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Relationships between horizontal force velocity profiling and starting block performance in elite sprinter athletes

Dissertação elaborada com vista à obtenção do Grau de Mestre em Treino de Alto Rendimento

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David Correia Mendes

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Abstract

Purpose: The main purpose of this study is to understand the relationship between block starting performance of elite male sprinters and their lower-body strength and power, obtained by force-velocity profile.

Methods: In this cross-sectional study of thirteen male high-level sprinters (age 23.8 ± 3.1 years; height 1.82 ± 0.04 m; body mass 77.1 ± 5.5 kg; 100m PB 10.53 ± 0.26 s) tested at the National Indoor Athletics High Performance Centre for both block starting and sprinting tests at the beginning of February. The anthropometry and external force data were collected from each block using force instrumented starting blocks custom-made force platforms, were used to determine block starting performance variables such as block velocity, maximal and average horizontal force, horizontal power and normalized average horizontal power. The velocity-time data were used to determine the variables of interest of the horizontal FPV profile (*F0*, *v0*, *Pmax,* DRF, and RFmax) according to the Samozino's method as well as sprint time to 40 m. Pearson's correlation coefficients (r) were used to test the relationship between dependent variables.

Results: The block starting performance variables correlations with NAHP were typically moderate to nearly perfect. However, when analyzing F-V profile associated with NAHP, F0 showed no correlation with start block performance, while *v0*, Pmax, DRF and RFmax indicates a large to very large correlations.

Conclusions: The data obtained in this study, provided a new view on the performance in the starting of blocks and initial acceleration of elite sprinters, indicating that the horizontal power plays a fundamental role in these phases of the 100m race. It should also be noted the importance of the maximum theoretical speed and the force ratio in the final sprint time and its association with the average horizontal power applied in the starting blocks. This data can help coaches to guide their athletes' training process, individualizing training stimuli and optimizing their sports performance.

Keywords: Athletics; Sprint start; Initial acceleration; Biomechanics; Normalized external power; Force-velocity profile; Strength and power assessment

Resumo

Objetivo: O presente estudo pretendeu analisar a relação estabelecida entre o desempenho na partida de blocos e as variáveis do perfil de força-velocidade-potência (F-V-P) dos membros inferiores em velocistas masculinos de elite.

Métodos: Treze velocistas masculinos de elite (idade 23,8 ± 3,1 anos; altura 1,82 ± 0,04 m; massa corporal 77,1 ± 5,5 kg; 100m RP, 10.53 ± 0.26 s) foram testados no Complexo de Atletismo do Centro de Alto Rendimento do Jamor, tendo realizado partidas de blocos e *sprints* de 40 m à máxima intensidade*.* As forças de reação dos apoios na partida foram registadas através de blocos de partida instrumentados com plataformas de força (1000 Hz), tendo permitido a determinação de variáveis de desempenho na partida de blocos (velocidade na partida, força horizontal máxima e média, potência horizontal máxima e media, e potência horizontal média normalizada). Os dados de velocidade-tempo dos sprints de 40m foram obtidos através de células fotoelétricas e usados para determinar o tempo de sprint a 40 m e as variáveis de interesse do perfil F-V-P (F0, *v0*, Pmax, DRF e RFmax). A relação entre as várias variáveis dependentes foi testada através de coeficientes de Pearson.

Resultados: A potência horizontal média normalizada (NAHP) apresenta correlações moderadas a quase perfeitas com as restantes variáveis de desempenho na partida de blocos. No entanto, ao relacioná-la com as variáveis do perfil F-V-P, não se verificou nenhuma associação com a F0, mas relações fortes a muito fortes com a *v0*, Pmax, DRF e RFmax.

Conclusões: Os dados obtidos neste estudo fornecem uma nova visão no desempenho na partida de blocos e fase de aceleração em velocistas de elite, indicando que a potência horizontal desempenha um papel fundamental nesta fase da corrida de 100m. De realçar ainda a importância da velocidade máxima teórica e do rácio de força no tempo final de sprint e a sua associação com a potência horizontal média aplicada nos blocos de partida. Estes dados podem auxiliar treinadores a orientar o processo de treino dos seus atletas, individualizando os estímulos de treino e otimizando o respetivo desempenho desportivo.

Palavras-chave: Atletismo; Partida de blocos; Aceleração inicial, Potência horizontal normalizada; Perfil força-velocidade; Avaliação de força e potência

Index of Contents

List of Tables

List of Figures

List of Acronyms

1. **BW**- Bodyweight
2. **COM** - Centre of mass
3. **DRF** – Decrease in the ratio of force
4. **F0** – theoretical maximum force
5. **F-V** – Force-velocity profiling
6. **FY** – Average horizontal force
7. **GRF** - Ground reaction force
8. **Hv** – Horizontal Velocity
9. **NAHP** - Normalized average horizontal power
10. **P** – Average horizontal block power
11. **PB** - Personal best
12. **Pmax** – Maximal power output
13. **P-V** – Power-velocity profile
14. **RF** – Ratio of force
15. **RFmax** – Maximum ratio of force
16. **SD** - Standard deviation
17. ***v0*** – theoretical maximum velocity
18. **VTC** – Vertical
19. **VTC-Pmax** - Maximal Vertical power output

Chapter 1: Introduction

INTRODUCTION

Sprint performance is quantified by the time to cover a short distance (Morin et al., 2012; Morin, Edouard, & Samozino, 2011; Stavridis, Smilios, Tsopanidou, Economou, & Paradisis, 2019). For sprinters competing in 100 m track and field events, the ability to run a short distance as fast as possible alone defines them as performers. In 100 m events, sprinters begin the race by assuming a crouching position in the starting blocks before driving forward and gradually moving into an upright position as the race progresses. The sprint start, is characterized by displaying the highest acceleration during a sprint race, highlighting the critical importance of the starting phase to overall performance (Brazil et al., 2017). Furthermore, the ability to accelerate and achieve higher velocity over 40 m was shown to discriminate between elite and sub-elite sprinters (Rabita et al., 2015), supporting that the acceleration phase is also very important in the overall sprint performance. During these sprinting phases, athletes try to generate high levels of horizontal ground-reaction force (GRF), and apply it with effectiveness onto the blocks and ground, despite increasing velocity (Morin et al., 2011).

The block phase involves a body position with substantial forward lean in order to direct the ground reaction force (GRF) in a horizontal direction as much as possible (Rabita et al., 2015) and produce considerable center of mass (COM) acceleration from the stationary “set” position (Brazil et al., 2018) and on “go” they have to generate the highest levels of horizontal force applying it effectively against both blocks, while increasing velocity (Haugen, Breitschadel, & Seiler, 2019; Morin et al., 2011; Rabita et al., 2015). This part is critical for sprinting performance, and any small improvement in sprint start performance could result in greater overall sprint performance (Brazil et al., 2018). The ability to produce great force against the start-block and achieve higher velocity and power output has been shown to discriminate between elite and sub-elite sprinters (Bayne, 2018; Rabita et al., 2015), meaning, even seemingly small improvement in performance, either a neuromuscular rate of force production or in technique, can make a large and meaningful difference, as highlighted in the 100m events.

Due to its clear importance in sprinting, the block phase has been the focus of considerable biomechanical research for decades (Bezodis, Salo, & Trewartha, 2010; Brazil et al., 2018; Schot & Knutzen, 1992; Willwacher et al., 2016). Several external kinetic variables have been identified as determinants for block starting performance, such greater rear block peak force (Fortier, Basset, Mbourou, Faverial, & Teasdale, 2005), greater front block average horizontal force (Brazil et al., 2015) and greater total (front + rear) average horizontal force (Brazil et al., 2015; Otsuka et al., 2014). Another variable that has also been gaining some weight in block start performance is the normalized average horizontal (NAHP) which is basically the average horizontal power, normalized to bodyweight (BW) and leg length (NAHP). It was has been identified as the best variable of starting block performance (Bezodis et al., 2010). In fact, NAHP account for 42% of the variance in 100 m personal best (PB) time (Willwacher et al., 2016), confirming the critical nature of the block phase to overall sprint performance. This indicates that the athlete's ability to produce horizontal power in a short period of time is a determining factor in this phase of the race.

It is also known that elite sprinters can apply high forward-oriented forces onto the supporting ground during the acceleration phase. This ability seems to be more important for sprint performance than the total amount of force they are able to produce (Morin et al., 2011). Recently, a biomechanical approach, based on kinematics and kinetics parameters of the sprinter's body COM during sprint acceleration can determinate the force-velocity-power (F-V-P) relationships, and the mechanical effectiveness of force application parameters (Cross, Brughelli, Samozino, & Morin, 2017; Morin & Samozino, 2016; Samozino et al., 2016). Theoretical maximal velocity (*v0*), horizontal force (F0), horizontal power (Pmax) and force-velocity profile (i.e., the slope of the force-velocity relationship; SFV) can be calculated from this method. Other indices with significantly correlation with sprint performance and commonly used to assess the mechanical effectiveness in force application (Morin et al., 2011), one being the maximal ratio of horizontal resultant force (RF) and the decrease in the ratio of horizontal-to-resultant force (DRF) throughout the acceleration phase. The RF is a ratio of the step-averaged horizontal component of the ground reaction force to the corresponding resultant force, while DRF expresses the athlete's ability to maintain a net horizontal force production despite increasing velocity throughout accelerated sprinting (Haugen et al., 2019; Morin et al., 2011).

Despite these variables and NAHP are determinant factors for overall sprint performance, providing insights into individual biomechanical limitations (Haugen et al., 2019; Morin et al., 2012; Morin et al., 2011; Rabita et al., 2015; Slawinski et al., 2017), there are no reports on the level of association between both. To the best of our knowledge, no research data has yet investigated whether starting block performance (NAHP) is associated with lower-body F-V-P profile variables (i.e., F0, *v0*, Pmax, SFV, RF and DRF). Thus, it would be interesting to examine the mechanical characteristics of top national sprinters in both sprint block starting and acceleration phase, trying to determine relations between them. Like this, the main purpose of the present study is to understand the relationship between NAHP and F-V-P profile variables of elite male sprinters. It was hypothesized that sprinters with greater relative block horizontal power would show a greater RF and optimal F-V-P profile, with a low DRF.

Chapter 2: Review of Literature

REVIEW OF LITERATURE

2.1. Starting blocks performance

Sprinting is an individual athletic effort, where the main objective is to cover a specific distance in the shortest amount of time possible (Bezodis et al., 2010; Bezodis, Willwacher, & Salo, 2019c; Haugen et al., 2019; Schot & Knutzen, 1992; Willwacher et al., 2016). It appears that for centuries, sprinting is been part of human culture. Until this day, the 100 m world record holder, Usain Bolt, with the best time of 9.59s, had a peak speed of 12.35m/s, located at 67.90m, recorded by the Laveg system during the World Championships 100 m final (Graubner & Nixdorf, 2011).

