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Force-velocity Profiling and sprint performance

A narrative review

Bachelor's thesis in Human Movement Science
Supervisor: Gertjan Ettema
March 2024

Bachelor's thesis

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Abstract

Background: Sprint performance is ultimately determined by how fast an athlete runs. Time will always be the gold standard for measuring how good a sprinter is. For an elite level sprinter more variables are needed to evaluate a performance. In this study we aim to analyze the biomechanical factors in sprinting with emphasis on how implicating force-velocity profiling can aid athletes in their strive for faster top running speeds. **Methods:** Using the PubMed database, we conducted a literature search which yielded 408 articles, 5 of these were included as our original articles. The remaining 3 articles were found by a manual search through reference lists of relevant articles, resulting in 8 original articles. **Results:** Our original articles show that force-velocity profiling does not give enough information to accurately predict the performance outcome of a sprint. Its strengths lay in the profiling of an athlete to create an accurate overview of where improvements can be made in training to increase performance output.
Conclusion: Force-velocity profiling can serve as a contributor for sprint-analyzation but lacks evidence of being a main variable to tailor training for optimizing sprint performance.

Abstrakt

Bakgrunn: Sprintprestasjon bestemmes av hvor fort en utøver løper. Tidtakning vil alltid være gullstandarden for å måle hvor god en sprinter er. For en sprinter på elitenivå er det nødvendig med flere variabler for å evaluere en prestasjon. I denne studien vil vi analysere de biomekaniske faktorene i en sprint med fokus på hvordan kraft-hastighets profilering kan hjelpe idrettsutøvere med å oppnå høyere topphastighet. **Metode**: Ved hjelp av PubMed-databasen gjennomførte vi et litteratursøk som ga 408 artikler, 5 av disse ble inkludert som våre originalartikler. De resterende 3 artiklene ble funnet ved et manuelt søk gjennom referanselister i relevante artikler, dette resulterte i 8 originalartikler. **Resultater**: Våre originalartikler viser at kraft-hastighet profilering ikke gir nok informasjon til å nøyaktig forutsi resultatet av en sprint. Profileringen kan hjelpe utøverne med å skape en oversikt over hvilke forbedringer som kan gjøres for å oppnå bedre resultater. **Konklusjon**: Kraft-hastighet profilering kan være et verktøy for sprint-analyse, men treningsplanleggingen bør ikke sentreres rundt profileringen.

Keywords: Athletic training, Biomechanics, Sprint training optimization, Force platform

1. Introduction

Sprint running is defined as increasing velocity from 0 to max. In this study we will conduct our research based on sprint performance at ≤100-meters. Increasing velocity is determined by acceleration (a) over time (t) (V=a*t). To alter the velocity from a static position into maximum velocity (Vmax), the athlete needs to produce maximum propulsive force. Force (F) is a product of mass (m) multiplied by acceleration (a) (F=m*a). Producing propulsive force becomes harder to do when approaching Vmax. To keep accelerating, a higher ratio of force (RF) is needed. RF is the horizontal force divided by resultant force. Resultant force is measured using a force plate. The resultant force is the net amount of force produced. To calculate force related to sprint performance the RF is of larger importance than resultant force. RF is set to establish the value of effective force output (1).

Force and velocity largely determine the sprint performance of the athlete (2). Collectively they form the Force-velocity profile (FvP). Individual correlation between force and velocity based on the collected data can be visually represented through graphs. The visual representation of FvP relationships is often described as either a hyperbolic relationship or a linear regression, see *figure 1*.

