A SIMPLE METHOD TO MEASURE EXTERNAL FORCE, POWER OUTPUT AND EFFECTIVENESS OF FORCE APPLICATION DURING SPRINT ACCELERATION

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The aim of this applied session was to introduce and show a recently validated simple field method to determine individual force, velocity, power output properties and effectiveness of force application onto the ground during a sprint running acceleration. This method requires the use of a radar device (or several timing gates), and models the horizontal, vertical and resultant force an athlete develops over sprint acceleration using a macroscopic inverse dynamic approach. Low differences in comparison to force plate data support the validity of this simple method to determine force-velocity relationship and maximal power output, as well as the index of effectiveness of force application onto the ground. Its validity and ease of use make it an interesting tool for sprint training and performance optimization, in a specific field context of practice.

KEY WORDS: acceleration, power output, ground reaction force, mechanical effectiveness.

INTRODUCTION: Sprint running is a key factor of performance in many sport activities (track and field events, soccer, rugby, etc.). Sprint performance implies large forward acceleration, which is directly depending on the capacity to develop and apply high amounts of horizontal external force onto the ground at various speeds over the sprint acceleration (Morin et al., 2011). The overall capability of athletes to produce external horizontal force during sprint acceleration is very well described by the linear force-velocity (F-V) relationship (Morin et al., 2012; Rabita et al., 2015). This macroscopic relationship describes the mechanical limits of the entire neuromuscular system during sprint propulsion and is well summarized through the maximal force (F_0) and velocity (V_0) this system can develop, and the associated maximal power output (P_{max}). Furthermore, the slope of the F-V relationship determines the individual F-V mechanical profile, i.e. the ratio between force and velocity qualities, which has recently been shown to determine explosive performances, independently from the influence of P_{max} (Samozino et al., 2012). These parameters are a complex integration of numerous individual muscle mechanical properties, morphological and neural factors affecting the total external force developed by sprinters lower limbs, but also of the technical ability to apply/orient the external force effectively onto the ground (Morin et al. 2011, 2012). Consequently, determining individual F-V characteristics and P_{max} specifically during sprint propulsion is of great interest for coaches and sport practitioners, and could be an objective functional assessment of muscular capability for sprint acceleration, in both training and injury management context. However, such evaluations hitherto required to test athletes on motorized instrumented sprint treadmills measuring force, velocity and power output very accurately, or to use track-imbedded force plates and complex experimental design (Morin et al. 2012; Rabita et al., 2015). This technical limitation made such measurements impossible to most scientists and sport practitioners. A simple method that accurately measures the main external mechanical outputs of sprint acceleration (F-V relationships, P_{max} and effectiveness of force application) in field conditions could therefore be interesting and useful to generalize such evaluations for training or scientific purposes. Such a simple method has been recently presented and validated against reference force plate measurements (Samozino et al., 2015), and the aim of this applied session was to show how to use this method, from data collection to data processing and results interpretation.

METHODS: The method presented requires completing a single all-out sprint starting from a null velocity position (starting-blocks or standing crouched position, depending on subjects' preference and specialization). The sprint distance must be long enough to allow for maximal or almost (>95%) maximal running speed to be reached. This distance depends on subjects skills and ranges approximately from 30 to 60 m. In the applied session, a 40-m distance was used. Running speed was measured with a radar device (Stalker ATS pro II, RadarSales, Minneapolis, USA) at a sampling frequency of 47 Hz (Figure 1). During such a running acceleration, the velocity-time curve has been shown to consistently follow a mono-exponential function: $V(t) = V_{\max}.(1-e^{(-t/tau)})$, with $V_{\max}$ the maximal velocity reached and *tau* the acceleration time constant. For more accuracy in V(t) derivation, the radar curve was fitted with such an exponential function using the least square regression method. Then, the horizontal acceleration (a) of the body center of mass as a function of time can then be expressed after derivation of V(t) over time as: $a(t) = (V_{\max}/t).e^{(-t/tau)})$. The net horizontal external force (F_H) was then modeled over time as: $F_H(t) = m.a(t) + Fair$, with Fair the aerodynamic friction force to overcome during sprint running computed from running velocity and an estimation of runner's frontal area and drag coefficient (Arsac et al., 2002).

