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Forearm wearable resistance effects on sprint kinematics and kinetics

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ABSTRACT

Objectives: Arm swing is a distinctive characteristic of sprint-running with the arms working in a contralateral manner with the legs to propel the body in a horizontal direction. The purpose of this study was to determine the acute changes in kinematics and kinetics when wearable resistance (WR) of 1 kg (equivalent to ~1% body mass) was attached to each forearm during over ground short distance (20 m) maximal sprint-running.
Design: Cross-sectional study.
Methods: Twenty-two male amateur rugby athletes (19.4 ± 0.5 years; 97.0 ± 4.8 kg; 180.4 ± 7.2 cm) volunteered to participate in the study. Radar and Optojump were used to examine kinematic and kinetics between WR and unloaded sprint-running conditions.
Results: No significant ($p < 0.05$) differences were found at 2 m or 5 m between conditions, however, the WR condition resulted in a significant increase in 10 m, 20 m and 10–20 m split time (all, ~2%, small effect size) compared to the unloaded condition. Significant decreases were also found in theoretical maximum velocity (V_0) (−1.4%, small effect size) and relative peak horizontal power production (P_{max}) (−5.5%, small effect size). Step length (2.1%, small effect size) and contact time (6.5%, medium effect size) were significantly increased, while step frequency (−4.1%, small effect size) and flight time (−5.3%, medium effect size) were significantly decreased.
Conclusions: WR forearm loading provides a movement specific overload of the arms which significantly alters step kinematics and sprint times ≥10 m.

1. Introduction

Sprint ability is a key performance factor in many sport activities such as track and field events, soccer and rugby.[1] Sprint performance involves a large forward acceleration, which is directly dependent on the capacity to generate and apply large amounts of horizontal external force onto the ground.[2] During sprint acceleration, the orientation of ground reaction force (GRF) was found to be a greater indicator of sprint performance than the overall magnitude.[3] Therefore, athletes that train with differing body orientations, and thus force application techniques, may exhibit different acceleration capabilities.[4] Understanding the specific mechanical determinants of sprint acceleration is pivotal for practitioners in designing optimal training programs. Research examining the most effective training methods for sprint acceleration are still being investigated. For example, resisted sprint training has been suggested as an effective training method for improving sprint acceleration.[5] Based on the principle of training specificity, it follows that training modalities that replicate the characteristics of a sporting action should be utilised leading to optimal transference to the sporting action.[5] However, although resisted sprint training is increasing in popularity, there is currently limited evidence supporting the choice of load placement and magnitude for training application.[6]

Previous resisted sprint studies have utilised sleds[6] and wearable resistance (WR) attached to the trunk,[7] legs,[8] or ankle.[9] In addition two WR studies have investigated the effects of upper limb loading during sprint-running, such loading providing the focus of this research. Previously, a 40 m over ground sprint was performed with 0.5 kg per arm weighted sleeves on 10 male recreationally trained athletes from field based sporting clubs.[10] Participant's body mass was not reported, therefore the magnitude of this load as a percentage of body mass (BM) is unknown. No significant differences were found between conditions in any performance measure (maximum velocity, and 10 m and 40 m times).[10] The authors proposed that as no detrimental effects were found in performance, the forearm loads may provide a suitable overload stimulus during

Abbreviations: BM, body mass; UL, unloaded; WR, wearable resistance.

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speed training sessions without negatively impacting on technique or performance. An earlier study on 24 male physical education students used loads of 0.2 kg, 0.4 kg, and 0.6 kg (0.3–0.9% BM) lead rods held in each hand during 30 m over the ground sprint-running.[9] No acute effects were found in sprint performance until the heavier loads (0.6 kg, 0.9% BM) were used, which resulted in a significant 1% decrease in velocity between the unloaded (UL) and hand-held loaded sprint conditions during the maximum velocity phase. Therefore, the magnitude of loads used in the aforementioned studies may not have been sufficient to significantly overload arm action during the acceleration phase, and future research with heavier loading is required.

Debate remains among coaches about the importance of arm action during sprint-running. Bosch and Klomp[12] suggested that arm action during sprint-running has a greater function than merely maintaining balance or compensating for the small disturbances in body posture. Moreover, it appears that arm drive seems to be of less importance once an athlete reaches their maximum velocity phase due to the more upright position of the body. Earlier studies by Mann[13] and Mann and Herman[14] have suggested that when body is upright during maximum velocity sprint-running the arms serve more as a counter balance to the legs. Contrastingly, during the start of the sprint, arm drive motion has been found to affect lower limb kinematics,[15] contributes 22% of the body's total kinetic energy when pushing from a block start sprint[16] and relates to the performance level of the sprinter in a 100 m race.[17] When arm drive motion was restricted by constraining scapular motion with tape, step length (−4.6%) and whole body lean position (−3.9%) during the first step was significantly decreased, subsequently reducing sprinting speed (−3.2%).[18] It would seem that for the sprint start and early acceleration phases at the very least, that finding training methods to enhance arm drive may benefit sprint performance.

