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Comparison of the propulsive force production capacities between flat acceleration sprinting and uphill running at constant velocity

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1. Introduction

Runner's velocity during uphill running (e.g. trail) is closely tied to runner's capacity to generate propulsive (i.e. tangential to the ground) force. Propulsive force capacities in running have been well described through the linear Force-Velocity (FV) relationship. The latter is characterized by the theoretical maximal force that can be produced at a null velocity (F_0), the theoretical maximal velocity above which no force can be produced (V_0) and the maximal power (P_{max}). Typically, FV relationship can be determined during a single sprint acceleration on flat ground. In this case, the inertia to overcome during the acceleration induces velocity changes (from 0 to maximal velocity) along the sprint and thus, various force production (Rabita et al. 2015, Samozino et al. 2016). FV relationship can also be determined during several resisted sprints on flat ground while focusing on force produced at maximal (constant) velocity. Under these conditions, the additional resistances (i.e. towed sled) across different trials limit the maximal velocity the runner can reach, which corresponds to various points along the FV curve (Cross et al. 2018). The equivalence in FV relationships reported between these two methods (Cross et al. 2018) supports the fact that, on flat ground, the FV relationship during running can be interpreted either as the decrease in the maximal propulsive force when velocity increases or as the decrease of the maximal velocity when the propulsive force to produce increases. Since in the initial phase of sprint running, the overall acceleration acting on the runner's body is similar to the acceleration acting when running at constant velocity up an 'equivalent slope', di Prampero et al. (2005) suggested that uphill running at constant velocity is mechanically analogue to acceleration phases during flat ground sprinting. Delaney et al. (2022) showed that variables of the FV relationship obtained from an acceleration on flat ground are correlated to maximal velocity reached over different slopes. However, this study only covered a narrow range of slopes and velocity conditions and did not

make any direct comparison between force production capacities on flat and uphill terrains. Di Prampero et al.'s (2005) analogy was also indirectly explored in lizard suggesting a decrease in maximal velocity when required force production increases due to increasing slope (Huey and Hertz 1982). Thus, it remains unclear whether propulsive force production capacities in running are similar during acceleration conditions on flat ground and at steady velocity conditions in uphill sections. This study aimed to test the di Prampero et al.'s mechanical analogy between sprint acceleration phases and uphill running at a constant velocity through the comparison of propulsive force capacities produced at the same velocity during uphill/flat and steady state/accelerated running. It was assumed that, regarding the mechanical analogy suggested by di Prampero et al. (2005), force production capacities at any given velocity conditions are equivalent whatever the mechanical conditions, be they imposed by hill gradients or inertia.

2. Methods

Twenty participants (14 men and 6 women; 23.3 ± 2.8 years old; 67.0 ± 8.8 kg; 1.75 ± 0.09 m), free of any recent injury, volunteered to participate in two sessions for flat ground and uphill sprint measurements, respectively. Each session started with a standardized warmup including 10 min moderate velocity running, athletic drills, and progressive sprints. Then, for the flat ground session, each participant performed 3 sprints at maximal intensity. A radar device (ATS Pro II, Stalker, Texas, USA) measured runner's instantaneous velocity during each sprint (46.875 Hz). The velocity-time relationships were fitted with an exponential function to determine, from an inverse dynamics approach applied to the center of mass, the running propulsive (horizontal) FV relationship for each sprint (Samozino et al. 2016). The 3 FV curves were then pooled and the highest forces in each velocity were fitted with a linear function to compute each subject's 'best' FV relationship. The same radar device measured runner's velocity during sprints of the uphill session. This second session comprised five 30-m sprints in slopes of 4, 8, 15, 20 and 28%. Propulsive (i.e. tangential) force production capacities were estimated at maximal (steady) velocity, from the fundamental dynamic principle as $F_p = m \cdot g \cdot \sin(\alpha) + F_{air}$ with m the participant's mass (in kg), g the gravitational constant (9.81 m s^{-2}), α the gradient (rad) and F_{air} the estimated aerodynamical force (Samozino et al. 2016). Propulsive forces at maximal velocity (mean of the last 2s of the sprint) during uphill conditions were compared to propulsive force production capacities at the same velocity obtained from FV

