**Wearable resistance loaded sprinting is superior in retaining speed qualities during in-season training.**

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INTRODUCTION

Lower limb wearable resistance training (WRT) is a type of training that involves attaching an external load, as little as 0.5% body mass (BM), onto the thigh or calf of the athlete thus allowing them to perform sport specific movement tasks under resistance. The placement of the load can be positioned to provide a direct overload to a joint, or multiple joints of interest, and therefore muscles of interest, for the given movement task. This makes lower limb WR use particularly applicable for sprint running training as the athlete can train under resistance at high movement velocities with the overload applied to the hip and knee joints (depending on the load location chosen) unlike what is possible with traditional resistance training equipment. Additionally, WRT is different to traditional resistance training, as the load is applied to the lower limb directly and therefore provides a rotational, not linear, overload. Given these factors, it would seem that lower limb WR offers better training specificity and therefore is more likely to optimise the transference of any strength or metabolic benefits to the activity of interest e.g. sprint running.1

Although the popularity of sprint training with lower limb WR has increased, the research on WR is limited and has yet to investigate the long-term effects of training with lower limb WR for sprint running with athletes. When investigated with university physical education students, Pajic, Kostovski, Ilic, Jakovljevic, Preljevic 2 found six-weeks of sprint training with 5% BM ankle WR produced a significant increase in stride length (5.2%) and a significant decrease in stride frequency (-5.6%) with no changes to maximal running speed. Although increases in running speed over time have been shown to occur concurrently with an increase in step length and it is believed important for maximal speed sprinting 3, the accompanying decrease in stride frequency seen in Pajic et al. 2 is counterproductive to the development of maximal sprint speed. Ultimately, it is challenging to apply these findings to an athlete population as the training status or history of the participants used in Pajic et al. 2 was not disclosed. Results from acute investigations have shown promise that lower limb WR provides an appropriate overload for sprint running training.4 In particular, contact time and step frequency are significantly overloaded (increased and decreased, respectively) during the acceleration and maximal velocity phases of sprint running.5,6 This has been shown to occur with no significant coinciding change to step length or flight time. These findings suggest that lower limb WR can be used to selectively overload particular determinants of sprint running.4 Overloading step frequency especially may be an ideal training strategy for well-trained sprinters as it has been suggested that training at this level should target enhancing step rate.7 Similarly, as coaches identify performance detriments for their athletes, they may choose lower limb WR to cue and stimulate changes in step frequency while other overload methods may provide different training benefits.8,9 It is not surprising that reported acute changes in step frequency with lower limb WR come with a change to contact time. The lack of change to step length may mean that joint kinematics are largely unchanged when using the loading schemes that have been investigated to date. Furthermore, the chronic adaptation to these acute changes have not been documented.

Researchers have also shown significant changes in the mechanical capabilities of the athlete when sprint running with WR. For example, a significant change in the relative force-velocity (F-v) profile has been measured with 3% BM lower limb WR, reflecting a more force dominant profile.6 With this, theoretical maximal velocity was significantly reduced with no significant change to theoretical maximal horizontal force.6 One of the mechanical determinants of high levels of acceleration and 100 m sprint performance, is a velocity-oriented F-v profile10, therefore training with lower limb WR may have the potential to elicit improved sprint performance over time as related to alterations in the mechanical sprint profile.

Given the paucity of research investigating the effects of sprint training with lower limb WR with athletes, it is of value to determine the performance adaptations that occur as an effect of lower limb WRT. This is pre-requisite to understanding how the body responds to control the limb load and how this can be manipulated for performance improvements. Therefore, the purpose of this study was to determine the effects of a six-week lower limb WR training intervention on sprint running time, velocity, and mechanical determinants.

**METHODS**

Twenty-eight athletes were recruited to participate in this study. The athletes were all members of the same collegiate/semi-professional rugby training squad. Inclusion criteria required athletes to have a minimum of one year of resistance training experience, be currently training, and trained as a field-based sport athlete. Athletes were excluded if they were under the age of 16, had a current or previous lower extremity injury that may be further aggravated by participating in the training, or did not pass the Physical Activity Readiness Questionnaire. All study procedures were approved by the host university Institutional Review Board.

