CHANGES IN ACCELERATION PHASE SPRINT BIOMECHANICS WITH LOWER BODY WEARABLE RESISTANCE

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Wearable resistance (WR) attached to the lower body may be advantageous for sprint acceleration training. The aim of this study was to quantify the kinematic and kinetic changes that occur during the sprint acceleration phase when lower body WR is worn. Radar and Optojump were used to assess fifteen male rugby athletes sprinting over 20 m under three different loading conditions: 0%, 3% and 5% body mass added weight (AW) attached to the lower body. Moderately loaded WR (3% AW) resulted in higher horizontal force and horizontal power outputs compared to heavier loading during the acceleration phase. Sprint acceleration biomechanics were minimally affected by WR loading up to 5% AW.

KEYWORDS: horizontal force, velocity, power, kinematics, kinetics.

INTRODUCTION: Recent advances in wearable resistance (WR) technology have enabled a greater degree of individualisation of load position, orientation and magnitude during sports training. Instead of vest loading, WR loading of 5% body mass (BM) or less attached to the lower body appears to be advantageous for sprint acceleration training (Simperingham & Cronin, 2014; Simperingham, Cronin, Pearson, & Ross, 2015). However, a detailed understanding of the changes in sprint biomechanics with lower body WR is necessary in order to prescribe optimal sprint training interventions.

Analysis of the effects of lower body WR during sprint running has been limited to a treadmill study with 5% BM loading attached to the thigh and shank and one overground sprint study with foot loading up to 2% BM (Ropret, Kukolj, Ugarkovic, Matavulj, & Jaric, 1998; Simperingham & Cronin, 2014). Ropret et al. (1998) reported a significant decrease in velocity and step frequency during acceleration and maximum velocity phases with foot loading as low as 0.6% BM. Treadmill sprinting with 5% BM attached to the lower body also resulted in a significant reduction in step frequency, reduced velocity after the initial 10 m, and increased ground contact time and vertical ground reaction forces (Simperingham & Cronin, 2014). No authors to date have reported on the effects of lower body WR with loads greater than 2% BM during overground sprinting. The aim of this study was to quantify the kinematic and kinetic changes that occur during the acceleration phase of overground sprinting with 3-5% BM added lower body WR.

METHODS: Fifteen male rugby union athletes (19.0 ± 0.5 years; 181.2 ± 7.3 cm; 91.0 ± 17.4 kg) completed three sets of two 20 m sprints on an indoor running track. Different loading conditions were used for each set of sprints: unloaded (control); 3% BM added weight; 5% BM added weight. Loading conditions were presented in a randomised order with five minutes of passive recovery between sprint repetitions and between sets. The WR was attached using Lila™ Exogen™ compression-based pants and calf sleeves (Sportboleh Sdh Bhd, Malaysia), with the load evenly distributed between the anterior and posterior aspects of the thigh and shank (respectively 2/3 and 1/3 of the total added weight) (Figure 1).

A radar (Stalker ATS II, Texas, USA) was used to measure (47 Hz) instantaneous horizontal velocity. The radar was positioned 10 m directly behind the sprint start position on a tripod set at a vertical height of 1 m to approximately align with the centre of mass of the sprinting subjects (Morin, Jeannin, Chevallier, & Belli, 2006). Instantaneous horizontal velocity was measured continuously with the radar device, which was connected to a laptop running Stalker ATS System™ software (Version 5.0.2.1, Applied Concepts, Inc., Texas, USA) for data acquisition. The data file for each trial together with the height and body mass of each subject was imported into a custom-made LabView (Version 13.0, National Instruments Corporation, Texas, USA) program that was used to calculate outcome variables consistent with procedures previously reported (Cross et al., 2015). Outcome variables included: theoretical maximum velocity (*v0*); theoretical maximum horizontal force (*F0*); maximum power output (*Pmax*), the slope of the force-velocity relationship (S_{Fv}) and split times for distances between 5 and 20 m. Relative values for *F0*, *Pmax* and S_{Fv} were calculated by dividing by system mass (i.e. body mass plus added WR), giving $F0_{rel}$, $Pmax_{rel}$ and S_{Fvrel} respectively.

