Proceeding

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Vertical jump test assessment in non-athlete adults: Systematic review

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ABSTRACT

Vertical impulse tests usually designated "jump tests", are regularly carried out in the assessment of physical performance in athletic performers. The present review aims to explore if such tests can be part of the performance evaluation processes in non-athlete performers. To achieve this, a systematic review was conducted according to PRISMA standards. The databases Pubmed, CINAHL Plus, Medline Complete and Google Scholar were accessed. After applying the inclusion and exclusion criteria, seven articles were selected. Overall conclusions indicate that countermovement jump (CMJ) gathered consensus as the preferred method to evaluate physical performance, particularly with the contribution of upper limbs movement and self-selected range of angular knee joint flexion. Other information gathered include test procedures to enhance vertical test results and the gender influence on test results. **Keywords**: Vertical jump test; Sargent jump; Countermovement jump; Drop jump; Performance assessment; Non-athletes adults.

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INTRODUCTION

Physical performance tests aim to obtain a tangible measure of an individual's performance by the analysis of its components. The outcome of these tests is consider to be a reflex of the body's physical ability to produce the multi-joint movements needed (Hegedus, E. J., McDonough, S., Bleakley, C., Cook, C. E., & Baxter, G. D., 2015), demonstrating the classic formulation (Bernstein, 1967) that human movement is the result of the control of redundant degrees of freedom. The vertical jump tests have commonly been used in scientific studies as they are considered an effective measurement of the energy expended, and by that offering an indirect measure of the individual's global performance (Klavora, P., 2000). These tests can help the teacher/coach to design the most suitable workout plan that is consistent with the performer's own characteristics, and to identify progress or setbacks in the performer's physical development. This kind of assessment does not require extraordinary technological apparatus and can be easily applied by exercise and health professionals in their normal practice (Hegedus, E. *et al*., 2015). Its applications may follow several protocols such as the *Squat-Jump* (SJ), *Countermovement Jump* (CMJ) and *Drop Jump* (DJ) tests. SJ consists on a vertical jump performed without previous countermovement, i.e., the initial position already starts from a flexion position of the lower limbs' joints (usually at 90 degrees of knee flection). In the CMJ, the initial position is standing, and the performer need to accomplish a quick countermovement of flexion into extension movement of the lower limbs' joints. By other hand, DJ consist of a jump where the initial position is over a step of different heights and the performer is instructed to fall down the step (drop) into the floor and to jump as soon as it touch the floor (Babillo, J & Ayestarán, E, 2011). The outcomes of the vertical jump tests give us an idea, not only of the jump height score, but is an outcome that comprises the performer's anatomy, muscular architecture, level of physical activity, motor control and coordination he used to fulfil that score (Markovic, S., Mirkov, D. M., Nedeljkovic, A., & Jaric, S., 2014; Blache & Monteil, 2013). As these tests are assumed to be a measure of the total body performance is commonly applied on athletes, regardless the sport modality (Caia, J., Weiss, L. W., Chiu, L. Z., Schilling, B. K., Paquette, M. R., & Relyea, G. E., 2016). Thus, although the importance of vertical jump tests in the sport environment has been already studied, its application in non-athletes subjects, with different levels of activity, is still unclear.

Considering the basis of scientific knowledge on vertical jump tests (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978), this systematic review aims to verify the existence of vertical jump tests application in non-athlete adults.

METHODS

Experimental approach to the problem

This systematic review was done according to the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA). PRISMA is composed by a set of evidence-based items intended to support researchers reporting and comparing different scientific studies (Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G., 2009). In later phases of this review, the "PICO" approach will be used (study population, intervention, control and main results) in order to organize and highlight the main characteristics of each study.

Four databases were accessed from January 2013 to July 2018 (5 years of time bound), aiming to focus on the most current studies about vertical jump tests for performance evaluation. The databases Pubmed, CINAHL Plus, Medline Complete and Google Scholar were accessed with the keywords "vertical jump" and "exercise test".

