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Kinematic and kinetic variable determinants on vertical jump performance: a review

Abstract

The vertical jump is a task performed in various sports modalities and is considered a lower limb power test, that may provide information about the efficacy of several training programs. Although of the various types of jumps, two have been more used: the Squat Jump and the Countermovement Jump. Kinematics and kinetics variables are presented to describe the Squat Jump and Countermovement Jump, however, little is known about which variables are intrinsic in vertical jump performance. Thus, this review has two objectives: 1- Identify the kinetic and kinematic variables of jump analysis and 2- Describe the intervening variables in VJ performance. For the search, the following terms were used "Vertical Jump and Kinetic", "Vertical Jump and Kinematic", and "Vertical Jump and Fatigue". The search was performed between June and July of 2019. The articles of this review were searched in two online databases: *PubMed* (MEDLINE) and EBSCO (EBSCO Industries Inc.). After the analysis of titles, abstracts and papers, were chosen 70 articles for this review. Although necessary in various motor skills, the maximal force does not predict the vertical jump performance. In contrast, kinetic variables related to power may interfere to performance. For kinematic analysis, the peak angular velocity seems to differentiate performance levels. Few studies defined the predictor variables of this task. Therefore, we suggest the realization of studies with predictive statistics to identify the predict variables of vertical jump and adopting other biomechanical variables, such as the continuous relative phase and temporal and force characteristics during the eccentric and concentric jump phase.

Keywords: vertical jump, kinematic, kinetic, performance

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Introduction

The vertical jump (VJ) is characterized as a motor skill that involves all lower limb joints in various recreational activities, sports modalities, and training programs.[1] This task is considered a method of testing power and muscular performance in lower limbs.[2] Among several jump technique variations, two have been more commonly utilized due to their association with specific sports movements and easy familiarization: the Squat Jump (SJ) and the Countermovement Jump (CMJ).[3]

The SJ start position is characterized by knee flexion at approximately 90º, followed by a knee extension, with predominant participation of agonist muscles, as the SJ consists of only the concentric phase.[4] In contrast, the CMJ start position is characterized by a standing position, followed by flexion (eccentric phase) and extension (concentric phase) of the knees and hips.[5] The main characteristic of this jump is the transfer of elastic energy through the eccentric-concentric cycle and superior activation of muscle spindle that allows more height in the CMJ.[6] To evaluate the coordination and intervenient factors related to VJ, kinetic and kinematic components have been used.

The peak force in the concentric phase and the force rate development have been indicated as determinant kinetic components for VJ performance.[7] In contrast, Dowling and Vamos related that high peak forces, although necessary, are not enough to predict the VJ. The authors suggested the utilization of peak power to evaluate performance. Thus, there is still no consensus about which kinetic variables may contribute to VJ performance.

As with the kinetic components, the kinematic analysis in VJ is conditioned by several factors. The larger knee flexion might increase joint angular velocities[8] and the contributions of the angles and joints to VJ performance can change according to the effort level.[9] Furthermore, the variety of factors that influence performance may interfere in the knowledge of which variables are intrinsic to improve VJ performance. Thus, this review has two objectives: 1- Identify the kinetic and kinematic variables of jump analysis and 2- Describe the intervening variables in VJ performance. This review will provide information to researchers and sports professionals about the parameters for VJ performance analysis.

Material & methods

The articles of this review were searched in two online databases: *PubMed* (MEDLINE) and *SportDiscus* (EBSCO Industries Inc.). With the following terms: "Vertical Jump and Kinetic", "Vertical Jump and Kinematic", and "Vertical Jump and Fatigue". The search was performed between June and July of 2019. Papers in Portuguese, English, and Spanish languages were accepted, published between 1989 and 2019. Papers that analyzed kinetic and kinematic variables of vertical jump performance, as the main objective, and the effects of these variables on fatigue conditions were chosen.

