Momentum: a practical solution to calculate the optimal load for resisted sled sprint training.

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Headline

Currently, there is a lack of consensus regarding the optimal load with which to expose athletes to during resisted sled sprint training for the purpose of training linear acceleration and sprint performance. We propose that the use of "momentum" is a practical method of determining the optimal load for resisted sled sprint training.

Introduction

Resisted sled sprint (RSS) training is an efficacious method of improving athletes' acceleration and sprint performance (1,2). Despite its efficacy, debate persists regarding the optimal load with which to expose athletes to during RSS training for improving acceleration and sprint performance. The determination of an optimal load is not a novel issue; it has been suggested that different loads can preferentially provide a training stimulus for either acceleration or maximum velocity. It has been posited that un-resisted sprint (URS) training as well as "*light load*" RSS training provides a physiological stimulus associated with improvements in maximum sprint performance (1). In contrast it is posited that "*heavy load*" RSS training provides a physiological stimulus associated with acceleration (1). However, more recently, it has been reported that "*very heavy load*" (up to and in excess of 80% of body mass) RSS training may provide a better stimulus for improving both acceleration and maximum velocity (3,4), when compared to the typical "*light load*" and "*heavy load*" RSS reported in the literature (5,6).

The rationale for including a horizontally directed force stimulus as a key component of the athletic development programme of team sport athletes is well understood. Recent research has explored relationships between the physical attributes of professional rugby union players and game-specific key performance indicators (7). Amongst forwards, 10 m sprint time (seconds) was correlated to half-breaks (r = -0.718) and % carries over the gain-line (r = -0.651). Amongst backs, momentum (kg·m·s-1) quantified over 10 m and a 5 m sled drive (seconds) were related to dominant collisions (r = 0.862 and r = -0.792, respectively) (7). This research illustrates the importance of both horizontal force and velocity to the success of contact phases of rugby union.

Momentum is defined in physics as mass multiplied by velocity (Equation 1). As evidenced by 'Newton's cradle', momentum into a collision equals momentum out of a collision. The concept of momentum in rugby union has been previously alluded to (8). Quarrie and colleagues (9) stated that "*the ability to obtain greater momentum is important in the body contact phases of the game*". Furthermore, it has been suggested that momentum is likely to be a key determinant of success in contact phases of rugby union (10). This is evidenced by the observation of Garraway and colleagues (11) who reported that for injuries sustained during tackling, players with lower momentum at the time of contact were more likely to be injured.

Equation 1.

$$p = m \cdot v \qquad [1]$$

p = momentum (kg·m·s-1); m = mass (kg); v = velocity (m·s-1)

Momentum (body mass (kgs) x maximal velocity (m·s-1)), quantified during sprinting can also discriminate between higher- and lower-level athletes in rugby codes (12). Baker and Newton (12) reported that first division National Rugby League players generated substantially more momentum during sprinting than second division National Rugby League players. These authors concluded that "*heavier, faster players would possess better drive forward and conversely be better able to repel their opponents' drive forward*" (12). Differences in momentum during the assessment of sprint performance have also been observed between senior and junior rugby union players (13), academy and school rugby union players (14), as well as between high- and low-grade rugby union players (9). Considering these observations, it is rational to conclude that momentum could be optimized by increasing a player's lower body strength and power, as well as increasing his/her body mass while simultaneously maintaining or improving his/her acceleration and/or sprint performance.

We propose that quantifying an athlete's momentum during the performance of RSS training is a practical method of determining the optimal load for the purpose of training linear acceleration and sprint performance. Consequently, we believe that a RSS load that optimizes an athlete's momentum is likely to provide a desirable training stimulus for improving linear acceleration and sprint performance.

Aim

The aims of this report are to: (1) Illustrate the relationships between momentum calculated during RSS training, maximum velocity and carry effectiveness in a cohort of professional rugby union players. (2) Demonstrate the application of momentum as a method of determining the optimal load for RSS training, to improve acceleration and sprint performance.

Design and Methods

Data from 13 professional rugby union players (age = 25 ± 3 years; height = 1.86 ± 0.06 m; body mass = 103.9 ± 10.7 kg) were collected over a training phase (8 weeks) of resisted sled sprint (RSS) training sessions. These data were collected as part of the players' usual athletic performance training. Each of the players consented to the use of their own "anonymised personal data" for research purposes, and ethical approval was received from the UCD Human Research Ethics Committee (LS-18-14-Tierney-Del).

