**Title**: Resisted sprint training in youth: the effectiveness of backward versus forward sled towing on speed, jumping, and leg compliance measures in high-school athletes.

Running head: Resisted Sprint Training in Youth

**Authors:**

Aaron Uthoff[1], Jon Oliver[1,3], John Cronin[1], Paul Winwood[1,4], Craig Harrison[1], and Jeong Eun Lee[2]

[1]Sports Performance Research Institute New Zealand (SPRINZ)
AUT Millennium
AUT University
Auckland
New Zealand

[2]School of Engineering, Computerand Mathematical Sciences
AUT University
Auckland
New Zealand

[3]Youth Physical Development Centre
School of Sport
Cardiff Metropolitan University
Cyncoed Campus
Cyncoed Road
Cardiff CF23 6XD
United Kingdom

[4]Department of Sport and Fitness
Faculty of Community Wellbeing and Development
Toi Ohomai Institute of Technology
Tauranga
New Zealand

**Corresponding Author:**
Aaron Uthoff, MSc, CSCS
Tel: +64 7 578 4029
Fax: +64 7 578 4853
Email: uthoffaaron@gmail.com

**Abstract**

Resisted sprinting (RS) is a popular training method used to enhance sprinting performance in youth. However, research has only explored the effects of forward RS (FRS) training. We examined the effects of FRS and backward RS (BRS) and compared these to a traditional physical education curriculum (CON). One-hundred and fifteen males (age 13-15 years) were matched for maturity and allocated to either a FRS ($n = 34$), BRS ($n = 46$), or CON ($n = 35$) group. Training groups towed progressively overloaded sleds (20-55% bodymass) 2 d·wk for 8-weeks. Pre and post-training data was collected for sprinting times over 10 and 20 m, countermovement jump (CMJ) height, and leg stiffness ($K_N$). Performance remained unchanged for the CON group (all $p>0.05$), while all variables significantly improved ($p<0.05$) following BRS and all but 10 m performance improved following FRS. Compared to the CON, BRS and FRS significantly ($p>0.05$) improved CMJ (ES = 0.67 and 0.38) and $K_N$ (ES = 0.94 and 0.69), respectively. No differences were found between training groups. The probabilities of improving sprinting performance following BRS (~70%) were on average ~10% and ~8% better than the FRS and CON groups, respectively. The BRS and FRS showed similar probabilities of improving CMJ (75% and 79%) and $K_N$ (80% and 81%), respectively, over the CON group. It appears that BRS may be a means to improve sprint performance and regardless of direction, RS seems to be a beneficial method for improving jumping height and leg stiffness in youth male athletes.

**Key Words**: backward running, adolescent, sprint training, transference

## 6.1 Introduction

Talent identification, team selection, and successful competitive outcomes for many youth athletes are dependent on their ability to sprint quickly over short bursts (13, 22, 33). Fast sprinting performance is facilitated by a combination of lower-body power and rapid stretch-shortening cycle function (28, 34). Running speed and the ability to produce force quickly naturally improve due to growth and maturation (28, 33); however, the development of speed and its underlying determinants may be further enhanced through specific and nonspecific training methods (25, 35). Specific-sprint training (i.e. resisted and unresisted sprinting) has been shown to be more effective than nonspecific training methods (i.e. resistance training and plyometrics) for developing sprinting speed in youth (35). Following the principle of specificity, specific sprint training methods aim to promote neurological and musculoskeletal adaptations, which are velocity and task dependent (6). Furthermore, novel sprint training methods such as backward running (BR) have resulted in greater improvements in speed, jumping height, and leg stiffness than more traditional forward running (FR) programmes in youth athletes (40). This is important as increased jumping height is related to improved strength qualities (4), and leg stiffness is essential for force transmission during sprinting (34).

The training principle of specificity is considered critical for maximising the benefits of speed and power training in youth (9). Resisted sprinting (RS) towing weighted sleds is a training method often used by speed and strength coaches because its technical and mechanical demands are similar to unresisted sprinting (30). It is believed that RS improves an athlete's ability to apply propulsive forces more effectively and leads to adaptations in sprint acceleration ability (17). This specific sprint training method has been shown to be particularly beneficial for midpubescent and postpubescent youth (2, 31, 36). For example, six to weeks of RS training using loads ranging from 2.5 to 20% body mass (BM) has resulted in small to large increases in propulsive force production

(31) and sprinting performances over 20 m (36) and 30 m (2, 31). Although these findings are promising for practitioners wishing to implement RS with youth, these results are limited to 3 known studies using RS towing weighted sleds up to 20% BM as a training stimulus (2, 31, 36). This is important because it has been recognised that loads >20% BM and up to 96% BM are most beneficial for improving peak power and acceleration performance in adults (7, 24, 30), yet the chronic influence of towing relatively greater loads has not yet been examined in youth.

Another specific sprint training method that has been identified as a means to improve athletic performance is BR (37, 38, 40). Backward running is a novel training stimulus that has been shown to increase lower body musculotendinous functions, jumping performance, and sprinting ability in adults and youth (10, 38-40). Uthoff et al. (40) reported that progressively overloading unresisted BR biweekly over 8 weeks resulted in improvements in 10-m and 20-m sprint times (7.47 and 5.01%, respectively), countermovement jump (CMJ) height (9.88%), and leg stiffness (10.6%) in youth male athletes. These findings were found to be similar to or better than a group performing an equal volume and intensity of FR training. Inclined BR training has also been recommended as a means to increase quadriceps functional strength while simultaneously reducing knee joint stress (15). Despite the recent evidence for integrating BR into athletic performance programmes, this training method has received little empirical attention compared with FR training. Although researchers have begun to understand the utility of unresisted BR, explorations into the prolonged effects of adding external resistance to BR have yet to be scientifically tested in youth or adults.

Given that sprinting is an essential movement for many sports (28, 34), understanding the most effective methods to enhance speed and musculotendinous functions in youth athletes is imperative. Specific sprint training methods of RS forward and unresisted BR have proven beneficial for enhancing midpubescent and postpubescent athletes' ability to produce force and sprint quickly (31, 40). However, research to date has only established the effectiveness of using forward RS training loads up to 20% BM. Moreover, the effects of resisted BR training have yet to be investigated. It is unknown whether using RS loads >20% will lead to positive adaptations in sprinting and musculotendinous performances in youth or whether these adaptations may also be realised after backward RS. Therefore, this study aimed to assess the efficacy of performing forward and backward RS towing loads from 20 to 55% BM on sprinting, jumping, and stiffness measures in youth male athletes. It was hypothesised that forward RS would be the most beneficial for improving sprinting ability, and that backward RS would be the most beneficial for improving jumping ability and leg stiffness.

