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INVITED COMMENTARY

# The Force–Velocity Profiling Concept for Sprint Running Is a Dead End

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***Purpose****:* In this commentary, I present arguments against the use of the force–velocity profiling concept in design and adaptations of training programs targeting sprinting. The purpose of this commentary is to make sports practitioners more aware of the rationale behind the concept and explain why it does not work. ***Rationale****:* Force–velocity profiling is a mathematical way to present the velocity development during sprint behavior. Some details of this behavior may be accentuated by transforming it to other variables, but it does not add any new information about sprint performance. Thus, contrary to what is often claimed, the force–velocity profile does not represent maximal capacities (ability of force and velocity generation) of the athlete. It is claimed that through force–velocity profiling one may identify the optimal ratio of force and velocity capacities. Furthermore, proponents of the force–velocity profiling concept suggest that through directed training force and velocity capacities can be altered (inversely dependent) to obtain this optimal ratio, without changing the capacity to express power. Fundamentally, this idea is unfounded and implausible. ***Conclusion****:* At best, force–velocity profiling may be able to identify between-athletes differences. However, these can be more easily deduced directly from performance time traces.

***Keywords****:* ballistic movements, athletics, biomechanics

Over about the last 2 decades, the concept of force–velocity profiling has been developed and promoted with the aim of providing practitioners with an evaluation tool to individually guide and modify training for explosive movements,[1] including accelerated sprinting.[2,3] Without doubt, the introduction of accurate force measurements in combination with kinematics of accelerated sprinting[4] has contributed considerably to the understanding of accelerated sprint running.[5] This has also made it possible to apply—or misapply—the force–velocity profiling concept to sprinting. In this commentary, I will explain this concept and discuss some important issues that occur when force–velocity profiling is applied to accelerated sprinting for the purpose of guiding training modifications.

## Force–Velocity Profiling for Accelerated Sprinting

Recently, Samozino et al[2] extensively described and investigated the use of force–velocity profiling as a method for guiding training for sprint performance. While I use this paper as the main reference for this commentary, the central point of this commentary is a reflection about the concept of force–velocity profiling.

For accelerated sprinting, the entire force–velocity concept is based on the commonly accepted and verified notion that in human motion force and velocity are inversely related. This is usually described by a negatively sloped (curvi-)linear force–velocity relationship of motion. The classic Hill's force–velocity relationship for isolated skeletal muscle is one of the contributors (causes), but also other factors in the neuromusculoskeletal system play a role (eg, muscles' length-force and force-activation dynamics, the resulting rate of force-development, neural aspects, coordination, technique). This rationale is also used in the force–velocity profiling concept in accelerated sprinting.[3] In accelerated sprinting from the stillstanding, or crouch start at each consecutive step, the generated propulsive force reduces while velocity (of center of mass) increases. Based on Newton's laws the propulsive force is directly related to the acceleration of the center of mass. Thus, the description of the time trace of center of mass velocity entails in principle all information to deduce the (behavioral) relationship between propulsive force and velocity of the center of mass that evolves during sprinting. It must be noted that such a relationship may depend (in part) on the intrinsic force–velocity properties of the musculoskeletal system, yet, these relationships are not one and the same as clearly shown in the case of vertical jumping.[6]

The velocity time characteristic is very well described by an exponential curve, about which there is large consensus. One may find different versions of this equation in the literature, but the basic form[2,7] is:

$$v(t) = v_{\max}\left(1 - e^{-t/\tau}\right). \tag{1}$$

$v(t)$ is time dependent velocity, $v_{\max}$ is the maximal velocity obtained, $\tau$ is the time constant that defines how, relative to $v_{\max}$, velocity changes in time. Thus, $\tau$ relates closely to acceleration; thereby, to propulsive force. Rearranging this equation, one may obtain a maximal force ($F_o$) that potentially can be generated at zero velocity and the theoretical maximal velocity ($v_o$) at zero force generation.[2] These 2 parameters form the basis of the so-called force–velocity profile ($S_{Fv}$):

$$S_{Fv} = -\frac{F_o}{v_o}. \tag{2}$$

The product $F_o \cdot v_o = P_o$ is a measure for the power capacity of the athlete.

