Comparison of step kinematics of active resisted 30 m sprints between experienced male and female sprinters

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Effect of active resisted 30 m sprints upon step and joint kinematics and muscle activity in experienced male and female sprinters.

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Abstract

This study compared the kinematics (step and joint) and muscle activity of unresisted and active resisted 30 m sprints with different loads (10-40% body mass) in experienced male and female sprinters. Step kinematics were measured using a laser gun and contact mat in 28 male and female participants during unresisted 30 m sprint, and sprints with 10-40% of body mass (BM) active resistance, while peak angular velocities of lower limb was measured, together with muscle activation of nine muscles. Increased resisted loads resulted in slower 30m times, as a result of lower step velocity mainly caused by shorter step lengths and frequencies, flight times and longer contact times, with a greater effect on women than on men. These step kinematic differences, due to increasing load were accompanied with lower peak joint movements. However, gender differences were only found for peak plantar flexion with unresisted and 10% BM resisted sprints. Furthermore, increasing load decreased calf and hamstring muscles activity, while medial vastus activity increased. Based upon these findings, it was concluded that when introducing active resisted sprints, women should sprint with approximately 10% less active loads than men to have equal step and joint kinematics development over the sprint distance.

KEY WORDS

step length, step frequency, contact time, flight time, gender, EMG

INTRODUCTION

Sprinting is an important ability which is use in many sports, such as soccer, football, rugby and athletics. Therefore, improving sprint performance is one important goal of training in these sports. Sprint training is primarily focused either on increasing power and strength, or on improving the sprinting technique by improving efficiency of certain movements.[1] A generally used training method for increasing sprint performance is resisted sprints, as described by reviews of Alcaraz, et al.[2] and Petrakos, et al.[1]. In resisted sprints, an external load is most often used, such as weighted sled pulling.[1,3,4] However, with weighted sled sprinting the challenge is friction, inertia of the sled and passive resistance. Initially, an additional force is required to overcome the effects of friction between the sled and the track surface, the static friction.[4,5] While, when the sled begins to move, the friction between the track surface and the sled represents the total friction and load that has to be pulled. As such, the resistance will become lower than at the start. Furthermore, when using different loaded sleds, differences in friction due to the interaction with the surface[6] makes it difficult to compare different studies.[5]

Nowadays, there are also pulley systems, such as the 1080Sprint™ and dynaspeed™ that can give a constant active resistance during the whole sprint by using a motor to employ a constant pulling force.[7,8] van den Tillaar[5] showed that an active force equal to 10–20% of body mass employed with the dynaSpeed™ increased 30 m times 13–28%, which was much higher than for weighted sled sprints with similar weights (7.5–20%).[4]

Although many studies have discussed various biomechanical aspects of sprinting,[9-11] only a few have investigated these parameters in resisted sprints and have not investigated the development of the kinematics per step.[4,12,13] Recently, van den Tillaar[14] showed that increased resisted loads resulted in slower sprint times, which was the result of a lower step velocity, mainly caused by shorter step lengths and frequencies, flight times, and longer contact times. He also showed that women had slower times due to an earlier and slower maximal step velocity, which was mainly caused by longer contact times, shorter step lengths, and frequencies compared with men. However, in that study no analysis of muscle activation and peak angular velocity of the lower limb were conducted which could explain the changed step kinematics between gender and load. Only Macadam, et al.[15] showed that a load of 3% body mass attached to the thigh had a 10-12% decrease of angular hip extension and flexion velocity when sprinting on a non-motorised treadmill.

To the best of our knowledge, none of these studies have investigated peak angular velocity of the lower limb and muscle activation during different resisted sprints that could give more information about the demands of these sprints upon the athletes while sprinting with these extra loads. This gained knowledge could help researcher, coaches and athletes about decision making what active loads should be used to target different muscles and kinematics, for enhancing sprint performance. Eventual difference in muscle activity due to increased load or between genders can help to plan training more specific to different muscles optimally, for enhancing sprint performance.