The ability to run a certain distance in the shortest amount of time, is crucial factor for success in 100 dash or in field-based team sport athletes (Jimenez-Reyes et al., 2019; Morin et al., 2011). When analyzing each components of sprint performance, such as block start (Figure 1), acceleration and maximal velocity, the exact definition of success becomes less clear (Bezodis et al., 2010; Haugen, Shalfawi, & Tonnessen, 2013).

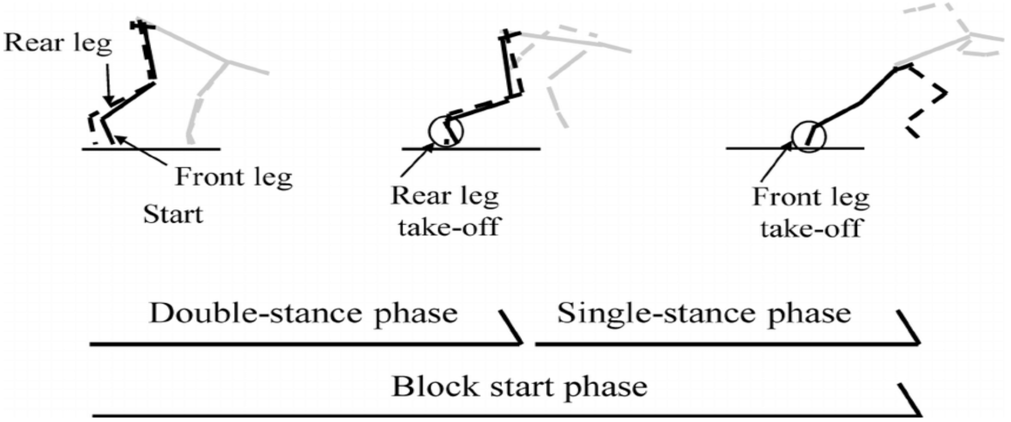


Figure 1- Definition of the double-leg and single-leg stance phases during the block start phase – Otsuka et al. (2015)

It has been demonstrated that striving to rapidly accelerate from stationary position to maximum velocity, thus reducing the amount of time until the runner achieve max velocity, is strongly correlated with overall 100 m time (Bayne, 2018; Bezodis, Salo, & Trewartha, 2015; Bezodis et al., 2019c; Brazil et al., 2018).Therefore, block starting is an important part of a sprint and any small improvement could result in greater overall performance (Haugen et al., 2019; Jimenez-Reyes, Samozino, Brughelli, & Morin, 2016; Schot & Knutzen, 1992).

2.1.1. Block settings and push phase

Block starting is generally used in track and field by sprinters in 400 meters or shorter distances in order to set their feet against at the start of a run and produce high values of force against the block. Since block starting has an important role in sprinting performance, in "set" position, sprinters may choose according to their anthropometrics characteristics: the location, antero-posterior distance between blocks and inclination of two foot plates in order to maximize the pushing phase (Bezodis et al., 2019c; Otsuka et al., 2014; Schot & Knutzen, 1992; Slawinski et al., 2017).

When choosing the distance between footplates, sprinter must considerer the height and specially leg length (Bezodis et al., 2019c). Harland and Steele (1997) mention that are three types of distances between blocks: (a) bunched is typically < 0.3m, (b) medium between 0.3 and 0.5 m and (c) elongated > 0.5m. Despite anthropometrics individual characteristics, medium spacing appear to provide the most favourable basis for push phase performance because it allows sprinters to generate relatively large forces without spending overly long doing, while bunched starts reduce the extension capability of both hips and the rear knee, and elongated starts has a longer push duration (Slawinski et al., 2017).

Foot plate inclination is also a very personalized feature. To identify individual-specific foot plate inclinations, the athlete must facilitate initial dorsiflexion, in order to generate more force against the block. When analysed within sprinters, Mero, Kuitunen, Harland, Kyrolainen, and Komi (2006) reduced front block inclination (from 70 to 30°, relative to the track) acutely increase block velocity (from 2.37 to 2.94 m/s) without significantly affecting push phase duration.

The pushing phase focus on maximize horizontal velocity (Hv) in the shortest time as possible. To do so, lower limb muscles must contract prior to the first visible movement or force production against the blocks (Boisnoir, Decker, Reine, & Natta, 2007). The ability to react in time is the next step and vary greatly between sprinters (Pain & Hibbs, 2007). Some factors, such as disqualification rule changes (Brosnan, Hayes, & Harrison, 2017), holding time (Haugen et al., 2013; Otsuka, Kurihara, & Isaka, 2017), start signal intensity (Brown, Kenwell, Maraj, & Collins, 2008), and the sprinter's focus of attention (Ille, Selin, Do, & Thon, 2013), may keep the athlete from reacting slower or faster, and this why this variable is very important in block performance.

Despite its force vector should be in the horizontal direction, sufficient vertical impulse must also be produced to overcome gravity and initiate a gradual rise (Nagahara, Matsubayashi, Matsuo, & Zushi, 2014). After rear block take-off, the front leg must also assist vertical motion, but its primary role therefore appears to be horizontal propulsion.

To summarize, body configuration, anthropometry and strength, combined with different block settings and "set" positioning should be taken to consideration, in order to optimize the mechanical variables that are directly associated with an optimal performance at the beginning of a sprint (Bezodis et al., 2019c).

2.1.2. The block starting performance variables.

There are some important aspects when analyzing start block performance (Bezodis et al., 2010; Harland & Steele, 1997). According to the literature, there is a set of variables of primary importance and with relevance in the overall performance of the 100m race. First and one of the most common measure, and it has been related to sprinters with faster PB times, its COM velocity at block take-off which is determined by push phase impulse, which results from the product of force by the time spent producing force (Bezodis et al., 2010; Bezodis et al., 2019c).

The ability to produce high levels of force is limited throughout the duration of the phase and, also because of the range of motion covered during the push against the blocks. Also attempting to increase the push time against the block in order to achieve higher block velocity may not be beneficial for overall sprint performance (Bezodis et al., 2010; Bezodis et al., 2019c; Haugen, Breitschadel, & Samozino, 2020; Rabita et al., 2015).

Bezodis et al. (2010) structured the blocks in different phases, having identified different variables for each of them. The results of this study revealed that block velocity has a measure of performance is potentially misleading. The ability to produce high levels of force is limited throughout the duration of the phase and because of the range of motion covered during the push against the blocks. Also attempting to increase the push time against the block in order to achieve higher block velocity may not be beneficial for overall sprint performance (Bezodis et al., 2010; Bezodis et al., 2019c; Haugen et al., 2020; Rabita et al., 2015). Also Bezodis et al. (2019c) mention that junior sprinters may lack the muscularity compared to their senior counterparts, however horizontal block force production, block velocity and push phase duration appear not to differ between adult and junior athletes. These authors have also identified several other kinetic and kinematic variables in block performance have been shown to be important for high level of performance during the start. Bezodis et al. (2010) used average horizontal block acceleration is potentially a more useful measure of performance than block velocity, because incorporates time, and it has previously been shown that whilst one athlete may exhibit a higher block velocity, another could have a higher acceleration due to a shorter push phase duration.

Average horizontal power, is another variable mention by Bezodis et al. (2010), Morin and Samozino (2016) and Bezodis et al. (2019c) as being important to measure it anywhere of the sprint. This variable is typically calculated based on the product of horizontal force and velocity, incorporating both time and velocity variables. Being a kinetic variable, power production ultimately determines acceleration (a kinematic variable), and since the overall aim in sprinting is to reach the finish in the least possible time, sprinter must produce considerable amount of work, in order to translate their COM horizontally over 100 m, and the time it takes to do this depends on horizontal external power production.

Theoretical studies have suggested that maximal external power production during the block phase appears to be paramount for performance. This strategy suggest that during sprint events, maximal horizontal external power must be produced from the very beginning, in order for the sprinter to spends less time running at submaximal velocities at the start (Bezodis et al., 2019c).

Adult senior sprinters of both sexes exhibit significantly longer first step lengths and achieve significantly higher velocities at 5 m than juniors possibly because younger sprinters are unable to generate as much knee joint power during stance (Debaere et al., 2017).

Also, Willwacher et al. (2016) made remarkable conclusion that sprinters with lower-limbs amputation, lack the ability to generate muscular force. Running-specific prostheses can only store and return but not produced force against the block, which results in reduced start performance (average reduction in block power=17.7%).

In training program is designed to improve sprint-acceleration performance, the focus should be not just on increasing Pmax, but also looking specifically to which component of average force and maximal horizontal running velocity and understand which one is influencing more than the other in sprint performance.

Regarding to injury prevention, this also suggests that when looking to a sprinter or an athlete, this could directly reduce the risk for sprinting-related injuries, by reducing the total time he would be exposed to strength training or speed training (Morin & Samozino, 2016).

In sum, average horizontal external power and maximal horizontal power should be used to objectively quantify performance during any discrete part of a sprint start.

More recently, in an attempt to analyze the characteristics of force production in the blocks, Brazil et al. (2015) presented others important kinetic and kinematic variables in block performance. Numerous studies have observed differences in maximal and average force production during the block phase between varying levels of sprinters and influence this criterion measure of performance. In the block phase, it has been highlighted that a superior technical ability to orientate the resultant force vector horizontally may be of greater importance than the magnitude of the resultant force (Otsuka et al., 2014).

It has long been known that sprinters with faster PB times and those with higher velocities after 2.5 m generate larger relative horizontal block impulses than their slower counterparts. These impulses are typically achieved despite the same or shorter push phase durations, i.e., they are due to increased average horizontal force (FY) production. Subsequent research has identified greater peak and average forces (Bezodis, Walton, & Nagahara, 2019b; Willwacher et al., 2016).

For example Willwacher, Herrmann, Heinrich, and Brüggemann (2013) data shown that world – class sprinters use their potentially superior explosive force capacities in a way that they do not maximize COM acceleration in the blocks, but rather try to minimize block time. Other observation was that they use both of their legs more equally for force production. This findings are according to those found by Fortier et al. (2005), where elite athletes, exhibited a smaller force difference between the rear and the front leg than the sub-elite sprinters (16% vs. 46%), meanwhile, the sub-elite counterparts produce more force in front plate then the rear one. This suggests that elite sprinters optimized their force production on the blocks by producing similar force in both blocks, while sub-elite focus their attention to the front leg. This concludes that better sprinters have a more specific motor patterns adapted to the sprint task and consequently have developed a better performance in the push phase (explosiveness) than their counterparts (Harland & Steele, 1997).

So, in order to increase performance, the focus should be putting an equally force in front and the rear block. In order to control the technical and conditional training progress, force measurements in the starting blocks could be used as a feedback system (Bezodis et al., 2019c).

