Tests of Vertical Jump: Countermovement Jump With Arm Swing and Reaction Jump With Arm Swing

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SUMMARY

THE AIM OF THIS ARTICLE IS TO ADAPT 2 VERTICAL JUMP TESTS OF LARGE COORDINATIVE COMPLEXITY AND LARGE DEMAND FOR THE NEUROMUSCULAR SYSTEM AND PROPOSE STANDARD PROTOCOLS THAT PERMIT THE COMPARISON OF RECORDED DATA FROM DIFFERENT STUDIES. THESE TESTS ARE THE COUNTERMOVEMENT JUMP WITH ARM SWING AND THE REACTION JUMP WITH ARM SWING AFTER A DROP FROM A FREE HEIGHT WITH LIMITED FLEXION OF THE KNEES AND A BRIEF CONTACT TIME.

INTRODUCTION

The purpose of this article is to justify a standardized protocol of 2 vertical jump tests which are complex and place a large demand on the neuromuscular system. These tests are the counter movement jump with arm swing (CMJA) and the reaction jump with arm swing after a drop from a free height with limited flexion of the knees and a brief contact time (1RJA). This work is needed for 2 reasons: (a) both CMJA and 1RJA jumps have been subjects of little study and (b) different variants of these have been applied in ways that have not been standardized (4,17).

The classic tests of the vertical jump are Sargent's test (1921) and Abalakov's test (1938) performed with arm swing (6). At a later date, the vertical jumps that were introduced, without the arm swing, were used to acquire data and establish a theoretic model of analysis of diverse expressions of explosive strength. These were the squat jump (SJ) and the counter movement jump (CMJ) (7). Both SJ and CMJ have been the most extensively studied jump tests in the last 2 decades of the 20th century.

This document proposes the standardization of the variant of the CMJ test with arm swing (CMJA) by means of a more restricted action of the arms compared with the protocols of Sargent or Abalakov. The aim of restricted action of the arms is to standardize jump conditions. Clear and detailed instructions about the CMJA performance are needed to compare results from studies using the CMJA.

The fundamental difference between Sargent's Test and Abalakov's Test is the method to measure the height of the vertical jump with arm movement. In the SJ, the individual jumps as high as possible from a static position and marks the wall with chalk. The difference between this mark and a standing reach mark determines the height of the jump. Abalakov's test uses a metric tape attached to the waist of the subject and the ground. In the literature, both tests are considered as well-standardized protocols; nevertheless, sometimes the authors do not apply the protocols properly. For this reason and for technological advances of record, in this article, we propose the CMJA test.

This standardization may be applied in other vertical jump tests with arm swing too: the 5RJA (Vittori-Bosco's test) (6) in 2 versions: (a) continuous jump test for a duration of 5 seconds; (b) jump test over hurdles 5 (Figure 1); and, vertical jump test after a drop from variable heights 20–100 cm ([drop jump, DJ] DJ20, DJ30, DJ40, etc), used frequently in scientific literature. The proposed test, 1RJA, allows the evaluation of the performance of the explosive strength in a contact time so brief that the involvement of the reflex pathway is possible

KEY WORDS:
assessment; protocol; vertical jump; arm swing

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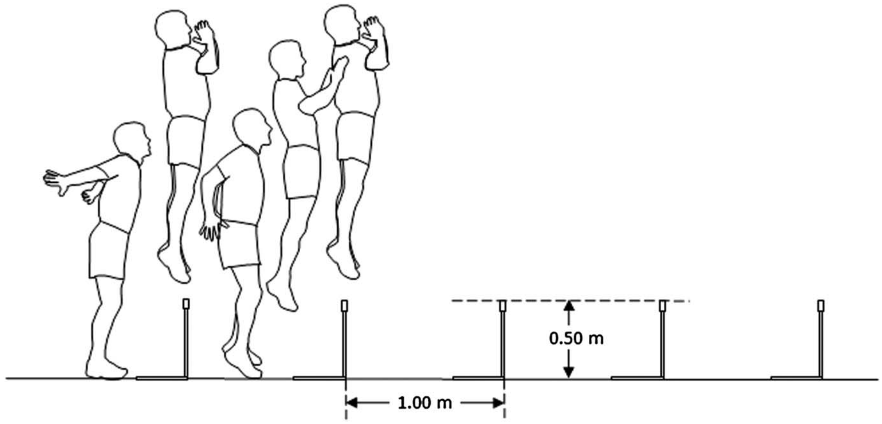

