A review of resisted sled training: implications for current practice

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OVERVIEW
The development of resisted sprinting methods, such as sled, parachute and bungees, is providing coaches with alternative and/or supplementary training strategies to the more classic power training techniques such as weightlifting or plyometric training. The aim of this review article is to provide a brief overview of the phases of sprinting relevant to resisted sled training (RST), examine the current RST literature base and provide some recommendations for the use of RST in practice, as well as to identify directions for further research.

Introduction
Sprint running is not only an athletic event in itself, but it is essential for success in many sports.15, 16, 21, 39 For example, speed is a crucial factor in field sports where the need to reach the ball first or be in position for play to develop is crucial.41 The benefits are highlighted further by findings that professional players tend to be faster than amateur performers in the same sport.26 The development of resisted sprinting techniques, such as sled, parachute and bungees, is providing coaches with alternative or additional training strategies to the more classic methods such as weightlifting or plyometric training.27

During resisted sled training (RST), the external resistance is provided by the mass of the sled and the coefficient of friction between the sled and the surface.10 As such, RST is performed in a horizontal direction, involving the relevant muscles, velocities and ranges of motion similar to those of un-resisted sprinting.27,28 Strategies of sled loading, as well as the sets and repetitions used to implement RST sessions, remain equivocal.1,11,33,38,47

Despite the lack of agreement in the literature, RST is often integrated into training programmes across many sports. This uninformed approach might limit performance gains or has the potential to prove detrimental to sprint performance, ie, negatively impacting on sprint kinematics.8,33,40 The aim of this review article is therefore to provide a brief overview of the phases of sprinting relevant to resisted sled training (RST), to examine the current RST literature base and to provide some recommendations for the use of RST in practice, as well as to identify directions for further research.

Physiological adaptations
The performance enhancement ensuing a training period may be attributed to a number of different physiological adaptations.4,6,9,30 The precise nature of the neuromuscular adaptations that occur are unknown; however, various alterations such as motor unit force development and enhanced muscular co-ordination probably contribute.5,20 Improvements during the early stages of a training programme are predominantly associated with these neuromuscular adaptations.6,30,36 In the later stages of a training programme, performance increases are commonly attributed to muscular fibre and contractile adaptations.8,33,34

Understanding the physiological adaptations that occur during RST is vital in order to determine relevant sled loading strategies and programme variables. Resisted sled training interventions have been shown to improve sprint performance,20,33,36,44,47 as well as various jump and strength measures.3,20,43 Researchers have also speculated as to which physiological adaptations may have led to the enhancements. Unfortunately, the simple outcome measures thus far recorded do not allow us to clearly ascertain this.

Although physiological adaptations have been researched extensively during resistance training,4,6,9,30 the movement velocity and programming variables associated with power training are generally more in line with RST.

Strength improvements following power training were attributed to neuromuscular adaptations in one trial.30 Adaptations transpired during the first 10 weeks, after which no further enhancements were seen.6,30 In contrast to resistance training,33,36,40 there were no changes in muscle fibre or contractile properties following a power training intervention.30

This finding is not surprising; research highlights that manipulation of the different training variables (sets, reps, recovery, intensity and loads) allows muscles to be stressed in very different ways. As such, the plyometric nature of
the power training programme will lead
to different adaptations when compared
to the resistance training programmes.4,30
The lack of hypertrophic development
resulting from power training or
RST is not generally an issue as
these exercises often form part of a
mixed methods approach, during the
course of which resistance training
will also be undertaken. This mixed
training approach has been found to
be superior to power training alone34
and is generally the recommended
programming method.