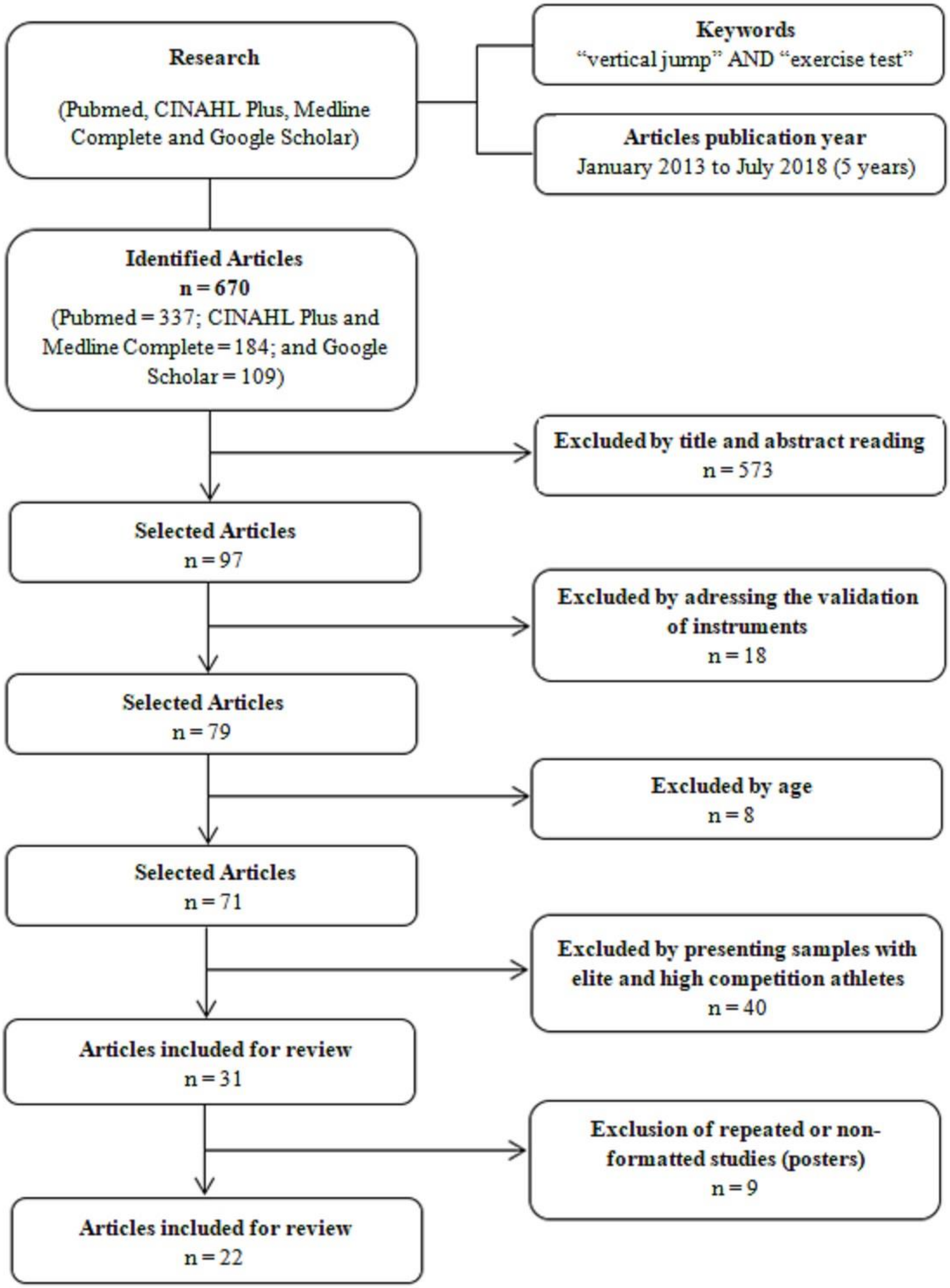

Figure 1. Eligibility flowchart for systematic review articles.

Subjects
The articles were selected accordingly to the following inclusion criteria: (1) complete article publications (abstracts or posters are not included), and (2) articles that involve humans in the study samples. The review of the articles included in the selection criteria were then submitted to the review process, consisting of the following procedures: (1) title; (2) abstract reading; (3) integral reading. Exclusion is applied to articles, throughout this process when not meeting the inclusion criteria or the following exclusion criteria: (1) articles addressing the validation of instruments for vertical jump tests (platforms, software, among others); (2) articles including samples with individuals under 18 years old; (3) articles including samples with elite or high competition athletes. In the end, 22 studies were considered for analysis in this review. Figure 1 shows a flow chart of this process.

