Methods of evaluating the force-velocity profile through the vertical jump in athletes: a systematic review

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Summary

Introduction: In the world of sport, the ability of humans to develop maximum muscular power (Pmax) is directly related to performance and sporting success. For this, the measurement of the force- velocity profile (F-v) plays a key role in the evaluation of the athlete. At present, there are different methodologies and technologies to assess this profile, with sprint and vertical jump being the most used forms. The objective of this review is to identify and analyze different methods and tools for assessing F-v profile through the vertical jump.
Methods: A search was carried out on the following databases, PubMed, SPORTDiscus, and Web of Science, of papers published between January 2010 and August 2017. The search terms were as follows: strength, speed, profile, vertical jump, squat jump (SJ), countermovement jump (CMJ), sports, strength training, resistance training, and all possible combinations of the above. Methodological quality was assessed using the PEDro scale.
Results: Nine out of a total of 254 articles met the criteria for inclusion: six of them evaluated the F-v profile using a force platform, while three used the photocell system. Analysis of their evaluation methods revealed that of the six studies using the force platform, one used the SJ as an assessment measure, two used the CMJ and three used both methods; all three studies using the photocell system used the SJ as the method of assessment.
Conclusion: The instruments most often used to evaluate the F-v profile are the force platform and the photocell system. Nevertheless, other new and interesting technologies exist that are capable of evaluating the vertical jump. for example, through mobile applications.

Key words:
Muscular power. Assesing force-velocity. Vertical jump.

Métodos de evaluación del perfil fuerza-velocidad a través del salto vertical en deportistas: una revisión sistemática

Resumen

Introducción: En el mundo del deporte, la capacidad que tiene el ser humano para desarrollar la máxima potencia muscular (Pmáx) está directamente relacionada con el rendimiento y éxito deportivo. Para ello, la medición del perfil fuerza velocidad (F-v) cumple un rol clave dentro de la evaluación del deportista. En la actualidad existen diversas metodologías y tecnologías para valorar este perfil, siendo el sprint y el salto vertical las formas más utilizadas. El objetivo de esta revisión es identificar y analizar diferentes métodos e instrumentos de evaluación del perfil F-v a través del salto vertical.
Método: La búsqueda se realizó en las siguientes bases de datos: PubMed, SportDiscus y Web of Science, entre enero del 2010 hasta agosto del 2017. Los términos de búsqueda fueron los siguientes; Fuerza, velocidad, perfil, salto vertical, Squat Jump (SJ), Countermovement Jump (CMJ), deportes, entrenamiento de fuerza, entrenamiento de resistencia y sus posibles combinaciones. La calidad metodológica fue evaluada a través de la escala PEDro.
Resultados: Nueve de los 254 artículos encontrados cumplieron con los criterios de inclusión al estudio, de los cuales, 6 evaluaron el perfil F-v a través de una plataforma de fuerza y 3 mediante el sistema de fotocélulas. En el análisis de los métodos de evaluación, de los 6 estudios que evaluaron el perfil F-v con plataforma de fuerza, uno lo hizo a través del SJ, dos a través del CMJ y tres utilizaron ambos métodos, mientras que de los tres estudios que valoraron el perfil F-v con el sistema de fotocélulas, todos usaron el SJ como método de evaluación.
Conclusión: Los instrumentos más utilizados para la evaluación del perfil F-v son; Plataforma de fuerza y fotocélulas, sin embargo, existen nuevas tecnologías capaces de evaluar el salto vertical, por ejemplo, a través de aplicaciones móviles.

Palabras clave:
Fuerza Muscular. Evaluación. Fuerza-Velocidad. Salto Vertical.

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Introduction

The vertical jump is an important factor in sports performance, due to its ballistic and explosive character.[1] The object of this rapid, high speed movement is to accelerate an internal or external mass in the least possible time.[2] The acceleration of body mass depends on the ability of the neuromuscular system to generate power,[3] which in turn is understood as the combined product of maximum strength and speed to generate movement through muscle contraction.[4] This relationship is known as the force-velocity profile (F-v),[5] and has three variables: maximum theoretical force at zero speed (F0), maximum theoretical velocity at zero load (V0), and maximum power (Pmax). These three variables represent the maximum capacity of the lower extremities to develop strength, power, and velocity.[6]