Performance outcomes
Sprint velocity is a product of stride
length and stride frequency; to
increase velocity, one or both of these
components must be increased.13 Both
stride length and stride frequency can be
increased by exerting larger forces or
increasing the rate of force development
(RFD) during the stance phase of the
sprint, thus producing a longer stride or
decreasing contact times.10,25,36,6 Contact
times during a sprint stance phase are
typically <0.2s.22,46 Maximum force takes
longer to generate and as such the RFD
in the early phase of rising muscle force
is essential when sprinting.28 Sprinting
and RST are often subdivided into
smaller sub-phases (acceleration and
maximum velocity) and in terms of
sprint mechanics each phase is very
unique.

Acceleration
Acceleration is defined as the capacity
to generate as high a velocity as possible
in as short a distance or time possible.21
It is generally accepted that although
maximum velocity is important in field
sports, the ability to accelerate is seen as
being of greater significance.13,35 Some
research has shown that an explosive
start requires a powerful drive of the
arms, hips and legs, resulting in short
contact times and an increased stride
frequency.23,29 Other studies placed a
greater emphasis on a forward body
lean (45 degrees), thereby increasing the
horizontal forces, from which the
athlete will rise as they approach
maximum velocity.23,29

When vertical ground reaction forces
(GRF) during the acceleration phase
are too high, contact times in the
stance phase become much shorter. This
thus reduces the time period in which
the propulsive horizontal forces
can be applied and therefore decreases
acceleration velocity.9,35

Acute RST studies are critical in order
to investigate how different loading
strategies can alter sprint mechanics
(see Table 1). Stride frequency and
stride length are the only two kinematic
variables that have been consistently
measured in all acute studies focusing
on the acceleration phase. Without
exception, stride length was found to
significantly decrease as sled loading
increased;3,33,39,40 this is due to the added
frictional resistance provided by the
sled. During the stance phase participants
will exert more force to
overcome the extra resistance. However,
unlike normal sprinting during RST,
frictional forces will still be acting on
the athlete throughout the flight phase,
leading to a decrease in stride length.
Stride frequency was significantly
reduced in three investigations,11,33,38
whereas reductions were found to be
negligible in others.47

The increase in ground contact time is
a result of the increased time taken to
produce the larger forces required
to pull the sled. Over time, the extra
muscular effort required to drive the
hips is thought to lead to increased
hip extensor strength.3,11,31,38 In
contrast, researchers have suggested
that participants may compensate for
the decrease in stride length by
increasing stride frequency with short
choppy steps.31 Although an increased
stride frequency can prove beneficial,
the athlete needs sufficient ground
contact time to exert the appropriate
horizontal force. This will provide a
negative training stimulus and it will be
observable by a significant reduction in
stride length.

Although acute studies can help the
coach to understand the manner
in which loading can alter sprint
mechanics, longitudinal interventions
are necessary to explore the adaptive
responses to such modifications (see
Table 2). Firstly, it is important to
note that out of all the intervention
studies,3,8,33,35,32,46,43,44,47 only two have
reported insignificant improvements
in acceleration post training.4,43 It is
therefore apparent that the current RST
guidelines are somewhat suitable for
the development of the acceleration
phase. Due to certain methodological
issues the unsuccessful studies need
to be interpreted with caution. Small
sample sizes or generalised sled
loading strategies (absolute load)
might have shaped the results in these
investigations.8,44

Three studies reported that sprint
improvements were the result of an
increased stride length.3,33,36 These
investigations used similar loading
strategies and two of them used
identical intervention periods (four
weeks). Interestingly, one of the testing
populations was highly trained3 and the
other two were untrained populations.36
Although RST appears suitable for
athletes of any training age,3,36,40 It
remains unclear how the training
variables need to be manipulated in
order to maximise the training effects
for different populations. Over the
relatively short intervention periods,
it is probable that neural adaptations
led to the improved stride length and
subsequent sprint performance.39

Stride frequency was measured in
four investigations.3,8,33,43 The findings
were equivocal: two studies reported
negligible differences pre and post the
RST intervention.33 However, another
found that the increase in stride
frequency was due to a significant
reduction in ground contact time post
the RST intervention,46 whereas the
fourth study reported a significant
increase in ground contact time.36 There
were no noticeable differences between
any of the successful aforementioned
studies. Similar loading strategies have
been implemented on populations of
mixed training ages over different time
periods. Consequently, it is not clear
which of the programming variables
need to be manipulated to improve
stride frequency.