Therefore, the purpose of the present study was to investigate the effect of different active resisted loads (10, 20, 30 and 40% of body mass) upon step and joint (peak angular velocity) kinematics and muscle activity during every 6th m (blocks of 20% displacement) of 30 m sprints for experienced male and female sprinters. It was hypothesised that the step length and rate will decrease, while contact time will increase with increasing active resistance and that this will have a larger impact on women than men[5,16-18]. This will be accompanied by lower peak joint movements, but with higher muscle activation of the prime movers in both men and women (quadriceps, gluteus and plantar flexors) due to the increased propulsion force demands of the active resistance.

METHODS

Participants

Fourteen experienced male sprinters (age 27 ± 6 years, body mass 76.6 ± 8.8 kg, body height 1.80 ± 0.07 m, with best 100m times of 10.81 ± 0.45 s) and 14 experienced female sprinters (age 22 ± 3 years, body mass 60.7 ± 5.1 kg, body height 1.68 ± 0.06 m, with best 100m times of 12.58 ± 0.58 s), participated in the present study. They were instructed to avoid undertaking any resistance training targeting their lower body in the 48 hours prior to testing. Each participant was informed of the testing procedures and possible risks, and written consent was obtained prior to the study. The study complied with current ethical regulations for research, was approved by the local ethics committee, and conformed to the latest revision of the Declaration of Helsinki.

Procedure

After an individualised warm-up, each participant performed two unresisted 30 m sprints. This was followed by two timed 30 m sprints with 10, 20, 30 and 40% of their body mass (BM) in a random order as active resistance provided by dynaSpeed (Ergotest Technology AS, Langesund, Norway) with 6-10 min pause between each sprint. Sprint times were measured with two pairs of wireless photocells placed at height of 1m (Brower Timing Systems, Draper, UT, USA). Participants initiated each sprint from a standing start in a split stance, with the lead foot behind a line taped on the floor 0.3 m from the first pair of photocells. Speed measurements were recorded continuously during each attempt using a CMP3 distance sensor laser gun (Noptel Oy, Oulu, Finland), sampling at 2.56 KHz. Contact time and flight time were also recorded using an infra-red device covering 35 m, to avoid kinematic adjustments at the end of the 30m sprint, sampling at 500 Hz. All recordings were synchronised with a Musclelab 6000 system (Ergotest Technology AS, Langesund, Norway), allowing measures of velocity, contact and flight time, step length and step frequency to be determined for each step of the 30 m sprint. These parameters were calculated and made available directly after each set of sprints. The step kinematics measured with the present equipment showed comparable accurate and reliable measurements as the Optojump.[5] The fastest attempt for each condition was used for further analysis. To account for the difference in number of steps between the conditions and between genders, kinematic data was averaged for every 6th m of the total distance.

Peak angular velocity of the propulsion movements of the lower limb: plantar flexion, knee extension and hip extension during each stride (one left and right step) was measured, using wireless 9 degrees of freedom inertial measurement units (IMU) integrated with a 3-axis gyroscope. Sampling rate of the gyroscope was 200Hz with maximal measuring range of 2000 degrees/second±3% attached to the dorsal side of right foot, right lateral malleolus, and distal end on the lateral side of the right femur (Ergotest Technology AS, Langesund, Norway). Orientation of each sensor was calculated using a sensor-fusion algorithm; in which angular velocity and acceleration data were combined to minimise the effects of accelerometer noise and gyroscope drift. The recorded waveforms from the IMU for kinematics of the thigh, leg and foot were separated in one-axis, corresponding to the sagittal plane. Only a local reference frame was needed for the analysis, therefore the magnetometer data was not utilised. Cross-over movement from other planes was assumed to be minimal since most recorded movements were around the frontal axis.[15] Previous IMU sprint studies have found that rotational kinematics measures (angular velocity) with IMUs were reliable and valid compared with high speed cameras.[19,20]