An F-v profile shows the balance that exists between the force and speed (SFV) of an athlete, and is tested by jumping with loads to reveal either optimal balance (Sfvopt) or imbalance (FVimb) between both variables.[7] Both results are determined by the slope of the F-v.[8]

In both cyclical and acyclic sports, the ability to generate high levels of mechanical power during the jump and sprint plays a determining role in the performance of the athlete.[9] The ability to generate power is determined by a series of mechanical, morphological, and neural factors that are related to each other.[6] Of particular importance are type of muscular action[10,11] execution time,[12,13] interaction between elastic-contractile components,[14,15] stretch reflex,[16] type of muscle fiber,[13,17] cross-section area,[11] recruitment of motor units,[18-20] firing frequency,[20-23] and intermuscular coordination.[24-26] However, in addition to knowing the level of mechanical power it is important to determine the F-v profile; this reveals the FVimb, through which it is possible to identify an athlete's mechanical deficits in order to schedule training and/or rehabilitation to reduce the FVimb and achieve Sfvopt.[7]

A wide range of methods, evaluation techniques, and tools are used to evaluate the Pmax of the F-v profile through the vertical jump, the gold standard being the force platform.[27,28] At the same time there are other instruments, such as the photocell system,[29,30] contact mats,[28,31,32] and now mobile applications,[33-35] not to mention other methods such as the sprint.[36]

F-v and Pmax are evaluated through the vertical jump since it is one of the most common actions performed in sport.[28,37] Irrespective of the method used, the important thing is that the measuring device is valid and trustworthy.[38]

The problem is that many of the technologies and methods used to evaluate athletes are unaffordable for the vast majority of professionals working in the field. Therefore, the objective of this review is to identify and analyze different methods and tools for assessing the F-v profile of sports people through the vertical jump, in order to clarify and identify effective assessment tool options for use in sports performance, injury prevention, and/or rehabilitation and reintegration.

Methods

Literature Search Strategy

To carry out the review, the following databases were used: PubMed, SPORTDiscus and Web of Science. The keywords used during the search were: Force, Velocity, Profile, Vertical Jump, Squat Jump, Countermovement Jump, Sports, Strength training, resistance training, and all possible combinations.

Selection criteria

The inclusion criteria were as follows: a) clinical papers published between January 01, 2010 and August 31, 2017; b) subjects were men and/or women older than 18 years who participate in cyclic or acyclic sports, regardless of whether or not they are prominent sports people; c) interventions include any type of method or instrument for evaluating the profile F-v through the vertical jump; d) articles are written in the English language.

Interventions that used the sprint to measure F-v profile were excluded, as were chapters of books, summaries of congress papers, and doctoral theses.

Evaluation of methodological quality

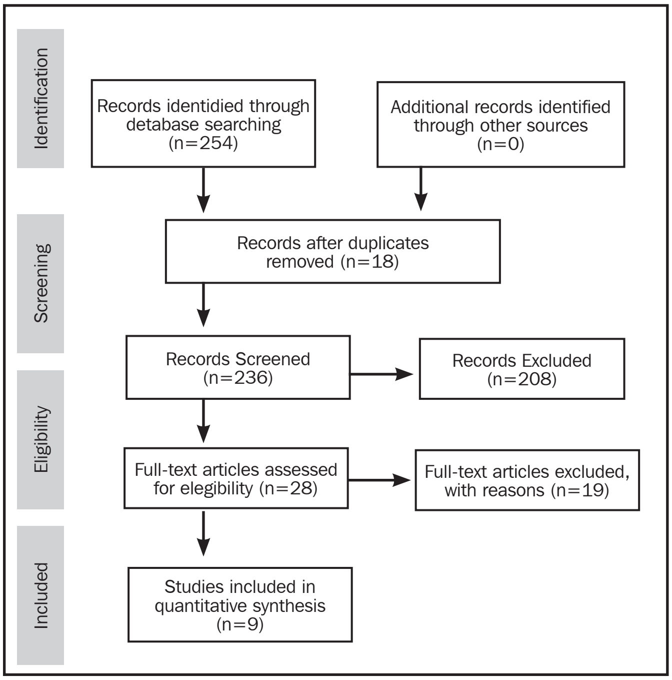
The methodological quality of the studies was assessed using the PEDro scale (Table 1), which uses 11 criteria to determine the internal

Table1. Classification of methodological quality.