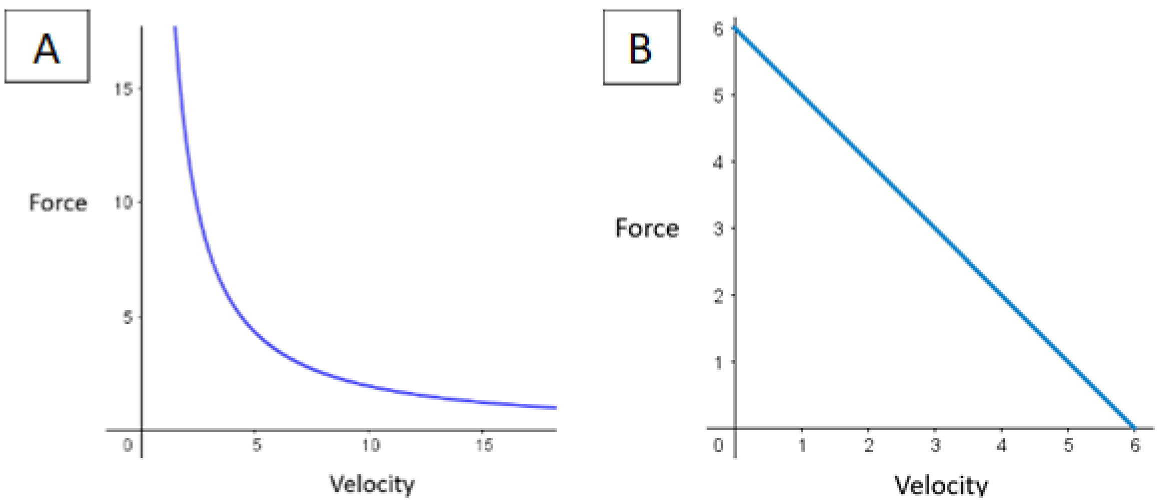

Figure 1- Example of a F-v relationship through a hyperbolic (Hills) curve (panel A). Example of a F-v relationship through a linear regression (panel B).

The individual FvP can be analyzed to further extend the knowledge of individual sprint performance and used to optimize training. To understand and utilize FvP in training one should have a basic understanding of power (P). Power is the force multiplied by velocity. It can be maximum power (Pmax) or an average (Pavg). Power is a vital component of a sprint performance and is often described as one of the main determining variables. Altogether, this forms the mechanical effectiveness in the horizontal direction (3).

Effective force is the ratio of force (RF) in horizontal direction (4). Collectively, force, velocity and power form the horizontal ratio of force (Drf) relationship (5). These determining variables contribute to the sprint outcome and can be analyzed for a greater understanding of sprint performance. In this study we will form a summary of the findings around FvP, the use of the profile, and how it's related to sprint performance.

F-v profiling is used as an analytical framework within sports science, aimed at interpreting the dynamics between an athlete's capacity to generate force and creating velocity (6). This profile sheds light on an athlete's current performance spectrum, highlighting whether they have a predilection towards force generation or if they are more efficient in creating high velocity. This can be used as potential pathways for tailored training programs (7). The direct relation between F-v profiling and sprint performance remains a subject of ongoing research. It suggests that understanding these variables can offer insightful perspectives into optimizing training strategies and plans to improve an athlete's strengths or reduce their weaknesses. However, F-v profiling is not undisputed, as it is a mathematical way to analyze the relationship between force and velocity. Sprinting is not considered an independent tasked demanded sport and the FvP will be a result of sprinting performance (8). The imbalances shown by the FvP might encourage trainers to improve the athlete's low performing traits, while it could lead to relinquishing some well-established elements (8).

Using an athlete's FvP when approaching training adaptations opens for the possibility for customizing the training regiments with individual physiological predispositions. The potential of such tailored training interventions lies in the ability to precisely target the specific components of an athlete's performance needing improvement. Whether it is force production for better acceleration or velocity for sustained speed. However, the extent to which F-v profiling can lead to performance improvements is still subject to empirical debate (8). The method offers a framework for potential performance optimization, yet its efficacy is dependent upon further validation through comprehensive research and practical application (9). The existence of an optimal FvP, and how it should be represented is subject of ongoing research. Some studies claim that it should be a linear regression, and some say it should be a hyperbolic (Hill-type) curve, (see *figure 1*). Optimization of the FvP is therefore a hot topic in the sport scene and forms the question; is there a universal and optimal FvP and should you program your sprint-training respectively?

2. Method

The literature search for this study was conducted on January 28, 2024, using the PubMed database. The search terms employed to identify relevant articles were as follows: "Force-Velocity profiling" (276 results), "Force-Velocity and accelerated running" (79 results), and "Sprint training for world-class athletes" (53 results). Subsequently, a manual search was conducted through the reference lists of relevant articles to identify any literature that may have been excluded by our initial search criteria. In total, eight original articles were included in our review, with five sourced from PubMed and three identified through our manual search.

2.1 Inclusion- and exclusion criteria

When selecting studies for inclusion in our research, we applied a set of inclusion and exclusion criteria to ensure that our findings would be relevant and rigorous, see *table 1*. We opted to include studies that specifically focused on our central research objectives. Mainly focusing on Force-velocity Profiling, sprinting and acceleration. When choosing articles to exclude we decided that studies that primarily focused on gender differences, systematic reviews and meta-analyses did not align with our area of research. We employed these criteria with the intent of ensuring that the included studies would be relevant and reliable, thus contributing to making our research outcome more robust.