In theory, there is an optimum $S_{Fv}$ value, that is, a $F_o/v_o$ ratio for a given $P$, that leads to the best sprinting performance for

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different distances (in Samozino et al[2] tested for 5–30 m). Of course, if one enhances $P_o$, one also will improve, but this is neither what is discussed here, nor the essence of the $S_{Fv}$ concept. A deviation of the athlete's $S_{Fv}$ from this optimum is referred to as a force–velocity imbalance.[2] It is argued that this may be useful information for the coach and athlete and that it allows for personalized training modification to optimize $S_{Fv}$, that is, change the slope of the force–velocity capacity curve and thus, performance.

Samozino et al[2] recorded accelerated sprinting performance of many athletes from different sports. Even though these may not be the world's best athletes, they can be regarded as well-trained experts in their sports. In the Samozino et al[2] paper, a figure is provided where all athletes' $S_{Fv}$s are compared with an optimal profile. The key findings are shown in Figure 1. It appears that athletes perform (close to) optimally at 10- to 15-m distance sprints. Small differences between sports-training backgrounds seem to be present, yet the overlap between groups is major. For shorter (<10 m) and longer (>15 m) distances, a deficit is present, that is, the athletes' $S_{Fv}$ is not optimal. Above 20-m distance, no athlete reaches the optimal $S_{Fv}$, that is, all have a velocity deficit. Hence, for accelerated sprinting more than 15 m, almost all athletes would be advised to modify training toward "velocity" oriented.

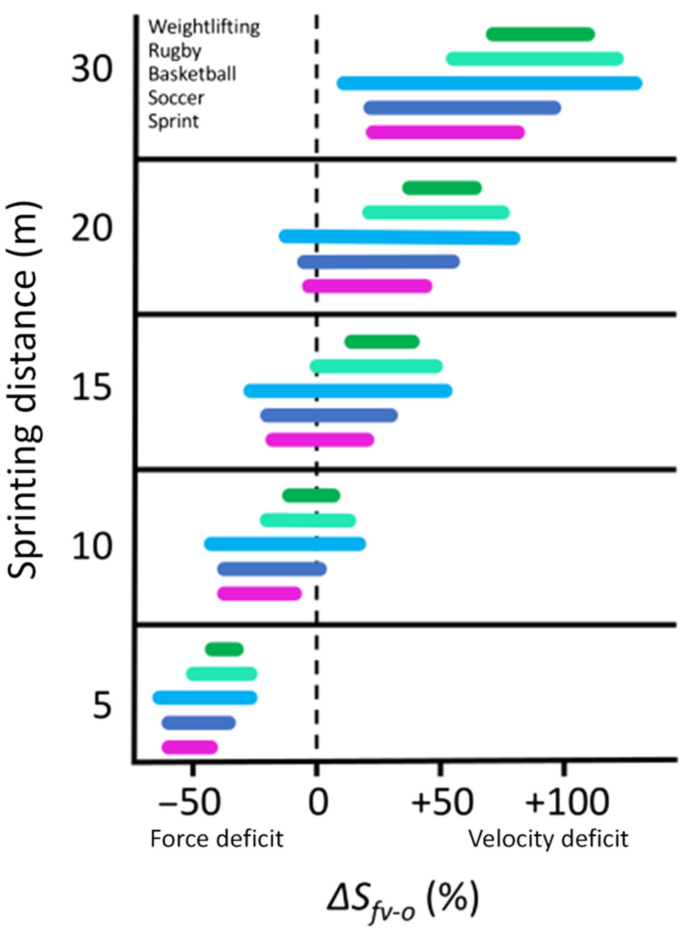


**Figure 1** — Force–velocity profiles ($S_{Fv}$) relative to the theoretical optimal profile for sprint distance and sport background. The bars indicate the 100% range in which all individual athletes appear. The vertical dashed line indicates zero deviation from optimal $S_{Fv}$. Note that the absolute optimal $S_{Fv}$ (in N·s·m$^{-1}$) corresponding to 0 $\Delta S_{Fv\text{-}o}$ (%) depends on distance. Modified from Figure 4 of Samozino et al.[2]

The reader should be aware that an athlete has only one $S_{Fv}$, and the optimal $S_{Fv}$ will change with sprinting distance (ie, the 0% line in Figure 1 does not refer to one constant $S_{Fv}$).