Furthermore, considering sprinters do not have the same anatomical size (leg length) and weight, Bezodis et al. (2010) suggest that NAHP is the best descriptor of starting block performance. Recently, NAHP (using height instead of leg length) has been found to account for 42% of the variance in 100 m PB time in a large sample of 154 sprinters with PB's ranging from 9.58 to 14.00 seconds (Willwacher et al., 2016), confirming the critical nature of the block phase to overall sprint performance. The formula to obtain NAHP is the following:

$$NAHP = P/(m * g^{1.5} * l^{0.5})$$

$$P = m(Vf^2 - Vi^2)/2Tblock$$

(Bezodis et al., 2010)

where:

m is the mass of the sprinter;

g is the gravity acceleration;

l is the leg length of the sprinter;

Vf is the velocity at block exit;

Vi is the velocity in the begging of the block (i.e., null).

The average horizontal block power *(P)* was defined as the change in horizontal kinetic energy during push-off from the blocks (TBlock, i.e., time block or push time) (Bezodis et al., 2010).

Based theoretical data acquired by Bezodis et al. (2010) and Sado, Yoshioka, and Fukashiro (2020), normalized average horizontal external power potentially offers an appropriate measure of performance for any stage of a sprint. It was identified as the most appropriate measure of performance, because it objectively reflects, in a single measure, how much a sprinter is able to increase their velocity and the associated length of time taken to achieve this, whilst accounting for variations in morphologies between sprinters.

2.2. F-V-P Profile in Sprint Acceleration

2.2.1. Force-Velocity-Power relationship

Force-velocity profiling (F-V) has gained popularity in recent years for both researchers and strength and conditioning coaches (Morin et al., 2012; Morin et al., 2015; Samozino et al., 2014; Samozino et al., 2016; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). The ability to produce high-levels of muscular power is a widely accepted muscular determinant of jumping and sprinting performance, which is determined by both force and velocity production capabilities (Samozino et al., 2016; Samozino et al., 2012). Since power is the product of force and velocity (Power = Force x Velocity), it is therefore understood that these two components underpin the ability to be powerful (Cronin & Sleivert, 2005). The Figure 2 represents the relation between Force and velocity, and the corresponding P-V.

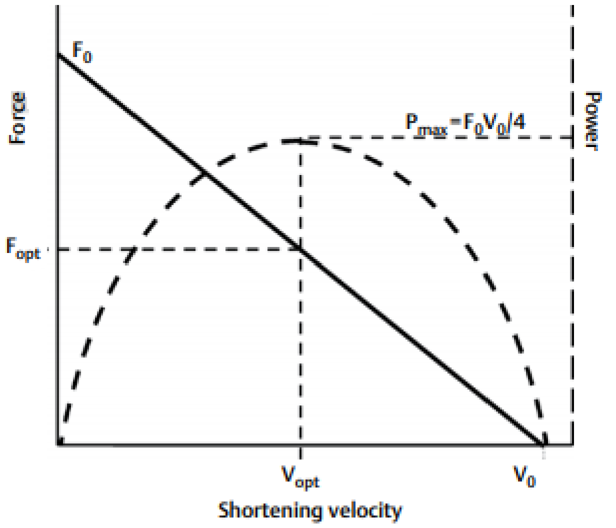


Figure 2- Typical F-V (solid line) and the corresponding P-V (dashed line) relationship obtained from a hypothetical muscle or muscle group. - (Jaric, 2015)

At the beginning of any sprint event, sprinters initiate their movement from a starting block, which they must produce considerable amount of impulse in order to move in forward direction. As mention before, Impulse is the product between force and time, in order to increase it, sprinter must increase time spend in block, which has already concluded that is not correlated with block performance. The other more reliable way is to increase force against the block. However, there is limitation mention by Haugen et al. (2019) which is related to produce high values of force in the limit range of motion and time.

Force is the product of mass of the athlete and the acceleration he produces. Increase body mass implies more resistance the athlete must overcome in block start. The other possible way is to increase the values of the acceleration, by increasing the take-off block velocity.

Another factors such the resistance that is implicit in start of the pushing phase, is not enough for the athlete produce high values of force. The only resistance sprinter must overcome in initial start is the body mass and air resistance (Cross et al., 2017; Samozino et al., 2016) .

$F = m.a - Faer$ (Morin & Samozino, 2016)

where:

m is the mass of the sprinter;

a is the accelaration produced in to the block;

Faer is the air resistence;

To support this fact, Bayne (2018) compared Six elite and six sub-elite sprinters in a 3-5 maximal effort 30 m sprint trials from a block start. there was different values of velocity and power and a very small difference in force between elite sprinter and sub-elite sprinter. Sustaining the fact that force in high level athletes is not so important then velocity and Pmax.

Rabita et al. (2015) also compared four elite (100-m best time 9.95– 10.29 s) and five sub-elite (10.40–10.60 s) sprinters performed seven sprints in overground conditions, show that F0 was not significantly correlated with these performance parameters.

Also when comparing athletes from difference sports, Haugen et al. (2019) reported higher F0 in bobsleigh then sprinters, however the results in performance in 10, 20, 30 and 40m show that sprinters had the best results. This supports the idea that F0, derived from a normal sprinting appears to be not so important.

This reflects the idea that F0 is higher with resisted sprinting compared to unloaded sprints (Haugen et al., 2019). Thus, F0 calculated with the simple method by Samozino et al. (2016) is not a true F0, as the resistance in overcoming body mass inertia appears insufficient for maximal horizontal force-capacity generation (Haugen et al., 2019).

2.2.2. Field method for determining FVP relationships

Until recently, the measurement of mechanical properties in sprint running was a complicated task. One of the first studies to be carried out implied the use of a instrumental treadmill, where the subject would have to accelerate the belt themselves by the action of their lower limbs, while their waist is tethered backward to a fixed point (Morin et al., 2011).

Despite the high accuracy of these methods, one of the limitation found was that by using a treadmill removes the natural over ground sprint running movement due to waist attachment, a belt narrower than a typical track lane, the impossibility to use starting block, and the need to set a default torque to, only partly, compensate for the friction of the treadmill belt bed (Morin et al., 2011; Morin & Samozino, 2016).

Another method emerges, using data from several sprints measured on a 6.60-m long force plate system, which allowed, for the first time, to provide the data to entirely characterize the mechanics of over ground sprint acceleration (Rabita et al., 2015). However not all strength and conditioning coaches have easy access to such rare and expensive devices, and often do not have the technical expertise to process the raw force data measured.

With all this difficulties, a simple method to determine F–V and P–V relationships and force application effectiveness during sprint running in a realistic conditions was required, and it would be beneficial to include in future assessment in order to optimize training process (Cross et al., 2017; Samozino et al., 2016).

The Samozino et al. (2016) method provides information on the run as a whole. Their approach is based on F–V and P-V relationships characterizing the mechanical capabilities of the lower limbs' neuromuscular system (Morin & Samozino, 2016), by using macroscopic inverse dynamics approach (Cross et al., 2017).

Mechanics and energetic system of sprint running have been approached by various kinds of mathematical models that aimed at describing sprint performance from the balance between the mechanical and energy demand of sprint running acceleration (Samozino et al., 2016).

Based on this mechanical model, an inverse dynamic approach, considering runners body COM could give valid estimation of GRF during sprint running acceleration from simple kinematic data. This could then be used to obtain the sprint mechanical properties without force platform system in typical field conditions of practice (Cross et al., 2017).

In this method, a mono-exponential function is also applied to the raw velocity-time data (Eq. 6). After this, the fundamental principles of dynamics in the horizontal direction enable the net horizontal antero-posterior force to be modelled for the COM over time, considering the mass (m) of the athlete performing the sprint in association with the acceleration of COM, and the constant aerodynamic friction of the body in motion (Faero) (Eq. 5).

After that, the values acquired in Eqs. 5 and 6, are used to determine F-V relationships and mechanical variables (F0 and V0). Pmax can be calculated as the interaction between F0 and *v0* (Eq. 4).

Furthermore, technical variables (RF and DRF) can be calculated similarly to previous methods, with the resultant force and horizontally oriented GRF (see Eq. 3). Where previous studies calculated technical variables from the second step, the variables were instead calculated from 0.3 s, given determining individual step characteristics is impossible.

Table 1-Mechanical profiling and their respective equations – adapted from Samozino et al., (2016)

Mechanical profiling type	Equation
The horizontal position (Xh) and acceleration (aH) of the body COM as a function of time during the acceleration phase	(1) $x_h(t) = v_{h_{max}} \cdot \left(t + \tau.e^{-t/\tau}\right) - v_{h_{max}} \cdot \tau$ (2) $a_H(t) = \left(\frac{v_{max}}{\tau}\right) \cdot e^{-\frac{t}{\tau}}$
Ratio of force, computed as the ratio of the step-averaged horizontal component of the ground-reaction force to the corresponding resultant force.	(3) $RF = \frac{F_H}{F_{Res}} \cdot 100 = \frac{F_H}{\sqrt{F_H{}^2 + F_V{}^2}} \cdot 100$
Maximal mechanical power output in the horizontal direction, computed as Pmax = F0 × *v0*/4, or as the apex of the P–V 2nd-degree polynomial relationship.	(4) $P_{max} = \frac{F_0 \cdot v_0}{4}$
External horizontal net force modelled over time with consideration for air friction	(5) $F_H(t) = m \cdot a_H(t) + F_{aero}(t)$
Exponential function of COM velocity-time relationship in sprinting	(6) $v_H(t) = v_{H_{max}} \cdot \left(1 - e^{-t/\tau}\right)$

The proposed method by Samozino et al. (2016) is a very accurate, reliable, and valid simple method to evaluate mechanical properties of sprint running propulsion and validated it through a very good agreement with gold standard force plate measurements.

As mention before, this method is based on a macroscopic biomechanical model using an inverse dynamic approach applied to the runner's CM. It is convenient for track and field sport practitioners and clinicians as it requires only anthropometric (body mass and stature) and spatiotemporal (split times or instantaneous velocity) variables easy to obtain.

This method could be further used to increase the understanding in the mechanical determinants of sprint acceleration performance in many sports, to study the adaptations of the mechanical properties of lower limb neuromuscular system in a variety of sprint running propulsion, and to optimize sprint performance by individualizing and orienting training or rehabilitation programs.