## 6.2 Methods

### 6.2.1 Experimental Approach to the Problem

A cluster randomised control trial was used to examine the effects of an 8-week progressively overloaded RS training programme, either forwards or backwards, in high-school-based physical education (PE) classes. The independent variables of interest were tested before and after training and included sprinting ability, jumping performance and leg stiffness. Boys enrolled in a PE programme at their school were matched for maturity and cluster randomised to a control group or two experimental groups. The boys in the control group (CON = 35) followed the usual PE programme curriculum comprised of 50 minutes of various modified sporting games such as touch rugby, cricket, soccer, or basketball which included periods of running and sprinting interspersed with active and passive recovery, whereas the boys in the training groups performed either backward resisted sprinting (BRS = 45) or forward resisted sprinting (FRS = 34) biweekly. The 8-week training programme was implemented during a 10 week academic term. Baseline testing was administered in the 1$^{st}$ week, supervised training was performed for the following eight weeks, and post-testing was completed in week 10. Quantitative analyses were conducted using Frequentist statistics to test scores from pre-training to post-training, whereas Bayesian and inferential statistics were used to examine the qualitative meaning of any observed changes in the independent variables.

### 6.2.2 Subjects

A group of 115 boys volunteered to participate in this study. Boys were matched for maturity and cluster randomised to either a backward resisted sprinting group (BRS; n = 46), forward resisted sprinting group (FRS; n = 34), or a control group (CON; n = 35). A summary of the subject's pre-training descriptive characteristics is outlined in Table 1. Maturity offset, measured as age from peak height velocity (PHV), was calculated using equation 1 developed by Mirwald, Baxter-Jones, Bailey and Beunene (23) using non-invasive anthropometric measurements. No significant differences between groups were observed for physical characteristics or maturity offset. Subjects were included in this study if they were boys between 13 and 15 years of age, enrolled in a PE programme at a public high-school, played a sport for their school or local sports team, were free of any medical issues or injuries that may have hindered their participation or performance, and adhered to the training programme with above 80% attendance. After being informed of the risks and benefits of participating in this study subjects provided a signed assent form and a parental informed consent form signed by a parent or guardian before participation in this study. The procedures for this research were reviewed and accepted by the Auckland University of Technology Research Ethics Committee.

**Table 6.1:** Subject characteristics (mean ± SD).

| Parameters | All Subjects (n = 115) | CON Group (n = 35) | FRS Group (n = 34) | BRS Group (n = 46) |
|---|---|---|---|---|
| Age (y) | 14.3 ± 0.49 | 14.4 ± 0.52 | 14.0 ± 0.27 | 14.4 ± 0.51 |
| Height (cm) | 168.9 ± 8.9 | 168.6 ± 10.1 | 170.2 ± 7.9 | 168.4 ± 8.8 |
| Body mass (kg) | 58.4 ± 11.1 | 56.3 ± 9.9 | 58.7 ± 10.8 | 59.5 ± 12.2 |
| Maturity offset (y) | 0.53 ± 0.92 | 0.53 ± 1.0 | 0.47 ± 0.90 | 0.58 ± 0.86 |

CON = control group, BRS = backward resisted sprinting group, FRS = forward resisted sprinting group.

**Equation 6.1**.

Maturity offset = -9.236 + 0.0002708 × leg length and sitting height interaction – 0.001663 × age and leg length interaction + 0.007216 × age and sitting height interaction + 0.02292 × weight by height ratio
.

6.2.3 Procedures

Testing sessions at baseline and post-training were conducted under the same experimental conditions i.e., on the same indoor gymnasium wooden sprung floor, at the same time of day, by the same testers, using the same randomised testing order. In addition, subjects wore the same school-issued clothing and personal footwear for each testing and training session, were advised to refrain from any strenuous activity in the 12 hours prior to each session and told not to make any changes in their normal dietary intake for the duration of the study. To habituate themselves with the experimental procedures and training protocols, all subjects took part in 2 familiarisation sessions 2 weeks before baseline testing at the end of the preceding school term.

At the beginning of the pre-training test session, subjects' anthropometric measurements i.e., height, seated height, and BM were determined. Following the collection of anthropometric data, participants performed a 10 minute standardised warm-up consisting of a combination of skips, jumps, FR, BR, and sideways runs progressively increasing in intensity over 20 m, interspersed with lower limb dynamic stretching. Pre- and post-test were used to determine sprinting ability, jumping performance, and lower limb compliance as assessed by 10 m, 10 to 20 m and 20 m sprint times, CMJ height, and leg stiffness, respectively. Each performance test was completed twice by all participants in each group during each testing session, with 3 minutes of passive recovery provided between attempts. Analysis was conducted on the average performance data for each test.

6.2.3.1 Speed, Jump, and Stiffness Testing

Sprint times over 0-10 m, 10-20 m, and 0-20 m were measured using SpeedlightV2 wireless dual-beam photocell timing gates (Swift Performance Equipment, Australia). Photocell heights were set at 92.5 cm (top beam) and 68 cm (bottom beam) and timing gates were placed at the start, 10 m, and 20 m distances creating a 20 m x 1.5 m wide running lane (40). Before to starting, subjects assumed a split stance lining up with the toes of their lead foot 50 cm behind the first timing gate and toes of the back foot in line with the heel of the front foot. Rocking and false starts were not permitted before starting. Sprinting was encouraged to be completed with maximal effort for each trial. Sprinting performance over 20 m was chosen because of youth athletes' having shown good test-retest reliability up to this distance (coefficient of variation [CV] = 1.3 – 2.8%) (11, 40).

Vertical countermovement jump (CMJ) performance off two feet using full arm action was assessed using a Vertec vertical jump tester (Sports Imports, Columbus, OH, USA). After adjusting the lowest vane so that it corresponded to within 0.5 cm of each participant's maximal standing reach height (27), participants were instructed to jump and land in the same place while striking the highest possible vane using an overhead arm swing with their dominant hand at the peak of their jump. Jump height was calculated as the difference between the standing reach height and the maximal jump and reach height determined from the highest vane reached on the Vertec system (14). All vanes were placed in their original position between attempts to allow for multiple trials to be recorded. Jumping performance using the Vertec system similar to this study has been reported reliable in youth male athletes (CV = 4.24%) (40).