## Challenges of the Concept

1. Does the force–velocity profile describe the athlete's capacity or behavior?

This question is important for understanding what to target when modifying training guided by $F$–$v$ profiling. In the $S_{Fv}$ concept, $F_o$ and $v_o$ and $S_{Fv}$ are depicted as capacity descriptors,[2] that is, characteristics of the underlying systems that lead to performance behavior, not behavioral characteristics. For vertical jumping, this appears not to be the case, and moreover, the force–velocity characteristics are task dependent.[6] In other words, each task will result in a different $S_{Fv}$ for one and the same athlete. Furthermore, in the sprinting application, the $S_{Fv}$ derivation is based purely on behavioral performance (sprinting) data and not on other independent tasks. It definitively is not based on theory about the properties and behavior of the underlying structures that make up the neuromusculoskeletal system, unlike as done in, for example, Lin and Pandy.[8] Moreover, force–velocity profiling ignores the vertical component, which is the largest component of the generated ground reaction force.[9] The $S_{Fv}$ that is obtained from the transformation of horizontal velocity time traces and thus, definitively not a representative of the complete performance profile of the neuromusculoskeletal system. Arguing that the concept is based on a holistic, macroscopic approach[2] does not help, it does not clarify what specifically to target in training for capacity optimization (eg, pure muscle strength/velocity, technique, or something else).

2. Does the practitioner need an—alleged—description of the force–velocity capacity?

The force–velocity profile is simply a mathematical rearrangement of the time–velocity relationship, which can easily be plotted to provide all information required to guide training. So, the question arises: why rearrange? In $F$–$v$ profiling, the rationale is that the rearrangement results in variables ($F_o$ and $v_o$) that are easier to understand and/or interpret for the practitioner, that is, that it provides insight that cannot be obtained before this rearrangement. Yet, any practitioner can determine from the velocity–time trace how quickly velocity develops (as quantified by $\tau$) and how high it becomes ($v_{max}$; see Figure 2A). Additionally, a reference curve can be easily added to a plot of the velocity–time curve (analog to the optimal $S_{Fv}$ 0% line in Figure 1, see, eg, Healy et al[10]). The visual analysis of the time traces will be more direct and far easier to interpret than any "one-number-quantification," for example, the $\tau$ value, which is, as mentioned, related to but not the same as acceleration and force. Rearranging information does not create new information but may still be useful. For example, the differences in initial acceleration (or force)—simply the slope of the velocity time trace—are badly shown in the velocity time trace (see Figure 2A). Indeed, by transforming signals, small, yet important details become more visible[11] (compare Figure 2A and 2B). Having made such transformations, the practitioner can evaluate all relevant information, there is no need for further abstraction. In the $F$–$v$ profile (Figure 2D), the time aspect of the performance behavior has been removed, making the information more abstract, harder to grasp. Please note, revisiting challenge 1, this curve is the relationship between generated propulsive force and the athlete's

