The Force-Velocity Mechanical Profile in Sprint Running: Perspectives in Hamstring Muscle Injury Follow-Up and Prevention

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ABSTRACT

Hamstring muscle injuries - the main type of injury related to athletics and other sports involving acceleration and sprints – can have substantial negative consequences for the affected athletes. Increased knowledge of the risk factors and mechanisms of these lesions based on a better understanding of the biomechanical and muscular determinants of performance in sprinting would, of course, be of great value. Studies have reported a change in the Force-velocity profile (F-v profile) and a decrease in maximum theoretical horizontal force (F_{H0}) following hamstring injury that could be a consequence of the injury. Collection of data related to the mechanical properties of sprinting, including the F-v profile, F_{H0} and maximum theoretical velocity (V_0), is possible in real-practice conditions using simple and easily available tools. Analysing the hamstring propulsion function in a maximum acceleration sprint looks promising and, in particular, F-v profile evaluation could be used to screen athletes at risk of hamstring muscle injury and to guide the return to maximum velocity sprinting after a hamstring muscle injury.

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Introduction

Injuries to the hamstring muscles are the main class of injury related to the practice of athletics[1-5]. From 2007 to 2015 hamstring injuries accounted for 17% of all injuries recorded in major international competitions[4]; in three recent editions of the annual Penn Relays Carnival in the USA, which had a total of 48,473 participants, they were 24% of all injuries recorded[5], and other studies have reported that between 5% and 50% of all injuries suffered by athletes over the course of a whole athletics season are to the hamstring muscles[6-12].

Hamstring injuries lead to important consequences for the athletes involved, including time loss from training and competition, risk of re-injury and persistent pain. As athletes normally require 100% recovery from such an injury for a full return to sport, one study has shown that of all the injuries sustained in major international competitions those to the hamstring cause the longest estimated time loss[4] while other studies have shown that the time-loss from competition can range from four to 140 days[13-15]. In addition, the risk of re-injury has been shown to be about 14%[14].

The prevalence and consequences of hamstring injuries makes it important for coaches and medical practitioners to find ways to reduce their incidence and or severity. An improved knowledge of the risk factors and mechanisms involved is highly relevant for screening athletes at risk and for the development of prevention measures[16]. It is also valuable for improving recovery management. Given the very close links between sprinting and hamstring injuries, a better understanding of the biomechanical and muscular determinants of sprint performance could be relevant for better understanding of the mechanisms and/or risk factors of this injury[17,18].

In this article we discuss the role of the hamstring muscles in sprinting before examining the Force-velocity mechanical profile (F-v profile) and how it applies to the context of hamstring injuries. The aim is to identify a means to screen athletes at risk of hamstring injury and to help manage the return full training and competition.

The Role of the Hamstring Muscles

Sprinting is an explosive activity and the ability to develop great power in the horizontal direction is often presented as a determinant of sprint performance[19]. Developing power is directly related to the muscle's ability to produce high levels of force at high velocity and, in the case of sprinting, the ability to effectively orient this force onto the ground, i.e. in the horizontal direction[20]. Indeed, it has been reported that the ability to correctly orient the force on the ground as running velocity increases, quantified by the change in the ratio between the horizontal component of the force and the total force developed when the running velocity increases (D_{RF}), is a decisive factor in sprinting performance - more important than the total force developed itself[20,21](see Figure 1).

It is clear, therefore, that learning to correctly orient the force on the ground as running velocity increases must be a training objective for sprinters[20,21]. This will help them to improve the ability to produce high net horizontal force at high running velocity, represented in the force-velocity relationship by the theoretical maximum velocity (V_0, discussed below), which corresponds to a key element of sprint performance[22].