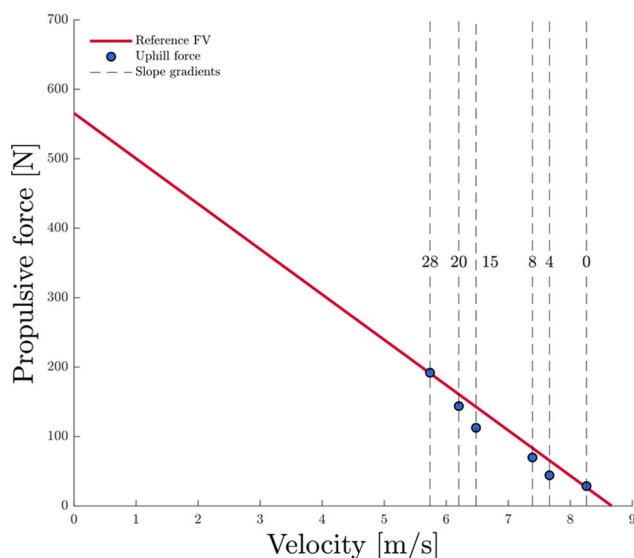


Figure 1. Typical data obtained for flat ground running FV relationship (red line) and force production capacities at maximal velocity reached during uphill running (blue dots).

relationship determined during flat acceleration sprinting, through systematic and random errors and correlation analyses. Results were expressed as mean \pm SD.

3. Results and discussion

Mean FV relationship parameters were $F_0 = 511 \pm 98.1$ N, $V_0 = 7.71 \pm 0.80$ m s⁻¹, and $P_{\max} = 997 \pm 257$ W. FV relationship and force production capacities from uphill sprints are presented in Figure 1 for a typical subject. For all subjects, systematic and random differences between propulsive force capacities predicted from FV relationship (red line) and estimated during uphill sprints (blue dots) were quite low with -16.4 N (17.0%) and 21.2 N (24.4%), respectively, for force values ranging between 15.5 and 224 N. The correlation between the predicted force capacities from the flat ground FV relationship and estimated in uphill running was very high ($r = 0.95$, regression curve: $y = -0.91x - 6.46$). These results evidenced that propulsive force production capacities are equivalent when compared at the same running velocity between flat sprinting acceleration and constant velocity uphill running (i.e. be they imposed by inertia on flat ground or slope during uphill running). The slight lower force capacities observed for uphill sprints (17.0%) may be explained by a potential small fatigue effect due to the repeated bouts or by potential differences in running biomechanics between the two running conditions. A similar shift was reported for the comparison between unique sprint and multiple sled towing sprints FV relationships (Cross et al. 2018). Associated to previous findings (Cross et al. 2018), present results support that propulsive force production capacities during running are

very similar whatever the running mechanical conditions (inertia, resistance, hill gradients), provided they are compared at the same velocity. This offers new insights in trail runners' evaluation since the force capacities evaluated on a flat track appear to be representative of those encountered for equivalent slopes. The FV relationship obtained during a single 30-m flat accelerated sprint can thus also describe the maximal velocity a trail runner can reach in various slopes (with slope = $\arcsin(F/(mg))$, in $^\circ$).

4. Conclusions

This study showed the similarity in propulsive force production capacities between acceleration phases on flat ground and constant velocity running uphill, supporting di Prampero et al.'s (2005) analogy. This finding offers a new perspective on assessing force production capacities in trail runners, as flat ground results can be extended to uphill mountain terrains, as long as the mechanical conditions are equivalent.

Acknowledgements

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KEYWORDS Sprint; force; velocity; uphill; trail

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