2.2.3. Sprint mechanical variables of force-velocity profile

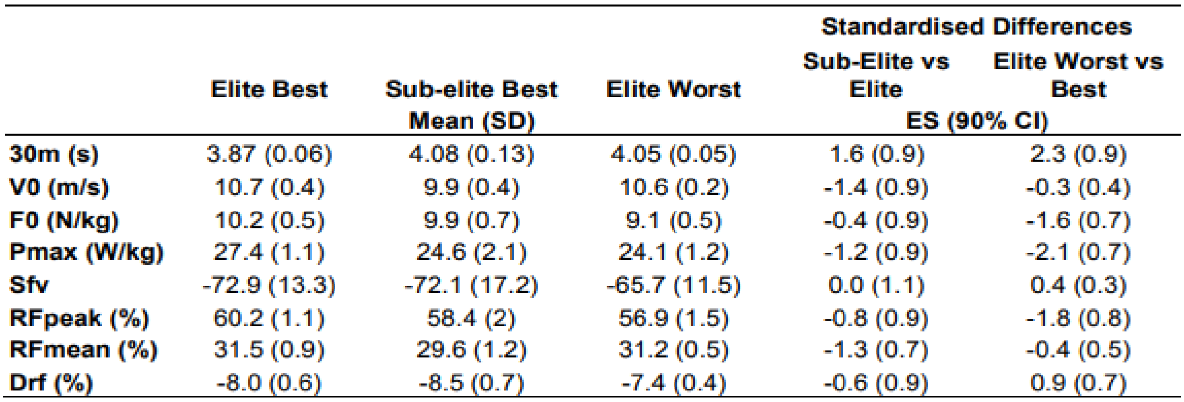
The mechanical properties obtained from multijoint F–V and P–V relationships are a complex integration of different mechanisms involved in the total external force produced during one (squat jump) or several consecutive limb extensions (sprinting) (Samozino et al., 2016).

Thus, force-velocity-power profile is used to describe in sprinters capability to produce external forces during block pushing phase and the mechanical effectiveness of the force applied on the rear and frontal plates, based on the inverse linear F-V and parabolic P-V relationships that occur during multi-joint activities (Samozino et al., 2016).

According to Haugen et al. (2019), Jimenez-Reyes et al. (2019), Morin et al. (2012), Rabita et al. (2015) and Samozino et al. (2016) the most common variables to assess block start performance during the pushing phase are the follow: F0, *v0* and the product of this two is associated with Pmax, the RF and DRF. As F0 represents the maximal force of the lower limb produced at zero velocity and *v0* being the maximal velocity at the lower limb can extend under no resistance. When we have a closer look at what block performance is, we can say it's a lower limb movement with a very low resistance (Faer + BW), and for this matter *v0* have a bigger important role when looking to individual mechanical variables (Haugen et al., 2019; Rabita et al., 2015).

Bayne (2018) made a very recent study with six elite and six sub-elite sprinters performed maximal effort sprint acceleration trials while their F-V-P profiles was being monitored. The main purpose of this study was to investigate mechanical variables of sprint performance in elite sprinters using inter- and intra-individual approaches. In the table 4 is represented the F-V-P variables in a 30m sprinting acceleration trail.

Table 2-Mechanical variables during maximal sprint acceleration of Elite (Best and Worst trial) and Sub-elite (Best trial) sprinters – Bayne, (2018)



				Standardised Differences	
	Elite Best	**Sub-elite Best**	**Elite Worst**	**Sub-Elite vs Elite**	**Elite Worst vs Best**
		Mean (SD)		**ES (90% CI)**	
30m (s)	3.87 (0.06)	4.08 (0.13)	4.05 (0.05)	1.6 (0.9)	2.3 (0.9)
V0 (m/s)	10.7 (0.4)	9.9 (0.4)	10.6 (0.2)	-1.4 (0.9)	-0.3 (0.4)
F0 (N/kg)	10.2 (0.5)	9.9 (0.7)	9.1 (0.5)	-0.4 (0.9)	-1.6 (0.7)
Pmax (W/kg)	27.4 (1.1)	24.6 (2.1)	24.1 (1.2)	-1.2 (0.9)	-2.1 (0.7)
Sfv	-72.9 (13.3)	-72.1 (17.2)	-65.7 (11.5)	0.0 (1.1)	0.4 (0.3)
RFpeak (%)	60.2 (1.1)	58.4 (2)	56.9 (1.5)	-0.8 (0.9)	-1.8 (0.8)
RFmean (%)	31.5 (0.9)	29.6 (1.2)	31.2 (0.5)	-1.3 (0.7)	-0.4 (0.5)
Drf (%)	-8.0 (0.6)	-8.5 (0.7)	-7.4 (0.4)	-0.6 (0.9)	0.9 (0.7)

As we can see in Table 2, elite sprinters achieved faster 30 m times than their sub-elite counterparts, with greater Pmax and *v0* but only a small difference in F0.

This study made by Bayne (2018) supports previous reports (Rabita et al., 2015) that *v0* and Pmax are very important factors in sprinting performance and are one of the main differentiators between elite and sub-elite sprinters, while F0 has a smaller importance.

Despite the importance of *v0* and Pmax in block performance, the ability to obtain F-V profiles would enhance the ability to evaluate individual athletes and determine the training status and orientation, and assist injury surveillance, as well as prevention processes and facilitate a more effective return to play strategy (Mendiguchia et al., 2016). Figure 3 represents a very good example made by Morin and Samozino (2016) on how to identify the neuromuscular strength and weaknesses of the player and with that information, direct the training to strength or velocity.

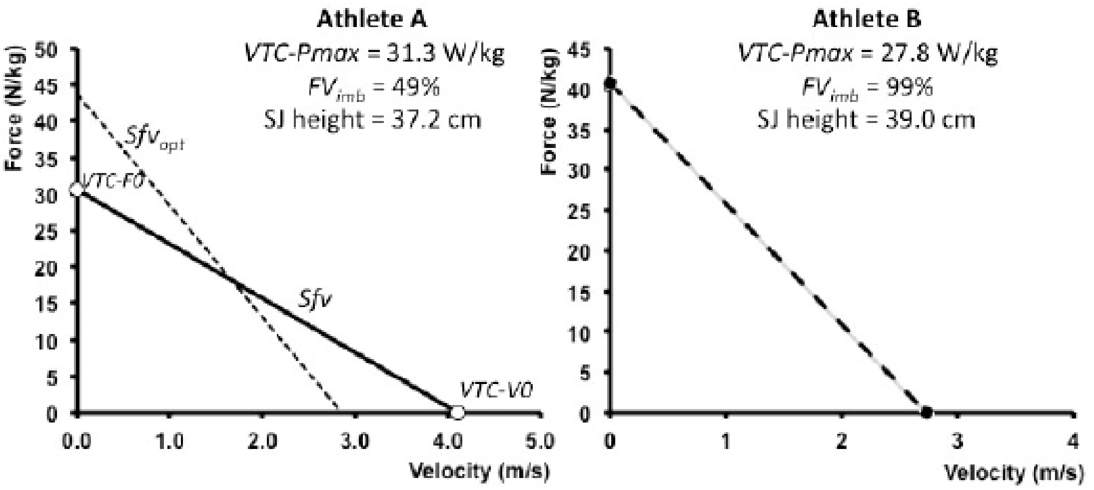


Figure 3-F-V profiles of 2 track and field athletes (body mass for A, 67.2 kg, and B, 82.8 kg; push-off distance for A, 0.34 m, and B, 0.35 m) obtained from maximal squat jumps against additional loads of 0, 10, 20, 30, and 40 kg. (Morin & Samozino, 2016)

Figure 3 made by Morin and Samozino (2016), athlete A, despite his higher maximal vertical power output (*VTC-Pmax),* his squat-jump performance is lower because he has an F–V imbalance. Athlete B has a lower *VTC-Pmax,* but his profile is almost exactly equal to his individual optimal profile. By using this approach and understand each individual component, athlete A's training should not be focus on developing maximal velocity capabilities, instead the periodization should be more directed to optimize maximal force capabilities, to correct his imbalance and preventing injuries. Once this goal is achieved, he may transition into training similar Figure 3 to athlete B, to improve his *VTC-Pmax* while maintaining his corrected (i.e., optimal) profile.

As mention before, evaluating each components of F-V profile, allow the strength and conditioning coaches to understand their athletes condition, which are they strength and weaknesses, allowing the training to be more specific, non-fatigue and prevent a state of overtraining leading to injuries. A study made by Mendiguchia et al. (2016) speculated that a fatigue-induced decrease in *v0* and effectiveness of force application led to a dramatic increase in force output at the beginning of the sprint. To maintain maximal velocity, an increase in force was needed. This increase in force put an unusually high stress on the hamstring muscle that resulted in injury (Mendiguchia et al., 2016). The ability to monitor fatigue with force profiling could possibly prevent injury and give information that could assist in rehabilitation and return to play strategies (Mendiguchia et al., 2016).

Other important variables in acceleration phase is the ability to apply effectively force to the ground during sprint running. Figure 4 exhibits the changes in horizontal component such has, the ratio of force (RF) which is the ratio of the step averaged horizontal component of the ground reaction forces to the corresponding resultant force, and index of force application technique. We can see in figure 4, RF decreases has speed increases thru out the run. A higher RF throughout the sprint is considered desirable as it suggests the athlete is applying higher amounts of horizontal force. However, as speed increases, the RF (%) will inevitably decline – typically referred to as the DRF.

DRF is the ability to maintain a net horizontal force production despite increasing running velocity (Morin et al., 2012; Morin et al., 2011; Rabita et al., 2015). So, F–V and P–V relationships provide a macroscopic and integrative view of the F-V and P-V mechanical profile of an athlete in the specific sprint running task. A lower DRF is considered desirable as this implies that the athlete is better at producing horizontal force as velocity increases.

$$RF = \frac{Horizontal\ ground\ reaction\ forces}{Vertical\ ground\ reaction\ forces}$$ (Morin & Samozino, 2016)

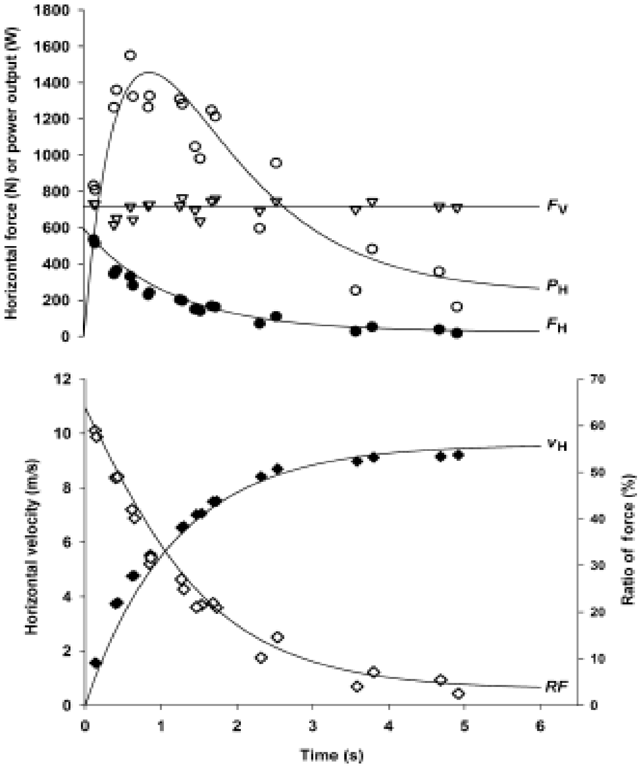
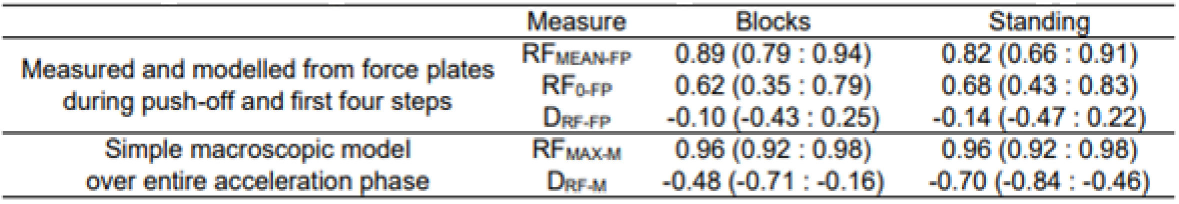


Figure 4- Changes over the acceleration phase in horizontal components, Force, velocity, power and ratio of force for a typical subject- (Samozino et al., 2016)

This two concepts can also be computed from the same method (Samozino et al., 2016) and are determinant factors for sprint performance, in line with the laws of motion, and provide insights into individual biomechanical limitations (Morin et al., 2012; Morin et al., 2011; Slawinski et al., 2017).