Table 1: Inclusion- and exclusion criteria for original articles

Inclusion	Exclusion
Clinical Trial, randomized control trial (RCT), observational-, cross-sectional-, experimental-, simulation- and validation studies	Systematic reviews and meta-analysis
Objective measurements	Subjective measurements
F-v profiling	Physiologically specific
Acceleration	Biological factors
Sprint (≤100meters)	Sprint (>100meters)
Full text (Free)	

3. Results

Eight original articles were included in this study to understand important mechanical variables and the use of F-v profiling for sprint running. The articles examine different aspects of the FvP, such as use, importance of mechanical parameters and how to collect data for profiling. *Table 2* presents a short summary of the eight different original articles. The main findings from the articles will be described in more detail below.

Table 2: Overview over original articles

ARTICLE	STUDY DESIGN	N, (M+F) LEVEL (N)	STUDY AIM	MAIN FINDINGS
Rabita et al. (2015)	Cross-sectional study	9 Elite (4) sub-elite (5)	**"***Characterize the mechanics of maximal running sprint acceleration in high-level athletes.* **"**	Sprint and acceleration are determined by resultant force, rather than the total ground reaction force (GRF).
Samozino et al. (2022)	Simulation study	230 Unknown (230)	*"The aim was to determine the respective influences of sprinting maximal power output (PH max) and mechanical Force-velocity (F-v) profile… on sprint acceleration performance."*	Maximum power output and a force dominant F-v profile correlated to a better acceleration (<30 meters).
Lindberg et al. (2021)	RCT	40 Elite (30) Sub-elite (10)	*"… examine the effectiveness of an individualized training program based on force-velocity (FV) profiling…"*	Force oriented- and balanced F-v oriented training yielded better training progression compared to velocity-oriented training.
Healy et al. (2019)	Observational study	82 Elite (82)	This study aimed to "*assess the roles of key sprint parameters with respect to 100-m sprint performance."*	Higher acceleration and maximum velocity were strongly correlated to a better sprint performance.
Weyand et al. (2000)	Experimental study	33 Sub-elite (33)	Testing the "h*ypothesis that top running speeds are determined by the amount of force applied to the ground rather than how rapidly limbs are repositioned in the air*"	Force output is of greater importance for sprinting than faster cadence.
Slawinski et al. (2017)	Observational study	70 Elite (70)	"*This study aimed to compare the force (F)–velocity (v)–power (P)–time (t) relationships of... world- class sprinters."*	Horizontal force production at high velocity is important to maintain peak velocity.
Samozino et al. (2016)	Validation study	9 Elite or sub-elite (9)	*"This study aimed to validate a simple field method for determining force– and power–velocity relationships and mechanical effectiveness of force application during sprint running"*	A validated and reliable method to calculate FvP without the use of force-plates.
Haugen et al. (2019)	Cross sectional study	666 Elite (666)	"*The main aim of this investigation was to quantify differences in sprint mechanical variables across sports and within each sport.*"	Sprint mechanical variables vary between athletes and their respective sports.

1. **Rabita et al. (4)** researched human mechanics in sprint-running during maximal sprint acceleration. 9 male subjects were divided into two groups: elite sprinters (n=4) and sub-elite sprinters (n=5). They conducted a virtual 40-meter sprint based on 7 trials. Ground reaction force (GRF) was recorded by using a force plate. From those values a ratio of force (RF) was calculated. RF was described as an effective force for sprint and acceleration in horizontal direction. The conclusion was that a total GRF did not relate to a better acceleration. Rather a larger RF was shown to be the main determining factor to a better acceleration.

2. **Samozino et al. (10)** collected 230 subjects from different sports to further analyze the relationship between FvP and Pmax. Individual physical performance was collected to conduct simulated sprint trials. Each individual athlete had different F-v profiles and a Pmax based on their respective sport. Results were then calculated for acceleration (<30 meters) and sprint (>30 meters). The main takeaway was that a higher Pmax and a more force oriented FvP resulted in a greater acceleration (<30 meters). Velocity had a gradually increasing importance at longer distances, suggesting that the velocity-oriented athlete performed progressively better at increased distances.