Muscle activity was measured by using a wireless electromyography (EMG) with a sampling rate of 1 kHz (Ergotest Innovation, Porsgrunn, Norway) with electrodes (Zynex Neurodiagnostics, CO, USA) on the muscles of the right leg. The skin to which the electrodes was fastened had been shaved and washed with alcohol before fastening the electrodes. The electrodes (11 mm contact diameter and 2 cm centre-to-centre distance) were placed along the presumed direction of the underlying muscle fibres on the lateral and medial vastii, rectus femoris, biceps femoris, semimembranosus, soleus, lateral gastrocnemius, tibialis anterior, gluteus maximus muscles according to the recommendations of SENIAM [21]. The EMG raw signal was amplified by 400 and filtered using a preamplifier located as close as possible to the pickup point with the intention of minimising the noise induced from external sources through the signal cables. The preamplifier had a common mode rejection ratio of 100 dB. The EMG raw signal was then bandpass filtered (fourth-order Butterworth filter) with cut-off frequencies of 20 Hz and 500 Hz. The resulting EMG signals were converted to root mean square (RMS) signals for the contact and flight phases of each step. The highest average RMS during one of the phases during each stride cycle (one left and right step) for each muscle was used for further analysis. All sensors were synchronised using Musclelab version 10.5.69 (Ergotest Innovation, Porsgrunn, Norway), which made it possible to measure and analyse kinematics and muscle activity for each step cycle and stride during the 30-m sprint. Since there was a difference in number of strides between the different loading conditions, the average maximal RMS and peak angular velocities were calculated for each 20% of each sprint (each 6m). To compare EMG activity between gender, EMG normalisation was performed by using the mean of the three peak amplitude contractions for each muscle from the unresisted 30m sprint as normalisation signal for each participant. This has shown to be a reliable, repeatable and sensitive method for normalising of EMG in sprinting.[22,23]

Statistical analysis

Assumption of normality and homoscedasticity of variance were tested with a Shapiro-Wilk and Levene's test. All data was normally distributed and homogeneity of variance. To compare the sprint times for different resisted sprints, a 2 (gender: independent groups) x 5 (unresisted–40% BM resisted sprints) model for analysis of variance (ANOVA) repeated measures was performed. To evaluate the effect of different loaded resisted sprints upon step kinematics, peak angular velocity and EMG, a 2 (gender) x 5 (unresisted–40 BM resisted sprints) x 5 (each 6 m of total 30m sprint distance) ANOVA for each step kinematic and joint velocity variable was used. When the assumption of sphericity was violated, the Greenhouse-Geisser adjustments of the alpha level was reported. When significant differences were found due to training load or gender, a oneway ANOVA per resisted sprint load was also performed. Holm-Bonferroni Post-hoc comparisons were applied to locate the differences for distance of the 30m sprints. The level of significance was set at $p < 0.05$. Analysis was performed with SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Effect size was evaluated with partial eta squared (η_p^2) where $0.01 < \eta_p^2 < 0.06$ constituted a small effect, $0.06 < \eta_p^2 < 0.14$ a medium effect, and $\eta_p^2 > 0.14$ a large effect.[24]

RESULTS

The 30 m times rose significantly with greater percentage of body mass active resistance ($F_{(4,104)} = 584$, $p < 0.001$, $\eta_p^2 = 0.96$) and was significantly longer for women than for men at each load. Running distance ($F_{(4,104)} \geq 21$, $p < 0.001$, $\eta_p^2 \geq 0.59$) and resistance ($F_{(4,104)} \geq 72$, $p < 0.001$, $\eta_p^2 \geq 0.83$) had significant effects for all step kinematics for both genders. Post hoc comparison revealed decreased step velocity, flight time, step frequency and step length and increased contact time with each increasing load (Figure 1).

