THE EFFECT OF LOWER LIMB WEARABLE RESISTANCE LOCATION ON SPRINT RUNNING STEP KINEMATICS

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This study quantified changes in step kinematics between unloaded, thigh, and shank wearable resistance (WR) at 2% body mass (BM) during over ground sprint running. Eleven male athletes completed two maximal effort sprint trials over 52 m of in-ground force plates, for each condition. There were no significant ($p > 0.05$) changes in sprint times between all conditions. Compared to unloaded sprinting, shank WR significantly changed step frequency (SF) (-2.1% acceleration phase and -2.5% max velocity phase (MVP)), contact times (CT) (2.1% MVP) and flight times (3.3% MVP); thigh WR significantly changed SF (-1.4% MVP) and CT (2.9% MVP). It appears peripheral loading (2% BM) of the thigh and shank affects SF and CT but not step length and width. Such differential loading could be used to train different mechanical determinants of speed.

KEYWORDS: sprinting, velocity, resistance, sport-specificity.

INTRODUCTION: Wearable resistance (WR) training involves attaching micro-loads (i.e., ≤5% body mass (BM)) to segments of the body to allow an athlete to perform sport specific movements under resistance. This type of training directly addresses the concept of training specificity and, therefore, has been proposed as an optimal method to train for sport specific movements (Macadam, Simperingham, & Cronin, 2017). One such movement is sprint running. Sprint running, and one's ability to perform maximal acceleration over short distance, is a key performance component for many sports (Morin, Edouard, & Samozino, 2011). Lower limb WR can be used to provide a rotational overload to the hip and knee joints during sprint running. However, limb loading will change the inertia properties of the limb potentially resulting in changes to movement mechanics (Martin & Cavanagh, 1990). Thus, it is important to understand how lower limb WR changes sprint running movement mechanics prior to further investigating its use as a training tool. Previously, researchers have assessed the effects of lower limb WR on sprint performance during ankle loading (4.8% BM; Ropret, Kukolj, Ugarkovic, Mtavulj, & Jaric, 1998) and whole leg loading (2.4-5% BM; Bennett, Sayers, & Burkett, 2009; Simperingham & Cronin, 2014; Simperingham, Cronin, Pearson, & Ross, 2016; Macadam et al., 2017) conditions. No research has measured the effects of differences in WR location by specifically comparing the effects of shank versus thigh WR during sprint running. Practitioners may be interested in understanding the effect of placing the WR more distal to the hip joint (i.e. moving the load from the thigh to the shank) which introduces an additional inertial manipulation to the knee joint. Therefore, the purpose of this study was to evaluate the acute effects on step kinematics when 2% BM WR was attached to the thigh or shank during over ground sprint running.

METHODS: Eleven male athletes (age: 21.2 ± 2.6 years, 175.3 ± 5.5 cm, 68.7 ± 4.3 kg) with 9.7 ± 2.9 years of sprint-based training and a personal best 100 m time of 11.30 ± 0.41 seconds volunteered to participate in the study. Prior to testing, participants completed a familiarised session for the 50 m over ground sprint testing protocols. Participants reported to a sports laboratory for two testing sessions. One testing session utilized WR attached to the thigh while the other utilized WR attached to the shank. The order of the two testing sessions were randomly assigned. An indoor running track containing 52 m of in ground force plates was used. Each testing session involved a series of over ground 50 m maximal effort sprints and began with a self-selected warm up which included dynamic stretching and a series of sub-max sprints (50%, 75%, 90% effort level). Following the warm-up, participants performed four sprint trials in a randomized order: two trials of unloaded sprint-running and two trials with WR equivalent of 2% BM attached the thigh or shank. All max effort sprints were from a block start. All test trials were preceded by at least five minutes of passive rest. Photocell units (TC Timing System; Brower Timing Systems, Draper, UT, USA) were placed at the side at 10 m and 50 m to determine sprint times during each trial. The initiation of the recording was done by the starting gun. Spatio-temporal variables were obtained from 54 force platforms (TF-90100, TF-3055, TF-32120, Tec Gihan, Uji, Japan; 1000 Hz). In order to appropriately detect the foot strike and toe-off instants the influence of random noise was eliminated by filtering in the ground reaction force (GRF) signals using a Butterworth low-pass, fourth-order digital filter at a cut-off frequency of 50 Hz (Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2017). Contact (CT) and flight times (FT), step length (SL), frequency (SF) and width (SW) were determined by using a threshold value of 20 N with the vertical GRF signal in accordance with Nagahara et al., 2017. Velocity (calculated as the product of SF and SL) was inspected to identify the end of the acceleration phase. Average speed began to plateau at step 13. Therefore, variables were averaged over steps 1-13 to represent the acceleration phase and steps 14-23 to represent the maximal velocity phase. This approach allowed us to discuss results with reference to previously reported WR research. A one-way repeated measures ANOVA was conducted to compare the effect of WR on step kinematic variables, sprint times, and maximal velocity output in the unloaded, thigh, and shank conditions. Paired samples t-tests were used to make post hoc comparisons between conditions. Cohen's d effect sizes (ES) were calculated for significant post hoc comparisons and were described as small (<0.5), moderate (0.51–0.79) and large (>0.8) (Cohen, 1988). Statistical significance was set at $p \leq 0.05$.

