Resisted Sprint Training for the Acceleration Phase of Sprinting

John Cronin
Edith Cowan University, Perth, Australia, and Auckland University of Technology, Auckland, New Zealand
Keir T. Hansen
New Zealand Warriors Rugby League Club, Auckland, New Zealand

Summary

First, the biomechanical differences between the acceleration phase and the maximum velocity phase of sprinting are considered. Second, research on the various resisted sprinting techniques is examined, linking these techniques to the biomechanics of the acceleration phase. Some suggestions are made regarding the application of these findings to the training of athletes.

Sprinting has previously been described as consisting of a series of phases: an acceleration phase from 0 to 10 m, a transition phase, and then a maximum velocity phase from 36 to 100 m during a 100-m sprint (7). Mero et al. (34) described the acceleration phase as being in the first 30–50 m, followed by a maximum velocity phase and a phase of deceleration. However, for many sporting activities such as soccer, rugby, football, netball, and basketball, maximum velocity is not always attained, and repeated short sprints are more common. As such, the ability to develop velocity in as short a time as possible (acceleration) may be of most importance to performance in many sporting activities. Furthermore, it is thought that acceleration and maximum velocity are relatively separate and specific qualities (9, 44). Therefore, it is the development of the acceleration phase of sprinting that would seem to be of greatest benefit to many sports people and is the subsequent focus of this article.

An athlete’s ability to accelerate his or her body mass during sprinting is dependent upon a number of factors. These factors include technique and the force production capability of the body, in particular the lower limb musculature. However, technical considerations may have less importance for acceleration phase performance than for a typical sprint event. That is, in many sports the athletes have to accelerate from lying prone or a crouch, from moving sideways or backwards, from landing on 1 leg and pivoting sideways, from catching a ball to chasing a kick and so on. Therefore, the force capability of muscle may be the more important consideration in developing sports speed. This contention that muscular force is important to acceleration phase performance was supported by Mann et al. (29), who stated that the ability to perform well in sprints over short distances is dependent on the ability to produce large amounts of force at crucial times.

Methods used to enhance force output for improving acceleration phase performance include various forms of weight training, plyometric training, and assisted and resisted sprinting techniques. This article will focus on resisted sprinting, which involves the athlete sprinting with added load, or utilizing other forms of resistance such as hills and stairs. In an attempt to provide velocity and movement pattern specificity during power training for the acceleration phase of sprinting, a variety of methods are used to provide resistance while sprinting. These methods include limb loading, uphill running, weighted vests, and resisted towing (13). The use of these resisted sprinting techniques is common both in athletics and in a variety of sports. However, there is very little experimental evidence that describes the merits of resisted sprinting or the different adaptations that may occur.
with the utilization of different resisted techniques. That is, it could be that limb loading, uphill running, weighted vests, and resisted towing provide different training stimuli and hence produce different adaptations. Therefore, each technique may need to be linked to the specific needs of an athlete in relation to the requirements of the athlete's sport. This paper addresses this premise through a review of the literature. First, the biomechanical differences between the acceleration phase and the maximum velocity phase of sprinting are considered. Second, research on the various resisted sprinting techniques is examined, linking these techniques to the biomechanics of the acceleration phase. Thereafter, loading parameters are discussed and recommendations are made regarding the application of these findings to the training of athletes.

**Biomechanics of the Acceleration Phase**

A brief comparison of biomechanical research associated with the acceleration and maximum velocity phases of sprinting would provide a useful introduction to an examination of the effects of resisted training techniques. A full treatise of this area is outside the scope of this article, but if interested the reader is directed to articles by Mero et al. (34) and Williams (43). This section will focus on kinematic aspects of the stance phase of sprinting during the acceleration and maximum speed phases. Thereafter, kinetic and electromyographic (EMG) characteristics of sprinting will be briefly introduced. The discussion is limited to the stance phase of sprinting.