A gender effect was found for step velocity, step length, step frequency and contact times at all resistances ($F_{(1,26)} \geq 4.8$, $p \leq 0.040$, $\eta_p^2 \geq 0.19$), except for flight time ($F_{(1,26)} = 0.11$, $p = 0.75$, $\eta_p^2 = 0.01$). Furthermore, a significant interaction effect for distance*gender was found for step velocity, step length, and contact time (except for the unresisted condition), for all conditions and flight times at 30% BM conditions ($F_{(4,104)} \geq 2.5$, $p \leq 0.049$, $\eta_p^2 \geq 0.10$). Post-hoc comparisons revealed that flight time, step velocity, length, and frequency decreased significantly and that contact time increased with each load for both genders. However, men reached a higher step velocity, and obtained this later than women in the 30m distance for the different resisted conditions. Furthermore, men had longer step lengths, shorter contact times and higher step frequencies than women. In the development of contact time over the 30m sprint distance both men and women reached the shortest contact times earlier with increasing load, and women showed an increase of contact time again, while men kept minimal contact time at a stable level after reaching it (figure 1). Especially with heavy loads the women showed another development than men for step length and flight time; i.e. women decreased step length the last 6 meters with 30 and 40% BM loads and decreased flight times from 12 to 24 m with 40% BM loads, while men did not show these decreases (Figure 1).

Peak angular velocities of knee extension, hip extension and plantar flexion were all affected by load ($F_{(4,104)} \geq 5.4$, $p \leq 0.01$, $\eta_p^2 \geq 0.33$), distance ($F_{(4,104)} \geq 35.4$, $p < 0.001$, $\eta_p^2 \geq 0.76$), and interaction ($F_{(4,104)} \geq 4.3$, $p < 0.001$, $\eta_p^2 \geq 0.28$). Only a gender effect was found for plantar flexion at 30 and 40% of BM loads ($F_{(1,26)} \geq 5.4$, $p \leq 0.01$, $\eta_p^2 \geq 0.33$). A significant gender*distance interaction effect was found for plantar flexion with 40% BM resistance, knee extension with 30 and 40% BM resistance and hip extension with 20 and 30% BM active resistance ($F_{(4,104)} \geq 3.1$, $p \leq 0.02$, $\eta_p^2 \geq 0.14$). Post hoc comparison revealed that peak angular velocities decreased with increasing load, however not significantly with each load for every joint (Figure 2). Furthermore, peak angular velocity increased from 6 to 12 m in both genders and in men also from 12 to 18 m for plantar flexion and knee extension in the unresisted and low resisted sprints (Figure 2). Men had also higher peak plantar flexion velocity in unresisted and 10% of BM sprints than women. With increasing resisted sprint loads (30-40% BM loads) women decreased peak angular velocity in the different joints, especially the last 6 meters, while in men this decrease was in general not found (Figure 2).

Only a significant effect of load was found for the rectus femoris, and semitendinosus muscles. However, when analyzed per gender also a significant effect of load was found in women for biceps femoris, gastrocnemius and soleus muscles and tibialis anterior in men ($F_{(4,104)} \geq 2.7$, $p \leq 0.042$, $\eta_p^2 \geq 0.22$). Post hoc comparison revealed that in women rectus femoris activity was lower with 10% BM compared with 40% BM and unresisted loads, while for the biceps femoris and semitendinosis significantly lower activity was found with the 40% (only semitendinosis), 30% and 20% BM (only semitendinosis) loads compared with the 10% BM and unresisted loads (Figure 3). Furthermore, in women, the gastrocnemius had significantly lower activity with 30 and 40% BM compared with 10 and 20% BM loads, while the soleus had lower activity in the 40% BM compared with the unresisted condition. In men only significantly higher tibialis anterior activity was observed with the 30% BM condition compared with the 10% and unresisted conditions (Figure 4).

A significant effect of sprint distance was found for the medial vastus, semitendinosus and gastrocnemius ($F_{(4,104)} \geq 4.4$, $p \leq 0.008$, $\eta_p^2 \geq 0.34$). Post hoc comparison revealed that gastrocnemius activity increased only significantly with the 20 and 30 % BM load from 6 to 12m in men and in women with 10% BM load from 12 to 18m and in the unresist condition from 24 to 30m. For the medial vastus a decrease over distance in muscle activity was observed, but mainly in women it reached significance level. In the semitendinosis an increase over distance was observed in women with most loads, while in men activity stayed the same and even decreased in the unresisted condition from 18 to 24m. This was indicated with a significant distance*group effect ($F_{(4,104)} = 7.9$, $p < 0.001$, $\eta_p^2 \geq 0.28$, Figure 3). No other significant interaction effects were found for any of the muscles ($F_{(4,104)} \leq 1.7$, $p \geq 0.19$, $\eta_p^2 \leq 0.31$).