Recent study made by Bezodis et al. (2019a) with twenty-four male sprinters (mean ± SD: age = 20 ± 1 years; height = 1.73 ± 0.06 m; mass = 65.7 ± 4.0 kg; 100 m PB = 11.26 ± 0.39 s) where the main objective was to assess the relationship between the DRF and maximum ratio of force (RFmax) outputs obtained from a simple macroscopic model, over the entire acceleration phase. The main findings are explicit in table 3.

Table 3-Pearson's correlations (r), (90% confidence limits)) between RF measures and early acceleration performance (normalized average horizontal external power over the block exit/push-off and the first four steps). – (Bezodis et al., 2019a)



	Measure	Blocks	Standing
Measured and modelled from force plates during push-off and first four steps	$RF_{MEAN\text{-}FP}$	0.89 (0.79 : 0.94)	0.82 (0.66 : 0.91)
	$RF_{0\text{-}FP}$	0.62 (0.35 : 0.79)	0.68 (0.43 : 0.83)
	$D_{RF\text{-}FP}$	-0.10 (-0.43 : 0.25)	-0.14 (-0.47 : 0.22)
Simple macroscopic model over entire acceleration phase	$RF_{MAX\text{-}M}$	0.96 (0.92 : 0.98)	0.96 (0.92 : 0.98)
	$D_{RF\text{-}M}$	-0.48 (-0.71 : -0.16)	-0.70 (-0.84 : -0.46)

This study found a very large positive relationship between mean RF and DRF and performance during early acceleration was observed from both block and standing starts. These results agree with those found by Haugen et al. (2019), Haugen et al. (2020) and Rabita et al. (2015), strengthens the hypothesis that the orientation of the total force that high-level sprinters applied to the ground during sprint acceleration is more important to performance than its magnitude.

To demonstrate in a more practical way the importance of this two variables and given the example made by Morin and Samozino (2016), between two different elite rugby union players (Figure 5) with similar 20-m times (maximal acceleration from a standing start) and *Pmax* values, yet with opposite F–V profiles and *RF*.

We can clearly see that player C has higher horizontal force production capabilities (in the specific context of sprint push-off), especially at the beginning of the sprint and notably due to a higher effectiveness of ground-force application (indicated in a higher *RFmax*). However, his *DRF* is more negative, meaning his higher initial effectiveness decreases at a greater rate as speed increases. On the other hand, player D shows a different scenario, with higher velocity capabilities, which explains the higher *v0* of this player. With this findings and knowledge of each player RF and DRF, Morin and Samozino (2016) suggest that the training program designed to improve sprint performance in each of these 2 players should target different capabilities.

This way F-V and power profiles, provides useful information on sprint performance and the mechanical effectiveness of force application (Morin et al., 2011).

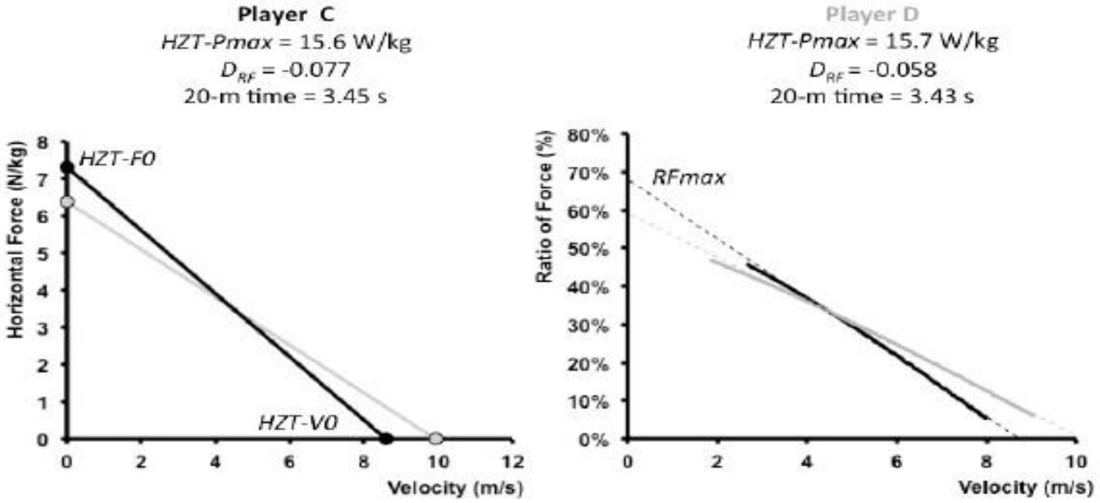


Figure 5-Horizontal force–velocity profiles of 2 elite rugby union players (body mass for C, 108.8 kg, and D, 86.1 kg) obtained from maximal 30-m sprints. Both players reached their maximal running speed before the 30-m mark. (Morin & Samozino, 2016)

Chapter 3: Methods

METHODS

3.1. Experimental design

The present work consisted of a cross-sectional design where block starting performance of male sprinters were assessed and correlated with the individual horizontal F-V-P profile. Participants were tested at the National Indoor Athletics High Performance Centre for both block starting and sprinting tests. Testing was conducted at the beginning of February, within the indoor competitive season, several months after the subjects' individual sprint training regime began. This time period was selected as it ensured that the subjects would be physically fit and present correct starting technique. In addition, testing was conducted indoor to ensure a consistent surface and to avoid any impact of wind speed and / or temperature. The sprinters were asked to maintain their normal intake of food and fluids, but to avoid any physical activity 24 hours and food 3 hours before testing. A standardized 20 min warm-up consisting of jogging, stretching exercises, skipping drills and short accelerations was performed before the sprint sessions.

3.2. Participants

Thirteen male high-level sprinters (age 23.8 ± 3.1 years; height 1.82 ± 0.04 m; body mass 77.1 ± 5.5 kg) participated voluntarily in this study. All participants were informed of the benefits and potential risks of the investigation before signing an institutionally approved informed consent. All procedures were approved by the local Ethical Board in agreement with the Declaration of Helsinki (CEFMH:24/2019). Despite experts in 100m, 400m, 110mH and 400mH, all participants had already run the 100 meters' dash (personal best 10.53 ± 0.26 s) and competed at national or international level in their main event. The 100 m personal best times were achieved prior to data collection, but not necessarily within the same competitive season.

3.3. Block start performance procedures

To determine individual block start performance, each participant performed three maximal 10 m sprints start on an indoor track, interspersed with 4 min rest. The blocks spacing and obliquity were adjusted according to athletes' personal preference, and the sprints start were performed with the own spiked shoes (**Erro! A origem da referência não foi encontrada.**). External force data were collected from each block using force instrumented starting blocks with custom-made force platforms containing four piezoelectric load cells (Kistler Instruments AG, Winterthur, Switzerland) mounted on to separate base units (Brazil et al., 2017; Willwacher et al., 2016). Force data were sampled at 10.000 Hz (post-processed to 1000 Hz), externally amplified (8-channel amplifier, Kistler). AD converted and interfaced with laptop computer running KiSprint software (KiSprint System, Kistler Biomechanics, NY, USA). Force signals were low-pass filtered (4th order Butterworth, 120 Hz cut-off) prior to analysis. Front and rear block force data were used to define the start (first derivative of the resultant force-time curve >500 $N.s^{-1}$) and end (resultant force <50 N) of the front and rear sub-phases, respectively, and these sub-phases were combined to define the total block phase. Block velocity, i.e., the resultant COM velocity at block take off was determined by integration of mass-normalized horizontal force curves with initial velocity equaling zero. Average horizontal force (FY) was calculated for the total (front + rear) force-time signals and were normalized to BW. Horizontal power was calculated from the product of the total horizontal force- and velocity-time signals, with velocity obtained through numerical integration of the total FY signal according to the impulse momentum theorem. To quantify block performance, horizontal power was then averaged over the duration of the block phase and normalized to body mass and leg length (Bezodis et al., 2010) to obtain the normalized average horizontal power (NAHP). The best NAHP obtained over the three trials was used for further analysis.

Figure 6-Overview of block start performance setup

3.4. Horizontal force-velocity-power profile

To determine individual horizontal FVP profile, each participant performed two maximal 40 m block start sprints interspersed with 10 min rest, and the fastest sprint was used for statistical analyses. Running speed was measured via dual-beamed timing gates (Microgate, Bolzano, Italy) covered the entire running course with 10-m intervals. This timing gate setup provides an appropriate criterion of validity for sprinting athletes mechanical outputs as recently demonstrated (Haugen 2018). Sprinters were instructed to start freely from a standing stance, behind the first pair of photocells, and to accelerate as fast as possible until the last pair of photocells positioned at a 40-m distance. The timing gates (10 – 40 m from the start line) were mounted on separate tripods 1.30/1.50 m above ground level, so that the photocells activation occurs at the moment the athlete's chest reached the vertical plane of the nearer edge of the line. Trigger criterion was the first occurrence of both beams being broken for each pair of photocells.

The velocity-time data were used to determine the variables of interest of the horizontal FPV profile (*F0*, *V0*, *Pmax, DRF, and RFmax*) according to the Samozino's method as well as sprint time to 40 m. The Samozino's method is a macroscopic biomechanical model that has been validated to estimate external horizontal force production during sprinting from the velocity of the COM using the inverse dynamic approach (Samozino et al., 2016). Briefly, a mono-exponential function was applied to raw velocity-time data using a custom-made spreadsheet and a least-square regression fitting procedure. From this point, the acceleration of the athlete's COM in the forward direction can be calculated from the changes in running velocity over time, and net horizontal antero-posterior ground reaction forces calculated by considering the body mass of the athlete and aerodynamic friction force. Finally, individual F-V linear relationships were generated by fitting force and velocity dataset with least squares linear regressions, and F0 and *v0* were determined as the x and y intercepts of these linear regressions. *Pmax* was determined as (F0·*v0*/4), as detailed by Samozino et al. (2016). The ratio of force was calculated as the ratio of the horizontally oriented (antero-posterior) component to the total ground-reaction force (Morin et al., 2011). *RFpeak* corresponded to the maximal value of the ratio of force (i.e. at the very beginning of the acceleration phase), and the linear decrease in the ratio of force with velocity was calculated and presented as an index of the ability to maintain high the ratio of force throughout the acceleration phase (DRF) (Morin & Samozino, 2016).