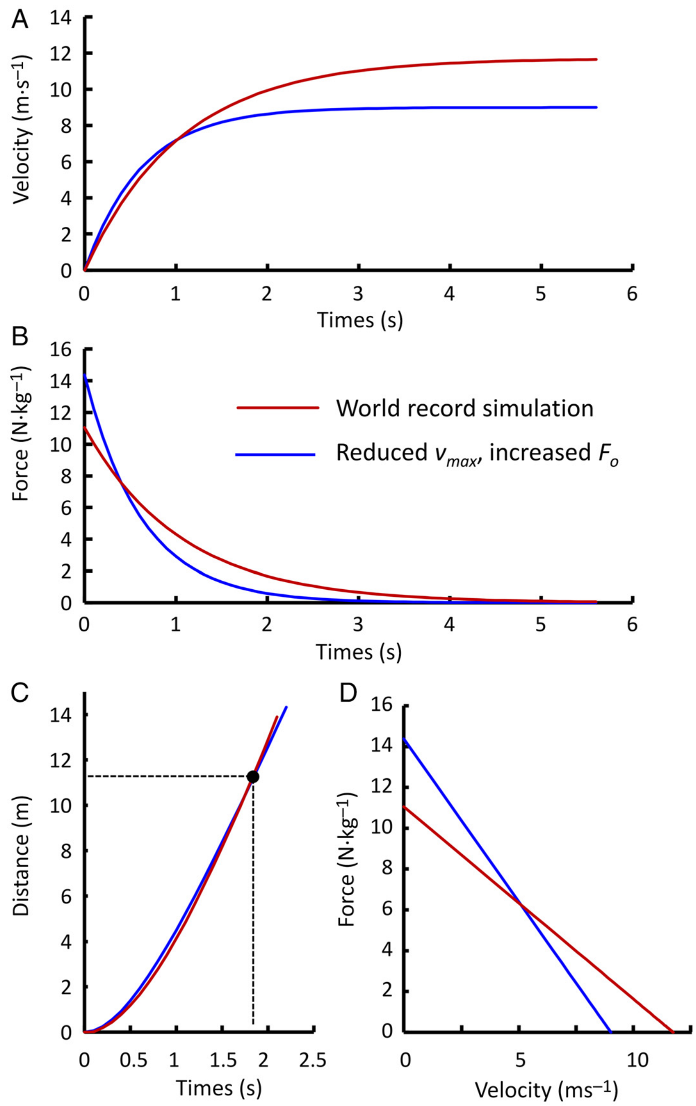


**Figure 2** — Simulation of time profile of the 100-m-sprint world record compared with reduced $v_{\max}$ and increased $F_o$, unaltered $P_o$. The world record simulation is based on reported $v_{\max}$,[8] $\tau$ calculated on the requirement that at 9.58 seconds distance equals 100 m. (A) Velocity against time, (B) force (normalized for body mass) against time, (C) distance against time, and (D) (mass normalized) force–velocity profile. The black dot indicates equal performance for the 2 simulations.

velocity while sprinting, and not analog a Hill like force–velocity curve of muscle or the athlete's "engine."

3. Is the optimal $S_{Fv}$ a relevant measure for training intervention?

The force–velocity profile for 2 simulated performances with equal $P_o$ but different force–velocity profiles are presented in Figure 2D. I argued that this way of presenting the performance information is not needed. The $S_{Fv}$ (when compared with the optimum value) provides no relevant information. This is clarified by considering data in Figure 1, where irrespective of sports and training background, a well-trained athlete is optimally designed for 10- to 15-m sprints. Not by chance, a similar break-even distance is found in my simulations in Figure 2. Even specialized track-and-field sprinters appear to be "too slow" in their specialism after about 15 m. One wonders what the gold standard reference of a force–velocity profile is based on. The experimental data (Figure 1) indicate that whatever the $S_{Fv}$, but within reasonable limits, an athlete is optimized for a 10- to 15-m sprint distance. I examined this notion further by using Equation 1 and the highest $v_{\max}$ during the world elite 100-m sprints from a data set including the world record,[10] and setting distance at 100 m at the world record time 9.58 seconds. Applying the $S_{Fv}$ concept, performance can only be improved by increasing $v_o$ (reducing $F_o$). Figure 2 shows the opposite profile adaptation: the athlete deviates from the world record at about 11 m, after nearly 2 seconds into the race (Figure 2C). Who knows, Usain Bolt may have solved the conundrum; anecdotally, he was known to be a bit of a "slow starter" with extreme top velocity. The main message is that the optimal $S_{Fv}$ for a distance outside the 10 to 15 m range must be regarded as a "Utopic" for athletes. If even the best 100-m sprinters in track and field were to be defined as "imbalanced," "too slow" after ~15 m, and even the strongest are "not forceful enough" up to ~10 m, something must be off with the benchmark rather than the athlete. The claim that the concept applies to sprint distances up to 30 m (Samozino et al[2]) must be reappraised because the profile only applies to sprint distances of about 10 to 15 m (a serendipitous, not scientific outcome—see challenge 4).