Lower limb compliance was assessed by calculating leg stiffness ($k_N$) through a field based submaximal hopping test, which has been identified as a valid and reliable (CV = 4.3-7.5%) method in youth athletes (19, 40). Subjects performed 20 consecutive bilateral hops on a portable contact mat with their hands on their hip (Fitness Technology, Australia). Subjects were instructed to minimise foot-ground contact time and keep in rhythm with a designated audio frequency of 2.5 Hz produced through an electronic metronome. The first and last five hops were excluded and the middle ten consecutive hops were used for analysis. Using BM, and flight and contact times during submaximal hopping, vertical ground reaction force was modelled to provide an estimate of absolute leg stiffness using equation 2 (8).

**Equation 2.**

$$K_N = \left(\frac{M \text{ x } \pi(T_f + T_c)}{T_c^2\left(\frac{T_f+T_c}{\pi} - \frac{T_c}{4}\right)}\right)/1000,$$

Where $K_N$ is leg stiffness (N $m^{-1}$), M is body mass (kg), $T_f$ is flight time (s) and $T_c$ is ground contact time.

6.2.4 Running Training Programme

The training programmes consisted of 8-weeks of biweekly progressively overloaded RS towing weighted sleds either forward or backward for a total of 16 sessions during the athletes' competitive winter sports season. This duration was selected to show how a RS programme can be applied and monitored over a typical high-school term. The RS intervention was conducted in place of the athletes' normal PE curriculum and was implemented on non-consecutive days. The same standardised warm-up routine used during the testing sessions was performed before each training session. Custom made sleds weighing 8 kilograms in conjunction with waist harnesses from XLR8 (Speed Power Stability Systems Ltd, Christchurch, New Zealand) and weightlifting plates were used to provide the training stimulus during RS training. The RS programme used six to nine sprints over 15-m, separated by three to five minutes, with undulated progressive overload to increase the training stimulus from 20 to 55% BM. The training programme progression can be observed in Table 6.2.

**Table 6.2.** Eight-week resisted sprinting programme for BRS and FRS groups.

| Week | Session | Load (% BM) | Reps | Distance (m) | Distance per Session (m) | Weekly Distance (m) |
|---|---|---|---|---|---|---|
| 1 | 1 | 20 | 6 | 15 | 90 | 180 |
| | 2 | 30 | 6 | 15 | 90 | |
| 2 | 3 | 25 | 7 | 15 | 105 | 210 |
| | 4 | 35 | 7 | 15 | 105 | |
| 3 | 5 | 30 | 8 | 15 | 120 | 240 |
| | 6 | 40 | 8 | 15 | 120 | |
| 4 | 7 | 35 | 9 | 15 | 135 | 270 |
| | 8 | 45 | 9 | 15 | 135 | |
| 5 | 9 | 30 | 6 | 15 | 90 | 180 |
| | 10 | 40 | 6 | 15 | 90 | |
| 6 | 11 | 35 | 7 | 15 | 105 | 210 |
| | 12 | 45 | 7 | 15 | 105 | |
| 7 | 13 | 40 | 8 | 15 | 120 | 240 |
| | 14 | 50 | 8 | 15 | 120 | |
| 8 | 15 | 45 | 9 | 15 | 135 | 270 |
| | 16 | 55 | 9 | 15 | 135 | |

BRS = backward resisted sprinting group; FRS = forward resisted sprinting group; BM = body mass.

Because towing weighted sleds adds an additional component of risk as a result of being a relatively novel task and absence of visual guidance, particular attention was dedicated to performing BRS with appropriate technique. See Figure 1 for the technical components used for the BRS for this study. To ensure both groups received similar training stimuli, the FRS group also received specific coaching instructions where they were encouraged to (a) “drive their arms”, (b) “punch their knees through”, and (c) “push maximally during each step”.

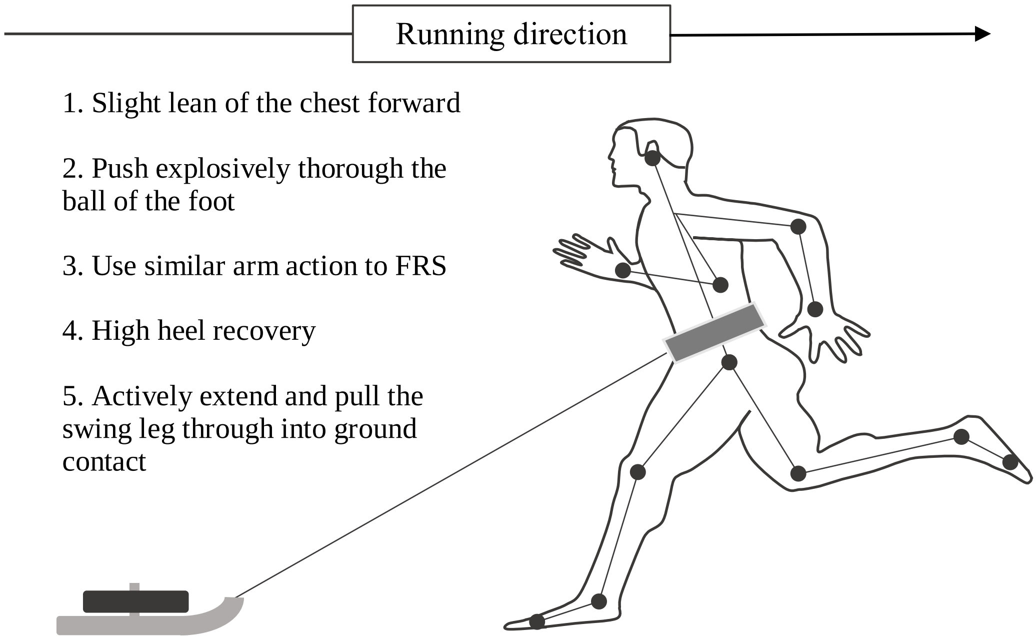


**Figure 6.1.** Technical cues emphasised for the BRS group. FRS = forward resisted sprinting; swing leg = the leg not in contact with the ground.

