaximal running. Furthermore, we suggest that coaches and practitioners adjust towing force magnitude for each individual and avoid using towing forces in excess of 3.8%BW.

Key words: overspeed; elastic-band; running; training

INTRODUCTION

For many athletic endeavors, running speed is highly influential in the outcome of the event. As such, coaches and athletes are continually seeking new and improved methods to develop this crucial component of human performance. Towing is one of many methods that have been implicated in the development of running speed. Over the past few decades, towing devices have improved substantially in efficiency and availability. Improved access to the devices has led to an increase in coach, athlete, and researcher interest in the method. Several studies have investigated the efficacy of towing in improving sprinting speed and the effect of towing on the kinematics of sprinting (2-11,13-16). However, results from the various studies have been inconsistent regarding some of the kinematic changes during towed sprinting. Those inconsistencies are due, in part, to the fact that researchers have opted for different methods of selecting the towing force magnitude used in their studies.

Currently, there are two popular methods used by coaches and practitioners to determine the appropriate towing force for training. The first, originally developed by Sandwick (14), states that an athlete should be towed at a speed such that his/her towed flying 50yd time is approximately 0.5s faster than his/her unaided flying 50yd time. The second method suggests that an athlete should be towed at no faster than 110% of his/her unaided maximum velocity. While some researchers have opted to use these guidelines in their studies on towing, others have selected towing force magnitude based on the device manufacturer's specifications, the available apparatus, or anecdotal observations.

For towing, there is currently no standard means by which to compare the magnitude of the force used by various researchers. Therefore, it is difficult to determine the reason for the inconsistencies in the observed effects. To our knowledge, only one study has attempted to quantify changes in the kinematics of supramaximal running under various towing force conditions (1), and no studies have provided practical guidelines by which towing force magnitude can be standardized across multiple studies. Therefore, the purpose of this study was to determine the influence of towing force magnitude on supramaximal sprinting kinematics and to provide a means by which future researchers can compare the towing force magnitudes used in various studies. The overlying hypothesis was that supramaximal running kinematics would change as the magnitude of the towing force changed.

METHODS

Approach to the Problem

In order to investigate the relationship between towing force magnitude and sprinting kinematics, a repeated measures experimental design was employed. Such a design permitted the quantification and comparison of the relative effects of four different magnitudes of towing force. In order to provide future researchers with a means by which to compare to the towing force magnitudes used in this study, towing force was represented as a percentage of the subject's body mass as opposed to an absolute value.

Subjects

Ten high school and recreational collegiate track and field athletes (6 men and 4 women) were recruited from local clubs and teams for this study. Parents or guardians (high school subjects) and all subjects signed an informed consent document which was approved by the Institutional Review Board prior to their participation in the study. Descriptive data for the subjects is shown in Table 1.
(Table 1 here)
Procedures

Subjects performed 60m maximal sprints under 5 conditions: non-towed (NT), Tow A (2.0% BW), Tow B (2.8%BW), Tow C (3.8%BW), and Tow D (4.7%BW). Subjects performed one condition per session, with a minimum rest period of 48 hours between sessions. At the start of each session, subjects performed a warm-up routine consisting of 800m of light jogging, a series of dynamic drills, and four submaximal 60m runs. Following the warm-up routine, subjects performed 5-9 maximal 60m sprints under the prescribed condition. Five to seven minutes of rest was allotted between each trial. All subjects performed the non-towed condition first to eliminate any effects the towed sprinting might have on the subject's unaided running mechanics. The order in which the remaining four towing conditions were performed was randomized for each subject.

Assistance for the supramaximal sprints was provided by various combinations of commercially available elastic tubing (Theraband, Hygenic Corporation, Akron, OH). Towed sprints were performed in a single-person fashion, with one end of the elastic tubing attached to the subject via waist belt and the other end of the tubing attached to a stationary anchor (Figures 1 and 2).

(Figures 1 and 2 here)

All trials were performed in an indoor track and field facility. Although every effort was made to tow each subject with an equal percentage of body mass within each condition, limitations in the available elastic tubing characteristics resulted in some small differences between subjects. Furthermore, since the towing force was provided by an elastic device, the magnitude of the towing force decreased over the course of a trial. Descriptive data regarding the towing force magnitudes for each condition are shown in Table 2. Tension in the elastic band during the trials was monitored using a load cell (Sensotec Model 31, Honeywell, Columbus, OH) mounted in the anchor, a data acquisition card (DaqPad 6015, National Instruments, Austin, TX), and custom LabView software (Version 8.0, National Instruments, Austin TX) (Figure 3). Tension data was sampled at 1250Hz for the entire trial and synchronized to the kinematic data using a time marker.