The review process was divided into three selection phases. The first phase consisted of paper title analysis. Papers with topics associated with the terms used in the database search were chosen. Descriptive and experimental research was accepted. Papers that presented the vertical jump analysis after any intervention training, rehabilitation, biomechanic models, review articles, case studies, studies with animals, and validations of VJ assessment methods were excluded. The second phase consisted of abstract reading. Papers were selected that presented kinetic or kinematic variables of VJ performance in the results. The third phase consisted of reading the papers chosen in phase two. In this phase, papers that presented kinetic and kinematic variables in the results and discussion were chosen and papers that did not present a clear explanation of methods, such as subject characteristics, type of jump, and description of instruments

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for quantification of variables analyzed were excluded. Figure 1 presents the flow chart of the review process.

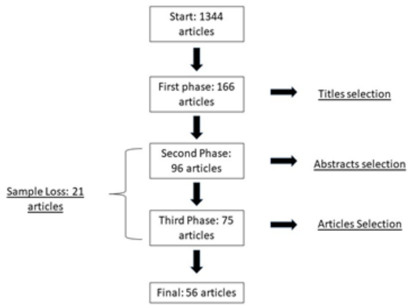

Figure 1 Review of article selection process.

Results

A high diversity of analyzed parameters was presented, characterizing a lack of consensus on variables to use for vertical jump performance analysis. Table 1 presents the summary of articles analyzed.

Discussion

CMJ kinetic analysis

Ground reaction force: According to Bermudez G[10] the maximal GRF cannot be considered a predictor of jump performance with fatigue. Moreover, despite the GRF being greater in men compared to women, when normalized by body weight, this variable was not correlated with jump performance[11,12] also verified that only 24% of data variance was explained by force variables, while 54% was explained by temporal variables. Thereafter, CMJ performance does not depend exclusively on maximal GRF.

Table 1 Summary of articles related to vertical jump performance.

Authors	Sample	Jump protocol	Kinetic variables	Kinematic Variables
Dal Pupo et al.[35]	24 male athletes (12 runners and 12 volleyball players)	3 CMJ and 3 SJ	Pmax, GRF, T-GRF, FRD and PV	-
Gómez and Elvira[19]	19 subjects (16 men and 3 women) students	3 CMJ x 4 arm position conditions	GRF, FRP, Pmax, NEG-IMP, POS-IMP, T-GRF, T-FRP and T-Pmax	-
Shetty and Etnyre [30]	18 men (students)	3 CMJ with arm swing and 3 CMJ without arm swing	GRF, Ţ, Pmax and L-Force	R-Vel
Rodano and Squadrone [46]	9 male athletes (sprinters in athletics)	5 series of 5 CMJ	Pmax, Moment	-
Bracic et al.[47]	12 male athletes (sprinters in athletics)	5 CMJ with two legs, 5 CMJ with preferred leg and 5 SVCM with non-preferred leg	GRF and IMP	R-Vel, hip angle, knee angle and ankle angle
Coh et al.[33]	4 men (2 jumpers and 2 sprinters in athletics)	3 CMJ, 3 SJ and 3 DJ	Contacttime, Ţ-CON, Pmax, GRF, NEG-IMP and POS-IMP	T-ECC, T-CON, R-Vel, hip flexion angle, knee flexion angle, ankle flexion angle and T-Flight
Gheller et al.[27]	22 men (basketball and volleyball players)	9 CMJ (3 squat depth conditions)	Vvert, Pmax, Pmean, GRF and FRD	Relative angles and Vangof hip, knee and ankle
Gutiérrez-Dávila et al.[2]	28 male students	5 CMJ and 5 horizontal jumps	-	T-ECC, T-CON, R-Vel, Jump Time, Vvert
Arakawa et al.[1]	8 healthy men	5 SJ and 5 SJwith ankle constraint	Pmax, Ţ, GRF	CMheight, Relative angles and Vang of hip, knee, and ankle
Dowling and Vamos [6]	97 adults (46 men and 51 women)	5 CMJwith arm swing	NEG-IMP, GRF, FRD, POS-IMP, T-GRF, T-ECC, Pmax, Vneg	-
Feltner et al.[49]	25 adults (14 men and 11 women)	5 CMJ with arms swing and 5 CMJ without arms swing	GRF, torque, T-ECC	Relative angles of trunk, hip, knee and ankle, Vang, Vvert, R-Vel, vertical acceleration
Jaric et al.[24]	39 men (experienced in handball and/or volleyball)	CMJ (number of attempts not specified)	GRF, T-COM, T-ECC, R-Vel	Relative angles of shoulder, hip, knee and ankle
Ugrinowitsch et al.[20]	27 male athletes of several sports modalities	5 CMJ	GRF, POS-IMP, FRD	CM velocity, R-Vel, T-COM, T-ECC, vertical acceleration
Laffaye [12]	273 adults (189 men and 84 women) athletes of several sports modalities	6 CMJ with arm swing	T-ECC, FRD-ECC, GRF	Jump Time
Maulder et al.[20]	10 male sprinters (in athletics)	3 attempts at different types of jump, such as CMJ and SJ	Highest Ptakeoff, Pmax, Pmean, GRF	R-Vel