Study	1	2	3	4	5	6	7	8	9	10	11	Total
Giroux *et al.*[39]	1	0	0	1	0	0	0	1	1	1	1	6
Jiménez-Reyes *et al.*[40]	1	0	0	1	0	0	0	1	1	1	1	6
Samozino *et al.*[8]	1	0	0	1	0	0	0	1	1	1	1	6
Jiménez-Reyes *et al.*[41]	1	0	0	1	0	0	0	1	1	1	1	6
Jiménez-Reyes *et al.*[42]	1	0	0	1	0	0	0	1	1	1	1	6
Cuk *et al.*[43]	1	0	0	1	0	0	0	1	1	1	1	6
Feeney *et al.*[44]	1	0	0	1	0	0	0	1	1	1	1	6
Garcia Ramos *et al.*[45]	1	0	0	1	0	0	0	1	1	1	1	6
Hansen *et al.*[46]	1	1	1	1	1	0	0	1	1	1	1	9

1. Eligibility criteria were specified; 2. Subjects were randomly allocated to groups ; 3. Allocation was concealed; 4. The groups were similar at baseline regarding the most important prognostic indicators ; 5. There was blinding of all subjects; 6. There was blinding of all therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; 10. The results of between-group statistical comparisons are reported for at least one key outcome ; 11. The study provides both point measures and measures of variability for at least one key outcome.

Figure 1. Diagram of the selection of articles for review.



validity of clinical trials. From those articles identified as being potentially eligible by this search strategy, the authors (GCD and DJM) then made a further selection on the basis of article titles and summaries.

Results

Search Results

The search process allowed us to identify 254 potentially eligible articles (PubMed, N = 44, Web of Science, N = 150, SPORTDiscus, N = 60). An initial analysis revealed 18 duplicates, which were removed to leave 236 articles. Of these, 208 were excluded after reading the title and summary, leaving [28]. A further 19 were excluded after reading the complete text, leaving nine relevant articles according to the eligibility criteria (Figure 1).

Photocell system

In three studies the F-v profile was measured using the Optojump® device. The first, by Giroux *et al.*[39], evaluated SJ in 95 elite athletes (38 women and 57 men) from different sports (cycling, fencing, taekwondo, and athletics), using seven different loads based on the percentage of one maximum repeat (1RM) (0, 10, 20, 30, 40, 50, and 60% of 1RM). Fifteen active control group subjects (7 women and 8 men) were also assessed. The authors found significant differences ($p < 0.05$) in the Sfv and Sfvopt between the control subjects (men and women), fencers (men and women), and Taekwondo athletes (men and women). In the second study, Samozino *et al.*[8] studied the F-v profile of 48 national and international athletes (31 soccer players, 11 sprinters, and six rugby players) using the SJ method with five additional loads (0, 25, 50, 75, and 100%) in relation to the body weight of each athlete. Their results showed a loss in individual performance as a result of FVimb (6.49 ± 6.25%). Finally, Jiménez-Reyes *et al.*[40] evaluated 84 trained athletes (semi-professional football and rugby players) divided into three groups: optimized group (n = 46), non-optimized group (n = 18), and control group (n = 20), using the SJ with five to eight loads ranging from 17 to 87 kg. They found large (Effect Size (ES) = 1.21-100/0/0) and moderate (ES = 0.73 100/0/0) differences in FVimb and height of leap in favor of the optimized group compared with the non-optimized group.