Understanding the role of the hamstring muscles in the sprinting movement in general and the production of power specifically is relevant for the prevention of injuries. Hamstring muscles, due to their bi-articular nature, act as an hip extensor and as a knee flexor[23]. During a sprint stride, the hamstring muscles are activated continuously, but they are particularly active during the terminal part of the swing phase and the ground support phase[23-26]. A recent study reported that the eccentric peak torque associated with the muscle activity of the late part in the swing phase is correlated with horizontal force production, and consequently

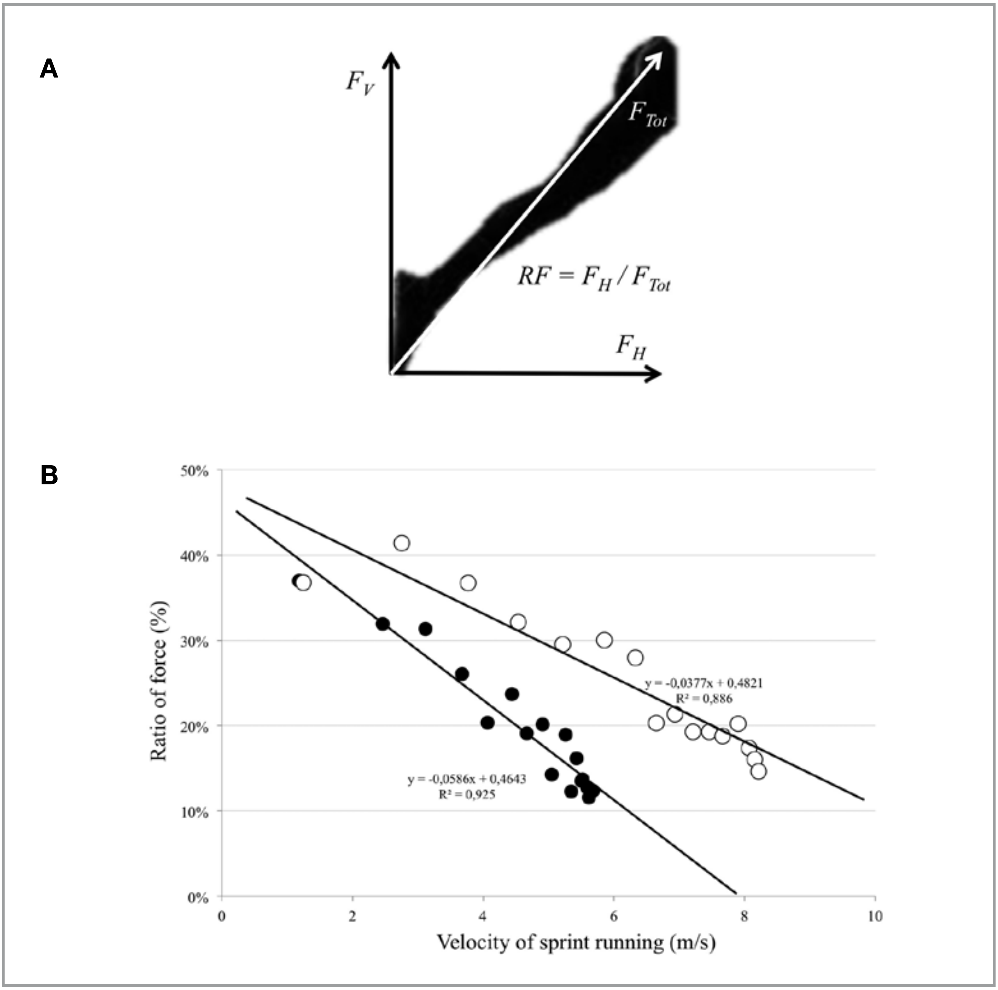

Figure 1: Index of force application technique (D_{RF}): the ability to produce high levels of force despite the increase in running speed is a determining factor in the sprint performance. (A: Schematic representation of the ratio of forces between the vertical ground force that can resist gravity and horizontal ground force that is effective for sprint performance. B: Graphic representation of the change in the ratio between the horizontal and vertical component of the ground force when the speed increases; the more the subject is able to maintain a significant horizontal force despite increasing speed, the more powerful in sprint.)

with the sprint acceleration performance[26]. In order to develop the greatest horizontal force during acceleration, high hamstring muscle activation at the end of the swing phase and high hamstring eccentric strength are necessary[26]. Thus, the hamstring muscles are preponderant in acceleration and their function is related to the ability to produce the horizontal force necessary to overall sprint performance.