3.5. Statistical Analysis

Descriptive data are presented as mean ± SD, unless otherwise stated. The assumption of normality was verified using the Shapiro-Wilk test. Pearson's correlation coefficients (r) were used to test the relationship between dependent variables. Qualitative interpretations of the r coefficients were provided: trivial ($r < 0.1$), small ($r = 0.1–0.3$), moderate ($r = 0.3–0.5$), large ($r = 0.5–0.7$), very large ($r = 0.7–0.9$), and nearly perfect ($r > 0.9$) (Hopkins, Marshall, Batterham, & Hanin, 2009). All statistical analyses were performed using SPSS software version SPSS 26 (IBM Corp. Armonk. NY) and statistical significance was set at an alpha level of 0.05. A post hoc power analysis, using G-Power 3.1 software, indicated that for the correlation between the main dependent variables (NAHP and the main variables of FVP profile, averaged to *F0*, *V0*, *Pmax*, *RFmax*, and *DRF*), the power to detect obtained effects at the 0.05 level was 0.95.

Chapter 4: Results

RESULTS

4.1. Block start performance

The block starting performance variables for each subject are presented in Table 4, and correlations between these measures were typically moderate to nearly perfect.

The correlation between block velocity and normalized (to BW) maximal and average horizontal block power was $r = 0.58$ ($P = 0.02$; power = 0.99) and $r = 0.67$ ($P = 0.02$; power = 0.99). respectively.

Normalized average horizontal power values were correlated with the block velocity ($r = 0.65$; $P = 0.009$), absolute ($r = 0.66$; $P = 0.007$) and normalized ($r = 0.75$; $P = 0.002$) maximal horizontal force, normalized average horizontal force ($r = 0.88$; $P = 0.000$), and maximal ($r = 0.60$; $P = 0.02$) and average ($r = 0.99$; $P = 0.000$) horizontal power.

Table 4-Block starting performance data for each of the 13 sprinters

Sprinter	Block velocity (m/s)	Maximal horizontal force (N/BW)	Average horizontal force (N/BW)	Maximal horizontal power (W/BW)	Average horizontal power (W/BW)	Normalized average horizontal power (NAHP)
1	3.32	1.72	0.90	64.87	14.61	0.441
2	3.42	2.34	1.21	120.50	20.11	0.624
3	3.59	1.52	0.98	76.52	18.17	0.554
4	3.70	2.00	1.10	112.80	20.05	0.611
5	3.35	1.51	1.00	61.70	16.81	0.487
6	3.29	2.16	1.23	54.24	19.03	0.585
7	3.45	1.80	0.98	52.23	16.51	0.510
8	3.28	1.38	0.86	73.42	13.88	0.407
9	3.32	2.05	0.97	67.82	15.76	0.494
10	3.15	1.60	0.96	59.19	14.84	0.435
11	3.29	1.50	0.87	63.94	13.95	0.408
12	3.53	1.65	1.12	95.42	17.58	0.522
13	3.53	1.72	1.04	69.79	17.64	0.522
Mean	**3.40**	**1.77**	**1.02**	**74.80**	**16.84**	**0.508**
SD	**0.15**	**0.29**	**0.12**	**21.60**	**2.16**	**0.073**

4.2. Force-velocity-power profile

The magnitude of the sprinters' FVP profile variables and sprint time are summarized in Table 5.

When inspecting the data for the thirteen sprinters, the Pmax which is calculated from the product of F0 and v0, averaged values of 25.6 ± 1.4 W/Kg. Regarding the components that constitute Pmax, F0 and v0 presents means of 10.1 ± 0.4 (N/kg) and v0 10.2 ± 0.5 m/s respectively.

The other mechanical variables that are also part of the F-V-P profile, RFmax obtained in testing procedures had a value of 52.5% and DRF being -9.0%. During the sprint test procedures, 40 meters run had a times 5.04± 0.14s.

A very large significant correlations were identified between 40m time and v0 (*r*= -0.970; *P*=0.000), Pmax (*r*= -0.895; *P*= 0.000), RFmax (*r*= -0.847; *P*= 0.000) and DRF (*r*= -0.734; *P*= 0.002).

Table 5-Descriptive data (mean ± standard deviation) of the Force–Velocity–Power mechanical profile and performance variables obtained in sprinting (horizontal) testing procedures.

	F0 **(N/Kg)**	***v0*** **(m/s)**	***Pmax*** **(W/kg)**	***RFmax*** **(%)**	***DRF*** **(%)**	**40m time (s)**
Mean	10.1	10,2	25.6	52.5	-9.0	5.04
SD	0.4	0.5	1.4	1.1	0.6	0.14

4.3. NAHP and FVP correlation analysis

Pearson's correlation coefficients between NAHP and FVP profile variables (F0, *V0, Pmax, RFmax , DRF* and 40m sprint time performance) are described in **Erro! A origem da referência não foi encontrada.**.

As expected, a very large significant correlation was identified between NAHP and Pmax (*r* = 0.825; *P*= 0.000) (Figure 7). A very large significant correlation was also observed between NAHP and *v0* (*r*= 0.823; *P*= 0.000) (Figure 8). There was also found a very large association between the NAHP and the RFmax (*r*= 0.802; *P*= 0.000) (Figure 9) Interestingly, there was also a very moderate association between the NAHP and the DRF (*r*= -0.568; *P*= 0.022) (Figure 10). There was also a very moderate association between the NAHP and the 40m time (*r*= -0.848; *P*= 0.000) (Figure 11) However, no significant associations were observed NAHP and F0 (*r*= 0.235; *P*= 0.220).

*Table 6 -Correlation matrix showing r Pearson coefficients between NAHP and FVP profile variables [maximum theoretical force (F0), maximum theoretical velocity (v0), maximum theoretical power (Pmax), decrease in the ratio of horizontal-to-resultant force (DRF),maximal ratio of horizontal-to-resultant force (RFmax) and sprint performance (40m time) indicate statistical significance (*p<0.05;**p<0.01).*

	F0 **(N/Kg)**	***v0*** **(m/s)**	***Pmax*** **(W/kg)**	***RFmax*** **(%)**	***DRF*** **(%)**	**40m time (s)**
NAHP						
r	0.235	.0.823**	0.825**	0.802**	-0.568*	-0.848**
P-value	0.220	0.000	0.000	0.000	0.022	0.000

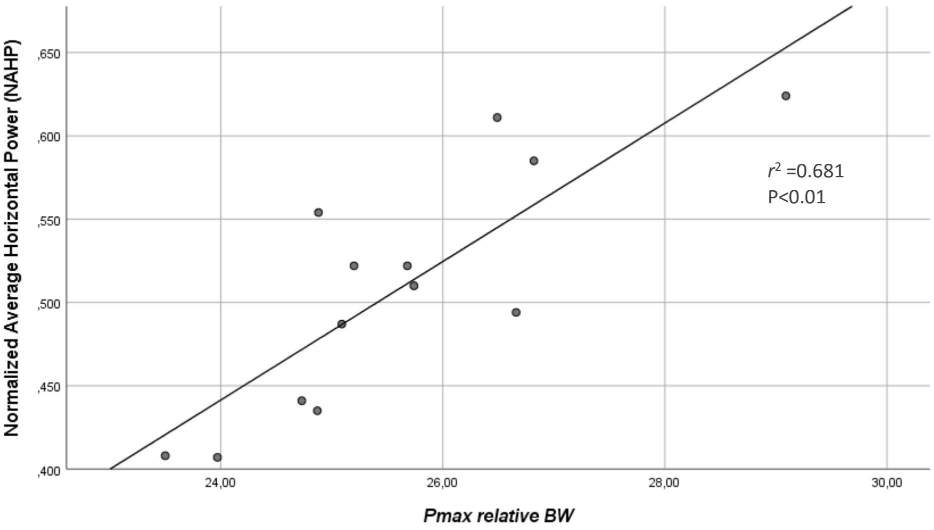


Figure 7-Pearson correlation coefficient (r) and p-value (p) between starting block performance (NAHP) and Pmax relative to BW, r= 0.825 (P = 0.000), indicates a very large positive correlation.

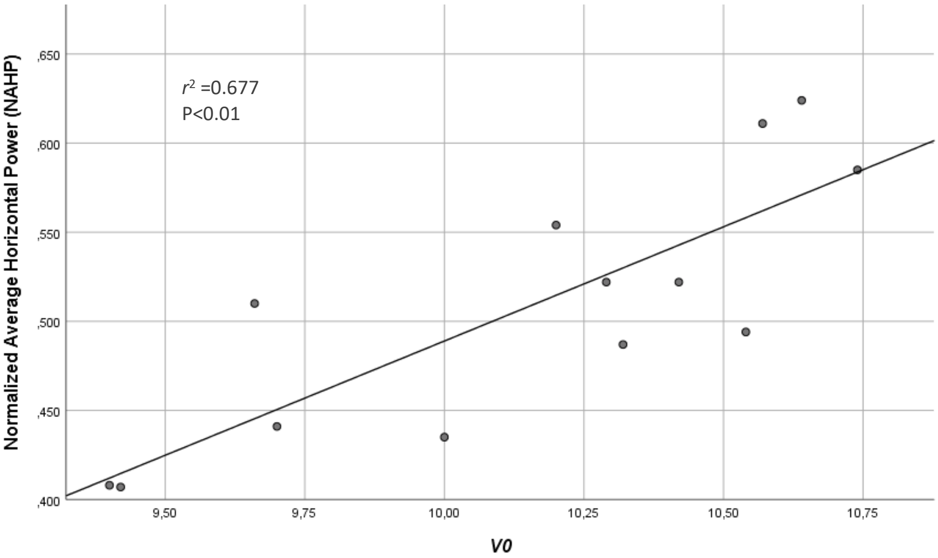


Figure 8-Pearson correlation coefficient (r) and p-value (p) between starting block performance (NAHP) and v0, r= 0.823 (P = 0.000), indicates a very large positive correlation.