**Performance Testing.**

Athletes reported to an indoor fieldhouse on two occasions to complete pre- and post-intervention performance testing. Each testing session started with the athletes completing the warm-up protocol consistent to their typical preparation for a practice session. Following, each athlete completed three maximal effort 30-meter (m) sprints, separated by a minimum of 15 minutes of rest. Each sprint was performed from a two-point, split stance start position. The athletes were told to “go when ready” after getting the all clear by the research staff. A radar device (Stalker ATS II, Applied Concepts, Dallas, TX, USA) was used to measure athlete velocity. The radar was positioned 5 m directly behind the starting position and at a vertical height of 1 m to approximately align with the participant’s centre of mass 6. The sampling rate for data collection was 47 Hz. Software provided by the radar device manufacturer (STATS software, Stalker ATS II Version 5.0.2.1, Applied Concepts, Dallas, TX, USA) was used to collect all data.

**Training Intervention.**

The sprint training occurred in tandem with a pre-season training block in which the athletes reported to two dedicated sprint training sessions a week. The athletes were match-pair randomized into the WR and control groups using the pre-intervention 30 m sprint times. Athletes in the WR group completed the sprint training sessions with 1% body mass (BM) load attached to the shank with a specialized compression garment (Lila™ Exogen™ Compression Calf Sleeves, Sportboleh Sdh Bhd, Malaysia). The load placement progressed through the training block from a proximal shank location to mid-shank and finishing at a distal shank location. A summary of the training sessions and WR placement protocol are listed in Table 1. An image of the load placements can be found in Figure 1.

At the conclusion of each practice session, all athletes answered the question “how was your workout” by selecting their response on a 0-10 modified Borg Rating of Perceived Exertion scale11. This allowed the research staff to monitor how the WR group was responding to the intervention and identify differences in perceived exertion between the control and WR groups.

Table 1. Study timeline.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Session 1** | **Session 2** | **WR Placement and Magnitude** |
| Week 0 | Pre-intervention Test (3x30m) |  |  |
| Week 1 | 4x22m  8x10m | 4x Flying 28m  5x Change of direction  (15m-diagonal cut-20m)  1x80m, 1x60m, 1x50m, 1x40m | Proximal 1% |
| Week 2 | 5x22m  11x10m | *Practice cancelled due to weather* | Proximal 1% |
| Week 3 | 6x22m  14x10m | 5x Flying 28m  8x Change of direction  (15m-diagonal cut-20m)  1x80m, 1x60m, 1x50m, 1x40m | Mid 1% |
| Week 4 | 5x22m  11x10m | 5x Flying 28m  6x Change of direction  (15m-diagonal cut-20m)  1x 80m, 1x60m, 1x50m, 1x40m | Mid 1% |
| Week 5 | 6x22m  13x10m | 5x Flying 28m  8x Change of direction  (15m-diagonal cut-20m)  1x80m, 1x60m, 1x50m, 1x40m | Distal 1% |
| Week 6 | 6x22m  16x10m | 5x Flying 28m  9x Change of direction  (15m-diagonal cut-20m)  1x80m, 1x60m, 1x50m, 1x40m | Distal 1% |
| Week 7 | Post-intervention Testing (3x30m) |  |  |

Figure 1. WR load placements.



A = Proximal, B = Middle, C = Distal

**Data Analysis.**

To represent athlete performance, the three trials completed at each testing time point were averaged. 12,13 The averaged velocity-time data collected pre- and post-intervention were then processed to calculate the horizontal force-velocity mechanical variables commonly used to profile an athlete’s sprint running capabilities. The procedures utilized are extensively outlined in but in summary, the general mechanical ability to produce horizontal external force during sprint-running is portrayed by the linear force-velocity (F-v) relationship.14 The mechanical capabilities of the lower limbs are characterised by the variables: theoretical maximum velocity (V0); theoretical maximum horizontal force (F0), peak power production (Pmax), max ratio of forces (RFmax), and index of force application (DRF).15 These mechanical profiling variables, along with sprint split times (5, 10, 20 and 30m), maximal velocity (vmax) and slope of the F-v profile (SFv), were calculated consistent with the method validated by Samozino, Rabita, Dorel, Slawinski, Peyrot, Saez de Villarreal, Morin 14 and again by Morin, Samozino, Murata, Cross, Nagahara 16.