Table Continued...

Authors	Sample	Jump protocol	Kinetic variables	Kinematic Variables
Markovic et al[22]	60 men (students)	3 CMJ and 3 SJ	Pmax, Pmean	-
Mandic et al.[8]	11 men (basketball players)	5 CMJ with arm swing and 5 CMJ without arm swing	GRF, Pmax	-
Lees et al.[13]	20 male athletes	3 CMJ in different intensity conditions	Pmax, torque, Ʈ	Vang
Domire and Challis [50]	10 healthy men	3 SJ in preferred squat position and 3 SJ in auto-selected position	Moment, GRF	Jump Time, relative angles of hip, knee and ankle
Lees et al.[31]	20 male athletes	3 CMJ for each type of intensity	Pmax, torque, Ʈ, GRF	CM displacement
Papaiakovou [26]	30 men (academic students)	3 CMJ and 3 Drop Jumps	IMP, GRF, FRD	CM displacement, relative angles of hip, knee and ankle, Vang
Kopper et al.[51]	18 healthy men	6 CMJ and 6 SJ	-	CM displacement, relative angles of trunk, hip, knee and ankle, Vang, R-Vel
Struzik and Zawadzki [52]	12 basketball players (7 men and 5 women)	6 CMJ with arm swing	GRF, Stiffness, T-Flight	CM displacement, relative angle of knee
Salles et al.[9]	10 men (academic students)	60 CMJ	GRF, Pmax, torque	CM displacement, relative angles of hip, knee and ankle, PV
Hara et al.[16]	5 healthy men	4 SJ with arm swing and 4 SJ without arm swing	Torque, GRF, Pmax, Ʈ, COP	Vang, CM displacement, angular acceleration, relative angles of shoulder, elbow, hip, knee and ankle
Mackenzie et al [7]	10 college volleyball players (women) and 10 college football players (men)	5 CMJ	GRF, FRD, Pmax, Vvert	Angular displacements of hip, knee and ankle
Lazaridis et al.[28]	24 men	3 CMJ, 3 SJ and 3 depth jumps	FRS, T-FRSmax	Vang, T-ECC, T-CON
Vanrenterghem et al.[53]	10 volleyball players	3 CMJ and 9 CMJ submaximal	GRF, Pmax, T-Flight, Ʈ, moment	Relative angles of hip, knee and ankle, T-ECC, T-CON
Lees et al.[13]	20 athletes	3 CMJ with arm swing and 3 CMJ without arm swing	GRF, torque, Pmax, Ʈ	Relative angles of hip, knee and ankle, R-Vel, Vvert, CM displacement, CMHeight, Jump Time
Anderson and Pandy [54]	5 male athletes	5 CMJ and 5 SJ	GRF, Contacttime, acceleration	Relative angles of hip, knee and ankle, CM displacement, Vvert
Hara et al.[18]	5 healthy men	4 CMJ and4 Sjwith and without arm swing (4 attempts for each condition)	COP, GRF, torque, Pmax, Ʈ	CM displacement, CMHeight relative angles of shoulder, elbow, hip, knee and ankle, velocity, acceleration, Vang
Bobbert et al.[57]	11 physically active men	3 SJ in 3 different conditions of trunk inclination	FRS, COP	CM displacement, T-ECC, T-CON
Moran and Wallace [55]	17 volleyball players	12 CMJ, 12 SJ, and 12 DJ for different knee flexion angles	GRF, Pmax, Moment	Vang, Relative angles of hip, knee and ankle, CM displacement, CMHeight
Moir et al.[56]	70 healthy subjects (35 men and 35 women)	3 CMJ in 4 sessions	GRF, POS-IMP, NEG-IMP, Stiffness, FRD	T-Flight, Vvert, CM displacement
Feltner and MacRae [49]	11 women	10 CMJ in 2 different conditions	GRF, IMP	-
Blache and Monteil [25]	8 men physically active	3 SJ	GRF	Vvert, CM displacement, Range of motion (knee and ankle), CMheight
Loturco et al.[58]	22 sprinters (13 men and 9 women)	6 CMJ, 6 SJ and 3 horizontal jumps	GRF, Pmean	-
McLellan et al.[59]	23 men physically active	3 CMJ and 3 SJ	GRF, Pmax, Pmean, FRP, T-GRF	-