Procedures
The analysis of the studies that met the criteria described above was based on the SPIRIT checklist defined by Chan, A. et al. (2013). This is a set of proposed guidelines for scientific trials aimed to support scientific transparency by describing in detail all phases of trials, guaranteeing, this way, the integrity of research protocols (Johansen & Thomsen, 2016). Considering that two of the studies that met the inclusion criteria referred to systematic reviews and not to scientific trial tests, they should be analysed through the PRISMA checklist, according to Moher, D. et al. (2009). This checklist was developed for reporting systematic reviews and meta-analyses. The summary table is presented below – Table 1 and Table 2 - and the complete tables are presented as supplementary information.

Table 1. Quality analysis of eligible studies – checklist SPIRIT

Reference	Result
Brusco, C. et al. (2018).	15/33
Caia, J. et al. (2016).	15/33
Carroll, K. et al. (2018).	14/33
Cuk, I. et al. (2016).	11/33
Ercan, S., et al. (2017).	13/33
Feeney, D. et al. (2016).	17/33
Ford, K., et al. (2017).	15/33
Jidovtseff, B., et al. (2014).	18/33
Kirmizigil, B., Ozcaldiran, B., &Colakoglu, M. (2014).	13/33
Mangine, G. et al. (2014).	17/33
Mayberry, J., Patterson, B., & Wagner, P. (2018).	17/33
Ong, J. et al. (2016).	19/33
Palmer, T. B., Followay, B. N., & Thompson, B. J. (2017).	13/33
Pelzer, T., et al. (2018).	15/33
Pinto, M. et al. (2014).	19/33
Rouis, M., et al. (2015).	15/33
Ryan, E. et al. (2014).	16/33
Singh, H., et al. (2014).	17/33
Son, C., et al. (2018).	15/33
Thomas, C., et al. (2015).	11/33

Table 2. Quality analysis of eligible studies – checklist PRISMA

Reference	Result
Harrison, J. et al. (2017).	7/27
Vogler, J. et al. (2017).	7/27

RESULTS

From the 22 articles selected, were considered those who at least fulfilled 50% of the respective quality analysis score. In the end, seven articles were included in this systematic review.

Both systematic review articles analysed by PRIMA *checklist* refer the same source reference (Hegedus, E. *et al*., 2015), which was considered and analysed accordingly to the same criteria, obtained a score of 20/27. However, this article was not eligible for further analysis because it includes high competition athletes, which was one of the exclusion criteria.

The articles included in this systematic review will be presented in Table 3 and Table 4, that highlights their main characteristics, using the "PICO" method: study population (sample = n), intervention, control and main results/outcomes.

Table 3. Descriptive table of eligible studies

Reference	Population	Intervation	Control	Mainresults
Feeney, D. et al. (2016).	10 men with an average of 22 years old.	The individuals performed maximum vertical countermovement jump (CMJ) with a vest that allowed the placement of loads varying from 0% to 40% of body mass.	To analyse the force-velocity relationship of leg muscles; to evaluate the reliabilityof the results obtained; to analysethe changes associated tomuscle workload and output power. The kinematics and kinetics of the ground reaction force and leg articulation were recorded.	Strong and nearly linear relationship of force-velocity. Although the increase in load was associated with a decrease in both depth of countermovement and absolute power, the absolute work increased, as well as the relative contribution of knee work. The results suggest that the vertical jumps with load can be developed not onlyto test the capacities of legs muscles, but also to reveal the mechanisms of adaptation of multi-articular movements under different load conditions.