An increased trunk lean may be
beneficial in that it overloads the body
in a specific manner to the acceleration
phase.43 This theory is supported by
Kugler et al.3 who proposed that if
the force vector points further forward
(trunk lean) then the ratio of vertical
to propulsive force will be biased towards
forwards propulsion. In this instance,
greater GRF can be applied without the
negative effects associated with high
vertical force application.

(text continued on page 27)
### Table 1. Acute resisted sled training investigations

<table>
<thead>
<tr>
<th>Subjects and training status</th>
<th>Protocol</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcaraz et al 18 competitive athletes (11 male and 7 females)</td>
<td>Sled loading of 16% BM, 30m sprints using a 20m run-in</td>
<td>Sprint times: RST significantly decreased maximum velocity Kinematic: RST significantly decreased stride length and significantly increased trunk lean compared to US No significant changes to the upper limbs or free leg in RST</td>
</tr>
<tr>
<td>Cronin et al 20 competitive athletes (16 male and 4 females)</td>
<td>Sled loading of 15 and 20% BM US and RST over 10 and 30m</td>
<td>Sprint times: RST significantly decreased 20% BM trials were significantly slower than 15% BM trials Kinematic: - Trunk lean and the stance phase significantly increased for both RST groups. - Stride length and stride frequency significantly decreased in the RST groups - RST 20% BM significantly increased stance phase and significantly decreased stride length compared to 15% BM</td>
</tr>
<tr>
<td>Kawamori et al 10 active males</td>
<td>Sled loadings of 10 and 30% BM US and RST over 5m</td>
<td>Sprint times: RST significantly increased sprint times 30% BM trials were significantly greater than 10% BM trials Kinetic: - No significant GRF differences between US and RST 10% trials - RST 30% BM trials significantly increased net horizontal impulse - Braking forces significantly decreased in the 30% BM trials</td>
</tr>
<tr>
<td>Lockie et al 20 active males</td>
<td>Sled loadings of 12.6 and 32.2% BM US and RST over 15m</td>
<td>Kinematic: - Horizontal hip velocity and stride length were significantly reduced in the 12.6% BM trials - Further significant reductions occurred in the 2.2% BM trials - US had significantly greater stride frequency than RST groups - GCT and trunk lean significantly increased in the RST trials</td>
</tr>
<tr>
<td>Maulder et al 10 elite male sprint athletes</td>
<td>Sprint starts off the blocks Sleds loaded at 10 and 20% BM US and RST over 10m</td>
<td>Sprint times: RST significantly increased sprint times Kinematics: - RST 10% BM had no significant impact on mechanics - RST 20% BM significantly decreased stride frequency</td>
</tr>
<tr>
<td>Murray et al 33 males (13 pro rugby and 20 competitive football players)</td>
<td>Sleds loaded at .5, 10, 15, 20, 25 and 30% BM US and RST over 10m and 20m</td>
<td>Sprint times: Greater sled loading significantly increased sprint times Kinematics: No significant difference in stride frequency but heavier loading significantly reduced stride length.</td>
</tr>
</tbody>
</table>

**Key:** (Protocol) US=unloaded sprinting, RST=resisted sled sprints (Measures) BM=body mass, GCT=ground contact time.
## Table 2. Long-term resisted sled training investigations