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Table Continued...

Authors	**Sample**	**Jump protocol**	**Kinetic variables**	**Kinematic Variables**
González-Badillo and Marques [23]	48 men athletes (sprinters and jumpers in track and field)	3 CMJ	GRF, Pmax, NEG-IMP, POS-IMP, Eccentric Force, Concentric Force	Vneg
González-Badillo and Marques [23]	48 men athletes (sprinters and jumpers in track and field)	3 CMJ	GRF, Pmax, NEG-IMP, POS-IMP, Eccentric Force, Concentric Force	Vneg
Floría and Harrison [60]	36 girls gymnasts	3 CMJ	GRF, FRD	CM displacement, Vvert
Yamauchi and Ishii [11]	67 subjects	3 CMJ	-	CM displacement
Mackala et al.[36]	6 men sprinters	3 CMJ and 3 SJ	GRF, Moment, Pmax	CM displacement, T-Flight, Relative angles (hip, knee and ankle)
Feltner et al.[48]	15 men physically active	5 CMJ in 2 different conditions	GRF, IMP, Torque	CM displacement, Acceleration
Bermudez and Fabrica [10]	10 male athletes (6 soccer players and 4 middle-distance runners)	50 CMJ in 2 conditions (with and without fatigue)	GRF, IMP	T-ECC, T-COM
Woolstenhulme et al.[42]	18 women basketball players	3 CMJ in 2 conditions (with and without fatigue)	Pmax	T-Flight
Smilios [43]	12 physically active men	3 CMJ in 3 fatigue conditions	τ	-
San-Román Quintana et al.[61]	9 national team basketball players	2 CMJ in 2 conditions	-	T-Flight
Dal Pupo et al.[4]	20 male athletes (university level, 16 volleyball players and 4 basketball players)	30 seconds of CMJ	Stiffness, GRF, Contacttime, Pmax	Relative angles of hip and knee, Relative phase
Rodacki et al.[44]	11 men (6 volleyball players, 3 rugby players, and 2 multiple sports athletes)	3 CMJ in 2 fatigue conditions	GRF, Moment, Pmax, Vvert, Stiffness	Vang, Relative angles of hip, knee and ankle, acceleration
Schmitz et al.[62]	30 men and 29 women (physically active)	2 CMJ in 8 conditions	GRF, Pmax, Moment	Relative angles of hip, knee and ankle
Rodacki et al. [44]	12 men (6 volleyball players, 4 rugby players, and 2 multiple sports athletes)	3 CMJ in 2 fatigue conditions	GRF, Moment, Pmax, Contacttime, Stiffness	Vang, Relative angles of hip, knee and ankle
Skurvydas et al.[63]	12 physically active men	3 CMJ and 3 SJ in 2 conditions	T-Flight	-
Houghton and Dawson [64]	6 cricket players (university level)	3 CMJ and 3 SJ in 3 conditions	T-Flight, Contacttime	-
Freitas et al.(2014)	16 male volleyball players	3 CMJ in 2 fatigue conditions	T-Flight	-
Horita et al.[65]	10 physically active men	2 CMJ in 5 conditions	GRF	CM isplacement, T-Flight
Gorostiaga et al.[66]	12 male athletes (sprinters)	2 CMJ in 6 conditions	-	T-Flight
Barker et al.[67]	26 male soccer players	3 CMJ	GRF, FRD, Reactive Strength Index, Pmax, Work, Concentric force, Kinetic energy	CM acceleration, CM velocity, Jump time
Boullosa et al.[68]	14 endurance athletes, 12 sprinters and 13 fire-fighter aspirants	2 CMJ	Pmax, Stiffness, FRD	-
Floría et al.[69]	50 rugby players	3 CMJ	Force, FRD	Velocity, Displacement

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Table Continued...