3. **Lindberg et al. (9)** aimed to "*examine the effectiveness of an individualized training program based on force-velocity (F-V) profiling on jumping, sprinting, strength, and power in athletes*." They tested 40 subjects at national level from handball, ice-hockey, and soccer. The subjects performed squat jump (SJ), 10- and 30-meter sprint, counter movement jump, 1RM leg press- and 1RM squat- test. They all got an estimated optimal FvP after performing SJ with different loads. The subjects were divided into groups where they trained with respect to the FvP through a 10-week training period. The athletes were divided into three subgroups. The groups were instructed to train toward, away, or irrespective of their theoretical optimal FvP. After the 10-week period the subjects performed the same tests as prior. Regardless of the

tailored training program, a greater improvement was shown in the subgroup focusing on force-oriented training. Implying that a training program regardless of the FvP should be based on a force-oriented split to improve the power output. Based on this study athletes should train to optimize power output, since it showed a larger progression than trying to optimize the FvP.

4. **Healy et al. (2)** conducted an in-depth analysis of 82 elite male 100-meter sprinters, aiming to assess the precision of a modeling method using 4-split times to generate velocity-time and velocity-distance curves. In addition, the analysis aimed to identify the difference between the faster and slower runners. The study showed a strong correlation between maximum velocity and sprint performance. The analysis also showed that the fastest sprinters were able to maintain a higher velocity and acceleration than their slower counterparts in the final stretch of the sprint. They concluded that maintaining high RF is pivotal for a good 100-meter sprint performance.

5. **Weyand et al. (11)** conducted a study to investigate whether achieving faster top running speeds is primarily influenced by the runner's ability to apply great ground force or if the speed of which the runner repositions its limbs is the determining factor. Using a treadmill-mounted force plate, the participants tested their maximal running speed on flat terrain, on a decline and incline treadmill. The results indicated a significant correlation between the applied force-to-body weight ratio and top running speed, with runners achieving faster speeds showing greater ground force application. At the same time, the test showed no significant difference in speed of limb repositioning. The study suggests that faster top speeds in human runners are primarily attributed to applying greater forces to the ground rather than repositioning limbs more rapidly in the air.

6. **Slawinski et al. (12)** conducted a study to understand the relationship between different mechanical outputs (force, velocity, power and time) that affects sprint performance. 70 subjects participated. Data from the distance-time curve for 100

races were obtained. Performance was calculated from the race based on the 100m time split minus the reaction time. The study concluded that producing an adequate horizontal force to maintain peak velocity through the final stage of the sprint is more important than producing high horizontal force during the start of the acceleration phase.

7. **Samozino et al. (7)** created a mathematical method to calculate the F-v relationship without the use of force plates. To validate his own method, he created a test using nine elite/sub elite subjects. The subjects performed seven sprints on force plates connected in series to collect F-v data. He compared the collected data obtained using force plates to his own calculated results. His method showed to be both valid and reliable compared to the gold standard; Force plates. Therefore, it is greatly used as a method to calculate FvP using simple field tests. The validity and reliability of his method relies on precise measurements, but has been proven effective when done with meticulousness.

8. **Haugen et al. (6)** conducted a cross-sectional study to understand sprint mechanics in different sports. Collecting data from 666 elite athletes from 23 different sports. They were tested in a 40 m sprint. Anthropometric and speed-time data were collected and used to calculate different force, power and velocity variables. The main conclusion was that a higher amount of force and power in horizontal direction was strongly correlated to an increased acceleration. Force and power were dependent on sport and individual differences. Sprint associated sports produced greater values for FvP variables. Same sport athletes also recorded individual differences in FvP values. The findings of this study implies that the sprint mechanical variables are based on the respective sport and the individual athlete. Therefore, coaches are encouraged to optimize the athlete's FvP based on the individual and its respective sport.

The findings from our eight original articles highlight the interplay of different variables resulting in the overall sprint performance. The main variables described by our articles consist of force, velocity, FvP and power and their applications towards tailored training and optimal sprint performance. The impact of force production for increased acceleration was greatly agreed by Rabita et al. (4), Haugen et al. (6) and Samozino et al. (10). Force production was shown to be of larger importance than velocity when tailoring training towards sprint performance (6,9). Power was also described as an impactful variable to increase acceleration (10). The relationship between force production and velocity contributes collectively to form a FvP and should be based on the individual (6). Slawinski et al. (12) and Rabita et al. (4) concluded the importance of RF in horizontal direction, both in the acceleration and velocity phase. Acceleration and velocity are the main factors resulting in sprint performance (2). The discovery of field-based data collection from Samozino et al. (7) made it possible to form a FvP without the use of force plates. Making use of FvP in training more accessible for athletes and coaches regardless of available resources.