**Kinematics**

Sprint velocity is a product of step length and step frequency (11, 19, 27, 34). Step length and step frequency are both increased to enhance velocity during the acceleration phase (see Figure 1) of sprinting (34). Each step comprises a stance phase and a swing phase. The time that the foot is in contact with the ground during the stride cycle is termed the stance phase, and the swing phase is from ipsilateral foot strike to ipsilateral toe-off (12). The acceleration phase of sprinting is characterized by a relatively long stance phase as the runner endeavors to generate velocity (27). The stance phase comprises 2 distinct components, braking and propulsion. The relative contributions of braking and propulsion to the stance phase differ during the acceleration phase of sprinting compared to the maximum velocity phase. During the acceleration phase, the stance phase is largely made up of a propulsive component, with minimal braking forces at foot strike. However, in the maximum velocity phase, braking constitutes up to 43% of the stance phase (33). Mero (31) found that when the athlete was accelerating, the braking phase constituted only 12.9% of the stance phase, and the remainder was associated with propulsion.

With respect to sprinting technique, the acceleration phase has been found to differ significantly from the maximum velocity phase of sprinting. Mero and colleagues (34) reported that during the first few strides in sprinting, the body’s center of gravity undergoes a posterior shift, from an anterior position at foot strike to a position posterior to the point of foot strike. Seagrave (39), based on coaching observations, has suggested that during the initial stages of the acceleration phase the body should be at an angle of approximately 45° to the surface of the ground. As the sprinter’s velocity increases, the body becomes more upright (16).

An athlete’s sprinting technique is determined by the angles of the trunk, thigh, knee, and ankle. There is considerable variation in the literature regarding thigh angle (angle between the thigh segment and a vertical line from the ground) during sprint running. Frischberg (16) reported a foot strike thigh angle of 29.9° at 50 m from a sprint start. In contrast, Letzelter and colleagues (25) reported a mean thigh angle of 22.6° at 30 m from a sprint start. The literature is inconclusive as to whether thigh angle varies considerably between the acceleration and maximum velocity phases of sprinting. Williams (43) in reviewing the literature reported foot strike thigh angles ranging from 20.8° to 30° and stated that thigh angle did not seem to change appreciably with increasing running speed. There is also
variation in the literature regarding optimal thigh angle at toe-off. Mann and Herman (27) stated that more efficient sprinters terminated the nonproductive latter part of the stance phase and began recovery more quickly, whereas Hay (19) believed that the thigh should move through as great a range as possible and that failure of the thigh to do so was a common fault in sprinting.

Knee flexion at foot strike has been reported to range between 10° (4) and 30° (20, 28). Following foot strike, the knee flexes further to absorb the energy associated with the ground reaction forces generated at foot strike. This flexion following foot strike was reported by Jacobs and colleagues (20) to be on average approximately 15°. Mann and Herman (27) reported a mean foot strike knee angle of 13° 180 m into a 200-m race. This is in contrast to Jacobs and colleagues (20) and Paradisi and Cooke (36) who reported mean foot-strike knee angles of 30° and 35° respectively during the acceleration phase. This suggests that knee flexion at foot strike is greater during the maximum velocity phase of sprinting. A lack of literature regarding ankle kinematics during sprinting makes comparisons between the acceleration and maximum-velocity phases difficult.

Researchers comparing slow and fast field sport athletes over the first 3 steps of a 15-m sprint found that the fast group had significantly (p < 0.05) lower (approximately 11–13%) left and right foot contact times, increased stride frequency (approximately 9%), and lower knee extension angles (approximately 11°; 35). It was concluded that those players who were relatively fast during the acceleration phase achieved this by reduced knee extension angles and ground contact times, which increased stride frequency.

Kinetics
Larger propulsive forces (526 N horizontally and 431 N vertically) are exerted during the longer stance phase while accelerating (31). Horizontal propulsive forces during the first ground contact have been reported to be 46% greater than those observed once maximum velocity is achieved. Vertical propulsive forces have been shown to be similar during the acceleration phase and the maximum velocity phase of sprinting (31). Braking forces during the acceleration phase have been reported to be relatively small, −153 N horizontally, and a net force of 148 N vertically (31), compared with −445 N horizontally and 1,707 N vertically during the maximum velocity phase of sprinting (34). Plamondon and Roy (37) found that vertical braking forces decreased between steps 1 and 12, whereas horizontal braking forces increased up to the 12th stride, where they started to plateau.