Authors	Sample	Jump protocol	Kinetic variables	Kinematic Variables
Gathercole et al.[70]	11 male collegiate level team-sport athletes	6 CMJ, 6 SJ and 6 DJ	Pmax, Pmean, FRD, Force, IMP,	PV, Minimum velocity, Flight time, T-ECC, T-CON, Peak displacement, Minimum displacement
Lesinski et al.[71]	10 male and 10 female volleyball players	3 CMJ and 3 DJ in 2 conditions	-	Time for braking phase, Time for push-off phase
Mandic et al.[8]	11 male elite basketball players and 11 male physically active	20-23 CMJ in 2 conditions	GRF, Pmax	T-CON, Countermovement depth
Nibali et al.[72]	113 high school athletes, 30 college athletes and 35 professional athletes	2-6 CMJ	FRD, GRF, IMP	-
Rousanoglou et al.[73]	27 men runners	3 CMJ in 3 moments (Pre, Post 1 and Post 2)	Pmax, GRF, Power in the concentric phase, Power in the Eccentric phase	Displacement, Velocity, T-CON, T-ECC, Total contact duration
Rubio-Arias et al.[29]	35 men and 29 women young adults	2 series of 3 CMJ	Ptakeoff	Vvert in takeoff
Sánchez-Sixto et al.[37]	11 team sports athletes	3 CMJ in 3 different conditions	-	T-ECC, Vneg, Squat Depth, T-CON, GRF, PV
Sánchez-Sixto et al.[38]	29 male basketball and soccer athletes	3 CMJ in 3 different conditions	IMP, GRF	Flight height, Height at the takeoff, Squat Depth, Velocity, Vneg, Velocity at the takeoff
Vaverka et al.[74]	18 elite male volleyball players	3 CMJ in 2 conditions	IMP, GRF	Relative angles (hip, knee and ankle), Velocity
Watkins et al.[75]	10 healthy resistance trained males and 7 females	Minimum of 2 CMJ in each condition (Daily sessional basis)	Pmax	-
Williams et al.[76]	14 women NCAA Division III student athletes	3 CMJ in 3 different conditions	GRF, Pmax	-

Pmax, power; Pmean, mean power; GRF, ground reaction force; T-GRF, time to maximal ground reaction force; FRD, force rate development; PV, peak velocity; FRP, force rate production; IMP, impulse; NEG-IMP, negative impulse; POS-IMP, positive impulse; T-FRP, time to force rate production; T-Pmax, time to maximal power; Ʈ, work; L-Force, landing force; R-Vel, release velocity; Moment, moment; IMP, impulse; CM, center of mass; $Contact_{time}$, contact time; T-ECC, time of eccentric phase; T-CON, time of concentric phase; T-Flight, flight time; Ʈ-CON, work in the concentric phase; DJ, drop jump; V_{ang}, angular velocity; V_{vert}, vertical velocity; Jump time, jump time; CM_{height}, center of mass height in takeoff; FRD-ECC, force rate development in the eccentric phase; $P_{takeoff}$, power in the takeoff; COP, center of pressure; V_{neg}, negative velocity

Force rate development: The force rate development (FRD) is defined by the average slope of the force-time curve, and is an important component for power production.[4,7] also suggest that this rate could be a good indicator of jump performance. In contrast, the FRD was not sensitive to discriminate the CMJ between different populations.[13] In addition, Dowling and Vamos verified that the FRD did not explain jump height, as the subjects with low FRD reached higher force, but with worse jump performance. In fact[14] claimed that the FRD depends on the type and velocity of contraction. Thus, the relation between FRD and jump height performance is not clear.