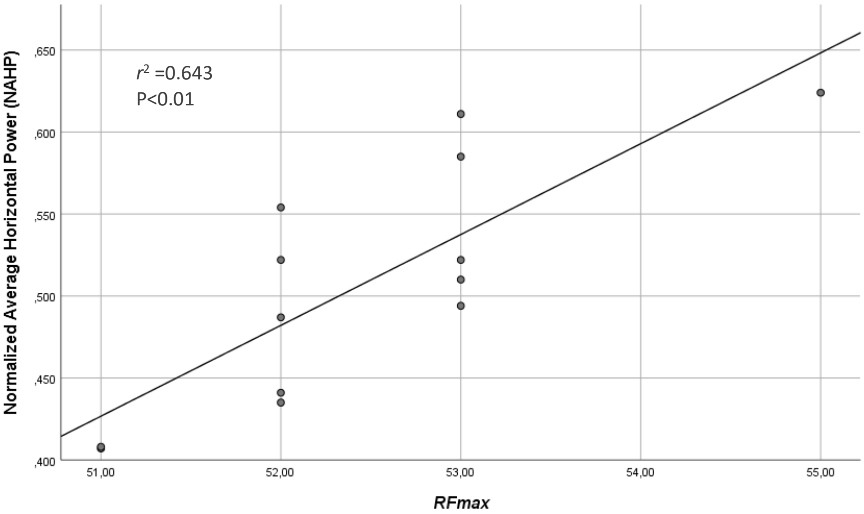


Figure 9-Pearson correlation coefficient (r) and p-value (p) between starting block performance (NAHP) and RFmax, r= 0.802 (P = 0.000), indicates a very large positive correlation.

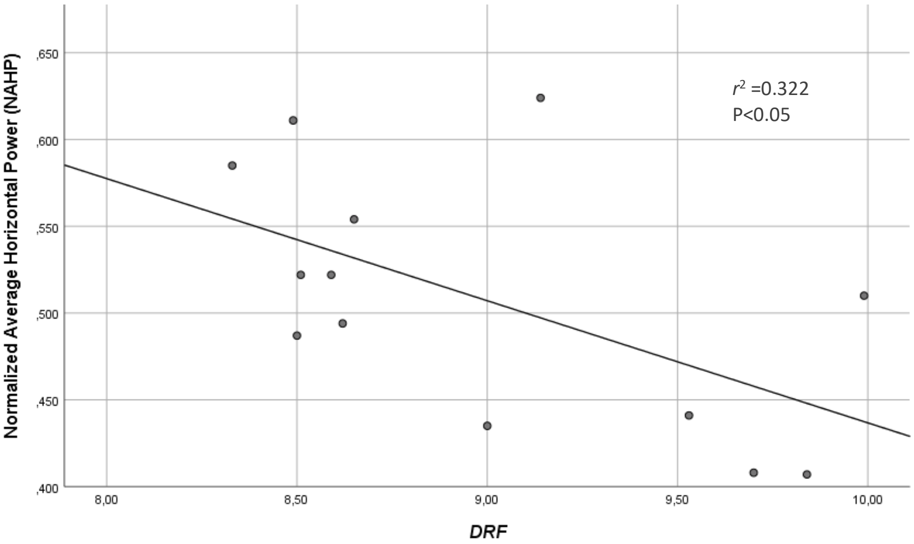


Figure 10-Pearson correlation coefficient (r) and p-value (p) between starting block performance (NAHP) and DRF, r= -0.568 (P = 0.022), indicates a large negative correlation.

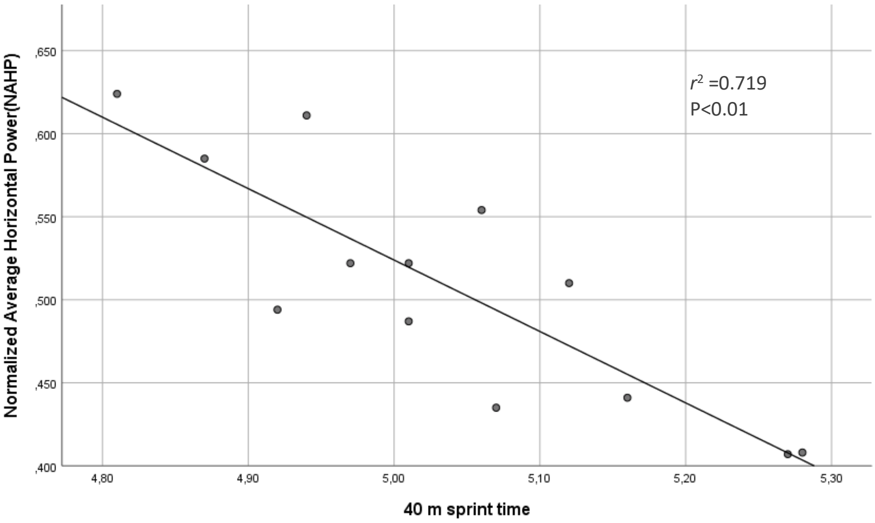


Figure 11- Pearson correlation coefficient (r) and p-value (p) between starting block performance (NAHP) and 40m sprint time, r= -0.848 (P = 0.000), indicates a very large negative correlation.

Chapter 5: Discussion

DISCUSSION

The main purpose of this study was to determine the relationship between NAHP and F-V profile variables of elite male sprinters. To the best of our knowledge, this is the first study to explore and relate starting block performance (i.e., NAHP) and F-V-P profile variables (i.e., F0, *v0*, Pmax, SFV, RF and DRF) during the acceleration phase.

The data collected from the thirteen male sprinters in a 40-m sprint allowed us to describe the mechanical characteristics of elite sprinters in the block starting and sprint acceleration phases. The main findings of this study were: (a) normalized average horizontal power was correlated with block velocity, which is a very important measure of sprinting performance; (b) there was a correlation between time at 40m and the variables *v*0, Pmax, RFmax and DRF; and (c) maximum theoretical velocity (*v0*) and maximum theoretical power (Pmax) were widely associated with block start performance (NAHP).

Block Start performance

Regarding to block start performance variables, there were correlations between NAHP and block velocity (*r*= 0.65; *P*= 0.009), absolute (*r*= 0.66; *P*= 0.007) and normalized (*r*= 0.75; *P*= 0.002) maximal horizontal force, normalized average horizontal force (*r*= 0.88; *P*= 0.000), and maximal (*r*= 0.60; *P*= 0.02) and average (*r*= 0.99; *P*= 0.000) horizontal power. This confirmed that different subject, with different body compositions, as described by Bezodis et al. (2010), influence the absolute magnitudes of power generated, and thus power data should be normalized to account for this when used as a measure of performance between subjects.

The most common measure is block velocity (Bayne, 2018; Bezodis et al., 2010; Brazil et al., 2017; Willwacher et al., 2016). However, when NAHP values were associated to block velocity, our Pearson coefficients were *r*= 0.65 (*P*= 0.009). Even if the results are slightly different (*r*= 0.88; *P*= 0.001) from those obtained by Bezodis et al. (2010), the data collected highlighted that block velocity sole measure of performance is potentially misleading. Block velocity is directly determined by horizontal impulse production, and because impulse is equal to the product of force and time, an increased block velocity could therefore be due to increase of force applied to the block or to an increased push duration, soiling the nature of an overall sprint performance (Bezodis et al., 2010; Brazil et al., 2017; Willwacher et al., 2016).

The potential influence of the choice of performance measure on the perceived ability of one single sprinter within the cohort is well illustrated by sprinter 3 (Table 6) – ranked the second-best sprinter based on block velocity, the twelfth based on maximal horizontal block force, the sixth average horizontal block force, the forth based on maximal, average horizontal external block power, and normalized average horizontal external block power. It is therefore clearly important to consider what measure quantifies, and to determine the most objective and appropriate measure of sprint start performance.

Other example is the comparison between sprinter 6 with sprinter 11, even though they have same block velocity performance (3.29 m/s), it is possible to notice differences in the other variables. Sprinter 3 had a better maximal and average horizontal force, 2.16 (N/BW) and 1.23 (N/BW), respectively and better normalized average horizontal power (0.585) than sprinter 11 (0.408). However, the last sprinter had a much greater maximal horizontal power which was a very important variable that influenced the starting block performance. With that, sprinter 11 could perform the same velocity as sprinter 3.

It is also known that sprinters with higher velocities, normally generate larger relative horizontal block impulses (Bezodis et al., 2019b; Rabita et al., 2015). These high values of horizontal impulses are typically achieved due to an increase in average horizontal force production. The increased block velocities of the faster sprinters were therefore due to an increased average horizontal force production and not to an increase in the duration of the push against the blocks (Bezodis et al., 2019b; Bezodis et al., 2010; Brazil et al., 2017; Brazil et al., 2015).

To support this notion data collected by this study, relate normalized average horizontal power values with the maximal horizontal force (r= 0.75; P= 0.002) and normalized average horizontal force (r= 0.88; P= 0.000). This finding by Brazil et al. (2015) showed a stronger correlation with performance, found for total horizontal and resultant force (r= 0.98 and 0.97, respectively, P< 0.05). In a more recent study by the same author, data base found that, by dividing average horizontal force, in front and rear leg in a multiple regression with NAHP, made it possible to understand the relationship between horizontal force production and block performance (Brazil et al., 2017). The results of this study showed an average horizontal force applied to the front (r= 0.46) and rear (r= 0.44) block, that explained 86% of the variance in NAHP. Concluding the importance of maximizing average horizontal and maximal block force for a successful starting block performance (Bezodis et al., 2015; Brazil et al., 2017; Brazil et al., 2015).

Power also incorporates the effects of force and velocity. Being a kinetic variable, power production ultimately determines acceleration (a kinematic variable), and since the overall aim in sprinting is to reach the finish in the least possible time (each sprinter must perform a specific amount of work to translate their CM horizontally over 100 m, and the time it takes to do this depends on horizontal external power production), power production is of critical importance (Bezodis et al., 2010; Haugen et al., 2020; Rabita et al., 2015).

As mentioned earlier, the capability of an athlete to generate maximal power during a sprint acceleration mainly depends : (a) his neuromuscular characteristics and musculoskeletal mechanical properties and (b) his sprint technical ability to move his body mass forward (Hunter, Marshall, & McNair, 2005).

Normalized average horizontal power values were correlated with maximal (r =0.60; P = 0.02) and average (r= 0.99; P= 0.000) horizontal power. Theoretical studies have suggested that the most preferable strategy in sprint events is one in which maximal horizontal external power is produced from the very beginning, therefore essential for performance (Bezodis et al., 2010, 2015). Furthermore, based on these theoretical data, maximal external power production also appears important during all parts of a sprint, and thus normalized average horizontal external power potentially offers an appropriate measure of performance for any stage of a sprint which is being analyzed (by trying to maximize power generation during the early stages of a sprint, or to minimize power loss during the latter stages of a sprint).

Horizontal force-velocity-power profile

To enhance sprint performance an athlete must produce large horizontal force and power in the shortest amount of time possible, from a stationary position until the first flight and stance, and continue to accelerate until he achieves maximum velocity (Bezodis et al., 2019c; Haugen et al., 2020).

The F-V-P profile is used to describe an athlete's capability to produce external forces during sprint acceleration and the mechanical effectiveness of the force application, based on the inverse linear force-velocity and parabolic power-velocity relationships that occur during maximal effort multi-joint activities (Cross et al., 2017; Samozino et al., 2016).

Regarding the correlations between sprint performance and the measured mechanical variables, the analyses of data collected in this study strengthen the previous findings by Bayne (2018), Haugen et al. (2020), Morin et al. (2011), Morin et al. (2012) and Rabita et al. (2015).