6.2.5 Statistical Analyses

The statistical analyses were performed using Microsoft Excel (version 15.28; Microsoft, Seattle, WA, USA) and SPSS 24.0 for MAC OS (SPSS, Inc, Chicago, IL, USA). The data were explored using histogram plots and distribution estimation, and normality of the distribution for all variables was tested using Kolmogrorov-Smirnov test in order to determine any obvious effects and estimate the distribution of the data. Homogeneity of variance was tested using the Levene's test. Taking a frequentist approach training-related effects within and between groups on pre- and post-test performances were assessed using a 2-factor mixed design analysis of variance (ANOVA). If a significant F value was observed Bonferroni post-hoc comparisons were applied to locate pairwise differences between groups. To quantify the magnitude of the performance change in each group's performance tests within-group percentage change and effect sizes were calculated. Effect sizes (ES = mean change/pooled standard deviation of the sample scores) were calculated to quantify the extent of the performance changes from pre- to post-testing within- and between-groups (3). Effect sizes (ES) of >1.2, >0.6 to <1.2, >0.2

to <0.60, and <0.20 were classified as large, moderate, small, and trivial, respectively (3, 16). Alpha was set at $p < 0.05$ and 95% confidence intervals (CI) were used for all analyses. Taking a Bayesian approach, mean parameter estimates were quantified to determine the average relative change from pre-test to post-test for the performance variables (post-test – pre-test/pre-test). Given all performance variables were symmetric around their median, a Gaussian distribution was chosen to model relative changes on performance rate (21). Using the Jeffery's prior on the parameter estimates, posterior probability of performance improvements for each group along with their 95% credible intervals was computed using the Markov Chain Monte Carlo method (12, 21).

## 6.3 Results

No injuries were reported as part of the training programme. Within-group changes from pre- to post-training and between-group differences in the performance testing data for the BRS, FRS and CON groups are presented in Table 6.3. Significant main effects ($p < 0.05$) for time were found for all performance variables. The within-group analysis revealed that BRS elicited significant changes ($p < 0.01$) in sprint times at all distances, CMJ height, and $K_N$ (-2.4 to 26.3%; ES = -0.22 to 0.79). Significant differences ($p < 0.05$) were reported after FRS for 10-20 m and 20 m sprint times, CMJ height, and $K_N$ (-0.90 to 19.3%, ES = -0.13 to 0.90). No significant improvements were reported in the CON group for any performance test.

**Table 6.3.** Descriptive performance testing results with for CON, FRS, and BRS groups including within-group changes from pre-training to post-training and between-group differences of the mean changes.

| Performance Test | Group | Pre (mean ± SD) | Post (Mean ± SD) | Performance change (%) (95% CI) | Post-pre training effect (ES) | Diff FRS-CON (mean ± SE) | Effect size | Diff BRS-CON (mean ± SE) | Effect size | Diff BRS-FRS (mean ± SE) | Effect size |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10m sprint (s) | CON | 1.94 ± 0.09 | 1.92 ± 0.10 | -1.1 (-2.0 to -0.13) | -0.09 | | | | | | |
| | FRS | 1.90 ± 0.10 | 1.89 ± 0.10 | -0.65 (-1.5 to 0.19) | -0.13 | 0.01 ± 0.01 | 0.09 | -0.03 ± 0.01 | -0.28[B] | -0.03 ± 0.01 | -0.36[B] |
| | BRS | 1.92 ± 0.09 | 1.87 ± 0.10† | -2.4 (-3.3 to -1.5) | -0.49 | | | | | | |
| 10-20m sprint (s)(s) | CON | 1.48 ± 0.07 | 1.47 ± 0.08 | -0.50 (-1.8 to 0.76) | -0.10 | | | | | | |
| | FRS | 1.42 ± 0.10 | 1.40 ± 0.11* | -1.2 (-2.6 to 0.23) | -0.18 | -0.01 ± 0.01* | -0.11 | -0.01 ± 0.01* | -0.15 | 0.00 ± 0.01 | -0.03 |
| | BRS | 1.43 ± 0.09 | 1.41 ± 0.08✧ | -1.4 (-2.3 to -0.49) | -0.22 | | | | | | |
| 20m sprint (s) | CON | 3.42 ± 0.15 | 3.39 ± 0.17 | -0.80 (-1.6 to 0.05) | -0.18 | | | | | | |
| | FRS | 3.32 ± 0.19 | 3.29 ± 0.20* | -0.90 (-1.8 to 0.00) | -0.16 | 0.00 ± 0.02 | -0.02 | -0.04 ± 0.02* | -0.24[B] | -0.04 ± 0.02 | -0.20[B] |
| | BRS | 3.34 ± 0.17 | 3.28 ± 0.17† | -2.0 (-2.7 to -1.3) | -0.39 | | | | | | |
| CMJ (cm) | CON | 45.6 ± 7.3 | 46.0 ± 7.0 | 1.7 (-2.2 to 5.6) | 0.05 | | | | | | |
| | FRS | 48.5 ± 7.0 | 51.6 ± 6.8† | 6.8 (4.2 to 9.4) | 0.45 | 2.7 ± 0.96✧ | 0.38[F] | 4.5 ± 1.0* | 0.67[B] | 1.8 ± 0.89 | 0.27[B] |
| | BRS | 46.1 ± 6.2 | 51.0 ± 7.6† | 10.8 (7.8 to 13.9) | 0.79 | | | | | | |
| Stiffness ($kN \cdot m^{-1}$) | CON | 27.0 ± 8.6 | 27.2 ± 5.6 | 4.5 (-1.1 to 10.1) | 0.02 | | | | | | |
| | FRS | 29.2 ± 5.8 | 34.4 ± 7.4† | 19.3 (11.7 to 26.8) | 0.90 | 5.1 ± 1.3† | 0.69[F] | 6.8 ± 1.4† | 0.94[B] | 1.8 ± 0.89 | 0.29[B] |
| | BRS | 28.3 ±6.0 | 35.1 ± 8.8† | 26.3 (17.7 to 35.0) | 0.79 | | | | | | |

CMJ = countermovement jump; CON = control; FRS = forward resisted sprinting; BRS = backward resisted sprinting; ES = effect size; SE = standard error; CI = confidence interval. F = Training effect towards FRS; B = Training effect toward BRS.
* Significant ($p < 0.05$) for within- and between-group performances.
✧ Significant ($p < 0.01$) for within- and between-group performances.
† significant ($p < 0.001$) for within- and between-group performances.

Significant main effects ($p \leq 0.05$) for group × time were found for the jumping and leg compliance tests, but not for sprinting performance. Compared with the CON group, significant favourable differences ($p \leq 0.05$) were reported for the BRS group for 10-20 m and 20 m sprint times, CMJ, and $K_N$ (ES = -0.15 to 0.94). The FRS group displayed significant improvements ($p \leq 0.01$) compared with the CON group for 10-20 m sprint times, CMJ, and $K_N$ (ES = -0.11 to 0.69). No significant differences were reported between the training groups.