EMG Activity
Limited research has been undertaken on the sequencing and degree of muscle activation across the acceleration and maximum speed phases of sprinting. It has been suggested that the hamstrings play an important role during the propulsive phase of stance, extending the thigh (22, 32, 42). Mero and Komi (32) suggested that knee extensor activity during the propulsive phase of stance during maximum velocity sprinting was limited. However, the propulsive role of the knee extensors during the acceleration phase may be greater (15). Wieman and Tidow (42) found that during the first few steps of sprinting, the vastus lateralis showed significantly greater activation during the stance phase compared to activity observed at maximum velocity. This increase in vastus lateralis activation was accompanied by a significant decrease in hamstring activation during the stance phase. Harland and Steele (18) also reported an increase in EMG activity of the vastus medialis during the sprint start. These findings suggest that the quadriceps are relatively more important for the acceleration phase as compared to the maximum velocity phase. DelecQu et colleagues (8) stated that although there was still a significant body lean during the acceleration phase, there was less reliance on the stretch-shorten cycle (SSC) and the knee extensors were the main accelerators.

Resisted Sprinting
The preceding literature review has suggested some significant differences between the acceleration and maximum speed phases of sprinting. During the acceleration phase, there is a longer stance phase, greater knee and trunk flexion at foot strike, greater propulsive forces, and possibly greater EMG activity in the knee extensors. It follows that these factors should be taken into consideration when choosing the mode of training for the acceleration phase of sprinting. As such, resisted sprint training has become a popular training method, with many sports teams and track athletes to develop acceleration. It is thought that such techniques increase neural activation and hence muscular force output of the leg, resulting in an increase in stride length over time (5, 6, 14) However, whether this is actually the case has not been empirically proven. It may be that each of these resisted techniques provides a different training stimulus and therefore each may be better suited for training different phases of sprinting. This contention is discussed in the ensuing sections.

Limb Loading
Limb loading involves the attachment of weights to the extremities of the athlete in order to provide overload while sprinting. The loads are typically placed at the ends of the distal segments and thus are likely to increase the moment of inertia considerably (19) and subsequently increase the muscle activity required during motion. Two studies have examined the effects of limb loading. Ropret et al. (38) studied the effect of arm and leg loading on sprinting velocity, step length, and step frequency. Arm loading up to a maximum of 0.66 kg did not have a significant effect on the athlete’s sprinting velocity, step length, or
step frequency. In contrast, leg loading at 0.6, 1.2, and 1.8 kg had a significant effect on performance. A load of 1.8 kg significantly reduced sprinting velocity. Step length remained the same, so the decrease in velocity was attributed to a decrease in step frequency.

Similar findings were reported by Martin (30), who compared the effects of loading the foot by adding lead to specially developed running shoes and loading the thighs by wearing lead-weighted bike pants during treadmill running. It was found that foot loading and thigh loading lengthened step length, increased recovery time of the contralateral limb, and increased swing phase duration. However, this effect was statistically significant with ankle joint loading only. Therefore, this study illustrated how the increased inertial forces associated with distal loading resulted in a greater effect on running technique, especially in terms of decreasing step frequency.

From these studies it would seem that loading of the distal segment of the lower limb at the ankle joints decreased velocity and that the mechanism of velocity decrease was likely to have been through a decrease in step frequency, whereas step length remained relatively unaffected. To the authors’ knowledge, there are to date no training studies examining the long-term adaptations using this training technique.

**Uphill Running**

Some practitioners have suggested that uphill running will place increased load on the thigh extensor muscles as athletes try to maximize step length (13). Because thigh extensor activity is thought to be important in the propulsive phase of sprinting, the associated gain in strength is thought to increase the athlete’s step length when sprinting on a flat surface. Dintiman et al. (10), based on observations, suggested that the hill incline should be at a grade that does not compromise running form. They suggested, based on their training experience, the use of steeper inclines to improve the start and acceleration phases of sprinting (8–10° in 2.5–3.5 seconds) and progressively reduced inclines for longer sprint training.

Kunz and Kaufman (24) examined the biomechanics of uphill running. They compared running on a 3° grade as opposed to running on a flat surface. The inclined run resulted in a decrease in velocity of 1 m·s⁻¹, no change in step frequency, a decrease in step length, and an increase in trunk-thigh angle. Kunz and Kaufman (24) concluded that uphill running might result in longitudinal adaptations, increasing step length, and shortening the stance phase during sprinting on a flat surface.