Firstly, according to Table 6, performance parameters of the block clearance phase were strongly related to theoretical maximal *v0, Pmax, RFmax, DRF* and 40m sprint measured in the forward direction and obtained from F-V and P-V relationships. Despite this important fact, the elite sprinters should be able to produce greater force during the push against the blocks, especially from the rear leg and particularly the hip (Bezodis et al., 2019a; Willwacher et al., 2016).

Thus, the maximum theoretical force (F0) showed no correlation (*r*= 0.235; *P*= 0.220) with NAHP. To support this finding, studies by Rabita et al. (2015), comparing F0 with sprinting performance, and Morin et al. (2012), comparing F0 with 4-s distance (m), for male sprinters, also found no association between F0 and sprint performance (*r*= - 0.129; P≥ 0.05 and *r*= 0.432; *P*= 0.14, respectively). Slawinski et al. (2017) also reported similar result between F0 and acceleration phase, for man and woman elite sprinters (0.24 ≤ r ≤ 0.02 and 0.09 ≤ P ≤ 0.9).

Slawinski et al. (2017) mentioned there was a limit for horizontal force production relative to body mass during accelerated sprinting. Also, Haugen et al. (2020) supported this idea by saying that F0 was a not a real maximal value of force produced by the sprinter, as the resistance in overcoming body mass inertia appeared insufficient for maximal horizontal force-capacity generation.

To support this idea, Jimenez-Reyes et al. (2018) reported F0 values in horizontal direction for male sprinters (n=15) of 8.10 ± 0.88 N/kg, and for rugby male players (n=9) of 8.90 ± 1.04 N/kg. Interestingly, although rugby players are generally heavier than sprinters players, they do produce higher F0. As an athlete gets heavier, the energy cost of accelerating mass also increases, as does the aerodynamic drag associated with pushing that wider frontal area through the air. Therefore, the results in 30-40m were as followed: sprinters showed a much better time (3.14 ± 0.10 s) then rugby players (3.29 ± 0.12s). Thus, more muscle mass and F0 is not necessarily better for sprinting, at least when there is no external mass to push.

Another study to support this theory was made by Bayne (2018) showing that elite sprinters have better Pmax and *v*0 than their sub-elite counterparts, despite a small difference in F0. These findings suggest that the ability to generate horizontal forces at high running speed was a more important differentiator between performance levels than horizontal force production at the beginning of the sprint.

Regarding to *v0*, our study showed a strong correlation with NAHP (r= 0.823; *P*= 0.000). According to the same previous study by Rabita et al. (2015) that also found a solid correlation of *v0* with block performance (*r*= 0.878) for 10-m sprint, and the correlation values grow higher with increasing sprint distance (Haugen et al., 2020).

Morin et al. (2012) also found a correlation between *v0* and 4s distance (m) (*r*= 0.841, *P*= 0.01), showing there is more relation between acceleration and *v0* then the actual F0.

As mentioned before by Haugen et al. (2020) the only resistance to consider when sprinting is air friction and the body mass the athlete has. Despite all things consider, sprinting is a low resistance movement pattern, and when related to force-velocity graphic relationship, we can understand the strong influence of maximal velocity and the small contribution of maximal force. Concluding that the aim of the push phase is to maximize Hv in as little time possible (Bezodis et al., 2019b).

To support this idea, Bayne (2018), when investigating mechanical determinants of sprint performance in elite sprinters and sub-elite sprinters in a 30m trial, concluded that the *F0* similar values, between this two groups, however when analyzing *v0,* elite sprinters were faster than their sub-elite counterparts, 10.7 (0.4) m/s and 9.9 (0.4) m/s, respectively. These values explain why elite sprinters had a faster 30 m times trail than their sub-elite counterparts (3.87 ± 0.06 s and 4.08 ± 0.13 s, for elite e sub-elite sprinters, respectively). According to this result, we can attribute a greater importance to maximum velocity.

Jimenez-Reyes et al. (2018) reported *v*0 values in horizontal direction male sprinters (n=15) of 10.3 ± 0.44 m/s and for rugby male players (n=9) of 8.62 ± 0.31 m/s. As mentioned, although rugby players are generally stronger than sprinters (8.90 ± 1.04 N/kg and 8.10 ± 0.88 N/kg, respectively). However, when comparing *Pmax* (20.7 ± 2.19 W/kg vs. 19.2 ± 2.36 W/kg) and the *v0* (10.3 ± 0.44 vs. 8.62 ± 0.31), sprinters have greater *Pmax* and *v0* than rugby players. Therefore, the sprinters showed better time in 30m sprint (3.14 ± 0.10 s) than rugby player (3.29 ± 0.12 s). Concluding the importance of *v0* and is effect on Pmax and in sprinting performance.

Therefore, the Pmax and NAHP strong correlation observed in this study (r= 0.825; *P*= 0.000) was expected. Haugen et al. (2019) mentioned that the shortest the distance the bigger correlation of Pmax with the sprint performance. Other authors had the same strong correlation between block performance and Pmax with *r*= 0.868, *P*< 0.01 (Rabita et al., 2015); *r*= 0.97 for 40m time and *r*= 1.0 for 10m time (Haugen et al., 2019); and *r*= 0.892, *P*= < 0.001 (Morin et al., 2012).

Jimenez-Reyes et al. (2019), comparing soccer and futsal players, reported values of F0 in male soccer players of 7.35 ± 0.69 N/kg, *v0* (9.25 ± 0.61 m/s), Pmax (16.9 ± 1.9 W/Kg) and for futsal players, F0 show values of 7.70 ± 0.51 N/Kg, *v0* (9.01 ± 0.43 m/s), Pmax (17.2 ± 1.4 W/kg). Even though, we already concluded the importance of *v0* in block start performance. Also, the Pmax showed a very strong correlation with sprinting performance, with increase in Pmax. That is why futsal player had better performance, either in 5m time and 20m time. This finding goes according to the study made by Bayne (2018) showing that maximum horizontal power and theoretical maximum velocity were very important and strongly correlated at the start of the sprint.

Also, the RF variable showed a strong correlation with NAHP (*r*= 0.802; *P*= 0.000). According to Rabita et al. (2015) that concluded that RF is one of the mechanical variables most highly correlated with the 40-m performance (*r*= 0.96; *P*< 0.001), and Haugen et al. (2019) that concluded that this relation is even strong the shortest the distance is (*r*=1.00 for 10m time) (Bayne, 2018).

RFmax reflects the proportion of the total force production that is directed in the forward direction of motion at sprint start (Samozino et al., 2016). According to Haugen et al. (2019) there is a perfect correlation between *RFmax and Pmax* (*r* = 1.0). Mechanically, Pmax corresponds to the peak of the power curve (i.e., the maximal product of horizontal force and velocity), hence, Pmax and RFmax are two measures with the same capability.

In a recent study made by Bezodis et al. (2019b), a very large and positive relationship was observed between *RFmax* and *NAHP* (*r*= 0.96) during early acceleration. This also supports previous evidence from the entire acceleration phase regarding the importance of RF and extends it to a specific early part of the acceleration phase (Morin et al., 2011; Rabita et al., 2015).

At last, the DRF variable reflects the sprinters ability to produce and maintain high levels of RF over the entire acceleration despite the increase of vertical force and speed increment (Morin et al., 2012; Morin et al., 2011). DRF variable showed a moderate correlation with NAHP (*r*= -0.568, *P*= 0.022).

According to Haugen et al. (2019), DRF has moderate correlation with 40m time (*r*= -0.42) and as reported by Bezodis et al. (2019b), there has also a moderate correlation between DRF and NAHP (*r*= -0.48). Morin et al. (2012), Morin et al. (2011) and Rabita et al. (2015) demonstrated that this parameter was highly related to sprinting performance. This means that the slowest sprinters, direct their ground reaction forces less effectively than the faster sprinters. However, with a higher deterioration of this ability with increasing speed.

Comparing the variables of the Horizontal force-velocity-power profile.

Comparing our sprinters' FVP profile variables and sprint time (Table 5) with Bayne (2018) sub-elite group (Table 2), duo the fact that their personal best values in 100m sprints (10,59 ± 0,16 s) are similar to our (10.53 ± 0.26 s).

Has we can see our values of F0, v0 and Pmax (10.1 ± 0.4; 10.2 ± 0.5; 25,6 ± 1.4, respectively), are in line with those of the study by Bayne (2018) (9.9 ± 0.7; 9.9 ± 0.4; 24.6 ± 2.1, respectively), except for some small differences in our favour, which allow us to explain the reason why our sprinters have a better result at 100m.

However, the results obtained by Bayne's sub-elite athletes (2018) regarding the RFmax and DRF variables (58.4 ± 2; -8.5 ± 0.7 respectively), appear to be better than those of our study (52.5 ± 1.1; -9 ± 0.6 respectively).

DRF has a difference of -0.5% compared to our study. This difference is due to the fact that in the study made by Bayne (2018) the acceleration test was done on a 30m course while ours was done on a 40m course. What he observed in our study is that in the last 10 m our sprinters continued to decrease the force values applied horizontally, or contrary to the study by Bayne (2018) that the time-speed data collection ends at 30m. With this information we can explain why values of the sub-elite group were better than ours.

The initial phase of acceleration is characterized by a great inclination of the trunk at the front, allowing the force to be applied horizontally in a more effective way, however in the data obtained in our sample we can say that our sprinters may have adopted a posture more vertical at the start of the acceleration phase. Explaining the reason why our values were lower compared to Bayne's sub-elite athletes (2018).

Chapter 6: Conclusions

CONCLUSIONS

In this study, our results showed that all the variables significantly related to the 40-m speed were also highly related with all measure of block performance (block velocity, average horizontal force, maximal horizontal force, average horizontal power, maximal horizontal power and NAHP). These results agree with previous studies that showed the essential contribution of the starting phase in the sprint performance (Bezodis et al., 2010; Brazil et al., 2015; Debaere et al., 2017; Harland & Steele, 1997; Slawinski et al., 2010).

However, despite the very good linear adjustment of the F-V profile, theoretical values of F0, showed no significant correlation with sprint performance. In contrast, the other variables showed strong correlation with NAHP, except DRF that presented only moderate correlation. These results suggested that: (a) F0 was not associated with block start because there is little resistance that had to be overcome and the time available to produce force was very short to reach maximum force, and (b) *v0* and Pmax were two important variables in sprint performance.

In conclusion, normalized average horizontal power is one of the most appropriate measure of performance, because it can be used as a performance analysis from any phase of a sprint, and also represents how much a sprinter can increase their speed and the time taken to achieve it, while accounting anthropometrics variations between sprinters.

Furthermore, with all the data related to the variables regarding the starting blocks, considering the F-V profile of each athlete and their anatomical and neuromuscular characteristics. An individualized assessment must be considered by strength and conditioning coaches, so it will be possible to optimize performance during the push phase and at the same time prevent the risk of injury.

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