(Figure 3 here)
(Table 2 here)

Lower extremity kinematics for a 4-segment model (pelvis, thigh, shank, foot) of the right side of the body were recorded for all trials using optical motion cameras. The motion capture system was comprised of 6 cameras operating at 250Hz (M2 Cameras, Vicon, Centennial, CO), synchronized through a datastation (Vicon 460, Vicon, Centennial, CO) that was connected via Ethernet to the data collection computer. Prior to the sprinting trials, a static trial was captured in which the subjects were instrumented with 12 skin-mounted spherical reflective markers and 4 marker triads (Figure 4). The marker triads consisted of 3 non-collinear spherical markers mounted to a fixed base such that the 3 markers moved as a group. The twelve spherical markers were placed on the left and right anterior superior iliac spine, left and right posterior superior iliac spine, medial and lateral epicondyle of the femur, head of the fibula, medial and lateral malleolus, head of the 2nd metatarsal, head of the 5th metatarsal, and calcaneus. One marker triad was attached to each of the 4 segments (pelvis, thigh, shank, foot). During the dynamic trials, the 12 individual markers were removed, leaving only the 4 marker triads (Figure 4). Prior to all data collection sessions, the motion capture system was calibrated according to the manufacturer's specifications. Marker locations could be pinpointed within 1.5mm of accuracy for all sessions.

(Figure 4 here)

One full stride cycle (right foot strike to the next right foot strike) starting at the 35m point of the sprint was digitized for each trial. Marker trajectories were filtered using a fourth order Butterworth filter and a cutoff frequency of 10Hz, as determined by the Jackson-Knee method. Stride length (SL), stride rate (SR), horizontal velocity of the center of mass (V_H), horizontal distance from the COM to the foot at touchdown (D_H), flight time (FT), and contact time (CT) were determined for each trial. Additionally, the hip (HA_T), knee (KA_T), ankle (AA_T), and shank (SA_T) flexion/extension (F/E) angle at the frame corresponding to touchdown were computed (Figure 5). The results from three to five trials for each subject and for each condition were averaged together and entered into the statistical analysis.

(Figure 5 here)

Statistical Analyses

A one-way repeated measures analysis of variance was used to determine the effects of the towing conditions on each of the dependent variables ($p<0.05$). A post-hoc pairwise comparison was then performed to determine how the dependent variables changed during the towed conditions as compared to the non-towed condition. Intra-class correlations were high for all of the variables and conditions, ranging from 0.761 to 0.997, while observed power ranged from 0.122 to 0.999. Statistical analyses were conducted using SPSS (Version 16.0; SPSS Inc, Chicago, IL).

RESULTS

Significant increases in SL, as compared to non-towed trials, were found for both the Tow C condition ($p=0.005$) and the Tow D condition ($p=0.017$). Similarly, significant increases in V_H were found in the Tow C ($p=0.002$) and Tow D ($p=0.002$) conditions. SR showed a trend to increase as towing force magnitude increased, but the differences did not achieve significance. CT decreased significantly during all towed conditions ($p<0.01$), while FT increased slightly for the same conditions. D_H tended to increase as towing force magnitude increased, however, the difference achieved significance only in the Tow D condition ($p=0.046$). For the joint angle variables, a significant difference was noted in the hip touchdown angle during the Tow D condition ($p=0.044$). No other significant changes were observed in the joint or segment angles during the towed trials. Results for all variables can be found in Tables 3 and 4.

(Tables 3 and 4 here)

DISCUSSION

For many sports, running speed is vital for success in the event. Therefore, coaches and athletes seek out new and innovative methods to improve that component of athletic performance. While towing has emerged as a popular option among coaches and practitioners, the answer to the fundamental question of how to select towing force magnitude remains unclear. The purpose of the current study was to help answer that question by evaluating

changes in running kinematics under four different magnitudes of towing force. We hypothesized that sprinting kinematics would be dissimilar amongst the four towing force conditions. That hypothesis was partially supported by the results, as many of the selected variables demonstrated significant changes only under higher magnitudes of towing force (Tow C and Tow D). However, many of the kinematic variables showed little change between all of the towing conditions.

V_H increased by between 1.2 and 6.1% during the towed conditions as compared to the non-towed condition, which is consistent with the observed results from previous studies on towing (1,4,7-10). However, most researchers and practitioners are more interested in the interaction between SL and SR, as towing has been suggested as a method to increase SR. In this study, increases in V_H resulted from increases in both SL and SR, with the former contributing substantially more to the end effect. The greater contribution of SL to the observed increase in V_H has also been noted in previous research (4,10).

Increases in SL caused by towing have been suggested to have detrimental training effects by previous researchers. However, a distinction should be made between an increase in SL and an elongated stride (shown by D_H), since the former is not necessarily a negative outcome. In sprinting, there is a significant flight phase during which the body can be thought of as a projectile. In the absence of other extenuating circumstances, increasing the takeoff velocity of a projectile will increase the projectile's range. Since towing generally involves applying an external horizontal force near the center of mass, one would expect the horizontal velocity of the COM to increase during towed conditions, as has been found in the current and other studies (1,4,7-10). Therefore, one should also expect the body (the projectile) to cover more distance during the flight phase. Accordingly, if the distance covered by the COM during the flight phase increases, the calculated value for SL will also increase. Thus, observed increases in SL during towing may not necessarily be accompanied by detrimental changes in running kinematics. Therefore, it is necessary to evaluate changes in other kinematic variables (D_H, joint and segment touchdown angles) before deeming that increases in SL have a detrimental training effect.