Paradisis and Cooke (36) also compared the kinematics and kinetics of sprinting on a flat surface to sprinting up a 3° slope. It was found that velocity was significantly decreased (3%) when sprinting uphill compared to sprinting on a flat surface. The researchers observed that the decrease in velocity was primarily attributable to a decrease in step length, which decreased by 5.2% (p < 0.05). These researchers also found significant changes in body position between sprinting uphill and on a flat surface. Trunk flexion was significantly increased, and the shank angle (the angle between the lower leg and the running surface) was reduced at both foot strike and toe-off. Thigh-to-thigh angle (the angle between the right and left thigh segments) was significantly decreased at foot strike and knee angle was significantly decreased at toe-off. A significant decrease in landing distance (the distance between a vertical line through the athlete’s center of gravity and the point of foot strike) was also noted. Paradisis and Cooke (36) suggested that these kinematic changes resulted in an increase in the contribution of the propulsive phase to the stance phase during uphill sprinting. Once more, the long-term application of such training has not been investigated.

**Weighted Vests**

The use of weighted vests while sprinting is another method of providing resistance during training (see Figure 2). Vest sprinting with loads of 15 and 20% of body mass has increased sprint times at 10 m (7.5 and 10%, respectively) and at 30 m (9.3 and 11.7%, respectively) (17). It was suggested that the athletes had less additional force to overcome in the early stages of the sprint during vest sprinting, but that as they developed velocity, the need to control the additional mass around the trunk resulted in decreased performance. The increase in sprint times was attributed to decreased step length and step frequency and to increased stance times. However, the joint kinematics was similar between loaded and unloaded conditions.

A series of longitudinal studies have investigated the practice of applying extra mass to the body of elite athletes for prolonged periods of time (1–3). The first in this series of investigations (3) attempted to create a “hypergravity” situation by loading the athlete for a 3-week period with a vest that equated to 13% of the athlete’s body mass. The load was worn from morning to evening, including training sessions. Training included jump training and weight training that did not deviate from normal training for the 3-week trial period other than by the additional load of the weighted vest. Following training, a significant increase in lower limb explosive power measured during squat jumps and drop jumps (approximately 10%) was found. Furthermore, a significant right shift of the force-velocity curve measured during squat jumping was observed. It was concluded that the high-gravity conditions influenced the muscle mechanics of even well-trained athletes.

Bosco (1) examined the force-velocity relationship of the lower limb musculature in 5 international-level male
jumpers over a 13-month period. During the first 12 months of training, in which the athletes did not wear vests, no improvements in the measured variables were found. However, after 3 weeks of a simulated hypergravity situation in which the athlete wore 11% of his body mass, a significant shift of the force-velocity curve to the right was observed during loaded squat jump assessment. The utilization of the weighted vest also resulted in an increase in average drop jump performance from 0.48 m to 0.55 m ($p < 0.001$). Bosco (1) did not examine whether the mechanisms behind the improvements found were neural or muscular. However, it was noted that after the high-gravity conditioning, execution time for the SSC during drop jumping and 15-second jumps was decreased, and force development was improved. Both of these tests assessed fast SSC movements as found during sprint running. Bosco suggested that this improvement in fast SSC performance might be a result of increased stiffness of the leg extensor musculature (1).

Another study by Bosco and colleagues (2) further investigated the effects of vest training by using sprinters performing jump and sprint training with a load of 7–8% of their body mass. As in previous studies, the athletes wore the extra load for 3 weeks from morning until evening, including during training times. Normal training volumes were otherwise unchanged. As found in previous studies, the force-velocity curve was observed to shift to the right. Therefore, the ability of those subjects who wore vests to produce greater force at higher velocities dramatically improved with this form of conditioning. No significant changes were found in the control group.

Bosco and colleagues (2) did not study factors related to sprint mechanics or sprint performance. However, it is possible that a vest worn during sprinting might increase the vertical force at each ground contact, thereby increasing the

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Figure 2. Example of vest that can have 1-kg lead weights added or subtracted.
eccentric load on the extensor muscles during the braking phase. This effect may serve to increase the muscles’ capacity to store elastic energy and improve power output (13, 39).