The Force-Velocity Mechanical Profile

In our approach to improving knowledge of the mechanisms and risk factors of hamstring injuries and for developing appropriate screening tools to detect athletes at risk, we have identified the evaluation and analysis of horizontal force production as an indirect marker of hamstring muscle function.

Power can be represented as the product of force and velocity ($P = F \times V$). In sprinting, the power output is the product of the horizontal force and the running velocity. A relationship exists between these two components, which changes in opposite directions during maximum acceleration[27]. The ability to produce and apply specifically high ground force levels in the horizontal direction depending on the running speed is well described by the linear Force-velocity relationship (F-v relationship)[28]. One of the main features of this relationship is its slope reflecting the Force-velocity mechanical profile (F-v profile - Figure 2)[22,28,29].

This F-v profile indicates the relative importance of force and velocity capabilities in determining the maximum power (P_{max})[22,28]. Thus, sprint performance may be determined by the power capacity of the athlete as well as by the F-v profile and its components of horizontal force and velocity[29]. The F-v profile in sprinting can be summarised by two extreme theoretical values, towards which the capabilities of the neuromuscular system tend (Figure 2)[28]:

- The theoretical maximum horizontal force that the lower limbs can produce during the zero-velocity contact phase (F_{H0});
- The theoretical maximum velocity at which the lower limbs could operate during a contact phase without external constraints (V_0; corresponding to the maximum velocity produced without generating any force).

Determining the Force-Velocity Mechanical Profile

Recently, a method has been validated to assess the F-v profile in sprinting outside of the laboratory, for example, at any sport facility (athletics track, football field, handball gymnasium...). This is done simply by measuring the instantaneous velocity and the mass and size of the subject[28].

In practice, the instantaneous velocity measurement can be taken during an acceleration of 30-40m, starting from the tripod position,

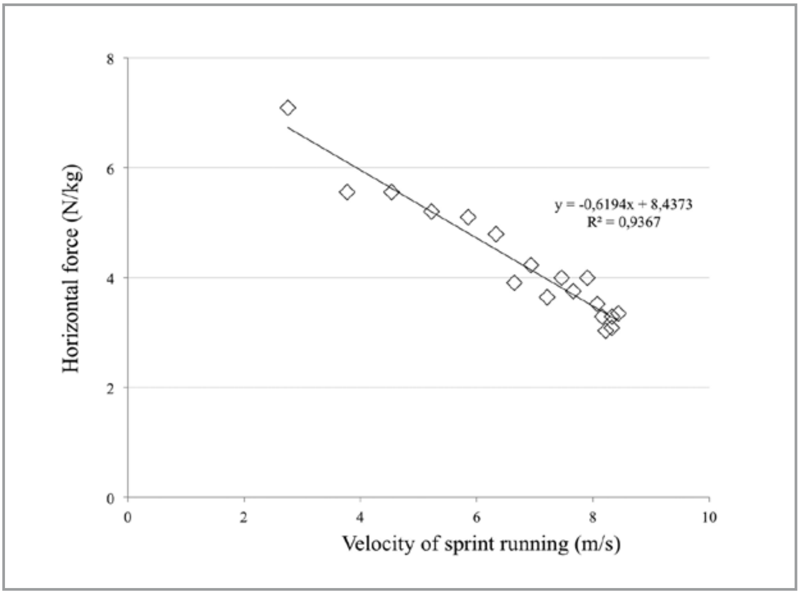

Figure 2: Force-velocity mechanical profile in sprinting. (Represented by the linear regression (y = ax + b) between the horizontal force and running speed.)

at maximum intensity. It is made using a radar gun, for example the Stalker ATS System™ (Applied Concepts, Inc./Stalker Radar 2609 Technology Drive Plano, Texas 75074) or four to five pairs of photocells, for example Racetime2 Light (Microgate, Bolzano, Italy) or, more recently, with a smart phone such as an iPhone 5s or 6 through the application "*My Sprint*"[28-30].