Bhowmick and Bhattacharyya[20] suggested that the horizontal component of the arm swing during acceleration may aid in increasing step length and regulating leg movement during the start of a sprint moreover, the importance of arm action has been highlighted in studies where arm action was constrained during running. Egbuonu et al.[21] reported a 4% increase in the energetic cost of treadmill running with the arms held behind the back, similarly, running with the arms crossed in front of the chest resulted in a significant increase (8%) in the net metabolic power demand compared to running with arm swing.[22] Moreover, running without arm swing significantly increased step width variability (9%) and step frequency (2.5%).[22] Given the evidence presented there would seem a case to investigate the effects of training methods that specifically overload the arms during the activity of interest. To these ends affixing WR to the arms during the sprint, would seem one such method. No studies to date have investigated WR arm loads in excess of 0.6 kg per arm. Therefore, given the limited research into this area and the potential importance of arm action during sprint acceleration, the purpose of this study was to determine the acute changes in kinematics and kinetics when WR of 1 kg (∼1% BM) was attached to each forearm during over ground short distance maximal sprint-running.

2. Methods

A cross-sectional design was used to investigate the effects on sprint kinematics and kinetics when WR was attached to the forearms during sprint-running. Twenty-two male amateur club or provincial age-group representative rugby union players (19.4 ± 0.5 years; 97.0 ± 4.8 kg; 180.4 ± 7.2 cm) volunteered to participate in the study. Written informed consent was obtained from the participants prior to their participation. The Institutional Ethics Committee of Auckland University of Technology provided approval for this study.

Fig. 1. Wearable resistance forearm loads of 1 kg per arm.

Participants wore Lila™ Exogen™ compression forearms sleeves (Sportboleh Sdh Bhd, Malaysia) for the duration of the testing session (Fig. 1). The Exogen™ exoskeleton sleeves enables loads (with Velcro backing) of 0.05–0.2 kg to be attached in numerous configurations. WR totalling ∼2% BM was attached evenly around the forearms with 1 kg (∼1% BM) on each forearm. WR of this magnitude was chosen to provide a greater overload compared to previously used loads (0.2–0.6 kg) in sprint-running studies.[9,10]

Participants performed maximum effort 20 m sprints with and without WR on an indoor track. Participants performed a 15 min standardised warm-up followed by four trials of a 20 m sprint, comprised of two repetitions under each conditions: (1) WR of 1 kg (∼1% BM) per arm; (2) UL (i.e. 0% BM). The average data from the two repetitions under each condition were used for analysis as this method has been found to provide acceptable reliability in short distance sprints.[23] The order of the conditions was randomised with a random number generator. Participants started from a split-stance position with their preferred lead-foot on the starting line. Each trial was separated by five minutes of passive rest.

Kinematic variables for flight and contact times, and step length and frequency were recorded over the initial 5 m of each sprint with an Optojump system (Microgate, USA). Optojump detects any interruptions in communication between two parallel bars and calculates the duration to obtain kinematic variables.[24] Instantaneous horizontal velocity data was collected (47 Hz) with a radar device (Stalker ATS II, Applied Concepts, Dallas, TX, USA) positioned directly behind the starting position and at a vertical height of 1 m to approximately align with the participant's centre of mass.[25] All data were collected using Stalker ATS system software (Model: Stalker ATS II Version 5.0.2.1, Applied Concepts, Dallas, TX, USA) supplied by the radar device manufacturer. The general mechanical ability to produce horizontal external force during sprint-running is portrayed by the linear force–velocity *(F–v)* relationship.[6,26] The mechanical capabilities of the lower limbs are characterised by the variables: theoretical maximum velocity (V_0); theoretical maximum force (F_0) and peak power production (P_{max}).[2] A custom made LabVIEW program (Version 13.0, National Instruments Corp., Austin, TX, USA) was developed to calculate the variables based on the raw horizontal velocity data: V_0; F_0; P_{max}; and sprint split times (2, 5, 10 and 20 m). The methods of obtaining these variables have been validated in previous research during maximal sprint-

Table 1
Average sprint split times and kinematic variables achieved for both conditions. Means ± standard deviation.