<table>
<thead>
<tr>
<th>Subjects and training status</th>
<th>Protocol</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcaraz et al(^1)</td>
<td>4 weeks RST or US intervention</td>
<td>Sprint times: RST significantly increased velocity in the 15-30m phase. US significantly increased maximum velocity. Kinematic analysis: RST significantly increased trunk lean and stride length in various phases at maximum velocity. PPO: RST significantly increased PPO at 45 and 70% of 1RM. US significantly increased PPO at 80% of 1RM. Isokinetic: Peak torque significantly increased in both groups. Jumps: No significant improvements in any of the jump tests.</td>
</tr>
<tr>
<td>(20 males and 10 females)</td>
<td>2 sessions p/w Sled loading to cause a 7.5% reduction in sprint times</td>
<td></td>
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<tr>
<td>Clark et al(^8)</td>
<td>7 week intervention [13 training sessions] Sled loading to cause a 10% reduction in maximum velocity.</td>
<td>No significant differences in kinematic measures or sprint times following intervention.</td>
</tr>
<tr>
<td>20 male elite lacrosse players</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrison &amp; Bourke(^2)</td>
<td>6 week intervention [2 sessions p/w] Sled loading of 13% BM</td>
<td>Sprint times: RST significantly increased velocity over 0-5m. Jumps: RST significantly increased jump height and starting strength.</td>
</tr>
<tr>
<td>15 pro/semi-pro males</td>
<td></td>
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<tr>
<td>Lockie et al(^3)</td>
<td>6 week intervention [2 sessions p/w] Sled loading of 12.6% BM</td>
<td>Sprint times: Both RST and US groups significantly increased velocity over 0-5m and 0-10m. Kinematic analysis: RST and US significantly increased stride length. US significantly increased stride frequency. Jumps: Both RST and US significantly increased active strength index. Strength: RST and US interventions significantly increased relative strength.</td>
</tr>
<tr>
<td>35 active field sport males</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Makaruk et al(^6)</td>
<td>4 week intervention [3 sessions p/w] Sled loading to cause a 10% reduction in velocity</td>
<td>Sprint times: Both RST and US groups significantly increased velocity in the acceleration phase. The velocity difference in these groups was non-significant. Kinematic analysis: RST significantly increased stride length, knee angle at toe off and GCT. US significantly increased stride frequency.</td>
</tr>
<tr>
<td>36 untrained females</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saraslandis(^4)</td>
<td>8 week intervention [3 sessions p/w] Sled loaded 5kg total</td>
<td>Sprint times: US significantly increased maximum velocity running. No significant changes for the RST group.</td>
</tr>
<tr>
<td>45 physically active males</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinks et al(^3)</td>
<td>8 week intervention [2 sessions p/w] Sled loading to cause a 10% reduction in maximum velocity</td>
<td>Sprint times: Both RST and US significantly increased velocity in the acceleration phase. Power: Both groups significantly increased lower body power. Kinematics: Trunk lean and hip velocity significantly increased for both groups. RST caused a significant decrease in GCT for the right foot.</td>
</tr>
<tr>
<td>30 recreational male athletes</td>
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<tr>
<td>West et al(^4)</td>
<td>6 week intervention [2 sessions p/w] Sled loading of 12.6% BM 2 groups: US training and a combined training programme (RST and US)</td>
<td>Sprint times: Both groups significantly increased velocity in the acceleration phase. The velocity difference in these groups was non-significant, although the combined group increased training programme (RST and US).</td>
</tr>
<tr>
<td>20 pro male rugby union players</td>
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<tr>
<td>Zafeiridis et al(^7)</td>
<td>8 weeks intervention [2-3 sessions p/w] Sled loaded 5kg total</td>
<td>Sprint times: RST significantly increased velocity in the acceleration phases. US significantly increased maximum velocity phase. Kinematics: RST significantly increased stride rate trunk lean. US intervention significantly increased stride length.</td>
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<tr>
<td>22 recreational male athletes</td>
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</table>

**Key:** [Protocol] US=unloaded sprinting, RST=resisted sled sprints [Measures] BM=body mass, GCT=ground contact time, PPO=peak power output.
Two of the investigations measured trunk angle changes during the acceleration phase of loaded sled trials.11,33 Both studies reported that RST significantly increased trunk lean when compared to unloaded sprinting.11,33 It must be noted that when the athlete’s trunk angle increases too greatly it will probably reduce their hip flexion capacity and limit stride length.31