As seen in Figure 6.2 and Figure 6.3, the BRS group had the highest relative number of individual beneficial responses for all performance tests i.e. 10 m times (85%), 10-20 m times (65%), 20 m times (74%), CMJ height (85%) and $K_N$ (85%). The mean parameter estimates in Table 6.4 signify that the average relative improvement is in favour of the BRS group compared with the FRS and CON groups for all performance tests. The mean parameter estimates for sprinting performance are displayed as a negative to suggest that decreases in sprint times are associated with performance improvements. The mean estimated posterior probability of performance improvements for each test variable along with their 95% credible intervals is shown in Table 6.4. The probability of improving sprinting performance is generally higher after BRS (66 to 73%), whereas BRS and FRS show similar probabilities of improving CMJ height (75% and 79%) and $K_N$ (80% and 81%), respectively.

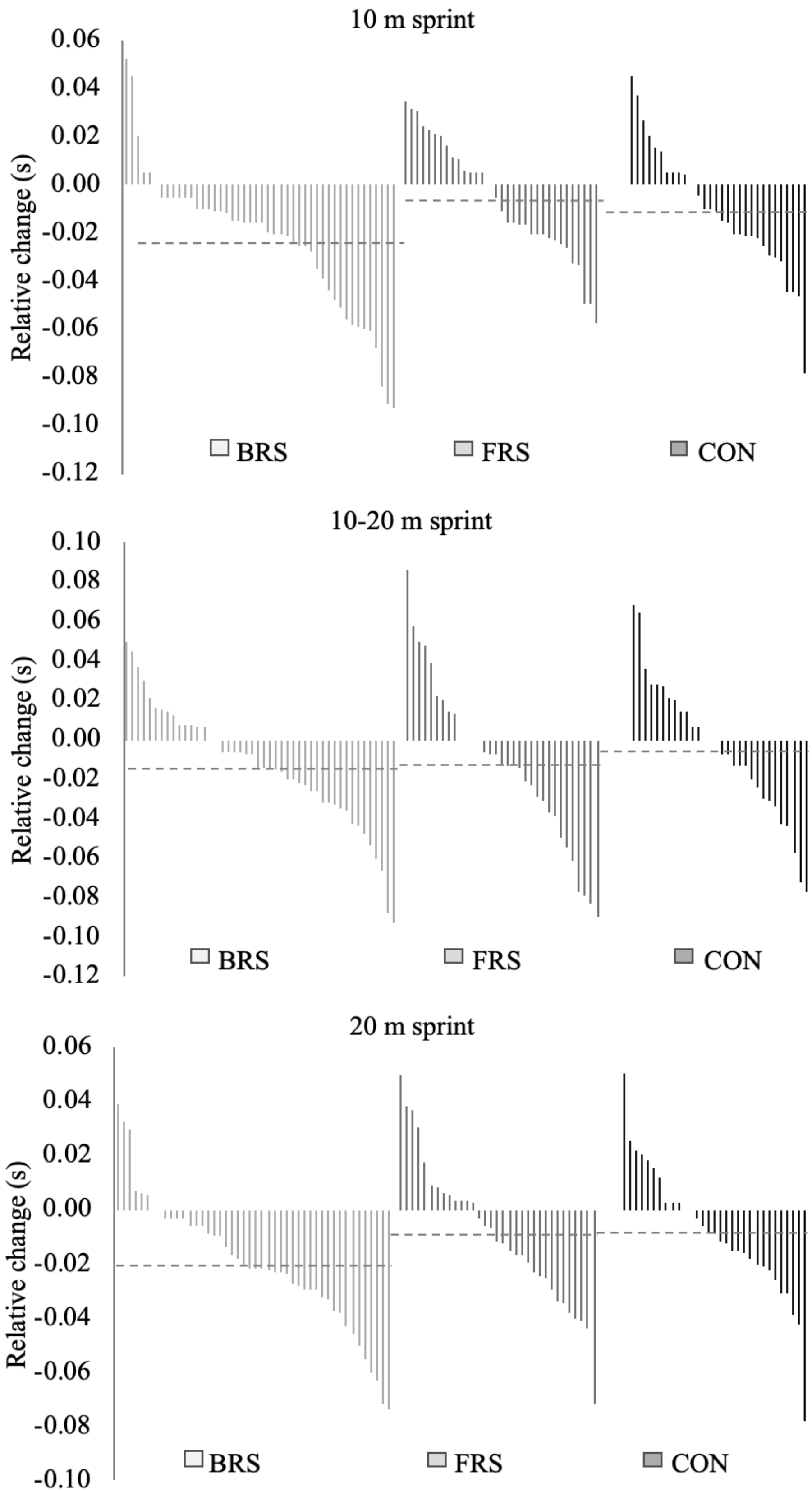
10 m sprint
Relative change (s)
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
BRS
FRS
CON
10-20 m sprint
Relative change (s)
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
BRS
FRS
CON
20 m sprint
Relative change (s)
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
BRS
FRS
CON

**Figure 6.2.** Individual relative change from pre- to post-test for sprint performances by group. — — denotes the average relative change (post-test – pre-test/pre-test) for each group. BRS = backward resisted sprinting group; FRS = forward resisted sprinting group; CON = control group.