Maximum velocity (*vmax*) was determined as the peak speed achieved during the 20 m sprint. The velocity-time curve [v(t)] for each sprint was fitted to an exponential function:

$$v(t) = vmax * (1 - e^{-t/\tau}) \quad [1]$$

Where *t* is the time and *τ* is the time constant. Instantaneous horizontal acceleration was calculated as the first derivative of Equation 1 and used to calculate horizontal force (F_h) from Newton's second law of motion:

$$F_h(t) = [m * a(t)] + F_{air}(t) \quad [2]$$

Where m is the body mass of the subject plus added WR and F_{air} is the air friction during sprinting, which is influenced by the frontal area of the subject (*Af*) (Arsac & Locatelli, 2002).

$$Af = (0.2025 * height^{0.725} * m^{0.425}) * 0.266 \quad [3]$$

F0 and *v0* were determined as the y-axis and x-axis intercepts of the force-velocity curve and were used to calculate *Pmax* and S_{Fv}:

$$Pmax = (0.5*F0) * (0.5*v0) \quad [4]$$

$$S_{Fv} = - F0_{rel} / v0 \quad [5]$$

An Optojump system (Microgate, Italy; 1000 Hz) was positioned over the intial 15 m of each sprint and was used to determine the flight time (FT), contact time (CT), step frequency (SF) and step length (SL) of each step. Sprint accelerations were split into the start phase (START; first 2 steps) and acceleration phase (ACCEL; steps 3-8). Dependent variables were averaged over the two or six steps in each phase.

Set mean and standard deviation was calculated for each dependent variable. Repeated measures ANOVA with post hoc Bonferroni comparisons were used to determine significant differences between the loading conditions. Statistical significance was set at $p \leq 0.05$.

Figure 1: Exogen compression-based pants and calf sleeves with added weight attached.

RESULTS: There was no significant change in sprint split times with 3% added weight (AW), but with 5% AW the time to cover 20 m was significantly increased by 1-2% compared to the unloaded and 3% AW condition (Table 1). Added WR (3% and 5% AW) resulted in a significant 5-6% reduction in *v0* compared to baseline and a significant 6% reduction in $Pmax_{rel}$ with 5% AW compared to the 3% AW condition**.** There was a significant main effect for $F0_{rel}$ but the post-hoc comparisons only indicated a trend ($p = 0.097$) towards a 4% higher level of horizontal force production with 3% AW compared to the unloaded condition. When *F0* was expressed relative to body mass rather than total system mass (8.7 ± 1.2 N/kg), *F0* was significantly higher by 9% compared to baseline. Considering $F0_{rel}$ relative to *v0*, compared to the unloaded condition there was a significant 10% change in S_{Fvrel} towards a more force-dominant force-velocity profile with 3% AW, but a non-significant 6% change with 5% AW.

During the START phase, FT, SF and SL were not significantly affected by the WR, but CT was significantly longer (5%) compared to baseline (Table 2). During the ACCEL phase, both CT (5-6%) and SF (-2-3%) were significantly altered compared to the unloaded condition.

Table 1. Radar-derived data from 20 m sprints under the three loading conditions: 0, 3 and 5% added weight.

	0% AW	3% AW	5% AW
5 m (s)	1.35 ± 0.10	1.33 ± 0.11	1.36 ± 0.08
10 m (s)	2.13 ± 0.12	2.12 ± 0.13	2.15 ± 0.11
20 m (s)	3.46 ± 0.19	3.48 ± 0.18	3.53 ± 0.18 *#
$v0$ (m/s)	8.4 ± 0.6	8.1 ± 0.6 *	7.9 ± 0.6 *
$F0_{rel}$ (N/kg)	8.0 ± 0.9	8.5 ± 1.1	8.1 ± 0.8
$Pmax_{rel}$ (W/kg)	16.8 ± 2.5	17.1 ± 2.5	16.1 ± 2.2 #
S_{Fvrel}	-0.99 ± 0.11	-1.09 ± 0.16 *	-1.05 ± 0.11

* Denotes a significant difference compared to the 0% AW condition ($p \leq 0.05$)
# Denotes a significant difference compared to the 3% AW condition ($p \leq 0.05$)
AW = added weight; $v0$ = theoretical maximum velocity; $F0_{rel}$ = theoretical maximum horizontal force relative to system mass; $Pmax_{rel}$ = maximum horizontal power output relative to system mass; S_{Fvrel} = slope of the force-velocity curve

Table 2. Kinematic data from the start and acceleration sprint phases under the three loading conditions: 0, 3 and 5% added weight.

	0% AW	3% AW	5% AW
START:			
FT (s)	0.062 ± 0.023	0.050 ± 0.015	0.051 ± 0.012
CT (s)	0.197 ± 0.021	0.206 ± 0.023 *	0.207 ± 0.020 *
SF (Hz)	4.00 ± 0.32	3.94 ± 0.30	3.92 ± 0.21
SL (m)	1.22 ± 0.13	1.23 ± 0.11	1.22 ± 0.11
ACCEL:			
FT (s)	0.080 ± 0.010	0.077 ± 0.011	0.077 ± 0.012
CT (s)	0.157 ± 0.012	0.164 ± 0.013 *	0.166 ± 0.013 *
SF (Hz)	4.24 ± 0.21	4.17 ± 0.23 *	4.13 ± 0.21 *
SL (m)	1.60 ± 0.14	1.60 ± 0.13	1.59 ± 0.13

