Ground Reaction Force and Joint Moment Differences When Sprinting on Uphill, Level, and Downhill Slopes

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Summary

Lower-limb joint moments have not yet been investigated during maximum speed sprinting on slopes. Participants sprinted maximally on an uphill, level, and downhill instrumented treadmill. Maximum sprinting speed increased with more negative slopes (downhill > level > uphill), as did peak and average vertical forces (Fz). However, the knee extensor (KE) was the only joint moment which increased with sprinting speed across all gradients. Hip extensor (HE) moments were only different between uphill and downhill sprinting, and plantarflexor (PF) moments did not change. As PF and HE, but not KE, moments usually increase with sprinting speed on level ground, these results likely indicate that increases in speed on downhill slopes are achieved using different mechanisms to level ground.

Introduction

As steady-state running speeds increase, so do ankle PF and HE moments during contact, whereas KE moments increase up to 5 $m.s^{-1}$ before decreasing with further speed increments [1]. By manipulating maximum running speed using uphill and downhill slopes, it has been shown that individuals who attain greater maximum running speeds apply greater Fz during ground contacts [2]. However, it is not known how joint moments contribute to these differences in vertical forces. Therefore, the purpose of this study was to investigate how maximum speed, lower-limb joint moments, and Fz change across uphill, level, and downhill sprinting.

Methods

Twelve physically active participants (7 Male, 5 Female, body mass [mean ± SD] = 74.1 ± 11.7 kg, height = 1.72 ± 0.10 m, age = 20.9 ± 2.1 years), completed maximal speed sprints on a level (0°), uphill (+4°) and downhill (-4°) instrumented treadmill. 3-D kinematics and ground reaction forces were collected at 500 Hz and 2000 Hz respectively for up to 20 steps. A generic musculoskeletal model [3] was employed for further analysis which was scaled to each participant before performing inverse kinematics followed by inverse dynamics to obtain net joint moments of the hip, knee, and ankle during stance. HE, KE, and PF moments were defined as positive. Peak and average Fz were scaled to bodyweight and joint moments were scaled to body mass. All variables were analysed for differences across the three gradients using either a one-way repeated measure ANOVA or a Friedman test with a Bonferroni correction and an alpha level of $p < 0.05$.

Results and Discussion

Across gradients, maximum speed and average Fz demonstrated similar relationships to previous research (Table 1) [2]. As expected, peak and average Fz increased with running speed across the gradients [1] but were accompanied by no significant changes in PF moments, which normally would increase with running speed on level ground [1]. HE moments did increase with speed, but this only reached the alpha threshold between uphill and downhill sprinting. Interestingly, the KEs generated greater peak moments to facilitate faster running speeds. During downhill trials, participants were able to attain higher speeds by using the HEs and KEs to contribute to larger Fz, whereas the PFs contribution did not change.

Conclusions

Whilst maximum speed increases from uphill, level to downhill slopes, the methods adopted to increase steady state speed differ from those used on level ground. KE moments have been shown to decrease with increasing speed on level ground [1] but increased when speed increased due to more negative slopes in this study (Table 1). Future research could analyse the antero-posterior forces, flexor moments at the lower-limb joints, and the positive/negative work performed in extension and flexion at each of the lower-limb joints throughout the whole stride cycle.

References

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Table 1: Maximum speed and kinetic parameters across uphill, level, and downhill sprinting (mean ± SD)

Gradient	Speed ($m.s^{-1}$)	Fz (BW)		Peak Moments ($Nm.kg^{-1}$)		
		Peak	Average	HE	KE	PF
Uphill (+4°)	7.72 ± 1.15†	2.91 ± 0.27†	1.88 ± 0.14†	4.24 ± 0.63†	2.53 ± 0.36†	3.95 ± 0.64
Level (0°)	8.62 ± 1.14*†	3.23 ± 0.29*†	2.01 ± 0.13*†	4.63 ± 0.72	3.04 ± 0.51*†	4.00 ± 0.70
Downhill (-4°)	9.25 ± 1.26	3.75 ± 0.33	2.17 ± 0.15	4.90 ±0.75	3.30 ± 0.52	4.06 ± 0.85

* different from uphill sprinting ($p < 0.05$), † different from downhill sprinting ($p < 0.05$), BW = Normalised to body weight