D_H increased under all towed conditions except Tow A, and increased significantly during the Tow D condition. An increase in D_H during towed runs has been noted by previous researchers (4,8-10). The increase in D_H demonstrates a potentially negative training effect, as the resulting elongated stride is implicated in increasing the braking forces experienced by the runner. However, increases in braking forces should be viewed in conjunction with the time period over which they act (CT), such that a braking impulse can be determined and related to potential changes in velocity. In the current study and those conducted by others (2,8-10), total contact time was found to decrease during towed trials, suggesting that the braking impulses may decrease. However, Mero and Komi (10) showed that the decrease in total CT was due to a decrease in the concentric portion of CT, and that the eccentric (braking) phase of contact actually increased. In conjunction with the force data, the CT results from Mero and Komi's work indicate that the braking impulses during towed sprinting increased while the propulsive impulses decreased. Therefore, it can be assumed that if a similar elongated stride were adopted in an unaided situation, detrimental decreases in VH would be observed.

D_H values for this study were substantially higher for all conditions as compared to previous studies (4,8-10). This discrepancy is likely due to the method by which D_H was calculated. For the present study, D_H was represented as a 2D vector in the transverse plane rather than a 1D vector in the sagittal plane (Figures 6 and 7). The 2D representation accounts for the possibility that the subject's running direction may not be perfectly aligned with the orientation of the coordinate axes. Furthermore, a subject's foot strike may not be directly in front of the COM, but rather medial or lateral of the line of the COM. The 2D representation also accounts for this possibility. (Figures 6 and 7 here)

For the joint and segment angle variables, the only significant difference was an increase in flexion noted for HA_T during the Tow D condition. However, this change in HA_T is a possible mechanism for increasing the eccentric portion of the CT. When landing in a more flexed position at the hip, there is a larger ROM for the thigh to travel through from the time of contact until rotating directly beneath the COM and transitioning to the concentric portion of CT. Thus, the thigh may take a longer period of time to pass through the larger ROM, resulting in an increased eccentric portion of CT. The increased flexion observed in HA_T may also partially explain increases in D_H. In the absence of changes in knee flexion angle, increasing hip flexion angle would cause the foot to move farther from the COM under normal running conditions. Consequently, calculated values for D_H would show an increase.

The results from the current study offer useful information regarding the selection of a proper towing force for elastic-based training. Based on potentially detrimental increases in D_H and changes in HA_T, towing with magnitudes of force equal to or above 4.7%BW appear to be contraindicated in this group of athletes. Although significant increases in SL were noted during the Tow C and Tow D conditions, those increases may be representative of the application of force during the flight phase. Furthermore, during the Tow C condition the increase in SL was not accompanied by other detrimental changes in sprinting kinematics. Thus, the results of this study suggest that towing force magnitudes up to 3.8%BW can be used in elastic-based overspeed training for high school and collegiate track and field athletes without adversely affecting sprinting kinematics.

The results from the current study and other studies also have implications for the two previously described methods of selecting towing force magnitude. The results from this study and the one performed by Corn and Knudson (4) show that potentially undesirable training effects can be derived from towing individuals at velocities of 6.1% and 7.1% greater than their unaided ability allows. As such, these two studies indicate that the commonly used speed maximum of 110% may be too high, and that athletes training at such a level have an increased probability of developing undesirable training effects. Similarly, it should be noted that a decrease of 0.5s over 50yd may represent an increase in velocity of 10% or more for many athletes. Therefore, the results from the present study and that of Corn and Knudson (4) suggest that selecting towing force magnitude through such a method may result in towing an athlete at too high of a level, thereby increasing the likelihood of producing poor training effects.

PRACTICAL APPLICATIONS

We concluded that towing force magnitude does influence the kinematics of supramximal sprinting. Therefore, coaches and practitioners choosing to use elastic-based overspeed training as part of their conditioning program should make an effort to adjust towing force magnitude for each individual. For high school and collegiate aged athletes, we suggest standardizing towing force magnitude as a proportion of the individual's body weight and using a maximum of 3.8%BW. For the Theraband tubing used by the authors, a force-elongation chart has been published by Page et al. (12). Our suggested %BW values correspond approximately to the 100% elongation values reported in the table. Therefore, coaches and practitioners can perform a simple calculation utilizing the equation below to find a suitable elastic band for each individual.

Equation 1:
$$\%BW = \left(\frac{force \ @ \ 100\% \ elongation}{subject \ body \ weight} \right) * 100$$

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ACKNOWLEDGEMENTS

Figure Legends

Figure 1. Waist belt attached to a subject

Figure 2. Elastic tubing attached to the waist belt

Figure 3. Anchor with load cell mounted

Figure 4. Subject prepared for a static trial (left) and dynamic trial (right)

Figure 5. Illustration of touchdown angle variables

Figure 6. Traditional method of determining D_H (sagittal view)

Figure 7. Current method of determining D_H (superior view)