A significant gender effect was found for the medial and lateral vastus and the soleus muscles. Post hoc comparison revealed muscle activity was higher in the women compared with the men but only significance was only reached in the unresisted condition for all three muscles and with the 30% BM load (soleus) and 20% BM (lateral vastus) ($F_{(1,26)} \geq 6.2$, $p \leq 0.020$, $\eta_p^2 \geq 0.21$). When compared per load also a significant gender effect was found in the unresisted condition for the rectus femoris, gluteus maximus, semitendinosis and tibialis anterior with higher muscle activity levels in women than men (Figure 3 and 4).

DISCUSSION

The main findings were that using increasing resisted loads resulted in slower 30m times, as a consequence of lower step velocity mainly caused by shorter step lengths and frequencies, flight times and longer contact times, with a greater effect on women than on men. These step kinematic differences, due to increasing load were accompanied with lower peak joint movements. However, gender differences here were only found for peak plantar flexion with unresisted and 10% BM resisted sprints. Furthermore, load and distance mostly affected EMG activity in women and less in men. Increasing load decreased calf and hamstring muscles activity, while rectus femoris activity increased, but only in women. Additionally, in women semitendinosus and gastrocnemius activity increased during the sprint distance, while it decreased for the medial vastus. For most muscles muscle activity was higher in women than men, but mainly only in the unresisted condition (Figure 3 and 4).

With increasing load, sprint times increased, which were mainly caused by the shorter step lengths, longer contact times and lower step frequency (Figure 1). This was in line with previous studies on resisted sprints [16-18,25]. Times over 30m with active resistance increased from 13 to 74% for men and from 16 to 109% in women, while peak velocity decreased with 48 and 56% (40% BM loads) for respectively men and women. These differences with 40% BM loads are comparable with sled towing studies with 80% BM [26,27] indicating that with active resistance less load is necessary than sled towing to have similar decreases of running velocity. This is important to know when planning training and comparing the acute effects of it.

With increasing active resistance load, peak step velocity occurred earlier during the 30m distance, even more in women than in men after which it decreased later in the distance. This was also visible in the step kinematics and especially in contact times, that decreased with unresisted and 10% resisted load, while it did not decrease with heavy loads and even increased over distance the last 6-12 m of the distance with the heavy BM loads. This resulted in lower step frequencies at the end of the heavy BM loaded sprint distances (Figure 1). These developments of increases in contact times and lower step frequencies over the sprint distance with heavy active loads were also visible in the maximal angular velocities of the joint movements (increased followed by a decrease with heavy active loads) indicated that fatigue occurs. It seems that women experience more fatigue than men with increasing active loads indicated by a rapid increase in contact time and decrease in step frequency on the end of the heavy loaded sprints, while men did not show this development so much (Figure 1). This was also visible in the development of the peak angular velocities, which decreased over the distance in women and not in men (Figure 2). These gender differences could be explained by a lower capacity for women to produce horizontal force at high running velocities.[28] Such a conclusion was consistent with women having a lower leg muscle mass relative to their total body mass and more adipose tissue than men[29] and thereby fatiguing earlier than men. Based upon the development of the step and joint kinematics between men and women it seemed that the 30m times and step and joint kinematics are comparable between genders when men sprinted with 10% more BM active resistance than the women. Only contact times did not follow the same pattern, which increased very much the last metres in women with increasing load, while this was not observed in men (Figure 1).