4. Discussion

Through a systematic review of eight original articles, we have introduced and identified the importance of the FvP. In this discussion we will obtain further insight into the optimal use of FvP for sprint performance, and consequently how FvP can help create tailored training for both elite- and sub elite athletes. By covering the impact of individual differences between athletes and their respective sports we will explore how FvP can be used as an analytical tool for both coaches and athletes. Our main aim is to discuss and conclude if there is an optimal FvP for sprint performance and if sprint training should be programmed respectively.

The FvP can help to identify strength and weaknesses based on collected force and velocity data. It offers an opportunity to dictate how each athlete could tailor training for optimal sprint performance. The results from Lindberg et.al (9) concluded that training in respect to an optimal FvP was not beneficial. Rather force/power optimized training resulted in better performance for short sprints. Samozino et al. (10) concluded that a higher maximal force production and a force oriented FvP is optimal for acceleration at shorter distances (<30 meters). When sprinting beyond 30 meters, having a velocity oriented FvP seems to be gradually favorable to maintain high speed for longer durations. Based on the gradual importance of velocity it seems to be important to collectively improve both velocity- and force outputs. Improving force production through training is generally easier than enhancing velocity (9). Velocity training seems to rely heavily on sprint technique, while force production is mainly improved by strength training (10).

Slawinski et al. (12) emphasized that producing horizontal force at high velocities is more important than producing high amounts of horizontal force during the acceleration phase. Keeping peak velocity with a sustained power output is optimal for improved performance (10). The importance of acceleration will decrease over longer distances, as velocity mainly peaks at 4 seconds. Acceleration and velocity are the main factors in total sprint performance. Attaining peak velocity as efficiently as possible though acceleration and keeping attained velocity will dictate the performance of the sprint (2).

Values such as; power, force and reaction time will contribute to the outcome of an athlete's performance, since they result in attained acceleration and velocity (12). These values contribute to the total RF used effectively. RF is defined as how much of the total GRF the athlete uses productively to produce horizontal force in the positive direction (4). GRF data is mainly collected by the use of force plates. The measurement is greatly used to obtain data towards sprint performance, by analyzing force output data. This data differs between the specific force plates. Some force plates have the capability to measure horizontal force and are therefore more suited to collect data towards sprint performance than less advanced force plates (13).
RF is generated during the acceleration-and velocity phase. The importance of RF through the acceleration-phase is to further extend the peak velocity. Sprint performance is greatly determined by the velocity reached and the ability to keep generating enough RF to sustain it. The ability to refrain from a negative acceleration is crucial for a sprinter. To counteract receding velocity, the athlete needs to produce enough RF in positive direction to sustain high velocity throughout the final stages of the sprint.

To conduct the FvP in a practical situation, one should analyze the sport specific qualifications such as; sprint distance, force and velocity capabilities and biomechanical adaptations (10). Haugen et al. (6) emphasize the importance of individualizing the profile due to differences in athletes and among sports. The task demand of each sport varies in the requirements of mechanical variables, meaning that an optimal FvP will vary across different sports. In the study from Lindberg et al. (9), the optimal FvP was calculated from SJ with different loads. Each subgroup trained according to their optimal FvP. The validity from the FvP based on SJ is not correlated to sprint outcome. SJ mainly measures vertical force production and is not validated and transferable towards sprint performance. The importance of producing RF in a horizontal direction is the main factor for sprint performance.This implies that the use of F-v profiling needs to be sport and task specific to optimally address the weaknesses an athlete needs to improve for a better performance in their specific sport.

To improve the combination of force and velocity values, one can implement an optimal loading regime directed towards maximal power output (14). Cross et al. (14) identifies the lack of research on optimal training strategies for sprinting when aiming towards power development, while highlighting that training with heavier loads (E.g. sled device) might improve sprint running performance. Cross et al. (14) also mentions the importance of individualizing exercise programming based on FvP and Pmax qualities. Two athletes that express similar Pmax values could illustrate two distinctively different F-v relationships. Assessing FvP in addition to Pmax when designing an individualized training program focused on improving sprint acceleration performance, may allow for more efficient and finely adjusted training protocols (10).