	UL	WR	% difference	Effect size	p-Value
2 m (s)	0.60 ± 0.04	0.61 ± 0.05	2.7	0.39	0.23
5 m (s)	1.12 ± 0.06	1.15 ± 0.08	2.4	0.48	0.08
10 m (s)	1.87 ± 0.08	1.91 ± 0.10	2.1	0.46	0.02*
20 m (s)	3.23 ± 0.16	3.30 ± 0.17	2.0	0.43	0.00*
10–20 m (s)	1.36 ± 0.08	1.39 ± 0.08	2.0	0.33	0.01*
V_0 (m/s)	7.5 ± 0.5	7.4 ± 0.5	−1.4	−0.21	0.05*
Flight time (ms)	0.050 ± 0.008	0.053 ± 0.014	−5.3	−0.22	0.01*
Contact time (ms)	0.197 ± 0.018	0.211 ± 0.017	6.5	0.73	0.00*
Step frequency (Hz)	4.03 ± 0.25	3.86 ± 0.24	−4.1	−0.67	0.00*
Step length (m)	1.10 ± 0.10	1.12 ± 0.11	2.1	0.22	0.04*

BM = body mass; UL = unloaded; WR = wearable resistance; V_0 = theoretical maximum velocity.
* Significantly different from unloaded condition $p \leq 0.05$.

running.[3,26] A high level of reliability (coefficient of variation V_0 1.11% P_{max} 1.87%, F_0 2.93%) for inter-individual comparisons was found for each variable during over the ground sprint running.[26] Moreover, from previously unpublished piloting, the methods used in this study are based on analysing a similar cohort where 40 m sprints were collected and an exponential fit was performed on this data. The trials were then cropped at 20 m, rerun with the exponential fit, which resulted in a small difference between them (V_0 and relative F_0 ~1.1–2.2%, relative P_{max} ~0.4–0.6%, split times ~0.1–0.5%). V_0; F_0; P_{max} are all reported relative to BM for the unloaded condition and relative to BM plus added 2% BM WR load for the WR condition.

Standard descriptive statistics (means and standard deviations) were reported for all statistical comparisons. Normal distribution was checked with Shapiro–Wilk's test. Kinematic analysis of flight and contact times, and step length and frequency was completed on the average value from the first three steps representing the start phase, obtained from the Optojump. Analysis of V_0, F_0, and P_{max} was completed over the 20 m sprint distance, obtained from the radar. Statistical differences in kinematic and kinetic variables across WR and UL conditions were determined using a paired t-test. Statistical significance was set at an alpha level of $p \leq 0.05$. Effect size (ES) were described as trivial (<0.2), small (<0.21–0.5), medium (0.51–0.79) and large (>0.8).[27] ES was determined by calculating the mean difference between groups, and then dividing the result by the pooled standard deviation.[27]

3. Results

The average sprint split times and kinematic variables achieved for both conditions are shown in Table 1. No significant differences were found at 2 m or 5 m between conditions, however, the WR condition resulted in a significant increase in 10 m, 20 m and 10–20 m split times compared to the UL condition. Small effect sizes were found for all split time variables of interest as well as V_0 which was significantly decreased (−1.4%) with the WR condition. WR resulted in a significant decrease in flight time (−5.3%, small effect size) and step frequency (−4.1%, medium effect size), while a significant increase was found in contact time (6.5%, medium effect size) and step length (2.1%, small effect size). Relative P_{max} was significantly reduced by 5.5% (small effect size) compared to the UL condition (Table 2). A small non-significant (−4%) reduction in relative F_0 was also observed.

4. Discussion

The purpose of this study was to determine the acute changes in kinematics and kinetics when WR of 1 kg (~1% BM) was attached to each forearm during over ground short distance maximal sprint-running. The main findings were that WR resulted in significantly: (1) longer 10 m, 20 m and 10–20 m split times (all ~2%); (2) decreased V_0, relative P_{max}, flight time and step frequency; and, (3) increased contact time and step length.

The aim of the start phase in sprint-running is to create the greatest horizontal velocity of the centre of mass through the athlete generating the greatest amount of impulse in the shortest time.[16] Forearm WR provided a movement specific overload resulting in small but statistically significant changes in the kinetic and kinematic patterns. The WR condition resulted in split times being significantly longer by ~2% at both 10 and 20 m. McNaughton and Kelly[10] found no significant changes in 10 m and 40 m split times with 0.5 kg loads, and a nominal change in maximum velocity (−0.5%) compared to the 1.4% ($p = 0.05$) decrease found in this study. No split times were reported by Ropret et al.,[9] however maximum velocity was significantly reduced by 1% but only with the heavier load (0.6 kg). The differential effects of WR may be attributed to the magnitude of load used in each study, for example, the greater load used in this study (1 kg per arm) compared to 0.5 kg[10] and 0.2–0.6 kg,[9] with significant changes only found with the heavier load (≥0.6 kg). Although the load added was relatively small (1 kg per arm), WR of this magnitude provided a sufficient overload to significantly reduce flight time (−5.3%; ES = 0.22) and step frequency (−4.1%; ES = 0.73) during the start phase. In contrast, Ropret et al.[9] found no change to stride frequency during sprinting with lighter hand-held loading (0.2–0.6 kg). It would appear that WR loads in the proximity of 1 kg per arm (totalling 2% BM) are the required threshold needed to significantly overload flight time-step frequency in young adult male athletes. The exact loading for other populations such as youth or females needs to be determined.