Peak angular hip extension velocity was much higher in the present study compared with the study of Macadam, et al.[15]. These differences were mainly caused by level of the participants (experienced male sprinters vs. recreational active healthy participants) and running condition (regular sprint track vs. non-motorised treadmill). Peak angular hip and knee extension velocities were comparable between genders, while the peak plantar flexion velocity was higher in men than women with the unresisted and 10% BM resisted sprints indicating that the proximal movements are similarly affected with increasing load, while distal movements were affected more in the women than men. Previous studies [30-33] have demonstrated that women can generate less muscle and tendon force in the calf, exhibit shorter tendon length and smaller cross-sectional area, and demonstrate less tendon stiffness in the lower leg compared with men. Thereby, the calf of women could be more affected and earlier fatigued by increasing load than men as shown by peak angular plantar flexion velocities (Figure 2).

With increasing load, step and joint kinematics changed, while maximal muscle activation did not show much change with increasing load. So did maximal hamstring and calf muscle activity decrease, while maximal rectus femoris activity increased when load increased. However, this was only found significantly in women. An explanation for the decrease in hamstring activity is due to the lower maximal hip and knee extension with increasing loads. The biceps femoris and semitendinosus are mostly active during the late swing phase in which knee extension occurs [34-36]. These two muscles work as antagonists of the quadriceps and their role is to control knee extension during the late swing phase to avoid too much extension and to create a knee flexion moment [36]. When the maximal knee extension decreased with increasing loads it is expected that hamstrings activation also would decrease. This was in accordance with the findings of Slawinski, et al.[37] who found that the hamstrings activation was lower when sprinting on an inclined surface compared to flat surface. When sprinting on an inclined surface the maximal knee extension velocity is less, which asks less activation of the hamstrings.

The calf muscles are most active during the also active during the late swing phase and braking phase during sprinting[37,38] in which the calf muscles are pre active and have to resist dorsal flexion during braking. As with increasing load the sprinter leans more forwards to resist the active resistance, the sprint seems to become more like inclined sprinting. This means that the foot contacts the surface earlier[37], with a lower plantar flexion action and thereby less activity of the calf muscles as shown in the present study. Only the rectus femoris showed increased activity when the active resistance higher. This muscle is both a hip flexor and a knee extensor and thereby one of the prime movers for propulsion during sprint.

Both the gastrocnemius and semitendinosis increased activity during the sprint distance to around 12-18 m with the low loads (unresisted, 10 and 20% BM) which was in accordance of previous studies [18,39] and indicate that during sprint acceleration these muscles are getting more important for propulsion due to the repositioning of the posture more upright during acceleration. However, when the load is too heavy (30 and 40% BM) not much repositioning is possible and thereby no increased muscle activation (Figure 4). The opposite seems to occur with the medial vastus in which activity decreases over the sprinting distance (Figure 3). The other muscles did not show much difference in activation over the distance, which is also in line with the earlier findings on 30 m sprints of van den Tillaar and Gamble[18] with a pulley system.

A gender effect was found in most muscles. However, this effect was mainly found in the unresisted condition in which women had a higher muscle activity than men (Figure 3 and 4). A possible explanation is the normalisation process in which the mean of the three peak amplitude contractions[22] during the unresisted sprint was used as normalisation signal. In general men have less adipose tissue than women and therefore the EMG signal stronger of each peak amplitude, which results in a lower percent of muscle activation during the unresisted sprints compared with women who will have less percent of activation decrease. Furthermore, it seems this normalisation affected EMG activity in women and less in men over the different loads and distance. It is possible, that due to the fact that we used men and women from different performance levels, this could cause different solutions in muscle activation to overcome the different conditions. Thereby showing too much variability in muscle activation to establish differences between the five conditions.

There were some limitations in the present study. Firstly, only step mechanics were specified in contact and flight times with mean muscle activity over these phases, which does not give information over the braking and propulsion phases during stance [40] that could change during sprints with different load and thereby give more information about possible muscle activity changes. It was not possible to identify these phases due to equipment. This made it also difficult to look at timing of the maximal muscle activation as discussed in a review of Howard, et al.[38] on muscle activity in sprinting. In that review it was also shown that none of the reviewed studies investigated the development of muscle activation over the whole sprint distance, but only at a specific point of the whole sprint distances. Moreover, none of these studies investigated the effect of different loads upon muscle activation, which makes the present study very interesting since it gives information about muscle use over the whole 30m distance that could be helpful for trainers to plan resisted sprint training for their athletes. Additionally, only EMG and angular velocity measurements were performed on the right limb and Inter-limb asymmetry in step characteristics and lower-limb kinematics have been observed in trained sprinters.[41] Therefore, assuming symmetry may overlook important information that could influence sprinting performance with and without extra resistance.