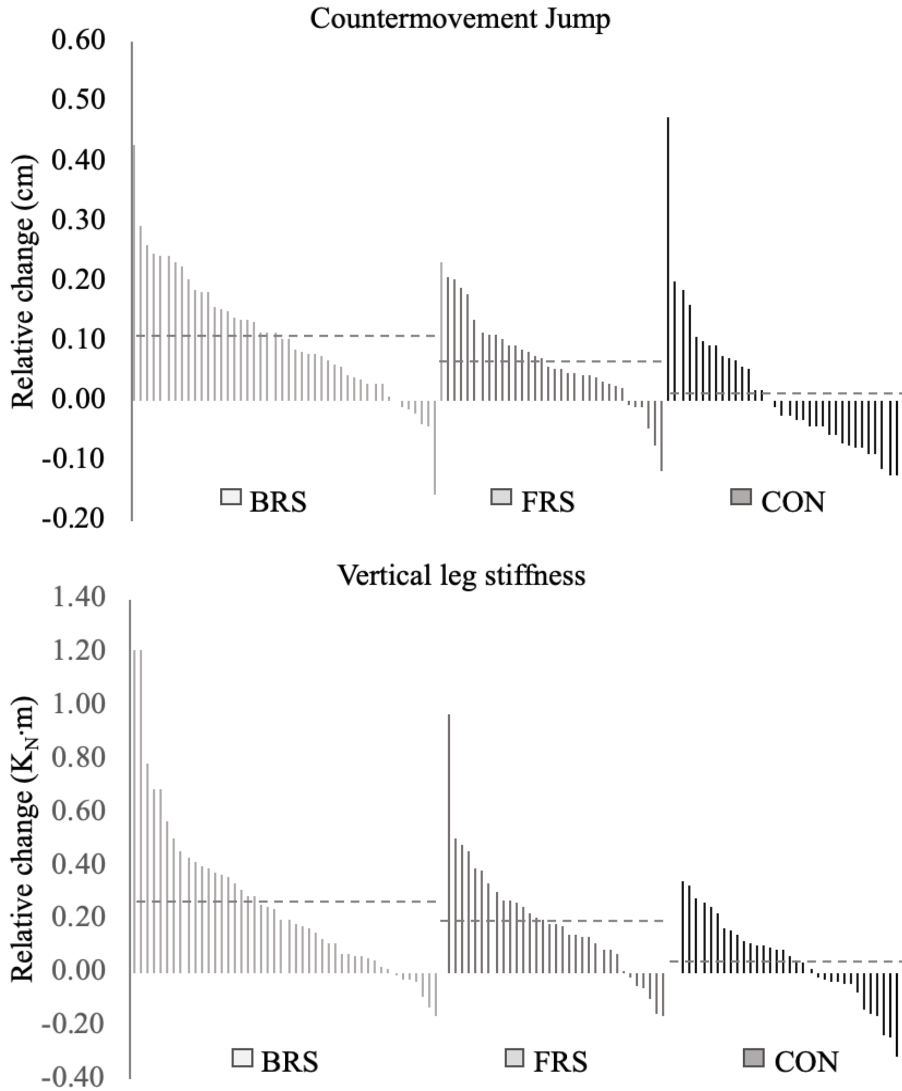


**Figure 6.3.** Individual relative change (post-test – pre-test/pre-test) for countermovement jump and vertical leg stiffness performances by group. — — denotes the average relative change for each group. BRS = backward resisted sprinting group; FRS = forward resisted sprinting group; CON = control group.

**Table 6.4.** Posterior probability of improving sprinting, jumping, and stiffness performance for each group.

| Performance variable | Group | Probability (95% credible intervals) |
|---|---|---|
| 10 m | CON | 0.65 (0.51, 0.78) |
| | BRS | 0.73 (0.61, 0.82) |
| | FRS | 0.56 (0.42, 0.68) |
| 10-20 m | CON | 0.55 (0.41, 0.69) |
| | BRS | 0.66 (0.55, 0.77) |
| | FRS | 0.60 (0.47, 0.73) |
| 20 m | CON | 0.63 (0.48, 0.76) |
| | BRS | 0.68 (0.56, 0.78) |
| | FRS | 0.59 (0.45, 0.72) |
| CMJ | CON | 0.55 (0.42, 0.68) |
| | BRS | 0.75 (0.65, 0.84) |
| | FRS | 0.79 (0.67, 0.89) |
| Stiffness | CON | 0.61 (0.48, 0.73) |
| | BRS | 0.80 (0.69, 0.88) |
| | FRS | 0.81 (0.68, 0.90) |

CMJ = countermovement jump; CON = control group; FRS = forward resisted sprinting; BRS = backward resisted sprinting.

## 6.4 Discussion

This research was the first to explore the chronic training adaptations associated with BRS vs. FRS on proxies of speed, jumping performance, and leg compliance capabilities in male youth. The main findings of this study were that sprinting performance improved the most after BRS, BRS and FRS resulted in similar improvements in CMJ height and $K_N$, and the training effects of BRS and FRS did not significantly differ for any performance metric. Our hypotheses were partially reinforced in that BRS was found to be effective for increasing CMJ height and $K_N$, although the postulate that FRS would be the best method for improving sprint performance was not supported. These results are important for researchers and practitioners given the dearth of published data on the effects of BRS and relatively heavy (e.g. >20% BM) FRS in boys.

The BRS group showed the greatest improvements in sprint performance over all distances (1.4% to 2.4%), albeit trivial to small compared with the FRS and CON groups. However, not only was the average relative change the highest after BRS for all distances, but the relative number of participants who benefitted from BRS training was, on average, 20% higher than the FRS group and 29% more than the CON group when all distances were considered. The significant improvements from pre-training to post-training for all sprint times in the BRS group signify the transfer of an 8-week training block of loaded BR to improve unresisted forward sprinting in youth athletes. These findings correspond to previous research into BR in youth (40). Uthoff et al. (40) reported that eight weeks of unresisted BR training had a moderate to large beneficial effect on 10 m and 20 m sprint times, which was significantly better than unresisted FR training. Although the training adaptations after BRS and FRS did not significantly differ in this study, the small beneficial effects toward BRS over 10 m and 20 m indicate that BRS may provide a unique training stimulus especially useful for enhancing short sprint abilities in youth athletes. This is highlighted by the probability that approximately 70% of new runners are expected to get faster after BRS, which is on average, ~10% and ~8% greater than the number of new runners expected to get faster if assigned to FRS and CON groups, respectively.

Curiously, our results and those of Uthoff et al. (40) both found that improvements in 20 m speed after BRS and unresisted BR primarily occur over the first 10 m. For example, our results show that 83% of the changes in 20 m performance (↓ 0.06 seconds) occurred over the first 10 m (↓ 0.05 seconds). It seems that BRS is particularly helpful for improving boys' early acceleration performance (i.e., 10 m), which consequently benefits performance up to 20 m. These reports are based on relatively few studies in youth populations and more research is needed to substantiate such observations.