In the vertical direction, during such an acceleration, the runner's body center of mass position goes up from the starting position to the standing running position, and then does not change from one complete step cycle to another. Since this initial upward movement is overall smoothed through a relative long time/distance (~40 m, Cavagna et al., 1971), we considered that the mean net vertical acceleration of the CM over each step was almost null throughout the sprint acceleration phase. Consequently, applying the fundamental laws of dynamics in the vertical direction, the mean net vertical GRF (F_V) applied to the runner's center of mass over each complete step can be modeled over time as equal to body weight: $Fv(t) = mg$, where g is the gravitational acceleration (9.81 $m.s^{-2}$).

Morin et al. (2011) proposed that the technical ability of force application during running acceleration could be quantified over each support phase or step cycle by the ratio (*RF* in %) of F_H to the corresponding total resultant GRF (F_{RES}, in N), and over the entire acceleration phase by the slope of the linear decrease in *RF* when velocity increases (D_{RF}, see Morin et al. 2011 and Rabita et al. 2015): $RF = (F_H/F_{RES}).100 = F_H/[(F_H^2+F_V^2)^{0.5}].100$.

For more accuracy (linear decrease in *RF* as speed increases, after the initial rise in center of mass position during the first few steps), D_{RF} was computed from F_H and F_V values modeled for t > 0.3 s.

Last, mechanical power output in the horizontal direction (P) was computed as $P(t) = F_H(t).V(t)$, and from these force-, velocity- and power-time expressions, we determined the linear F-V and second degree polynomial P-V relationships, and compute F_0, V_0 and $P_{\max}$ for the subjects tested.

DISCUSSION: The main advantage of the method presented during this applied session is that it makes possible to accurately measure the main macroscopic output of sprint running performance from a few input variables that are pretty simple to obtain in field conditions of practice. This method makes possible to estimate GRFs in the sagittal plane of motion during one single sprint running acceleration from anthropometric (body mass and stature) and spatiotemporal (split times or instantaneous running velocity) data. Furthermore, this model can then be used as a simple method to determine the F-V and P-V relationships and the associated variables, as well as the mechanical effectiveness of force application parameters (*RF* and D_{RF}). The concurrent validity and the reliability of this method have been clearly demonstrated by a direct comparison to track-imbedded force plate measurements (for full details, see Samozino et al., 2015), and the devices required are pretty cheap and easy to use compared to the only existing alternative, i.e. track-embedded force plates. In addition, to date no data has been published on direct measurements of ground reaction forces over 40-m sprints. Such data have only recently been approached using a multiple sprint study design (Rabita et al., 2015).