Jidovtseff, B., et al. (2014).	10 adultmen.	8 verticaljumps: 1) SJ; 2) CMJ with minimal flexion of lower limbs; 3) CMJ with natural flexion oflower limbs; 4) CMJ with sharp flexion of lower limbs; 5) CMJ with 20 Kg; 6) drop jump with minimal flexionof lower limbs; 7) drop jump with sharp flexion of lower limbs; 8) sixconsecutive vertical jumps.	Comparison between 8 different vertical jumps in: time, displacement, speed, acceleration, force, power, impulse and stiffness.	All the jumps with sharp flexion of lower limb produced heel heights and higher concentric velocities when compared to shallow jumps. The exercises relatedto higher power outputs were the drop jump with minimum lower limbs flexion and the six consecutive vertical jumps, which involved short pulse times and very high accelerations. The highest values of muscle stiffness were not observed during the highest vertical jumps. Thismeansstiffness is not critical for the jump.
Mangine, G. et al. (2014).	28 adults: 14 menwith anaverage of 24 years old; and 14 women withan average of 22 years old.	Phase 1) all subjects performed ultrasound to assess the muscle architecture. Measurements of muscle thickness, penetration angle, cross-sectional area, and echo intensity were collected from the rectus femoris and vastus lateralis of both legs; Phase 2) 1 to 2 days after phase 1 the whole sample performed 3x CMJ; Phase 3) one week later the whole sample performed 3x 30 meters sprint.	Analysis of the relationship between vertical jump power peak and mean, 30 meters sprint speed and muscle architecture.	Men present lower echo, greater muscle size, are faster and powerful than woman. Gradual regression showed that muscle quality and size influenced speed and strength in men. In woman, asymmetry of the vastus lateralis adversely affected vertical jump power peak and mean, while echo asymmetry of vastus lateralis and rectus femoris positively influenced the vertical jump power mean and 30 meters sprint, respectively. The muscular architecture of the thigh seemed to influence the jump power and the run speed,

				although the effect may vary accordingly to gender in non-athlete active adults. A proper assessment of ultrasound variables applied in men and women before training may provide a more specific exercise prescription.
Mayberry, J., Patterson, B., & Wagner, P. (2018).	High school students (n = 1571), university students (n = 393), e professionals (n = 373).	3x CMJ. Subsequently the sample was divided into 2 groups: treatment group (with specific strength training plan) or control group (in which athlete chose his own exercises).	Comparison between 2 sample groups on CMJ performance in the variables: ground reaction force, eccentric force development rate, vertical concentric force and vertical concentric impulse.	This study analyses the efficacy of prescribed exercises in theimprovement of movement quality during CMJ. There are significant differences in changes ground reaction forces measured between both groups. There were identified 4 primary muscle groups that should be considered in efficient training plans:the divided squats increase vertical concentric impulse and decrease eccentric force development rate; deadlifts increase vertical concentric force and decrease vertical concentric impulse; alternating squats and split squats increase eccentric force development rate and decrease vertical concentric force; and alternate squats/deadlifts increase eccentric force development rate and vertical concentric force, and decreasevertical concentric impulse.

Ong, J. et al. (2016).	14 menbetween25 and 35 years old.	4 CMJ performed 3, 6, 9 and 12 minutesaftereccentric exercise performedonlegpress at 105%, 125% e 1RM (in 3 different days).	Comparison of CMJ performance results after different loads of eccentric muscle stimulus.	The best results were observed in CMJ at 3 minutes and 6 minutes in legpress with previous work at 105% and 125%. Thus, individuals can apply eccentric work in heating routines to increase further performance.
Pinto, M. et al. (2014).	16 men, between 20 and 22 years old.	3x CMJ.	To compare the performance and power of CMJ with the previous execution of a static stretching position with less than 45 seconds or more that 60 seconds, or compared with no stretching.	Regarding no stretching, the 60 seconds stretching showed worse results in CMJ, as well as in power generated. There were no differences between the results obtained after 30 seconds stretching and 60 seconds stretching or no stretching. It is concluded that the multi-articular power task (CMJ) can be impaired if performed immediately after a moderate duration stretching (60 seconds to 8 minutes), while the short duration stretching (30 seconds to 4 minutes) has an insignificant influence.
Singh, H. et al. (2014).	n= 60 27 men and 33 woman (between 55 and 75 years old).	The body composition and the sarcopenia of each individual were evaluated. 3 vertical jumps were performed on a jump mat to evaluate jump power (JPow), jump speed (JVel) and jump height (JHt). Muscle strength was measured by the 1RM test on the legpress (LP) and right	To analyze the jump power (JPow) and muscular strength, comparing them with the status of sarcopenia in older adults.	Sarcopenia was found in 20% (12/60) of the participants. Jump power was significantly lower in the sarcopenia group compared tothe normal group. JPow and Jht were significantly positively correlated with ASM and lean body mass bone free. Significant positive correlations were also reported between