The radar or smart phone must be manually maintained by the experimenter, 5m behind the subject at a height of 1m, corresponding approximately to the height of the centre of mass of the subject[30]. The running distance for the measurement must be adapted to the performance level of the subject, because high-level sprinters will be able to accelerate for up to 60m. With the instantaneous velocity measurement, the P_{max}, F_{H0}, V_0, and F-v profiles can be calculated using the equation recently validated by SAMOZINO et al.[28].

The Force-Velocity Mechanical Profile in the Context of Hamstring Muscle Injuries

Sprinting Force-velocity profile after a hamstring injury

MENDIGUCHIA et al.[31] measured the mechanical properties of 14 semi-professional footballers (performance parameters and F-v profile) after the athletes had suffered a hamstring injury - both at the time of full recovery and authorisation to return to the field and again two months later. These data were compared to 14 other semi-professional footballers without any history of hamstring muscle injury.

At the time of full recovery and return to the field, the values of P_{max} and F_{H0} were significantly lower in the injured players than in the healthy footballers. Two months after the return to sport, the values of P_{max} and F_{H0} had returned to values similar to healthy subjects[31]. This shows *i)* a hamstring muscle injury mainly affects the capabilities for high levels of horizontal force production and thus maximum horizontal power, and *ii)* that at the time of return to sport, muscle capabilities were still altered, and these alterations were detectable by this simple method of evaluation.

MENDIGUCHIA et al.[32] also reported changes in the sprinting F-v profile for a professional footballer before and after a hamstring muscle injury. They reported a decrease of 21% of the slope coefficient of the F-v relationship, a decrease of 21% of F_{H0}, and no change of V_0. after hamstring injury.

Sprinting Force-velocity profile before a hamstring muscle injury

In the same study, MENDIGUCHIA et al.[32] reported on a rugby player who suffered a hamstring muscle injury in the fifth of a series of 10 sprints at maximum intensity. The Force-velocity profile changed during the sprint in which the injury occurred, with a 21% increase of the slope coefficient of the F-v relationship, a 14% increase of F_{H0}, and no change V_0 (-6%) compared to other sprints. The other players tested at the same time showed decreased F_{H0} and V_0 (8% on average) and a stability of the slope coefficient of the F-v relationship.

Discussion

These results indicate changes in the F-v profile within injured hamstring muscles, especially changes in F_{H0}, which could be a consequence of the injury[31,32]. We can hypothesise that the decrease of F_{H0}, corresponding to the decrease in horizontal force production during the sprint, could be a result of the decrease in muscle strength induced by the injury. Indeed, a decrease in the muscle strength of hamstring muscles and in particular in the eccentric strength of the hamstring muscles and the ratio of eccentric hamstring to concentric quadriceps strength is reported in the literature[33,34]. These elements would be consistent for a perspective of use in clinical practice of monitoring the F-v profile and F_{H0}, to indirectly evaluate hamstring muscle strength and function, and to guide the post-injury recovery and optimise the return to sprinting.

There appears to be a close link between hamstring muscle strength and horizontal force production[26], a close link between hamstring muscle strength and a history of hamstring muscle injury[33,34], and a close link between hamstring muscle injury and horizontal force production[31,32]. Moreover, a deficit and/or imbalance in hamstring muscle strength have been reported as predisposing to the occurrence of hamstring muscle injury in football[35] and athletics[12]. As such these can be considered as a risk factor for hamstring muscle injury. We can imagine that the deficit and or imbalance in strength could be indirectly assessed using the F-v profile and F_{H0}, which would thus be a relevant screening tool for the risk of hamstring muscle injury.

Conclusions

Analysing the forward propulsion function of hamstring muscles during a maximum acceleration sprint looks promising given the close links between the strength and function of the hamstring muscles and the horizontal force production in sprint, given the very functional and practical evaluation in field conditions, and given these encouraging preliminary scientific results.

This measure of F-v profile could be used to guide the return to sprinting and allow maximum recovery from a hamstring muscle injury and to screen athletes at risk of hamstring muscle injury. Further prospective cohort studies are needed to confirm these preliminary results and hypothesis, and to better define which the parameters and/or criteria are relevant to follow athletes after hamstring muscle injury and/or to screen athletes at risk in a prevention approach.

Declaration of interest

The authors declare that they have no conflicts of interest related to this article.

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