Force platform

In six studies the F-v profile was measured using the force platform measuring instrument. In a study by Jiménez-Reyes *et al.*[41] which evaluated the SJ and the CMJ of 54 trained subjects (jumpers and sprinters) with five to eight loads ranging from 17 to 87 kg, significantly different values ($p < 0.001$) were found for SJ and CMJ, except for displacement of the center of mass from the beginning of the concentric phase until takeoff (hPO), sfv and FVimb ($p > 0.05$). In a more recent study, Jiménez-Reyes *et al.*[42] assessed the CMJ of 16 subjects (runners and jumpers) with five different loads (17 to 87 kg), using a force platform versus a simple method to determine F-v profile. They obtained high reliability (Intraclass Correlation Coefficients (ICC) > 0.980 and Coefficient of Variation (CV) < 1.0%) for all variables between the two methods of evaluation. Cuk *et al.*[43] studied the F-v profile of 30 subjects (divided into three groups: strength group, active group, and sedentary group) through SJ and CMJ with 10, 20, and 30% of body weight using the force platform. They reported coefficients ranging from r = 0.949-0.995 ($p < 0.01$) in the averages of the F-v relations between the participants of every group, and found that the force group obtained better results on F0 and Pmax compared with the other groups. Feeney *et al.*[44] studied the F-v relationship in ten physically active subjects through the CMJ with loads of 0 to 40% of body weight, using the force platform and an isokinetic device for evaluating knee extension. Their results showed a strong and linear F-v relationship (the coefficients of individual interrelations ranged between 0.78 and 0.93) and a moderate to highly reliable relation (0.67 < ICC < 0.91) between the slopes of force and speed. Garcia Ramos *et al.*[45] determined the F-v profile of 23 physically active subjects using the SJ and CMJ with six different loads (0, 17, 30, 45, 60, and 70 kg), and found a linear interrelation in all F-v relations (r > 0.98) when participants data were divided equally and when considered individually (r = 0.94-0.98). Finally, Hansen *et al.*[46] evaluated the F-v profile of 18 elite rugby players through SJ without external load (with body weight) and with three external loads (20, 40, and 60 kg). The group was then divided into two, with each new group receiving a different type of training (traditional training group and cluster training group). The results showed a significant increase ($p = 0.05$) in post-training F0 in both groups, the increase being greater ($p = 0.05$) for the traditional training group (Table 2).

Discussion

The objective of this review was to identify and analyze instruments and methods for evaluating F-v profile through the vertical jump in

Table 2. Results of the evaluations and interventions to determine force-velocity profile.

Study	Description of Subjects	Design of Study	Evaluation Instrument F-V profile	Evaluation Protocol	Outcomes	Test Results
Giroux *et al.*[39]	Study Group: N = 95 Age: 23.6 ± 4.0 Height:176.2 ± 5.3 cm Weight: 70.4 ± 7.8 kg Group Control: N = 15 Age: 25.1 ± 2.1 Height: 172.5 ± 5.7 cm Weight: 68.6 ± 7.2 kg	Experimental design, Cohort study Evaluated Group: Squat Jump (SJ) (n = 95)	Optojump Next (Microgate, Bolzano-Bozen, Italy)	SJ: 0, 10, 20, 30, 40, 50, 60% of 1 RM.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power F0th: Maximum optimum strength V0th: Optimum maximum speed	Sprinters and cyclists present values of F0 > than other groups. F0 < F0th for Female Fencers, Group Control, Sprinters, Fencers and Male Taekwondo. V0 > V0th for Female Fencers, Control Group, Sprinters, Fencers and Male Taekwondo.
Jiménez-Reyes *et al.*[40]	Study Group: N = 84 Age: 23.1± 4.4 Weight: 75.5 ± 8.5 kg Height: 1.79 ± 0.046 m	Longitudinal experimental design Evaluated Group: All groups performed Squat Jump Optimized Group: - Force deficit Group (FD) - Speed deficit Group (VD) - Well-balanced group (WB) Non-optimized group Control Group	Optojump (Microgate, Bolzano, Italy)	SJ without load and with loads ranging between 17 and 87 kg.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Sfv: Slope Force-Velocity profile Sfvopt: Optimum slope Force-Velocity profile FvIMB: Force-Velocity imbalance	Optimized group: FD, VD, and WB, all subjects show improvements in jump height and a decrease in FVimb compared with non-optimized group and control group, who show varying results.
Samozino *et al.*[8]	Study Group: N=48 Age: 20.9 ± 4.4 Weight: 75.8 ± 12.0 kg Height: 1.79 ± 0.06 m	Experimental design. Evaluated Group: Squat Jump (SJ) (n = 48)	Optojump (Microgate, Bolzano, Italy)	SJ: 0, 25, 50, 75, and 100% of subject's body weight.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Sfv: Slope Force-Velocity profile Sfvopt: Optimum slope Force-Velocity profile FvIMB: Force-Velocity imbalance	Loss of individual performance, due to FVimb (6.49 ± 6.25%)
Jiménez-Reyes *et al.*[41]	Study Group: N= 54 Age: 23 ±4.4 Height: 1.80 ± 0.06 m Age: 77.9 ± 6.0 kg	Randomized clinical trial. Evaluated Group: Squat Jump (SJ) and Countermovement Jump (CMJ) (n = 54)	Smith Machine (Multi-power Fitness Line) Force platform (Bertec, type 4060-15)	SJ and CMJ: with 5 to 8 additional loads ranging between 17 and 87 kg.	SJ and CMJ: F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Jump height Sfv: Slope Force-Velocity profile Sfvopt: Optimum slope Force-Velocity profile FvIMB: Force-Velocity imbalance	SJ vs. CMJ F0 > CMJ V0 > CMJ Pmax > CMJ Jump Height > CMJ Sfv > CMJ Sfvopt > CMJ FVimb > SJ
Cuk *et al.*[43]	Study Group: N = 30 Age: 24. 4 ± 2.3 Height: 182.4 ± 6.2 cm Weight: 80.2 ± 7.0 kg Body Mass Index (BMI): 24.1 ± 2.1 kg/m Muscular Mass: 40.7± 5.0 kg Body fat: 11.5 ± 5.7% 1 RM Squat: 139.6± 44.9 kg Maximum Voluntary Contraction (MVC) 884 ± 174	Experimental design Evaluated Group: 1 RM Squat MVC Knee Extenders (n = 30	MVC: Isokinetic Dynamometer (Kin-com) Squat Jump (SJ) + Countermovement Jump (CMJ) (Force platform, AMTI, USA)	Warm up: 5 minutes of trot + Dynamic Stretches. SJ and CMJ with 10, 20, and 30% of subject's body weight.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Force-Velocity profile	Pmax: Force Group > Active group and Sedentary group