Sleds are generally attached via a lead and shoulder harness or waist belt. Researchers suggest that a shoulder harness will increase forward trunk lean to a greater extent because the applied load is higher compared to the pivot point (the hips) and the athlete will compensate by leaning forward. However, when attached via a waist belt the load passes through the pivot point and as such produces no torque. More detailed kinematic analysis is required to fully understand which harness attachment site is best suited for RST. It appears possible that due to different force application requirements the acceleration and maximum velocity phases may benefit from different attachment sites.

Again, although the acute studies indicate that RST alters sprint mechanics in a way beneficial to the acceleration phase, longitudinal investigations are important to monitor these adaptations. A number of longitudinal studies have looked at the participant’s trunk lean following a RST intervention.3,36,47 Results indicate that the RST interventions did lead to significantly greater forward trunk lean in the acceleration phase. As discussed previously, the increased trunk lean should aid acceleration as it enhances horizontal force application.29,35 In contrast, this increased lean may reduce maximum velocity performance as vertical forces are imperative to minimise contact times.29 The findings of Zafeiridis et al.30 who measured sprint kinematics following a prolonged RST programme, support this adaptation. They found an increased trunk lean and subsequent improvement in acceleration, whereas no significant differences were found in the maximum velocity phase. Supplementary research is required to establish whether this kinematic adaptation is a result of changes in GRF application or a transferable change in skill execution.

**Force application**

Since the overall aim of a RST programme is to enhance an athlete’s force application during sprinting, it seems unusual that little research has been conducted on this aspect of performance.6 Factors such as the direction of force application, rate of force development and net force will ultimately determine the kinematics of performance and therefore allow us to further understand the training stimulus that will be provided. A recent article by Kawamori et al.25 investigated the acute kinetic effects of RST during the acceleration phase of the sprint. Specifically, GRF data was collected for the stance phase of the participant’s second step and was compared across three conditions (unloaded, 10% BM and 30% BM loading). They reported that the GRF measures for the 10% BM group were not significantly different from the unloaded group. As such, the researchers suggest that this loading strategy may not provide enough resistance to produce the overload needed for adaptation to occur.

It thus appears possible that sled loading strategies that do not impact on kinematics might not be providing enough resistance to stimulate physiological adaptation. However, the significantly different GRF values were explained simply by longer ground contact times during which more horizontal and propulsive force could be applied. The findings of this investigation need to be interpreted with caution for a number of reasons. Participants (inside the laboratory) were attached to the sled (outside the laboratory) using a 23.1m lead. Not only did the two surfaces have different coefficients of friction, the extended attachment lead meant the resistance of the sled was acting on the participants from an angle uncommon to that of RST practice. Although significantly longer ground contacts are not an ideal training stimulus, the adaptations following such an intervention period are unknown. Further investigations need to be more in line with common RST practice, thus allowing them to be replicated in a team/club environment.

In order to identify which muscle groups are being overloaded during RST, more kinetic and joint-specific angular kinematic analysis is required.6 Net horizontal and propulsive impulses were much greater in the 30% BM trials than those recorded for the unloaded sprint group.