**Statistical Analysis.**

A series of preliminary analyses were used to determine if there were significant differences between the control and WR group for each of the dependent variables at the pre-intervention testing time point. To determine the effect of the sprint training intervention (with or without the WR), a paired samples t-test was conducted for the dependent variables measured for each group. To compare the control and WR group responses to the sprint training, an independent samples t-test was conducted for each of the dependent variables using the post-pre testing percent difference scores. A series of follow-up analyses were performed using a one-way analysis of covariance (ANCOVA) to assess the influence of practice attendance (covariate) on between group difference for each of the dependent variables.

All data presented is unadjusted unless otherwise stated. Analyses were performed using a software package (IBM SPSS Statistics, Version 25). Significance was set at *p* < 0.05. Effect size (ES) statistics (Cohen’s d) were calculated and described as (<0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, >2.0 very large)17.

**RESULTS**

Twenty-two athletes completed the study (control group = 10 and WR group = 12). There were no significant differences for mass measures between the pre-intervention and post-intervention testing time points for either group. Frequency distributions were explored and extreme outliers were removed to ensure a p > 0.05 for the Shapiro-Wilks test. A preliminary analysis was performed and confirmed that there were no significant differences between the control and WR group for each of the dependent variables at the pre-intervention testing time point. The exponential modeling of the velocity-time data was well fit with an average R2 = 0.98 and all R2 > 0.95. Mean, standard deviations, mean difference, and mean percentage difference scores for the sprint running time, speed, and mechanical determinants variables are presented in Table 2.

The results of the paired samples t-tests and independent samples t-tests for these measures are reported in Table 2. With regards to the control, all variables were found to detrain significantly over the training period (~ 9.00 to -16.0%) the largest detraining effects (ES > 1.20) noted for F0, DRF, RFmax, 5 m and 20 m times. In terms of the WR group, there were no significant changes to the recorded variables and any effects of training were trivial or small. Significant between group differences of a moderate or large effect were found for all variables except vmax and V0.

There were no significant differences in athlete RPE or attendance scores between the control and WR groups. The average reported RPE scores were 6.6 ± 0.86 for the control group and 6.6 ± 0.86 for the WR group. Athletes in the control group attended 66.4 ± 24.99% of practices, while athletes in the WR group attended 65.9 ± 18.63% of practices. When adjusted for practice attendance, there were no changes to the between group significant differences except for the 30 m mean percentage difference score. Adjusted mean percentage difference scores were not significantly different (p = 0.52) between the Control group (adjusted mean (AM) = 2.23%) and the WR group (AM = 0.16%).