As arm action may be an important aspect of sprint-running, an increase in moment of inertia of the arms may alter the transfer of momentum to and from the body in the arm swing.[28] From the

Table 2
Change in kinetic variables achieved for both conditions. Means ± standard deviation.

	UL	WR	% difference	Effect size	p-Value
Relative F_0 (N/kg)	14.2 ± 1.8	13.6 ± 2.1	−4.2	−0.34	0.17
Relative P_{max} (W/kg)	26.5 ± 3.7	25.0 ± 4.1	−5.5	−0.39	0.05*
Relative *F–v* profile (/kg)	−1.91 ± 0.3	−1.87 ± 0.3	−3.0	−0.21	0.39

BM = body mass; F_0 = theoretical maximum force; *F–v* = force–velocity relationship; P_{max} = peak power production; UL = unloaded; WR = wearable resistance.
* Significantly different from unloaded condition $p \leq 0.05$.

increased contact time (6.5%) and step length (2.1%) it is proposed that during the start phase the overloaded rotational motion of the arm action may provide a horizontal stimulus. Findings from this study are in agreement with an earlier proposal by Bhowmick and Bhattacharyya[20] who suggested that the horizontal component of the arm swing during acceleration may aid in increasing step length and regulating leg movement during the start of a sprint. Slawinski et al.[16] stated that all segments of the body contribute to translation energy at the start phase of sprint-running, highlighting the importance of the arms during this phase. WR attached to the forearms resulted in a longer step length. The initial increase in step length may be comparable to the increase in propulsion force and jump distance found in horizontal jump studies with hand-held loads.[29] A significant increase in the ratio of horizontal force occurred when jumping with hand-held loads improving an athlete's ability to produce horizontal force during ground contact.[29] As velocity is a product of step length and step frequency,[14] the increase in step length found in this study may be of interest for start phase training due to a greater step length at take-off, however, further research is required to explore this contention. To date, no other kinematic variables have been reported in upper limb loaded sprint studies limiting the comparisons to this study. Optimal WR loading should provide a suitable overload stimulus for adaptation without negatively affecting the sport action technique.[30] As this is a novel form of loading, responses may differ due to individual characteristics (i.e. training backgrounds, arm action technique, upper body strength) among subjects. The emergence of positive, neutral and negative responders was found when analysing individual results across a range of dependent variables in this analysis. This is highlighted in that although 16 subjects increased their step length with forearm WR, 6 subjects decreased their step length.

There are some limitations that the reader should be cognisant of. First the participants used in this study were young rugby athletes (average age 19 years) and the effects of arm loading on other populations (females, sprinters, greater training age, youth, etc.) remain unknown. Second, further testing on a non-motorised treadmill or using in-ground force platforms would improve understanding of the effects of WR on important kinetic values (i.e. F_0, P_{max}). Third, this was the first time the participants had sprinted with WR forearm loading, it may be possible that sprint technique may change after a familiarisation period. Future research utilising three-dimensional motion analysis to quantify changes to arm drive mechanics would be valuable. Fourth, due to the difference in body position from block starting compared to the upright split stance position, research is required to investigate potential differences between track and sport starting positions and subsequent acceleration phase transition. Finally, longitudinal research is required to fully assess the effects of long term adaptation to WR forearm loading on sprint-running performance.

5. Conclusions

The principle of specificity provides insight into how loading and training stimuli can be applied to optimise transference to the activity/sport of interest. In this regard it is desirable that the contraction forces, movement velocities, and technical demands simulate the activity of interest. From this study loads in the proximity of 1 kg per limb were found to significantly increase contact time and step length whilst decreasing flight time, step frequency, and horizontal power. Even though the changes were statistically significant the effects were deemed small or medium and so may be interpreted as appropriate loading to overload the sprint start i.e. not major disruptions to technique. The small increases in step length were interesting and were assumed to be the result of arm loading resulting in similar ground reaction force magnitudes applied over a longer contact time i.e. greater horizontal impulse. However, whether such assumptions are correct would need force plates to quantify the vertical as well as the horizontal ground reaction forces used in tandem with motion capture to capture changes in joint angle positions.

Practical implications

- Given the results we speculate that WR forearm loading provides a training means that may potentially improve arm drive mechanics significantly overloading step frequency and ground contact forces, however, further research is needed to verify such a contention.
- Forearm WR causes an acute overload resulting in a small but significant increase in sprint times for distances $\geq$10 m.
- During the start phase forearm WR can increase step length (2.1%) which may be due to the longer ground contact time (6.5%) i.e. potentially greater impulses.

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