**Maximum velocity**

The maximum velocity phase is often overlooked by the strength and conditioning community. Field sport athletes reach near maximal speeds much earlier than track athletes and the majority of their sprints do not occur from a standing start.6,15 Therefore, it would seem that maximum velocity training has an important place in the strength and conditioning programmes of field sport athletes. During maximum velocity sprints, athletes must preserve optimal postural stability, minimise braking forces and increase the vertical propulsive forces. Greater vertical GRF are essential in allowing faster sprinters to reduce foot contact time during the stance phase.46 The athletes’ RFD will greatly impact their sprint performance: when the GRF are not applied quickly enough, sprint performance will suffer as the limb’s mechanical advantage and natural spring-like rebound in the later portion of the contact are both compromised.3,27

Phase-specific (acceleration and maximum velocity) loading strategies are important as each has its own unique characteristics and requirements. There is a lack of research into RST for the maximum velocity phase, with only one study investigating the acute responses.1 Alcaraz et al.23 compared RST (loaded based on a 10% reduction in velocity) with a parachute (medium-sized) and weighted belt (9% BM). Unsurprisingly, the RST condition resulted in the largest reductions in maximum velocity due to the additional frictional forces (sled). None of the three conditions impacted significantly on stride frequency and stride length was only significantly reduced in the RST trials. Trunk lean was also significantly increased in the RST trials. As discussed previously, this increased trunk lean is not beneficial for the maximum velocity phase as vertical force application is important in reducing contact time and braking forces.3,47 When RST is implemented for the maximum velocity phase, a waist belt attachment would seem more suitable as the athlete’s trunk lean will be minimised.3
Maximum velocity

Studies have measured maximum velocity after a RST intervention period. Unfortunately, all used the same loading strategies for both the acceleration and maximum velocity phases. As two of the aforementioned investigations reported significant improvements in the acceleration phase and none found any increases in maximum velocity, it would appear that the RST loading strategies or programming variables being implemented at present are not suited to this phase. In line with the acute investigations, an increased trunk lean was the only adaptation that occurred in both of the studies that undertook a kinematic analysis for the maximum velocity phase.

The sled weight is clearly a limitation when training for the maximum velocity phase. Sleds generally weigh between 4.0-4.5kg and as a result it is not possible to train with lighter loads. In this instance other forms of resisted sprint training such as parachutes might be more suitable. Neural adaptations (ie, improved co-ordination and timing) are crucial to the maximum velocity phase due to the limited stance phase and therefore it is not surprising that some researchers have suggested that unloaded sprint training is more beneficial than RST for this high velocity phase. As such, it is recommended that RST programmes should be either designed with the acceleration phase in mind or are combined with unloaded sprints so the athletes retain the high velocity training stimulus while developing muscle force. Recent research suggests that this combined approach is more beneficial than unloaded sprinting or RST alone.

Programming considerations

PROGRAMME PERIODISATION

Resisted sled training needs to be carefully scheduled into a periodised training plan. This type of training is suited to the late general or early specific preparation phases, benefitting from the strength, co-ordination and postural stability qualities developed in the earlier programme. Research informed RST is crucial in order to maximise physiological adaptations. Numerous studies have employed a four-week intervention period in comparison to other studies that completed an eight-week RST intervention. Both intervention periods have been reported as having a significant impact on sprint performance (Table 2). Alcaraz et al suggested that improvements in sprint velocity were the result of an increased rate of force development. Such adaptations are probably neural in nature and as a result occurred during a four week RST intervention.

To date, no investigations have extended the intervention period over 10 weeks. Research suggests that contractile and fibre type adaptations may not have occurred during these shorter interventions. Although investigations into power training found no muscle fibre adaptations, it is not known how athletes will respond to a heavier or combined RST intervention. As such, a longer RST intervention study with regular testing is necessary to determine the point at which adaptations are optimal for sprint performance. Although more investigation is required, at present six weeks of RST appears to be a sufficient intervention period.

Similarly to any training that has a high neuromuscular demand, RST should be undertaken when athletes are minimally fatigued. Programming a RST session the day after a physically demanding training day or match would probably be counterproductive to performance. Research suggests that a period of 24-48 hours should be left between RST sessions. Participants in the longitudinal RST investigations were required to attend between two and three training sessions per week for the entire intervention period. Many of the successful RST intervention studies followed a programme of two training sessions per week. Although two training sessions per week seems sufficient to improve performance, research into resistance training found that participants training three times per week experience a greater degree of neural adaptation. As such, it is recommended that future RST investigations look to compare programmes with different volumes of training sessions.