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Study	Description of Subjects	Design of Study	Evaluation Instrument F-V profile	Evaluation Protocol	Outcomes	Test Results
Jiménez-Reyes *et al.*[42]	Study Group: N = 16 Age: 23.1± 4.1 Weight: 76.3 ± 6.4 kg Height 1.81 ±0.06 m	Cross-cutting experimental design Evaluated Group: Countermovement Jump (CMJ) (n = 16)	Smith Machine (Multi-power Fitness Line, Peroga, Spain) Force platform (Bertec, Tipo 4060-15, USA)	Warm-up: 10 minutes of trot on treadmill+ Dynamic Stretches + Preparatory Vertical Jumps. CMJ jumps without load and with 5 different loads (17-87 kg) on force platform and on soil (simple method).	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Force-Velocity profile	Variables calculated by a simple method show high reliability: ICC < 0.980 CV > 1.0%
Feeney *et al.*[44]	Study Group: N = 10 Age: 21.9 ±3.2 Weight: 72.2 ± 5.4 kg Height: 1.78 ± 0.12 m Body Mass Index (BMI): 22.8± 1.2 kg/m	Experimental cross-sectional design Evaluated Group: Knee Extensions against Resistance and Countermovement Jumps (CMJ) (n = 10)	Isokinetic Dynamometer Kin-com (Chatex corp, Chattanooga, USA) Force platform (Bertec FIT, Columbus, OH, USA).	Warm Up: 5 Minutes of Stationary Bike + Dynamic Stretches. CMJ with loads of 0-40% of body weight. Knee extensions in isokinetic device.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Force-Velocity relation	Coefficients of individual correlation of strength and velocity of 0.78-0.93. The relation between the slopes of Force and Velocity are from moderate to highly reliable (0.67 < ICC < 0.91)
García Ramos *et al.*[45]	Study Group: N = 23 Age: 23.1 ± 3.2 Weight: 74.7 ± 7.3 kg Height: 177.1 ± 7.0 cm	Experimental Design Evaluated Group: Squat Jump and Countermovement Jump (n = 23)	Force platform (Dinascan/IBV Institute of Biomechanics of Valencia)	10 minutes warm-up: Joint Mobility and Dynamic Stretches SJ and CMJ with loads: 0, 17, 30, 45, 60, and 70 kg.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power Force-Velocity relation	There is a linear relationship in all force-velocity relationships: r > 0.98.
Hansen *et al.*[46]	Study Group: N = 18 Age: 26.8 ± 4.5 Weight: 103.5 ± 8.6 kg Height: 1.89 ± 0.1 m	Experimental design Group traditional training (TT) (n = 9) Cluster Group training (CT) (n = 9) (Total n = 18) Both groups received force and potency training on the lower extremities twice per week.	Force platform (Accupower, AMTI, Watertown, MA, USA)	Squat Jump with body weight and 3 external loads: 20, 40, and 60 kg.	F0: Theoretical maximum force V0: Theoretical maximum velocity Pmax: Maximum power	↑ in maximum force in the TT and CT Groups.