**Resisted Towing**
The towing of weighted devices such as sleds (Figure 3) and tires is the most common method of providing towing resistance for the enhancement of sprint performance, although the use of parachutes has also been documented (40). Faccioni (13), again based on coaching observations, suggested that using towing as a form of resistance may increase the load on the athlete’s torso and therefore may require more stabilization. This training stimulus may increase pelvic stabilization, which may have a positive effect on sprint performance.

Letzelter et al. (25) studied the acute effect that different loads had on performance variables with a group of female sprinters during sled towing. They found that a 2.5-kg load resulted in an 8% decrease in performance over 30 m, and 10 kg resulted in a 22% decrease in sprint performance. Step length was affected to a far greater extent than step frequency by the increased resistance. As the load increased, decreasing step length accounted for a greater proportion of decreasing velocity. The variable affected most by increasing resistance was stance phase duration, which increased significantly with all loads. Increased loads also caused increased upper-body lean and increased thigh angle at both the beginning and the end of the stance phase. This increased thigh angle reflects the increased need for force production during the prolonged stance phase. Unfortunately, this study did not quantify towing loads relative to body mass or provide anthropometric data on the subjects. It is therefore difficult to relate the results found to previously recommended loading guidelines.

Lockie et al. (26) studied the effect of sled towing on acceleration-phase sprinting kinematics in field-sport athletes. Athletes towed weighted sleds with loads equaling 12.6 and 32.2% of their body mass over a 15-m distance. Sled towing resulted in a decrease in stride length of 10 and 24% for the 12.6 and 32.2% loads respectively. Stride frequency was significantly decreased compared to baseline with both towing loads, but there was no significant difference between the 2 towing loads. The duration of the stance phase was also significantly increased during the towing conditions. Trunk flexion and hip range of motion were also significantly increased compared to baseline with both towing loads. Knee joint range of motion was increased for load 1 only on stride 1 of the sprint. The authors concluded that the heavier load led to a greater disruption of running kinematics, and recommended training with lighter loads.

Kafer and colleagues (23) studied the effects of resisted and assisted training on sprint times over 20-, 40-, and 60-m distances. A weighted sled was used to provide resistance, and a bungee cord (rubber rope) to provide assistance. The training groups included an assisted group, a resisted group, a group combining the 2 techniques, and a control group performing unloaded sprint training. The resisted group recorded an average improvement of 0.08 seconds ($p < 0.01$) and 0.35 seconds ($p < 0.01$) in sprint times over 20- and 60-m distances respectively. The combined group was significantly faster posttraining over both 40 m (0.19 seconds) and 60 m (0.34 seconds). The control group and the assisted group displayed significant improvements between pretraining and posttraining only over 60 m (0.08 and 0.27 seconds, respectively). It was suggested that the generic improvements in 60-m sprint performance were attributable to the subjects’ being rugby union players, who were unfamiliar with running the longer distances that are required only occasionally in their sport. Between group comparisons showed that only the combined resisted-assisted group was significantly faster ($p < 0.05$) than the control group posttraining. The mechanisms behind improvements in performance were not investigated. It was suggested, however, that a possible reason for the improvement was that the increased resistance from the sled resulted in increased force production to develop and maintain velocity. The researchers specu-
lated that this effect would increase the load associated with the SSC, increasing muscle stiffness and vertical force at each ground contact. Further research examining mechanical adaptations with resisted towing is required in order to examine mechanisms behind any improvements in sprinting performance.

In terms of the loading parameters, towing loads of less than 10% of body mass have been recommended, but this is based on practical observations rather than research (5, 25, 39). Kafer and colleagues (23) suggested that a load less than 15% of the athlete’s body mass will not affect the sprinter’s technique, but they also stated that the evidence was anecdotal and not scientifically substantiated. Seagrave (39) believed that the load should be determined by the extent to which performance is affected. If performance variables decrease by more than 10%, the load being used is too great and will have a detrimental effect on sprinting technique (5, 39).