* Denotes a significant difference compared to the 0% AW condition ($p \leq 0.05$)
AW = added weight; START = start phase (steps 1-2); FT = flight time; CT = contact time; SF = step frequency; SL = step length; ACCEL = acceleration phase (steps 3-8)

DISCUSSION: Short (20 m) sprint split times were not significantly changed by an added lower body load equivalent to 3% BM. Heavier loading equivalent to 5% BM also resulted in unchanged split times over the initial 10 m, but subjects were significantly slower over 20 m compared to both the unloaded and 3% AW conditions. Both WR loads resulted in a 5-6% reduction in theoretical maximum sprinting velocity ($v0$). It would appear that the added lower body loading was well tolerated during the leg pumping or "piston-like" action of the acceleration phase.

Changes in sprint step kinematics with lower body WR were generally consistent with previous findings, with longer ground CT and lower SF (acceleration phase only) (Ropret et al., 1998; Simperingham & Cronin, 2014). Substantial changes in sprint mechanics with WR may be deleterious to sprint running technique, but the magnitude of step kinematic changes recorded did not exceed 6% for any loaded condition, so the findings provide support for the use of lower body loading up to 5% BM during acceleration.

Higher horizontal force production during acceleration is associated with better sprint performance (Kugler & Janshen, 2010; Rabita et al., 2015). Compared to unloaded sprinting, *F0* expressed relative to BM was significantly higher with 3% AW, but no different to baseline with 5% AW. When the horizontal force data was expressed relative to total system mass, the same trend was apparent, although the specific contrasts did not achieve statistical significance. These results indicate that a lower body WR load equivalent to 3% BM may intrinsically reinforce the importance of horizontal force production during the acceleration phase. With heavier loading (5% AW), early acceleration speed and $F0_{rel}$ were still maintained compared to baseline, however maximum horizontal power output was reduced compared to the more moderately loaded condition (3% AW). It may be hypothesised that subjects more accustomed to sprinting with WR could better tolerate the heavier loading conditions.

CONCLUSION: Moderately loaded WR (3% BM) attached to the lower body of field-based team sport athletes provides a loading stimulus that serves to increase horizontal force output during the acceleration phase of sprinting. Sprint acceleration biomechanics were changed by no more than 6% with WR loading up to 5% BM. Such loading configurations can therefore provide specific overload without substantially altering sprint mechanics. Longitudinal research is required to fully understand the efficacy of this training technique on sprint acceleration.

REFERENCES:

Arsac, L. M., & Locatelli, E. (2002). Modeling the energetics of 100-m running by using speed curves of world champions. / Modelisation de l ' energetique d ' une course de 100 m par l ' utilisation des courbes de vitesse des champions du monde. *Journal of Applied Physiology, 92*(5), 1781-1788.

Cross, M. R., Brughelli, M., Brown, S. R., Samozino, P., Gill, N. D., Cronin, J. B., & Morin, J. B. (2015). Mechanical properties of sprinting in elite rugby union and rugby league. *International Journal of Sports Physiology and Performance, 10*(6), 695-702. doi:10.1123/ijspp.2014-0151

Kugler, F., & Janshen, L. (2010). Body position determines propulsive forces in accelerated running. *Journal of Biomechanics, 43*(2), 343-348. doi:10.1016/j.jbiomech.2009.07.041

Morin, J. B., Jeannin, T., Chevallier, B., & Belli, A. (2006). Spring-mass model characteristics during sprint running: correlation with performance and fatigue-induced changes. *International Journal of Sports Medicine, 27*(2), 158-165. doi:10.1055/s-2005-837569

Rabita, G., Dorel, S., Slawinski, J., Sàez-de-Villarreal, E., Couturier, A., Samozino, P., & Morin, J. B. (2015). Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scandinavian Journal of Medicine and Science in Sports, 25*(5), 583-594. doi:10.1111/sms.12389

Ropret, R., Kukolj, M., Ugarkovic, D., Matavulj, D., & Jaric, S. (1998). Effects of arm and leg loading on sprint performance. *European Journal of Applied Physiology and Occupational Physiology, 77*(6), 547-550. doi:10.1007/s004210050374

Simperingham, K. D., & Cronin, J. B. (2014). Changes in sprint kinematics and kinetics with upper body loading and lower body loading using Exogen exoskeletons: a pilot study. *Journal of Australian Strength and Conditioning, 22*(5), 69-72.

Simperingham, K. D., Cronin, J. B., Pearson, S., & Ross, A. (2015). Acute changes in sprint running performance following ballistic exercise with added lower body loading. *Journal of Australian Strength and Conditioning, 23*(6), 86-89.

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