Table 2. Dependent variables during pre- and post-testing for the control and WR groups.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Control group (n = 10)^** | | | | | **WR group (n = 12)ǂ** | | | | |  |
|  | **Pre** | **Post** | **Post-Pre** | | | **Pre** | **Post** | **Post-Pre** | | | **Control group – WR group** |
|  | **(SD)** | **(SD)** | **mean difference** | **mean % difference** | **p-value; ES** | **(SD)** | **(SD)** | **mean difference** | **mean % difference** | **p-value; ES** | **p-value; ES** |
| **F0 (N-1)** | 7.87 (0.91) | 6.73 (0.71) | -1.10 | -13.92 | 0.003\*; 1.25 | 7.50 (0.69) | 7.28 (0.63) | -0.22 | -2.71 | 0.203; 0.32 | 0.007\*\*; 1.28 |
| **Pmax (W-1)** | 17.26 (2.53) | 15.31 (1.94) | -1.95 | -10.52 | 0.006\*; 0.77 | 16.56 (1.68) | 16.29 (1.84) | -0.23 | -1.51 | 0.480; 0.16 | 0.024\*\*; 1.05 |
| **V0 (ms-1)** | 9.01 (0.41) | 9.35 (0.34) | 0.34 | 3.81 | 0.002\*; 0.83 | 8.90 (0.58) | 9.00 (0.67) | 0.11 | 1.25 | 0.255; 0.19 | 0.088; 0.79 |
| **Sfv (%)** | -90.04 (25.48) | -68.12 (14.31) | 21.92 | -21.37 | 0.019\*; 0.86 | -81.71 (14.10) | -77.93 (13.00) | 3.77 | -4.18 | 0.101; 0.27 | 0.005\*\*; 1.34 |
| **DRF** | -8.09 (0.96) | -6.73 (0.85) | 1.35 | -16.24 | 0.002\*; 1.42 | -7.67 (0.65) | -7.36 (0.78) | 0.31 | -3.72 | 0.114; 0.48 | 0.005\*\*; 1.36 |
| **RFmax (%)** | 61.71 (4.21) | 55.99 (3.95) | -5.72 | -9.06 | 0.003\*; 1.36 | 60.09 (3.44) | 59.00 (3.49) | -1.09 | -1.72 | 0.224; 0.32 | 0.007\*\*; 1.28 |
| **5m (s)** | 1.27 (0.08) | 1.37 (0.07) | 0.11 | 8.70 | 0.003\*; 1.28 | 1.30 (0.07) | 1.30 (0.07) | 0.02 | 1.27 | 0.381; 0.00 | 0.008\*\*; 1.26 |
| **10m (s)** | 2.04 (0.11) | 2.14 (0.10) | 0.10 | 5.20 | 0.006\*; 0.91 | 2.05 (0.07) | 2.06 (0.05) | 0.01 | 0.58 | 0.617; 0.14 | 0.015\*\*; 1.16 |
| **20m (s)** | 3.28 (0.09) | 3.42 (0.13) | 0.13 | 4.00 | 0.003\*; 1.56 | 3.34 (0.09) | 3.34 (0.08) | 0.00 | 0.04 | 0.989; 0.00 | 0.004\*\*; 1.51 |
| **30m (s)** | 4.46 (0.12) | 4.59 (0.14) | 0.13 | 2.84 | 0.004\*; 1.08 | 4.57 (0.17) | 4.58 (0.21) | 0.01 | 0.20 | 0.733; 0.06 | 0.015\*\*; 1.18 |
| **Vmax (m∙s-1)** | 8.58 (0.29) | 8.71 (0.25) | 0.12 | 1.45 | 0.023\*; 0.45 | 8.45 (0.43) | 8.52 (0.51) | 0.07 | 0.81 | 0.332; 0.14 | 0.554; 0.27 |

^ = n of 9 for the V0, 20m, 30m and Vmax measures; ǂ = n of 11 for the 10m and 20m measures; \* = within-group significant differences (*p* < 0.05), \*\* = between group significant differences (*p* < 0.05)

DISCUSSION

The purpose of this study was to determine the effects of a 1% BM lower limb WR sprint running training intervention on performance measures in athletes. The main findings of the study were: 1) the control group experienced significant detraining over the course of the intervention with the largest detraining effects (ES > 1.20) noted for F0, DRF, RFmax, 5 m and 20 m times; 2) the use of WR enabled the intervention group to retain pre-intervention scores over the course of the intervention with all changes in the variables of interest considered trivial to small; 3) WRT proved superior to unloaded training in maintaining all the force-velocity variables of interest with the exception of Vmax and V0; and 4) RPE was similar between groups.

The control group was found to detrain across several variables suggesting there was insufficient recovery time between training sessions or the sprint training protocol was insufficient to provide a training stimulus to maintain or improve performance. Sufficient recovery and training frequency are required to produce muscular performance adaptation. 18 It is unlikely the recovery time between training sessions was insufficient or that a general fatigue status increased due to sudden exposure to pre-season training as the intervention group did not display the same decrement in performance over the training period. While the exact training frequency required to maintain sprint performance through sprint training alone is not known, a training frequency of 2-3 times per week has been suggested to produce sprint performance improvements using resisted sled training.19 The consideration of training frequency cannot come without the consideration of training session volume and intensity (i.e. volume load). The athletes in this study were allocated two sprint training sessions a week through the pre-season and therefore an adequate volume load is required to maintain or improve performance capabilities for the allocated training frequency. It appears the prescribed volume load, provided at a two session per week frequency, was inadequate to maintain performance capabilities. However, it also appears that the use of WR increased the volume load of each training session reaching a threshold necessary to maintain performance capabilities for the short distance sprint running measured in this study.