Theoretical maximum force (F0), Theoretical maximum speed (V0), Maximum power (Pmax), Slope Force-Velocity profile (Sfv), Optimum slope Force-Velocity profile (Sfvopt), Force-Velocity imbalance (FvIMB) Squat Jump (SJ), Countermovement Jump (CMJ).

athletes. The main finding is that most of the studies in this review used the force platform as the sole instrument of evaluation. Other studies have considered other methods. For example, García-Ramos *et al.*[47] Correlated, compared, and determined the reliability of F0, V0, and Pmax values obtained using a force platform and a linear encoder during jumps with loads (25, 50, 75, and 100% of body weight). They found a high correlation ($p < 0.0001$) between both evaluation methods, suggesting that the linear Encoder is a valid tool for measuring F-v profile. This study is consistent with that of Padulo J. *et al*.[48], who used a linear Encoder to evaluate the F-v profile of ten sports people across two types of movement (squat and leg press). Other authors have also searched for an evaluation method of similar validity to that of the force platform. Balsalobre-Fernández *et al*.[33], for example, analyzed the validity and reliability of a mobile application (My Jump®) for measuring vertical jump and F-v profile, and found almost perfect agreement between the height of jump as measured by the application and that measured using a force platform, thus demonstrating another valid and easily accessible option for evaluating F-v profile. Finally, Jiménez-Reyes, *et al*.[42] validated a simple method of evaluating F-v profile through the CMJ using three parameters; body mass, height of jump, and distance of propulsion. A comparison of these results and those obtained using a force platform showed strong interrelations between the F-v profile variables of both methods, thereby providing another assessment option.

While it is the case that the objective of this review was to evaluate the F-v profile through the vertical jump, other methods do exist. Samozino *et al*.[49] studied the F-v relationship using an ergometer fitted with a car seat, in which horizontal movement is enabled through ballistic push with the aim of quantifying the bilateral force deficit (BLD) associated with mechanical alterations of the F-v profile. On the other hand, Dobrijevic *et al.* [50], evaluated the F-v profile using an ergometric tape with an indicator connected to the subject by means of a belt. In addition, Romero-Franco *et al*.[51] examined the validity and reliability of the results of sprints measured using a mobile application (My Sprint) compared with existing methods (photocell and radar gun), and obtained an almost perfect correlation between the times, F0, V0, and Pmax measured with the mobile application and the photocell system.

As Samozino *et al*.[5] concluded, regardless of the method and instrument of evaluation, sports performance during a jump or race is not based exclusively on the Pmax but rather on the balance that exists within the F-v. Therefore, it is vital to measure this profile in order to improve the training and rehabilitation of sports people.[7]

Practical Applications

Is necessary to emphasize the importance of evaluating sports people, and to consider the methods most appropriate to meet the requirements of sports and the valid and reliable instruments that can give accurate evaluations and results. Doing so will allow the correct training loads to be prescribed and adjusted that will favor optimum performance with the lowest incidence of injuries.

On the basis of this review it is suggested that future investigations are undertaken with mobile applications and other more accessible instruments, comparing their ability to determine the F-v profile of sportsmen with that of the Gold Standard or the photocell system with the aim of facilitating and enhancing the work of sports science and health professionals to the benefit of athletes and the field of sport generally.

Conclusions

The methods and instruments for evaluating the F-v profile identified and included in this review are based primarily on the force platform or photocell system. Nevertheless, there are other methods that are more accessible to the majority of sports science professionals. It is therefore necessary to investigate whether these other measurement options are as valid and trustworthy as more commonly used instruments.

This research suggests that mobile applications may be a valid option for studying the F-v profile in sports people submitted to jump and sprint evaluations, allowing FVimb to be determined.

Conflict of interest

The authors do not declare a conflict of interest.

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