RESULTS: Sprint times at 10 m and 50 m, and maximal velocity are presented in Table 1. Though times were unchanged, the maximal velocity achieved was significantly reduced with thigh WR ($p = 0.012$; ES = 0.40; -1.8%) and shank WR ($p = 0.003$; ES = 0.37; -2.0%) when compared to the unloaded condition.

Table 1: Sprint times and maximal velocity for each condition (mean ± SD).

Variable	Unloaded	Thigh	Shank
10 m sprint time (s)	2.14 ± 0.08	2.15 ± 0.09	2.13 ± 0.08
50 m sprint time (s)	6.61 ± 0.26	6.63 ± 0.27	6.60 ± 0.27
Maximal velocity (m/s)	9.50 ± 0.46	9.33 ± 0.38*	9.31 ± 0.56*

* = significant difference ($p < 0.05$) from the unloaded condition

Step kinematic variables measured during the acceleration and maximal velocity phases are presented in Table 2. During the acceleration phase, shank WR significantly decreased SF ($p = 0.016$; ES = 0.32; -2.1%) compared to the unloaded condition. During the maximal velocity phase, shank WR significantly changed CT ($p = 0.001$; ES = 0.33; 2.1%), FT ($p = 0.036$; ES = 0.42; 3.3%), and SF ($p = 0.010$; ES = 0.52; -2.5%) compared to the unloaded condition. Thigh WR significantly changed CT ($p = 0.002$; ES = 0.44; 2.9%) and SF ($p = 0.028$; ES = 0.32; -1.4%) compared to the unloaded condition. Furthermore, there was a significant difference between the thigh and shank conditions for FT ($p = 0.006$; ES = 0.47) in which the shank WR produced a 3.3% increase in FT over the thigh WR condition.

Table 2: Step kinematic variables during each phase of sprinting (mean ± SD).

	Acceleration			Maximal Velocity		
Variable	Unloaded	Thigh	Shank	Unloaded	Thigh	Shank
CT (ms)	151 ± 12	155 ± 13	154 ± 13	105 ± 7	109 ± 7*	108 ± 7*
FT (ms)	99.0 ± 12	99.0 ± 10	101 ± 10	123 ± 10	123 ± 8	127 ± 9*
SL (m)	1.70 ± 0.14	1.70 ± 0.13	1.70 ± 0.12	2.10 ± 0.13	2.09 ± 0.12	2.09 ± 0.11
SF (Hz)	4.34 ± 0.30	4.28 ± 0.24	4.25 ± 0.26*	4.39 ± 0.21	4.33 ± 0.17*	4.28 ± 0.21*
SW (m)	0.25 ± 0.04	0.25 ± 0.04	0.25 ± 0.05	0.09 ± 0.05	0.10 ± 0.05	0.09 ± 0.05

* = significant difference ($p < 0.05$) from the unloaded condition.