Research conducted by Jimènez-Reyes et al. (15) and Haugen et al. (6) suggested that FvP should be individualized and task specific for optimal usage. As concluded by Loturco et al. (16) the force plate can measure data from maximal force and velocity to form a valid FvP towards sprinting. Jimènez-Reyes et al. (15) suggests that FvP should be conducted and used specifically to the respective field. A sprinter should collect data as validly as possible towards the sprint race in which the athlete will compete. A further analysation of F-v output can help create a training program to optimize the progression of sprint performance. To get an understanding of the F-v relationship in relation to overall performance, one can use the method by Samozino et al. (7). This field based method suggests that the force plate isn't necessary, making it more accessible to obtain a validated and reliable calculation without extensive equipment. Force plates are still superior in accuracy to obtain an optimal FvP. Even with a cost-efficient method, the elite athletes will still opt towards the use of force plates to accumulate data and optimize sprint performance (17).

FvP data needs to be collected by validated tests which can formulate an approach with reliability for the athlete to further use in the programming. It is important to collect data individually as each athlete has an own optimal force-velocity-power exchange. Improving velocity has been proved to be difficult. Force and power (F&P) have shown to be easier for the athlete to improve (9). Both F&P are strongly related to a better acceleration (10). By utilizing this information, it concludes that sprinters greatly benefit from increasing their F&P output to be able to generate high RF for a maximum acceleration (4). Complimentary, producing high RF through the velocity stage enables the athlete to maintain high velocity. The acceleration- and velocity phase combined with RF production ultimately determines the sprint performance (2,12).

The optimal FvP is shown to be both task- and individually dependent as previously shown by Jimènez-Reyes et al. (15) and Haugen et al. (6). Samozino et al. (10) described the use of FvP to program training this way; "This *can then be used to orient training modalities to improve the maximal power output while orienting the F-v profile closer to the optimal one by focusing training of horizontal force production at low or high sprinting velocities, or throughout the entire velocity spectrum*." (10). By opting towards a force- or velocity-oriented profile, the athlete is expected to exceed in performance by adjusting towards an optimal- task specific profile. The findings from Samozino et al. (10) implies that the athlete can expect improved acceleration by increasing force- and power output. Further extending the topic of an optimized FvP. Ettema (8) discussed the obsession towards attaining an optimal FvP and concluded that the chase towards attaining a perfect FvP is a "dead end" (8). Athletes spend time and money on the best resources to accumulate FvP from force plates and tailor specific training regimens respectively. By neglecting other determining variables (technique, reaction time, power), the athlete can limit its progression while trying to attain an optimal FvP. The main findings from current research suggest that there is no such thing as a task specific FvP, rather it needs to be both individual- and task specific.

Utilizing the information collected in this study, it suggests that the use of FvP isn't universal, but largely dependent on the individual athlete. Using the FvP as the main source for tailoring training has not been proven optimal, but can still be used as a guidance to modify the training program. The optimization of FvP and programming the training respectively, is both time and cost dependent. Ettema (8) described the FvP for sprinting as a "*dead end*" (8). The article suggested that the analytic approach towards an optimized FvP could lead to sacrificing other traits for sprint performance. The utilization of information can overcomplicate basic sprint training principles. Analyzing sprint training can be done by looking at time-lapse, videos, or other variables who neither take a lot of time nor money.

As the FvP provides information on the athletes performing attributes, it might misguide coaches to put too much emphasis on training towards the low performing. This can result in decreasing an athlete ‘s well performing attributes or other important traits for sprint running performance (8). Structuring a balanced training regime which attends a full spectrum of important sprint variables will be more beneficial to an athlete’s overall performance (9). The independent stages of a sprint lack accuracy, as most of the obtained data is achieved by analyzing the sprint performance through a mathematical equation (8).

5. Concluding remarks

Collectively, these studies suggest that there are some benefits by utilizing FvP to optimize the athletes training but have lacking evidence of being a valid tool for enhancing performance. FvP cannot be used to accurately predict sprint performance since the results conducted from recent studies suggest that the benefit lies in an analytic approach of empirical data. Predominantly the data is based on lab tests, and not sprint performances in competition. Which means that it’s not a valid indicator of overall sprint performance in practical use. In many cases effective force is not correlated to the FvP-results, because the FvP data is often conducted from tests that lack validity towards sprinting. The basic equation behind the athlete’s performance is the amount of RF produced to maximize acceleration and velocity throughout the sprint. The sprint performance is most accurately measured using time-lapses and not by data collected from force plates. For the data to be valid, it must be analyzed throughout the sprint and collect data from variables such as; force, velocity, reaction time and technique. Using force plates to measure sprint performance will not give an adequate amount of data to be able to predict the outcome of the sprint. Therefore, the main conclusion is that the FvP is an estimation, but not a valid dictator of overall sprint performance. Concluding that there is no universal FvP and that the athlete should refrain from using the FvP as the main foundation for tailored training.

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