Torque: In the vertical jump, the torque is calculated by inverse dynamics[15–17] found that improvement in hip joint torque is responsible for the higher height reached in maximal jumps compared to submaximal jumps. Verified[18] an improvement in hip joint torque when jumps were performed with countermovement and arm swing. Therefore, it is suggested that torque is an important variable in the description of rotational force used by muscles over the joints in different vertical jump strategies.

Impulse: The impulse is represented by the force-time function and may be analyzed in the eccentric phase (negative impulse) and in the concentric phase (positive impulse) jump.[19,20] According to Dowling JJ[6] the rate between the negative impulse and positive impulse has a correlation with vertical jump height. Therefore, it is suggested that more than force, the application force time and jump phase duration are important for this variable.[20] demonstrated that higher impulse in the concentric phase resulted in higher CMJ height. Ferragut C[21] that the concentric impulse may explain 77% of jump height variation. Thus, the impulse is an important kinetic variable for vertical jump analysis.

Power: Identified[6] the kinetic and temporal factors related to CMJ performance in 97 adults. According to the authors, higher peak forces are necessary, but not enough to improve performance, and only the peak power may be considered as a predictor variable. The peak power is an indicator of how effective the energy transferred between the segments is in the movement performance. In fact, according to Markovic S[22] the peak power may be the best variable to analyze the muscle power in the jump and presents a good relation with performance when compared to mean power values. González Badillo J[23] that CMJ performance was related to peak power during the concentric phase in athletes. Therefore, it is suggested that power, to evolve force and velocity characteristics, is one of the kinetic variables that most influences vertical jump performance.

CMJ kinematic analysis

Angular position: The description of joint angles is important information for jump kinematic analysis. In this review, data were found on shoulder, trunk, hip, knee, and ankle joint angles.[18,14] These measures provide information about the movements performed in these joints in different types of jumps (SJ and CMJ), squat depth, arm swing, and other relative joint positions.[25,26]

Angular velocity: The angular velocity is measured by the derivative of joint angular position divided by time[26,27] verified that the hip, knee, and ankle angular velocities were superior in subjects that presented higher ankle dorsiflexion, proving that the movement range influences velocity development. However, an immature jump technique and higher activation of antagonist muscles are factors that reduce the angular velocity. Gheller[26,28] demonstrated that volleyball and basketball players generate higher angular velocities in jumps with large squat depth, due to the greater trajectory for application of force and acceleration. Thereafter, it is suggested that angular velocity, despite involving several other factors, may explain different levels of jump performance.

Take-off velocity: Another variable that may influence jump performance is the take-off velocity Rubio-Arias[29] In addition to verifying differences between types of jumps and populations, this variable also provides information on the influence of arm swing in the movement. Shetty and Etnyre[30] found higher take-off velocity in vertical jumps with arm swing compared to jumps with movement restriction. According to Lees[31] a series of events that begins at the start of the movement, but only manifests itself at the end of the jump, influence the larger take-off velocity. In the arm swing condition, the trunk leans forward more, and consequently, extends earlier and faster, allowing more power and work generation. Thus, it is suggested that arm swing has great influence on this variable.

Continuous relative phase (CRP): The CRP is determined by the derivative in the domain of the position-velocity phase between two sine wave oscillators and may be used to analyze cyclic and acyclic action Gheller[27] analyzed that the CRP of the thigh-trunk relation was higher in the squat position with the knees flexed at less than 90°, when compared to different positions (preferred and higher than 90°) in the CMJ. Thus, it was suggested that the motor control prioritizes the thigh-trunk coordination in generation of angular movements important for CM displacement. Tomioka[32] verified that independent of muscle force, jump performance may be lower if there is alteration in knee-hip coordination. Despite these two studies, there are still few studies that have evaluated this variable regarding jump performance. However, it is suggested that this variable is important to jump coordinative analysis.

Other factors involved in vertical jump performance: Based on the presented studies, a schematic figure was proposed to try to represent the factors involved in a vertical jump (Figure 2). It was demonstrated that the kinetic and kinematic variables are influenced by factors, such as: squat depth, type of jump, and fatigue.