The relationship between RSS momentum, and bodyweight (BW) momentum derived from players' maximum velocity (V_{max}) were analysed. RSS momentum was calculated by multiplying the velocity during the RSS, by the total mass

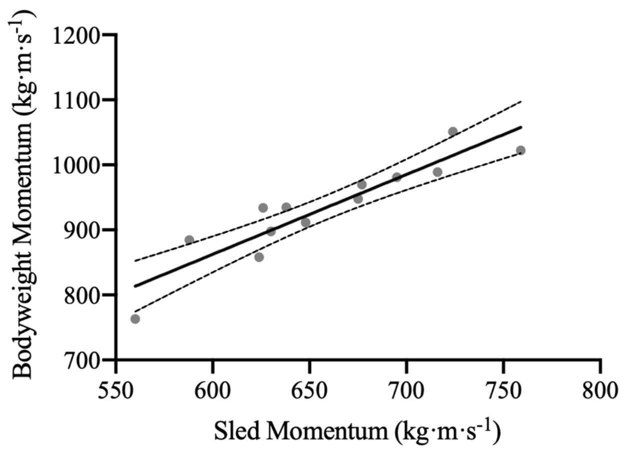

Fig. 1. The relationship between peak sled momentum and peak bodyweight momentum.

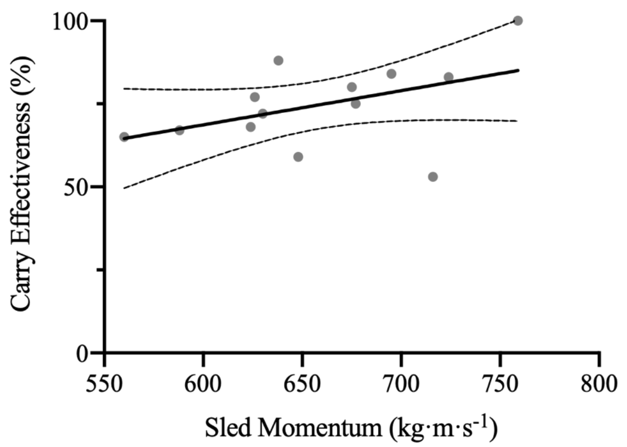

Fig. 2. The relationship between peak sled momentum and carry effectiveness (%).

(player's body mass + sled mass, + sled load). BW momentum was calculated by multiplying the V_max achieved by the player during the training phase, by his average body mass during the training phase. Each players' peak velocity (m.s-1) achieved from all field-based trainings and matches during the 8 week training phase were collected and utilised as his V_max. Players' V_max was derived from data acquired by micro-sensor technology units (StatSports Group Limited, Co. Down, Northern Ireland). These units collect 10 Hz GPS data (augmented to 18 Hz), accelerometer data at a rate of 600 Hz, magnetometer data at a rate of 10 Hz and gyroscope data at a rate of 400 Hz.

For the purpose of this report "dominant carries" were defined as those whereby the player "won" the contact phase/collision. Each players' carry effectiveness percentage was calculated for competitive matches he participated in during the same time period alluded to above. This data was independently provided by a professional rugby union performance analyst.

Results

The relationship between resisted sled sprint momentum, players' maximum velocity and carry effectiveness. The relationship between RSS momentum and BW momentum is displayed in Figure 1 (r = 0.92; nearly perfect). Without applying causation, it would seem logical to suggest that an improvement in RSS momentum may result in improved BW momentum (not necessarily just at maximal velocity, but at subsequently lower velocities). The relationship between RSS momentum and carry effectiveness is displayed in Figure 2 (r = 0.46; moderate).

The application of momentum as a method of determining the optimal load for resisted sled sprint training. In the following paragraphs, we present and discuss data collected from a number of individual players. In an attempt to identify the optimal load (peak momentum) to expose players to during RSS training, each players' first session consisted of 1 repetition of a 10 m RSS at a total external resistance of 30 kg, 45 kg, 60 kg, 75 kg (sled and harness mass = 14.8 kg). Subsequent sessions were prescribed based upon the external resistance associated with the highest quantified momentum.

In Table 1 we present data for a forward (age = 22 years, body mass = 115 kg) during his first RSS session completed (profiling session). This player's momentum peaks at a mass of 175 kg (additional external resistance of 60 kg (sled + 45 kgs)), even though his time through 10 m is slower than at lighter resistance. As the external resistance to which he is exposed increases to 75 kg (sled + 60 kg) his time to complete the 10 m sprint slows to a point where his momentum decreases. We suggest that this load may be too heavy a stimulus for this player, and that the optimal load is likely to be where the momentum produced is the largest (See Table 1).