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<th>(A) Biomechanical characteristics</th>
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<th>Exercises</th>
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<tr>
<td>Trunk position</td>
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<td>Thigh angle at footstrike</td>
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<td>Knee angle at footstrike</td>
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<td>Propulsion</td>
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<td>Swing phase</td>
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<th>(B) Biomechanical characteristics</th>
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* denotes the relative importance of that muscle group during each phase of sprinting. The greater the number of stars, the more important that muscle group is to that phase.
Frictional forces contribute to the resistance experienced by the athlete when towing a sled. It is difficult to quantify these frictional forces. The magnitude of the frictional force (coefficient of friction) is dependent on the mass on the sled and the characteristics of the ground surface and the sled. It is relatively independent of the total surface area and is also independent at velocities between 0.01 and several m·s⁻¹ (21, 41). For training purposes, the load on the sled and the surface over which it is moving will be the variables that can be most easily manipulated to change the frictional force and hence the resistance against which the athlete is working. Therefore, when assigning load during sled towing, coaches not only must be conscious of how much mass they are adding to the sled, but also must be aware of the characteristics of the surface on which they are towing. For example, towing on grass is likely to result in a different coefficient of kinetic friction from towing on a track. Furthermore, James (21) has shown that the coefficient of kinetic friction was less for wet steel than for dry steel. The same is likely to be the case for a track surface with a decrease in frictional force when towing on a wet track.

It is possible that during resisted sprinting, different loads could be used for training the different phases of the sprint. It has been suggested that greater resistance should be used for training the acceleration phase and light loads for increasing the maximum velocity phase (7, 10, 40). Increased loads that increase forward body lean and increase stance phase duration may be beneficial to the acceleration phase of sprinting. However, there is a lack of information on the kinematic, kinetic, and EMG differences between loading parameters and their effects. Therefore, these thoughts are also based on anecdotal evidence.

**Practical Applications for Resisted Sprinting**

As described previously, different phases of the sprint generate different kinematic, kinetic, and EMG responses. The acceleration phase, for example, is characterized by a longer stance phase, a large proportion of which is propulsion. During the acceleration phase, there is greater trunk flexion, greater knee flexion at foot strike, and greater recruitment of the knee extensor musculature. Taking into consideration the principle of specificity in strength and power training, it follows that those modes of training that replicate these characteristics should be utilized. It is clear that different resistance training methods overload the body in a different manner, and therefore the training effect provided by each of the resisted training techniques results in a specific adaptation.

One method of providing this specificity in resistance training is to add load to the athlete while sprinting. The adjustments in sprinting technique made during towing and uphill running seem to replicate the acceleration phase more closely than do other resisted techniques. Both these techniques increase trunk lean, stance duration, and the need for horizontal force production during the propulsive phase of stance. Hill sprinting will also increase the need for horizontal propulsive forces, although the need to counter the grade may also result in an increased need for vertical propulsion. The specific need for increased propulsive forces may make modes of resistance such as resisted towing and hill sprinting more appropriate for training the acceleration phase of sprinting, in which propulsive force production comprises a large proportion of the stance phase.

Weighted vests provide overload in a different manner, by increasing the vertical load during foot strike, increasing the braking forces, and perhaps overloading the SSC to better effect. As such, weighted-vest training may have better applications for maximum velocity adaptation. Nonetheless, such training may also have an application to the training of the acceleration phase of sprinting by increasing eccentric strength and muscle stiffness and therefore decreasing the duration of the stance phase. It is not clear whether this type of overload or the greater horizontal overload provided by resisted towing results in greater increases in acceleration phase performance. Likewise, the optimal load to be used during resisted sprinting has not been determined. That is, it may be that greater resistance should be used for training the acceleration phase and light loads for increasing the maximum velocity phase. However, the practitioner should be aware that there is a risk that too much load may result in technique adjustments that could compromise the athlete’s sprinting technique.

Resisted sprinting provides a highly specific and convenient method of training muscular power for the acceleration phase of sprinting. Table 1 attempts to summarize some of the information into a format that may assist the training of athletes. However, the reader needs to be mindful that most evidence in this area is anecdotal, with very few randomized controlled designs validating the most desirable mode of resistance training, the mechanisms behind improvements in the acceleration phase, the possible negative effect on technique, and the optimal training loads. Answers to these questions are necessary if resisted sprinting is to be utilized effectively by coaches and athletes.

**References**


John Cronin is an Associate Professor at Edith Cowan University and has worked as a consultant for many sports organizations and athletes.

Keir T. Hansen has been the head trainer of the New Zealand Warriors Rugby League team for the last four years.