Type of jump: The SJ and CMJ are the most commonly used jumps in vertical jump analysis. Coh[33] verified that the vertical velocity was 9.5% higher when the jump had two movement phases (eccentric and concentric). The differences between the CMJ and SJ may be explained by the higher muscle active state during the propulsion phase, allowing the hip extensors to generate more force and work during the CMJ concentric phase Bobbert & Casius[34] Dal Pupo[35] besides explaining that the existence of countermovement favors the pre-active state contraction, suggest that in the SJ, the neural recruitment exerts greater influence on performance. Finally, according to Mackala[36] while in the SJ the concentric force works only against the body mass, in the CMJ this force works additionally against the inertial forces, possessing higher muscle activity and reutilization of elastic energy.

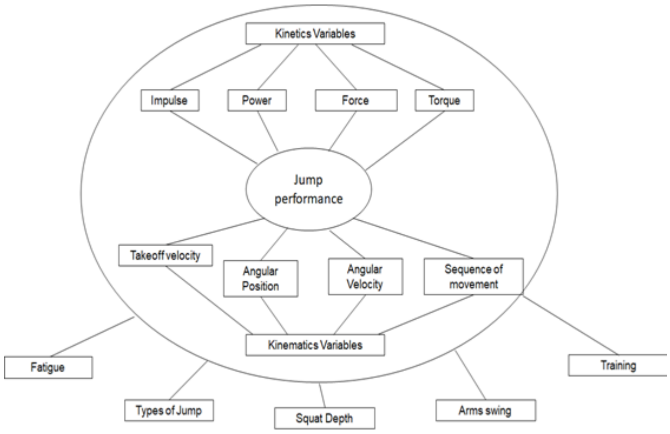

Figure 2 Factors involved in vertical jump performance.

Squat depth: The squat depth may influence performance in SJ and CMJ Sánchez-Sixto, Harrison[37]

Sánchez-Sixto, López-álvarez[38] this occurs mainly due to the change in joint position, resulting in differences in the muscle contraction process. Gheller[27] verified that CMJ performance is better when the knee flexion was smaller than 90°. Furthermore, smaller peak force was found in conditions with more depth, due to the greater trajectory to be travelled in the jump. Mandic[39] found that the increase in squat depth is related to the decrease in GRF and maximal power, and there is an "optimal" squat depth to increase jump height. Salles[9] reported that the depth was inversely correlated to GRF. Furthermore, it was claimed that jumps with higher squat depth are not always advantageous in sports practice, due to the higher time necessary to perform the task. Thus, differences in performance according to the chosen position are suggested.

Fatigue: Fatigue may be understood as the incapacity of a muscle or muscular group to sustain a certain force level Bigland-Ritchie & Woods[40] Bermudez and Fabrica[10] reported that fatigue caused a decrease in force, impulse, concentric phase duration, and jump height in athletes. A possible explanation for this decrease in performance is the reduction in the stretch reflex sensitivity, induced by muscle damage after the fatigue activity. Some studies, however, showed maintenance of jump height even after application of high training load, as in volleyball and basketball players Freitas[41] Woolstenhulme[42] Furthermore, the force reduction caused by lower limb fatigue was not proportional to decreases in jump height, as the jump does not depend exclusively on force, but also on velocity production Smilios[43] and movement control Andre L F Rodacki[44] Even in a fatigue state, the muscle activation pattern continued in the proximal-distal sequence during the jump Rodacki[45] suggesting a stereotypical muscle activity pattern even in fatigue conditions Rodacki[45] Therefore, there is not a consensus about the use of jump height as a sensitive variable in fatigue.

Conclusions

To evaluate lower limb power, the vertical jump may provide information about the efficacy of several training programs and other interventions applied with the objective of improving performance. In this review, kinematic and kinetic variables involved in vertical jump performance were presented. It is suggested that the variables of power may contribute to vertical jump performance analysis. For kinematic analysis, the peak angular velocity seems to differentiate performance levels. In the literature, little is found about the predictor variables for performance of this task. Therefore, we suggest the realization of studies with predictive statistics and adopting other biomechanical variables, such as the continuous relative phase and temporal and force characteristics during the eccentric and concentric jump phases.

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Conflicts of interest

The author declares that there is no conflict of interest.

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