In Table 2 we present data for a back (age = 24 years, body mass = 103 kg) during the first RSS session completed (profiling session). This player's momentum peaks at a mass of 178 kg (additional external resistance of 75kg (sled + 60kgs)), even though his time through 10 m is slower than at lighter resistance. We suggest that this player's optimal load for RSS training is likely to be 75 kg external resistance, or potentially even higher (See Table 2).

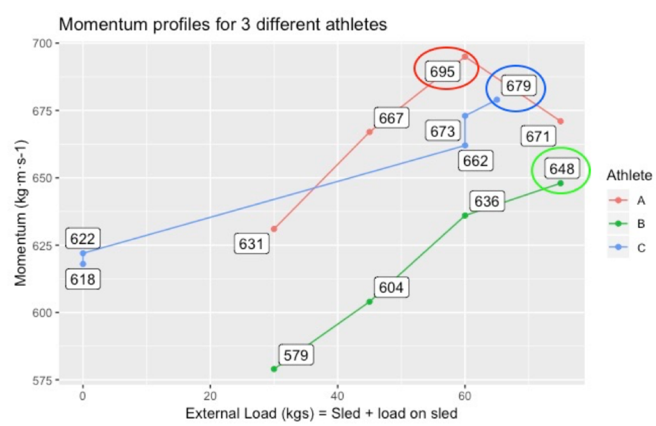

Fig. 3. 3 athletes' momentum profiles and external loads associated with each repetition of a resisted sled sprint. Note: the peak momentum values for the 3 athletes here are different, and also achieved at different external loads. Athlete A – 115kg body mass; Athlete B – 103kg body mass; Athlete C – 106.9kg body mass.

Table 1. Resisted sled sprint training data for a forward (profiling session)

External resistance/load	Total mass (kg)	Distance (m)	Time (seconds)	Velocity (m·s-1)	Momentum (kg·m·s-1)
30 kg (sled + 15 kg)	145	10	2.30	4.35	631
45 kg (sled + 30 kg)	160	10	2.40	4.17	667
60 kg (sled + 45 kg)	175	10	2.52	3.97	695
75 kg (sled + 60 kg)	190	10	2.83	3.53	671

Momentum = total mass (kgs) · velocity (m·s-1). In this example the player has a body mass of 115 kg.

Table 2. Resisted sled sprint training data for a back (profiling session)

External resistance/load	Total mass (kg)	Distance (m)	Time (seconds)	Velocity (m·s-1)	Momentum (kg·m·s-1)
30 kg (sled + 15 kg)	133	10	2.30	4.35	579
45 kg (sled + 30 kg)	148	10	2.45	4.08	604
60 kg (sled + 45 kg)	163	10	2.57	3.90	636
75 kg (sled + 60 kg)	178	10	2.75	3.64	648

Momentum = total mass (kgs) · velocity (m·s-1). In this example the player has a body mass of 103 kg.

Discussion

In Table 3 we present data for a different back, in a RSS training session. This player completed 2 maximal un-resisted sprints (URS), followed by 3 RSS at a pre-determined external resistance derived from his peak momentum achieved in a previous session. His peak momentum with external resistance (679 kg.m.s-1) was higher than that achieved during URS (618-622 kg.m.s-1), which we suggest represents an overload training stimulus.

This principle of an overload stimulus is clearly demonstrated if we compare the forward's data (Table 1) to that described in the literature during unloaded carry scenarios in rugby union (average momentum of 563 kg.m.s-1) (8). The same can be seen for the back's data (Table 2); a momentum of 645 kg.m.s-1 is substantially greater than that reported for unloaded carry scenarios in rugby union (438 kg.m.s-1) (8). If we compare the forward and back players, we clearly see the need to individualise the external load applied during RSS training. Peak momentum for the forward was achieved at a total external load of 52% of his body mass (Table 1), whilst peak momentum for the back was achieved at a total external load of 73% of his body mass (Table 2). We feel that the use of momentum accounts for these players' bodyweight, acceleration capabilities, horizontal force production, and strength levels. Momentum also allows for comparison between varying distances of RSS training. For example, it may be that an athlete's momentum may peak at a lower weight and a higher distance, or a higher weight and a lower distance.