		and left hip abduction exercises.		the variables of JPow, JVel and JHt and muscle strength (LP and right/left hip abduction). Individuals classified as sarcopenic had significantly lower input strength but not muscle strength, compared to other individuals with normal amounts of muscle mass. The jump test variableswere positively correlated with lean tissue and legs muscles strength. Based on this study JPow may be useful for screening sarcopenia in middle-aged and elderly adults.

Table 4. Summary table of the eligible studies interventions and outcomes

References	Population	Intervention (Jump)	Control	Comparison
Feeney, D. et al. (2016).	10	CMJ with arms impulse and withload variations.	Strength-velocity ratio of the leg muscles.	Between different levels of load in CMJ performance.
Jidovtseff, B. et al. (2014).	10	8 different vertical jumps (SJ, CMJ, DJ, with variations).	Time, displacement, speed, acceleration, strength, impulse and rigidity.	Between different types of vertical jump.
Mangine, G. et al. (2014).	28	CMJ with arms impulse.	Relationship between peak and mean vertical jump power and muscular architecture.	Between male and female individuals.
Mayberry, J., Patterson, B., & Wagner, P. (2018).	2335	CMJ	CMJ performance in the variables: ground reaction	Between the existence or not of an individual training plan for muscle strength development.

			force, eccentric force rate development, vertical concentric force and vertical concentric impulse.	
Ong, J. et al. (2016).	14	CMJ without arms impulse.	CMJ performance (jumpheight).	Between different stimulus loads prior to CMJ performance.
Pinto, M. et al. (2014).	16	CMJ without arms impulse.	CMJ performance (jumpheight).	Betweendifferentstretchingdurations.
Singh, H. et al. (2014).	60	CMJ, with arms impulse	Jump power and muscular strength.	Between individuals with different levels of sarcopenia.

DISCUSSION

Intervention

Based on the gathered evidence, CMJ is the most commonly used test for the evaluation of vertical jump, with or without arm impulse, in non-athletes. This matches existing evidence that compares the results between CMJ and other protocols such as the SJ or DJ (Bobbert & Casius, 2005). Accordingly to the same authors this can be justified by a difference in active state during the propulsion phase of both jump protocols: in CMJ the active state is developed during the preparatory countermovement, where as in SJ it inevitably developed during the propulsion phase. When released the tension developed in CMJ preparatory countermovement, it increases the contractile capacity of the muscle at the propulsion phase of vertical impulsion, producing more energy and, consequently, obtaining better results – cycle stretching-shortening.

Four out of the seven reviewed articles added on their intervention protocols the arms for impulse. In two studies, the hands were positioned on the waist and in one other the used protocol was unclear. The permission to use the swing propulsion movement of the arms for vertical jump execution, adopted by most of the authors, sustain the idea that this impulse can significantly improve the performance in the vertical test and related outcome result (Harrison, A., & Moroney, A., 2007; Akl, A., 2013).

Regarding the allowed lower limbs' joint range of motion in the vertical jump performance, the jumps with an accentuated lower limbs range of flexion have produced higher heights scores and higher concentric velocities compared to the jump performed with less flexion on the three main joints, ankle, knee and hip (Jidovtseff, B., Quievre, J., Nigel, H., & Cronin, J.,2014). Just one of the included studies, the range of flexion was imposed prior to analysis, as the remaining studies did not have an imposed range on their samples. Moreover, in a study of Domire & Challis (2007) the authors found that there were no significant differences between the jumps performed with imposed initial deep squatter position or self-selected flexion. Concluding, the performance outcomes were more related with individual coordination than to a condition of imposed squatting position or pre-selected lower limbs' flection. According to the same authors, the vertical jumps performed with grater flexion at the initial position is not common or consensual, since it seems to require more effort and increased tension in tendons and joints involved than those were a free initial position is allowed. These results were also supported by other study of Gheller, R. G., Dal Pupo, J., Ache-Dias, J., Detanico, D., Padulo, J., & dos Santos, S. G. (2015), in which better performances were observed in jumps executed freely regarding the lower limb amount of flection.