Training sessions should include a standardised warm-up protocol, followed by a number of RST sets and reps, and finishing with a cool-down element. Typically investigations have employed protocols with similar sets and rep ranges. Passive rest periods between reps varied from 1 to 4 minutes. Rest periods between sets differed between studies: these were generally between 3 and 8 minutes in length but sometimes as much as 10 minutes. Research indicates that sets, reps and recovery periods of 3, 3, and 2 minutes respectively can be employed successfully for the acceleration phase. Longer rest periods of 4 minutes are sufficient between sets.

Loading strategy

Sled loading can be determined using various strategies, such as using an absolute load (ie, 5kg); many of the earlier studies employed this methodology. Investigations have set loads based on allometric scaling in accordance with the athlete’s body mass (eg, 10% BM). These generalised strategies are somewhat limited as the athlete’s individual physical strength and performance ability are not considered.

Particular attention needs to be paid to the individual’s strength qualities as research shows that faster sprinters produce much greater relative forces than slower sprinters. Larger sled loading will probably be needed to provide sufficient overload in these stronger athletes.

Although more time-consuming, the sled loading strategy most commonly employed in research is to load the sled based on reductions in sprint velocity (eg, 10% reduction in velocity over 20m). The importance of this loading strategy is emphasised in research by Alcaraz et al, who found that a loading of 16% BM resulted in a 10% decrease in maximum velocity on their cohort of high level track athletes.

In comparison, Makaruk et al reported that a load of 75% BM was sufficient to cause a 10% reduction in sprint velocity in a population of active females. If sleds were loaded equally for the different populations, participants would probably be under or overloaded and as such RST adaptations might not prove beneficial for sprint performance in the long term.
In a team sport environment this method will require an initial testing session and regular re-assessment, thus allowing effective individual sled loadings for training phase to be determined. Coaches also need to consider the training surface when determining sled loadings. The coefficient of friction between the sled and the training surface will impact on the resistance placed on the athlete. Detailed EMG analysis to investigate how different sled loading strategies impact on the key sprint musculature in terms of recruitment and activation would also help improve knowledge.

Further research investigating the impact of different sled loading strategies on sprint performance (phase specific) and the physiological adaptations after such an intervention period is required. Much of the longitudinal intervention research has been undertaken using similar sled loading strategies. As suggested by Clark et al, lighter or heavier loads may be more beneficial to performance in the long term.

Future directions

At present much of the RST research focuses on performance outcomes such as sprint velocity and jump performance. Although this is an essential element, a more in-depth look at the specific physiological adaptations is required, such as kinetic and joint-specific angular kinematic analysis. Detailed EMG analysis to investigate how different sled loading strategies impact on the key sprint musculature would also help improve knowledge.

Further research investigating the impact of different sled loading strategies on sprint performance (phase specific) and the physiological adaptations after such an intervention period is required. Much of the longitudinal intervention research has been undertaken using similar sled loading strategies. As suggested by Clark et al, lighter or heavier loads may be more beneficial to performance in the long term.

Conclusion

Resisted sled training (loaded based on a 10% reduction in velocity) has been shown to improve sprint performance in the acceleration phase. At present the programmes used during RST investigations have not highlighted any clear benefit for the maximal velocity phase and in some cases (with sled-only interventions) it has proved detrimental.

RST should be incorporated in a mixed training programme in the late general preparation phase of training. Sleds should be loaded based on a percentage of sprint velocity reduction, monitored and calculated for all the training surfaces. The current strategy of loading sleds not to impact on kinematics may not provide the ideal resistance for overloaded the musculature and giving sufficient stimulus for adaptation.

Further research is necessary to investigate the optimum sled loading strategies for sprint performance (phase-specific) and the physiological adaptations that occur following a prolonged intervention period.

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