In Table 4 we present data from a range of players, further highlighting the need to individualise the external load applied during RSS training. We advocate against the use of arbitrary absolute external loads or relative external loads (e.g. each player uses an external load equal to 20% of his body mass). A statement by Petrakos (15) (*"I would not ask a squad of 15 rugby players to each back squat 100kg, or hang clean 50% of their bodyweight. Why generalize these methods to RSS training?"*) in a recent blog written on the topic is consistent with the data presented in this report, as well as our sentiment about the need to individualize the external load applied during RSS training.

A recent review suggested that the external load applied during RSS training should "*never be >20% of body mass*" (2). However, investigations from other research groups (3,4), and the data presented in this report refute this statement. The peak momentum in our player cohort was achieved at body mass percentages ranging from 35% to 76% (Table 4). This is likely explained by the large inter-player variability in sprinting capabilities, lower limb strength and force application; so we disagree with the generalising principle of confining the external load applied during RSS to <20% body mass.

There are a number of limitations that require consideration. Our testing procedures and numeric calculations did not account for friction. This is an important variable to consider when calculating the external load to be applied during RSS training (16). However, it has been observed that there are minimal changes in friction force during RSS training when players achieve a velocity of between 4.0 – 6.0 m·s-1 (16). The average and standard deviation of the velocities of the players included in our cohort were 4.19 m·s-1 and 0.28 m·s-1 respectively, with a standard error of the mean of 0.03 m·s-1. During profiling and training sessions, shoulder harnesses were worn by this player cohort to tow the sleds. It is possible that a waist-harness should be considered in future investigations as it has been proposed that this will result in "*fewer kinematic alterations and greater net horizontal impulse when compared with the shoulder harness*" (17). We only evaluated momentum during a distance of 10m. It is possible that peak momentum is achieved at varying distances for different players. We recommend that future investigations should quantify mo-

Table 3. Resisted sled sprint training data for a back (training session)

External resistance/load	Total mass (kg)	Distance (m)	Time (seconds)	Velocity (m·s-1)	Momentum (kg·m·s-1)
Un-resisted	106.9	10	1.73	5.78	618
Un-resisted	106.9	10	1.72	5.81	622
60 kg (sled + 45 kg)	166.9	10	2.52	3.97	662
60 kg (sled + 45 kg)	166.9	10	2.48	4.03	673
65 kg (sled + 50 kg)	171.9	10	2.53	3.95	679

Momentum = total mass (kgs) · velocity (m·s-1). In this example the player has a body mass of 106.9 kg.

Table 4. Resisted sled load as % of body mass for professional rugby union athletes

Players	Body mass (kgs)	External Resistance (kgs)	External Resistance (% Body mass)
Player 1	115	70	61 %
Player 2	117	60	51 %
Player 3	109	45	41 %
Player 4	115	40	35 %
Player 5	100	55	55 %
Player 6	104	60	58 %
Player 7	112	60	53 %
Player 8	103	45	43 %
Player 9	79	45	56 %
Player 10	95	60	63 %
Player 11	103	60	58 %
Player 12	92	70	76 %
Player 13	107	55	51 %

External resistance is the sum of load on the sled, and the weight of the sled (14.8kgs). Data presented in this table is each individual athlete's body mass, the external load which maximised peak momentum, and this load expressed as a percentage of their body mass.

mentum across a range of different distances. It must also be considered that we have chosen to derive training sled loads from the peak momentum from profiling; however, it may also be pertinent to consider loading players at the lowest momentum recorded. The consideration of this method would be based on the idea of training deficits in a player's momentum profile.

Conclusion

We believe that the calculation of momentum is an easily applicable and practical method of determining an optimal load during RSS training for improving acceleration and sprint performance. In our opinion, momentum accounts for a number of different variables that contribute to RSS performance, including:

1. Player's body mass.
2. Inter-individual differences in acceleration and sprint performance.
3. Varying distances of resisted accelerations (i.e. momentum can be compared across various distances, whereas % body mass cannot).
4. The quantification of peak momentum allows for periodisation of number of exposures.
5. Tolerance to a variety of external resistance – the range of load that maximised momentum in this sample of athletes was 35 – 75% of body mass.

We invite discussion and critique of the data we present in this report. There are a number of experts who have contributed a substantial body of research on the topic of RSS training. Their work is referenced throughout this piece, and warrants consideration during the design of future research on RSS training. This report is not intended to discredit already established training methods (force-velocity profiling, alternative sled-loading strategies), but rather to offer a practical method of determining an optimal load for RSS training.

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