DISCUSSION: The purpose of this study was to evaluate the acute effects of 2% BM thigh and shank WR on step kinematics during over ground sprint running. The main findings were: 1) both the thigh and shank WR significantly decreased the maximal velocity achieved while 10 m and 50 m sprint times were minimally changed; 2) during the acceleration phase, the only significant difference to the unloaded condition was SF with shank WR; 3) during the maximal velocity phase, thigh and shank WR significantly changed CT, SF, and FT (shank WR only). An interesting finding is the minimal, non-significant changes to sprint times despite the significant decrease in maximal velocity. Previous researchers have also reported similar findings with whole leg WR of 2.4% BM significantly reducing stride velocity (-4.7%) during the maximal velocity phase (Bennett et al, 2009) and whole leg WR of 5% significantly reducing peak velocity during the acceleration phase (-2.3%) and maximal velocity phase (-5.3%) (Simperingham and Cronin, 2014). Only with 5% BM whole leg WR was there also a measured significant decrease in total sprint time (3.3%, 25 m) (Simperingham and Cronin, 2014). As sprint times were measured at 10 m and 50 m for this study and maximal velocity was achieved on average by step 20 for these participants, these measurements reflect different aspects of sprint performance. Readers should be cognizant of the differing results that can be found depending on the speed measurement that is chosen. During the acceleration phase, only shank WR produced a significant change to step kinematics by significantly decreasing SF (-2.1%) when compared to the unloaded condition. All other step kinematic measurements were not significantly different between conditions. These findings differ from previous research findings where whole leg WR of 3% BM significantly changed both CT (3-5%) and SF (-2 to -3.6%) during the acceleration phase of sprint running (Macadam et al., 2017; Simperingham et al., 2016). Practitioners interested in overloading the acceleration phase of sprint running with WR may need to consider a load greater than 2% BM depending on load location and the overload variable of interest as these results show that shank, but not thigh, WR of 2% BM significantly changed SF and no other step kinematic variables. This study is one of the few that has measured step kinematics during the maximal velocity phase of sprinting with WR. Specifically, both thigh and shank WR produced significant changes to CT (2.9% and 2.1%, respectively) and SF (-1.4% and -2.1%, respectively) when compared to the unloaded condition. Similarly, Simperingham and Cronin (2014) noted significant changes to CT (4.7%) and SF (-3.5%) with whole limb WR of 5% BM sprint running condition on a non-motorized treadmill. It is not surprising to see changes to SF alongside changes to CT as a decrease in SF comes at a consequence of longer contact times. A specific concern with resisted sprint training is that the added load can result in large changes to movement mechanics that may disrupt future movement performance. The loading used in this study did not appear to produce significant changes to the sprint running movement pattern as neither WR condition caused a significant change to SL nor SW. Even the WR of 5% BM used in Simperingham and Cronin (2014) did not result in a significant change to SL. Taking these findings together, it seems as though lower limb WR as little as of 2% BM and as much as 5% BM can be used to stimulate an overload to CT and SF during the maximal velocity phase with no significant changes to the sprint running movement pattern. However, an interesting change to step kinematics that occurred during the maximal velocity phase was the significant increase (3.3%) to FT with shank WR. This change was found to be significantly different from the unloaded condition and the thigh WR condition and it was the only variable that varied significantly between the shank and thigh WR conditions. Previous researchers that measured FT during the maximal velocity phase of sprint running with whole leg WR of 2.4% BM (Bennett et al., 2009) and 5% BM (Simperingham and Cronin, 2014) did not find significant changes to FT. These findings indicate the greater overload effect when the WR is positioned further from the hip joint during sprint running and points to ability to differentially load the lower extremity to target different mechanical aspects of sprint running. The details regarding the joint kinematic and kinetic changes to sprint running that occur with lower limb WR were not investigated in this study, thus creating a limitation to our understanding of the underlying causes to the changes to sprint running step kinematics found in this study. Future studies should work to quantify important force production values like the ratio of forces or net impulse which have been shown to provide better insight into the technical abilities needed for successful sprint performance (Morin et al., 2011). Additionally, more advanced kinematic analyses should be used to confirm no detrimental changes to sprint running technique occurs with lower limb WR. As the subjects included in this study were of high level sprinting ability, it is unknown how athletes of lesser sprint ability would respond to a loading of 2% BM. Moreover, the individual differences in subject stature and limb segment lengths will affect the rotational inertia overload and should be considered for further research. Given the increased rotational inertia from WR, practitioners should take care to progressively overloading the athlete, especially during the beginning of the training season, to reduce possible risk of injury.

CONCLUSION: This study was the first to quantify the effects of WR location (thigh versus shank) on step kinematics during over-ground sprint running on force plates. This form of resistance training aligns with the concept of sport-specific training, and from the findings in this study 2% BM attached to the lower limbs allows athletes to perform sprints in an overloaded manner without significantly reducing total sprint times. As slightly greater changes to step kinematics were found throughout both phases of the sprint distance with shank WR, practitioners may wish to utilize this placement for athletes needing to overload the acceleration and maximal velocity phases. Furthermore, it appears that such differential loading can be used to target particular mechanical determinants of sprinting performance.

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ACKNOWLEDGEMENTS: This project was completed in partnership with the National Institute of Fitness and Sports in Kanoya, Kanoya, Japan. We are grateful to the researchers who assisted in data collection for their valuable participation in this project.