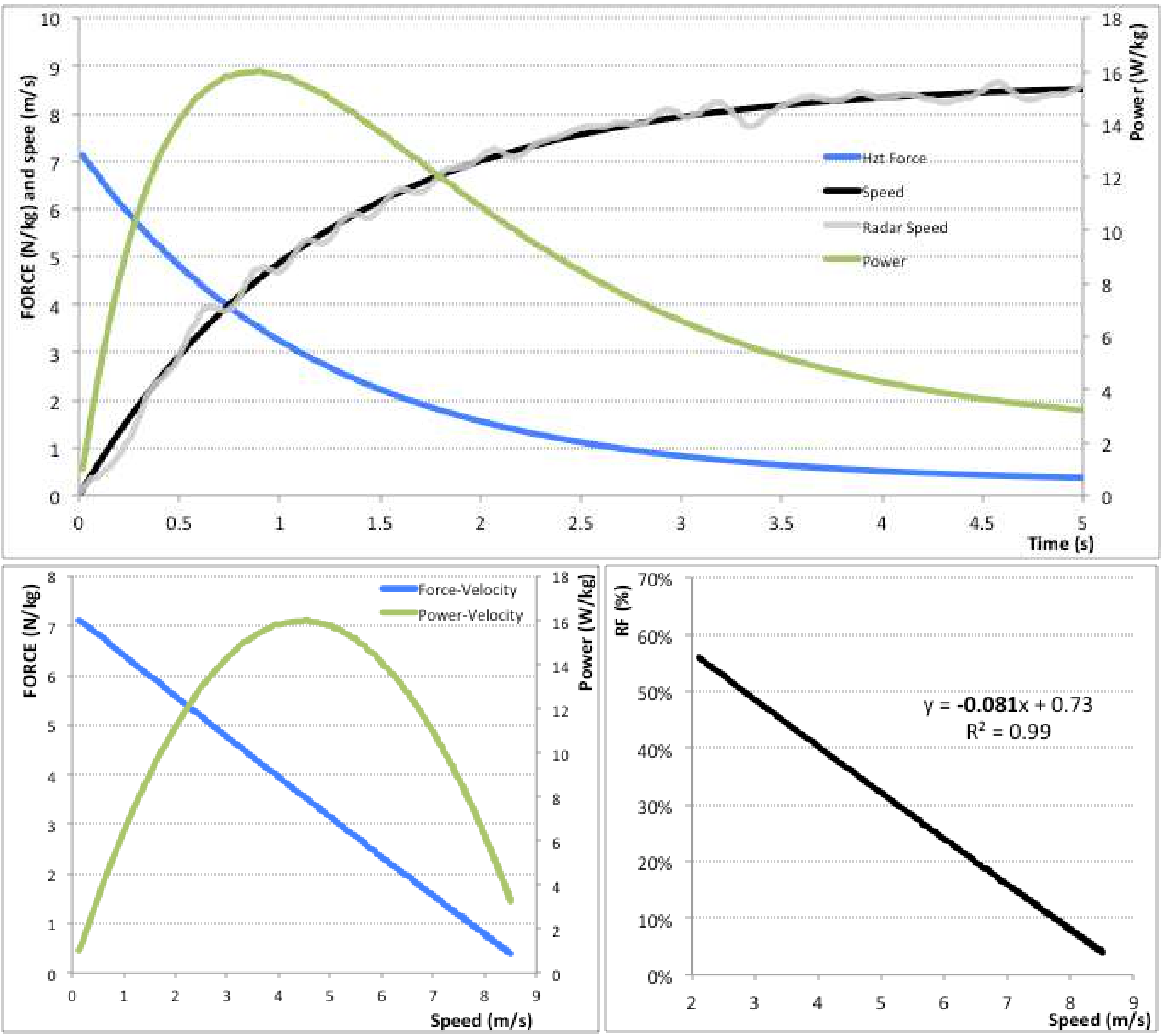

Figure 1: Typical computations using the method presented (data for a 20 years old physically active subject, 72 kg, not sprint specialist). The instantaneous running speed was measured with a radar device (47 Hz, upper panel, grey trace) from start to maximal speed. Then, the speed-time curve was modeled with a mono-exponential equation (upper panel, black trace), and instantaneous horizontal net ground reaction force (upper panel, blue trace) and corresponding mechanical power (upper panel, green trace) were computed. The lower left panel shows the force-velocity (blue trace) and power-velocity (green trace) relationships. The lower right panel shows the linear decrease in the ratio of force with increasing speed. The D_{RF} for this individual is -0.081.

Although it allows computation of variables that were hitherto impossible to obtain in such conditions (i.e. sprint acceleration mechanical outputs and effectiveness of ground force application over an entire sprint acceleration), this method has limitations. For instance, it does not consider the inter-step variability, or other important variables such as ground impulse of rate of force development. Furthermore, it does not help better understand the determinants of F_0, V_0 and other integrative variables described. Therefore, further research is needed to go further into the details of the important features of these F-V and P-V profiles in sprinting, with potential improvements of performance (through training) and injury prevention (through a more accurate understanding of the mechanical key features of the acceleration capability).

In conclusion, the simple field method presented in this applied session allows sport scientists and practitioners to accurately measure the main sprint acceleration mechanical outputs, draw and explore the force-velocity and power-velocity relationships, and investigate the effectiveness of force application onto the ground. This might have direct applications in the field of performance analysis, training, rehabilitation and injury prevention, in all the sports that include sprint accelerations.

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