The WR used in this study provided an adequate training load to retain sprint performance and mechanical capabilities for the intervention group athletes and this WRT was superior to the unloaded training in maintaining the variables of interest except for Vmax and V0. It seems that WRT could be used to increase training load when frequency is low which often occurs during pre-season and in-season time frames. This idea is supported by previous work that has found that carrying an additional load on the limb during running comes with an increased physiological cost and directly effects the mechanical work needed to move the limb segments.20,21 There is also the possibility that WRT provides a unique training stimulus to influence sprint running. The micro-loading inherent to WRT allows the athletes to perform the sprint running movement pattern under resistance at or near unloaded movement velocities.4,8,22 This is a valuable consideration when planning athlete training as the velocity adaptations that occur with resistance training are greatest at or near the velocity of the training performed23 and sprint running requires rapid muscular force production. Proficiency for faster sprint running comes with an improved ability to produce high levels of force to the ground.24 For short distance sprint running, DRF is useful to quantify an athlete’s technical ability to apply force into the ground with increasing speed25 and has been shown to be significantly correlated to maximal speed, mean 100 m speed, and 4 sec distance measures.10,26 Athletes in the Control group experienced a decrease in DRF (-16.24%) and RFmax (-9.06%) to large effects while the WR group experienced no significant changes.A comparison between these significant between group differences point to what mechanical output changes are influenced with shank WRT and it appears that WRT offers a means to maintain an athlete’s technical ability to produce horizonal force and maintain horizontal force production with increasing speed.

Session RPE was used to monitor athlete response to the training loads. This data provided information throughout the training intervention time frame to monitor the WR group’s response to completing the sprint running protocol with additional limb load and determine how the progressive overload of moving the WR placement distally was handled. There were no differences in average RPE scores between the two groups. This is surprising as information from previous research20,21 and anecdotal athlete feedback has indicated an increased difficulty in performing running with an external load attached to the limb. It may be that session RPE does not provide the sensitivity needed to distinguish objective differences in training loads associated with lower limb WRT or a 1% BM WR loading scheme allows the athletes to complete a relatively higher training load without an increase in perceived exertion. RPE has been reported as a valid measure to indicate exercise intensity27 but it has yet to be investigated what correlation exists between WR induced changes in RPE and objective internal workload measures.

A limitation in this study was the lack of specificity between the training and testing protocol running distances. Researchers have previously suggested that separate training strategies may need to be employed to elicit improved sprint running times for difference distances28. The training protocol utilized in this study utilized a variety of running distances (10 m – 80 m) while the performance testing protocol measured one sprint distance (30 m) and it is unknown how the athletes sprint times changed over short distances (e.g. 10 m) or longer distances (40-80 m). Future work to understand the effects of lower limb WRT for sprint running should consider investigating the necessary exposure to WRT needed to elicit sprint running performance improves, potential changes to step and joint kinematics, and how to best quantify the internal and external workload changes associated with different WR magnitudes and placements for applied scenarios.

PRACTICAL APPLICATIONS

The main finding of this study is that WR provided adequate intensity during a planned two session per week training frequency to retain sprint running performance and the provided intensity was superior to sprint training with no WR. Coaches can use WRT during in-season when training time is limited and fitness qualities typically detrain to compensate for a lower training frequency.

CONCLUSIONS

The athletes that completed the WRT intervention did not significantly improve (or decrease) in sprint running times or velocity. However, comparatively, these athletes were able to maintain baseline performance while the Control group experienced detraining of mechanical output and sprint times. These results suggest a 1% BM lower limb WRT intervention is sufficient to provide a training stimulus that retains sprint qualities, which is superior to training with no load. However, the volume or frequency of exposure needed to produce an increase in performance following introduction of the training stimulus is still unknown.

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