Youth CMJ height has been shown to improve following plyometric, strength, and unresisted sprint training (20, 26, 40). To our knowledge, this is the first study in youth to quantify the effects of RS, either forward or backward, on vertical jumping ability. We found that CMJ height improved after BRS (↑10.8%; ES = 0.79) and FRS (↑6.8%; ES = 0.45). The meaningfulness of these results for practitioners can be translated from the posterior probabilities, which indicate that if the intervention was repeated with a similar population, 75% and 79% of new athletes would expect to improve CMJ performance after 8-weeks of BRS and FRS training, respectively. As CMJ height and lower body strength qualities are known to have a strong relationship in youth (4), using BRS and FRS could be a means to improve lower body strength capabilities. Furthermore, the longer ground contact times associated with towing heavy sleds (5) may rely more heavily on the contractile and parallel elastic elements and promote adaptations specific to the CMJ task. However, as this study did not measure the musculotendinous adaptations directly it is difficult to say if performance changes were a result of neural, muscular, or tendinous modifications.

Leg stiffness has been proposed as a critical characteristic for achieving high sprinting velocities in youth athletes (34). Herein, it was observed that BRS and FRS resulted in ↑26% (ES = 0.79) and ↑19% (ES = 0.90) in leg stiffness, respectively, over the course of 8-weeks. Our findings differ from those of Rumpf et al. (31) who concluded that 6-weeks of FRS with loads ranging from 2.5% to 10% significantly reduced relative leg stiffness by 45% (ES = -2.2) in fourteen mid-PHV to post-PHV boys. It was postulated that chronic kinematic adaptations of longer ground contact times associated with increased sled loading (5) lead to greater vertical displacement (31) and, subsequently, a more compliant lower limb. However, with the use of relatively greater loads (i.e., 20-55%), our findings indicate that ~80% of new athletes are expected to decrease limb compliance by developing stiffer, more reactive, lower body capabilities after BRS and FRS. It should be noted that making direct comparisons between studies is problematic because leg stiffness was measured using a hopping test in this study, whereas Rumpf et al. (31) calculated stiffness using a non motorised treadmill. Although quantifying leg stiffness on a non motorised treadmill allows for the measurement during the actual performance task (i.e., sprinting), the speeds that were achieved by the boys in the study by Rumpf et al. (31) were slower than typical speeds reached during overground sprinting (40). Performance appears to be influenced by youth athletes' ability to overcome the resistance of a non motorised treadmill (32, 33), in which case Rumpf et al. (31) was measuring stiffness in a slower stretch-shortening cycle movement. Therefore, further research using the same leg stiffness calculation methods is required to understand the chronic influence of BRS and FRS on lower-limb compliance in boys mid-PHV and post-PHV.

In regards to loading intensity, for adults, it has been suggested that loads < 20% BM should be used to reduce disruptions in natural sprinting technique (1), loads > 20% should be used to improve acceleration (30), and loads between ~20 and ~80% should be used to maximise power output (7, 24). On the other hand, minimal loading with sensible upper limits of 10% BM have been recommended for youth (29). Although suggestions have been made to limit RS loads to 10%, it has been shown that training with loads up to 20% results in improved force capabilities and sprinting performance in boys (36). In addition, findings from this research demonstrate that towing weighted sleds ranging from 20 to 55% BM can safely be used to overload BRS and FRS, minimise negative adaptations, and cause meaningful changes in a variety of athletic tasks in mid-PHV to post-PHV boys. If RS, either forward or backward, is used as a resistance exercise rather than a technique exercise, then resistance training guidelines, which state that youth benefit most from working at higher loads (i.e., 80-89% of 1 RM) (18), should be considered when loading RS.

The results of this study demonstrate that BRS training is most beneficial in improving athletic performance in youth boys. Although previous studies using FRS training programmes have reported improvements in sprinting performance using loads ≤ 20% BM (2, 31, 36), the aim of this study was to evaluate the effects of using loads ≥ 20% BM and compare them with a novel training stimulus (i.e., BRS). The findings that BRS improved forward sprint performance and that relatively heavy FRS improved vertically oriented tasks (i.e., CMJ height and leg stiffness) indicate a transfer effect for specific sprint training methods exists. Furthermore, the dynamic leg extension action characterised by BRS may help facilitate neurological and structural adaptations to the knee extensors and subsequently develop both contractile and elastic elements of muscle-tendon units. However, the true nature of the musculotendinous adaptations resulting from chronic BRS and FRS training is unknown. Therefore, investigations using different jump testing strategies (e.g., squat jump versus CMJ vs. drop jump) and ultrasound scanning technologies are required to understand the muscle mechanical and structural responses to BRS and FRS training in youth populations.

## 6.5 Practical Applications

Progressively overloading BRS and FRS using relatively heavy loads up to 55% BM are recommended as safe and effective training methods for improving performance in a variety of athletic tasks in pubescent and post-pubescent boys. Anyone interested in using RS as a method to enhance athletic performance in youth athletes should consider the following points:

1. Eight weeks of BRS leads to adaptations that transfer to forward sprinting.
2. Although RS has been developed as a specific sprint training method, adaptations from both BRS and FRS also transfer to vertically-oriented athletic tasks.
3. BRS is the recommended method to improve early acceleration.
4. With the probability of a new athlete improving jumping and stiffness by 75-80% after BRS and 79-81% after FRS, practitioners can be confident that implementing RS methods will lead to positive adaptations in jumping ability and enhanced stiffness capabilities in youth athletes.