Accordingly, to the results of this review, it seems that vertical jumps performance in non-athletes is influenced by gender and age. It was observed that the masculine gender present measures of muscular size and thickness significantly greater as compared to those of the feminine gender, which can be responsible for higher values of contractile velocity and muscular power (Mangine, G. *et al.*, 2014). The same conclusions were obtained by Quatman, C. E., Ford, K. R., Myer, G. D., & Hewett, T. E. (2006). These authors also observed that this gender difference exists since early age, as in the normal growing process, men gradually and significantly reduce their reaction time and simultaneously increase their force and muscular power.

The study of Singh, H*., et al.,* (2014) demonstrates that lower values in power and impulse register in jump tasks are present in older performers. These results also support the former concept from Bosco & Komi, (1980) were the best results – peak performance – in the variables mean strength, centre of gravity height, impulse and power, were seen in both genders between the ages of 20 and 30 years old. From the age of 30 and more, the performance tends to decrease with the maturation and aging processes that affect the muscle elastic behaviour and its reflex power (Palmer, T., Followay, B., Thompson, B., 2017).

Muscle activation

The relationship between vertical jump performance and different levels of individual muscular activation in non-athletes, either by increasing external loads, by previous muscle stimulation work, or previous muscle stretching work, was the aim of five studies.

The human body behaviour in the performance of the vertical jump is adapted to the increment of external load (Feeney, D., Stanhope, S. J., Kaminski, T. W., Machi, A., & Jaric, S., 2016). A deeper depth of the countermovement and an increased muscular power has been observed as an adaptation to load increment. Performing vertical jumps with 5% of external load can increase the jump performance after removing the load (Hoffman, A., Halteman, T., Hamzabegovic, S., Wallace, C., Paulson, S., & Sanders, J.,2018). It was also seen that different strength exercises focusing the lower limbs (squats and deadlifts) contribute to increased efficiency of the vertical jump execution, through development of muscular groups responsible for concentric and eccentric energy production (Mayberry, J. K., Patterson, B., & Wagner, P., 2018). Better performance results were observed after previous leg press exercise work at 105% and 125% of 1-RM (one repetition maximum), meaning that the usage of lower limb strength exercises routines in the warm-up will contribute to superior performance results (Ong, J. H., Lim, J., Chong, E., & Tan, F.,2016).

Regarding the develop of stretching muscles routines as a way to enhance the vertical jump outcomes, Pinto, M. D., Wilhelm, E. N., Tricoli, V., Pinto, R. S., & Blazevich, A. J. (2014), concluded that CMJ performance may be decreased after static stretching from 60 seconds to 8 minutes, and there is no influence on jump performance if static stretching decreases its duration from 30 seconds to 4 minutes. This evidence is supported by Brusco, C. M., Pompermayer, M. G., Esnaola, B. W., Lima, C. S., & Pinto, R. S. (2018), with a study that demonstrated relation of lower limb power reduction on CMJ after a passive static stretching for 30 seconds with consequent reduction of vertical jump outcome scores. A static stretching of 20 seconds, however, seems to contribute to significantly better results in CMJ outcome scores (Ercan, S., Başkurt, Z., Başkurt, F., & Parpucu, T. İ., 2017). Accordingly to Kirmizigil, B., Ozcaldiran, B., & Colakoglu, M.,(2014), the dynamic and proprioceptive stretches seems to lead to an improvement in CMJ outcome scores, in different levels of flexibility, as compared with those register after static stretching protocols. However, when these stretching methods were combined with static stretching for 30 seconds, there was a decrease in CMJ performance.

CONCLUSIONS

Most of vertical jump tests studies samples are composed by athletes, although and event less prevalent, there are also some studies of non-athletes. It is even less observable the existence of studies that apply vertical jump tests in non-athletes in adults between 30 and 50 years old, prevailing young adults samples with 20 years old average.

Accordingly to the results of this review the vertical impulse test protocol most used in studies with non-athletes is the CMJ.

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