Another limitation is that from the used IMUs only maximal angular velocities were available and not joint angles that could give more information about the angles at touch down and toe off and leaning during the sprints with different loadings that could explain the findings more detailed. Therefore, in future studies 3D kinematics, together with kinetics and EMG on both limbs should be included to investigate the effect of different active resisted loads upon joint kinematics, force production and timing of muscle activation in more detail.

CONCLUSION

Increased active loads resulted in slower 30 m times, as a result of a lower step velocity, mainly caused by shorter step lengths and frequencies, flight times and longer contact times. These active loads had a larger effect on women than on men, which were the result of an earlier and slower maximal step velocity, which was mainly caused by longer contact times, shorter step lengths and lower frequencies in women compared to men. Only maximal hamstrings and calf muscle activity was affected with increasing load by a reduction of activation, but mainly in women. Additionally, in women semitendinosus and gastrocnemius activity increased during the sprint distance, while it decreased for the medial vastus. The practical implication for trainers and athletes is that when introducing active resisted sprints, women during training should sprint with approximately 10% less BM loads than men to match the responses of step and joint kinematics development over the sprint distance. Furthermore, muscle activity changes due to load seems to be more sensitive for women than man, and with increasing load less distance should be covered to prevent fatigue, and thereby avoid training more for endurance rather than for acceleration ability. Moreover, trainers should be aware that with resisted loaded sprints hamstrings and calf muscle activation may be reduced.

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Table 1. 30m times (±SD) of the male and female sprinters with the different loads

	unresisted	10% BM load	20% BM load	30% BM load	40% BM load
Men	3.95±0.23	4.57±0.31	5.16±0.46	5.96±0.65	6.99±0.85
Women	4.29±0.14	5.07±0.42	5.91±0.33	7.25±0.50	8.95±0.82

A signficant increase in time was observed with each resistance and 30 m times were signficantly higher in the women at each condition than men on a $p<0.05$ level.
BM = body mass of active resistance

Figure legend

FIGURE 1 Average velocity contact and flight times, step length and frequency (± SEM) per 6 m distances of the 30 m sprint for all resistances for men and women. All step kinematics significantly changed at each sprint condition for both genders.

† indicates a significant difference between men and women for each of the sprint conditions on a $p < 0.05$ level.

+ indicates a significant difference with the previous distance for this sprint condition on a $p < 0.05$ level.

FIGURE 2 Average peak angular velocity of hip extension, knee extension and plantar flexion (± SEM) per 6 m distances of the 30 m sprint for all resistances for men and women.

† indicates a significant difference between men and women for this sprint conditions on a $p < 0.05$ level.

* indicates a significant difference with all other sprint conditions on a $p < 0.05$ level.

‡ indicates a significant difference between these two sprint conditions.

+ indicates a significant difference with the previous distance for this sprint condition on a $p < 0.05$ level.

FIGURE 3 Average peak EMG activity of the quadriceps and hamstring muscles (± SD) per 6 m distances of the 30 m sprint for all resistances for men and women.

† indicates a significant difference between men and women for this sprint conditions on a $p < 0.05$ level.

‡ indicates a significant difference between these two sprint conditions.

+ indicates a significant difference with the previous distance for this sprint condition on a $p < 0.05$ level.

FIGURE 4 Average peak EMG activity of the gastrocnemius, soleus, tibialis anterior and gluteus maximus muscles (± SD) per 6 m distances of the 30 m sprint for all resistances for men and women.

† indicates a significant difference between men and women for this sprint conditions on a $p < 0.05$ level.

‡ indicates a significant difference between these two sprint conditions.

+ indicates a significant difference with the previous distance for this sprint condition on a $p < 0.05$ level.