References


1. Alcaraz PE, Carlos-Vivas J, Oponjuru BO, and Martínez-Rodriguez A. The effectiveness of resisted sled training for sprint performance: a systematic review and meta-analysis. *Sports Med* 48: 2143-2167, 2018.
2. Borges JH, Conceição MS, Vechin FC, Pascoal EHF, Silva RP, and Borin JP. The effects of resisted sprint vs. plyometric training on sprint performance and repeated sprint ability during the final weeks of the youth soccer season. *Sci Sports* 31: e101-e105, 2016.
3. Cohen J. *Stastical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.
4. Comfort P, Steward A, Bloom L, and Clarkson B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *J Strength Cond Res* 28: 173-177, 2014.
5. Cronin J, Hansen K, Kawamori N, and McNair P. Effects of weighted vests and sled towing on sprint kinematics. *Sports Biomech* 7: 160-172, 2008.
6. Cronin J, McNair PJ, and Marshall RN. Velocity specificity, combination training and sport specific tasks. *J Sci Med Sport* 4: 168-178, 2001.
7. Cross MR, Brughelli M, Samozino P, Brown SR, and Morin JB. Optimal loading for maximizing power during sled-resisted sprinting. *Int J Sport Physio Perf* 12: 1069-1077, 2017.
8. Dalleau G, Bell A, Viale F, Lacour JR, and Bourdin M. A simple method for field measurements of leg stiffness in hopping. *Int J Sports Med* 25: 170-176, 2004.
9. Faigenbaum AD, Kraemer WJ, Blimkie CJR, Jeffreys I, Micheli LJ, Nitka M, and Rowland TR. Youth resistance training: Updated position statment paper from the National Strength and Conditioning Association. *J Strength Cond Res* 23: S60-S79, 2009.
10. Flynn TW and Soutas-Little RW. Mechanical power and muscle action during forward and backward running. *J Orthop Sport Phy Ther* 17: 108-112, 1993.
11. Gabbett TJ. Physiological characteristics of junior and senior rugby league players. *Br J Sport Med* 36: 334-339, 2002.
12. Gelman A, Carlin J, Stern H, Dunson D, Vehtari A, and Rubin D. *Bayesian Data Analysis.* Chapman and hall, 2013.
13. Gissis I, Papadopoulos C, Kalapotharakos VI, Sotiropoulos A, Komsis G, and Manolopoulos E. Strength and speed characteristics of elite, subelite, and recreational young soccer players. *Res Sport Med* 14: 205-214, 2006.
14. Harman E and Garhammer J. Administration, scoring and interpretation of selected tests, in: *Essentials of Strength Training and Conditioning*. TR Breachle, RW Earle, eds. Champaign, IL: Human Kinetics, 2008, pp 250-292.
15. Hewett TE, Paterno MV, and Myer GD. Strategies for enhancing proprioception and neuromuscular control of the knee. *Clinical Orthoppaedics and Related Research* 408: 76-94, 2002.
16. Hopkins WG. A scale of magnitudes for effect statistics. http://sportsci.org/resource/stats/effectmag.html, 2002.

17. Kawamori N, Newton R, and Nosaka K. Effects of weighted sled towing on ground reaction force during the acceleration phase of sprint running. *J Sports Sci* 32: 1139-1145, 2014.
18. Lesinski M, Prieske O, and Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. *Br J Sport Med* 0: 1-17, 2016.
19. Lloyd RS, Oliver JL, Hughes MG, and Williams CA. Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *J Sports Sci* 27: 1565-1573, 2009.
20. Lloyd RS, Radnor JM, De Ste Croix MB, Cronin JB, and Oliver JL. Changes in sprint and jump performance following traditional, plyometric and combined resistance training in male youth pre- and post-peak height velocity. *J Strength Cond Res* 30: 1239-1247, 2016.
21. Mergersen KL, Drovandi CC, Robert CP, Pyne DB, and Gore CJ. Bayesian estimation of small effects in exercise and sports science. *PLoS One*, 2016.
22. Meylan CM, Cronin JB, Oliver J, and Hughes M. Talent identification in soccer: the role of maturity status on physical, physiological and technical characteristics. *Int J Sport Sci Coach* 5: 571-592, 2010.
23. Mirwald RL, Baxter-Jones ADG, Bailey DA, and Beunene GP. An assessment of maturity from anthropometric measures. *Med Sci Sport Exerc* 34: 689-694, 2002.
24. Monte A, Nardello F, and Zamparo P. Sled towing: the optimal overload for peak power production. *Int J Sports Physiol Perf* 12: 1052-1058, 2016.
25. Moran J, Sandercock G, Rumpf MC, and Parry DA. Variation in responses to sprint training in male youth athletes: A meta-analysis. *Int J Sport Med* 38: 1-11, 2017.
26. Moran JJ, Sandercock GR, Ramirez-Campillo R, Meylan CM, Collison JA, and Parry DA. Age-related variation in male youth athletes' countermovement jump after plyometric training: A meta-analysis of controlled trials. *J Strength Cond Res* 31: 552-565, 2017.
27. Muehlbauer T, Pabst J, Granacher U, and Büsch D. Validity of the jump-and-reach test in subelite adolescent handball players. *J Strength Cond Res* 31: 1282-1289, 2017.
28. Oliver JL, Lloyd RS, and Rumpf MC. Developing speed throughout childhood and adolescence: The role of growth, maturation and training. *Strength Cond J* 35: 42-48, 2013.
29. Oliver JL and Rumpf MC. Speed development in youths, in: *Strength and Conditioning for Young Athletes: Science and Application*. RS Lloyd, JL Oliver, eds. New York, NY, USA: Routledge, 2013.
30. Petrakos G, Morin JB, and Egan B. Resisted sled sprint training to improve sprint performance: a systematic review. *Sports Med* 46: 381-400, 2016.
31. Rumpf MC, Cronin JB, Mohamad IN, Mohamad S, Oliver JL, and Hughes MG. The effect of resisted sprint training on maximum sprint kinetics and kinematics in youth. *Eur J Sport Sci* 15: 374-381, 2015.
32. Rumpf MC, Cronin JB, Oliver J, and Hughes M. Kinematics and kinetics of maximum running speed in youth across maturity. *Ped Exerc Sci* 27: 277-284, 2015.
33. Rumpf MC, Cronin JB, Oliver JL, and Hughes M. Assessing youth sprint ability-methodological issues, reliability and performance data. *Pediatr Exerc Sci* 23: 442-467, 2011.

34. Rumpf MC, Cronin JB, Oliver JL, and Hughes MG. Vertical and leg stiffness and stretch-shortening cycle changes across maturation during maximal sprint running. *Hum Mov Sci* 32: 668-676, 2013.
35. Rumpf MC, Cronin JB, Pinder SD, Oliver J, and Hughes M. Effect of different training methods on running sprint times in male youth. *Ped Exerc Sci* 24: 170-186, 2012.
36. Sekine Y and Okada J. Effects of resisted sprint training on sprint performance in high school baseball players. *Am J Sports Sci* 4: 90-97, 2016.
37. Swati K, Ashima C, and Saurabh S. Efficacy of backward training on agility and quadriceps strength. *Elix Hum Physio* 53: 11918-11921, 2012.
38. Terblanche E and Venter RE. The effect of backward training on the speed, agility and power of netball players. *S Afr J Res Sport Phy Ed Rec* 31: 135-145, 2009.
39. Uthoff A, Oliver J, Cronin J, Harrison C, and Winwood P. A new direction to athletic performance: Understanding the acute and longitudinal responses to backward running. *Sports Med* 48: 1083-1096, 2018.
40. Uthoff A, Oliver JL, Winwood PW, Harrison C, and Cronin JB. Sprint-specific training in youth: backward running versus forward running training on speed and power measures in adolescent male athletes. *J Strength Cond Res* Published ahead of print, 2018.