4. Can we change the $F_o$–$v_o$ ratio independent of change in $P_o$?

Only if the $S_{Fv}$ can be changed independently of any change in $P_o$, that is, $F_o$ and $v_o$ can be changed inversely by adapting training, the $S_{Fv}$ can be of relevance on its own account. Of course, one can change the $F_o/v_o$ ratio by enhancing either $F_o$ or $v_o$. In such cases, the real target is not to change the ratio itself but the performance capacity of the athlete (expressed in $P_o$). However, in the $S_{Fv}$ concept, the key idea is that changing the ratio by itself is beneficial[2]: I cite "Or could a change in its slope (ie, an increase or decrease in $S_{Fv}$) independently from its overall position also contribute to performance improvement?"[2] ("its" refers to the force–velocity relationship; "position" to $P_o$). Unlike force and velocity during behavior (performance), these 2 parameters describing the capacity of the athlete are physiologically independent of each other, they cannot be exchanged by training, for example, increasing $F_o$ at a physiologically linked cost of decreasing $v_o$. (eg, at the muscular level, $F_o$ is related to physiological cross-sectional area, $v_o$ to fiber type and length.) This implausible notion that one can exchange the force and velocity capacities is embedded and implied in the $S_{Fv}$ concept. Finding the reference optimal $S_{Fv}$ by modeling is done in this way, a nice academic exercise but pointless for practice if the athlete cannot do the same thing. Suggesting that the $S_{Fv}$ by itself is of practical importance implies the belief in that it can be modified independently of changing $P_o$. Otherwise, any $S_{Fv}$ change is a mere mathematical by-product of enhancing $P_o$, a notion I advocate.

The term "imbalance" suggests that an—apparent—underperformance is not necessarily due to a deficit in one of the capacities ($F_o$ or $v_o$) but because the ratio of these 2 is out of order, as if an athlete can be too forceful for her velocity or too fast for his might. Changing the $S_{Fv}$ (independently of $P_o$) would be like changing the internal "gear" of the athlete's "engine." Unfortunately, or maybe fortunately, unlike gearing in cycling, humans only have one internal gear.

In team sports, athletes are not sprint specialists for one particular distance they rather need to be able to sprint over a relatively large range of distances. Oddly, the $S_{Fv}$ concept suggests that if we were able to optimize the $S_{Fv}$ (at constant $P_o$) and improve performance for one sprinting distance, performance will decline at any other distance. Please, note that this idea of changing $S_{Fv}$ independently of $P_o$ is something else than the "24/7" challenge: Every hour used on improving $v_o$ is not used on improving $F_o$ and vice versa. The consequences on spending less training on one aspect in favor of another are not part of the $S_{Fv}$ concept.

Recently, the $S_{Fv}$ concept was critically investigated regarding vertical jumping, and found to be of little value.[6] In my view, the same applies to accelerated sprinting. It reminds me of the Jewelry salesman Rufus in the movie "Love Actually" having a Christmas present wrapped for an impatient and anxious client Harry, evidently with all best intention to make it a better present: Rufus: "Oh this isn't a bag, sir." [Harry: "Really?"] Rufus: "This is SO much more than a bag . . . ." I'm afraid I must agree with Harry, it's just a bag. In fact, in the case of force–velocity profiling it is worse: It is a wrapping suggesting a present inside that simply is not there.

## Practical Implication

An athlete may well be found too slow or too weak for a certain sprinting distance. Obviously, it makes sense to focus on enhancing attributes that are below the required capacity. This may also imply some sacrificing of attributes that are well in order. However, this is, unlike the $S_{Fv}$ implies, not a necessity and may be avoided.

## Conclusion

Because the practical inference of force–velocity profiling is based on implausible assumptions, when applied to accelerated sprinting, it is a dead end. At best, it may be able to identify between-athletes differences. However, these can be deduced more easily from performance time traces.

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