Figure 1. Schematic presentation of the rebound jump test over the hurdles adapted, 5RJA.

without establishing fixed external loads. In other words, to assess, it is not necessary for the height of the drop (20, 30, 40 cm, etc) to be the same for all subjects. Some heights of the fall in the DJ have shown a low reliability (4) and have thus justified the search for an individual drop height.

It has also been reported that the jump displacement and center of mass velocity at takeoff are significantly larger when the arms move in the direction of the jump (10). When jumps with arm swing are compared with jumps without arm swing, there is empirical evidence that the average height of the jumps is greater than 10% when the arms are used (13,16,19) and that the vertical speed of the mass center is greater when there is arm swing (9). The explanation for the mechanism of the greater height of jump by means of the arms swinging or the arms' momentum has not been described sufficiently. Nonetheless, it was concluded that the improvement of performance is based on several mechanisms operating together: neurophysiologic, mechanical, and coordinative (15). The arm swinging and the legs countermovement influence the work of the legs but in an independent way, thus the coupling of both actions generates a higher jump (12). Significant differences for the power peaks (W/kg) and the work peaks (J/kg) registered in the ankle have been reported between 2 groups of athletes with different levels of performance in CMJ and CMJA. However, only significant differences are found between these groups for the power peaks in the CMJA (W/kg) registered in the knees (20). This can be explained because the CMJA test has a higher demand on the joint activation of the neurophysiologic, mechanical, and coordinative processes, in the flexor and extensor muscles of the knee.

The SJ with arm swing (SJA) allows the achievement of a greater height than the SJ (10). The angular velocity of the hip in the jumps with countermovement (CMJ and CMJA) is slightly greater after the start of the push-off phase, than in the jumps without countermovement (SJ and SJA). Then, it is possible to conclude that the muscular state is more active in the CMJs than SJs (12), although it can make use of the arm swinging (SJA). This is because of the significant increase in the total work of the lower-limb joints, especially of the hip and ankle. Note that when the arms are moved, the increase in performance is because of the increasing magnitude of the resistance on the legs and, therefore, their work (11).

STANDARDIZED PROTOCOL: CMJA AND 1RJA

The proposed protocols of the vertical jump tests with arm swinging are described below:

Counter-movement jump with arm swing (Figure 2): The feet are placed parallel on the platform at a distance equal to the width of the shoulders, knees straight (180°), trunk fully upright, arms at the level of the shoulders (flexed 90°), hands with mild pronation and arms totally still without swinging. After 2–3 seconds at the starting position, a downward countermovement is performed by a fast flexion of the legs, the knees angle in the range of 90–120° (after individual motor adjustment) and the arms move down with the elbows extended.

The maximum flexion of the knees is done at the same time when the arms are downward. Immediately after, the vertical jump begins by an explosive extension of the legs. The elbows flex and the hands go up to the height of the face. The shoulders and elbows would be locked in place when the maximum height of the jump has been achieved. The landing is with both feet and knees extended (in the same position as the takeoff) with several bounces on the tips of the toes to help extend knees and feet (Figure 2). Thereby, the bounces reduce flight time and allow a proper recording of the jump height.

Reactive jump with arm swing (Figure 3): The feet are placed parallel on the platform at a distance equal to the width of shoulders, knees are straight (180°), trunk remaining fully upright, and the arms straight to the

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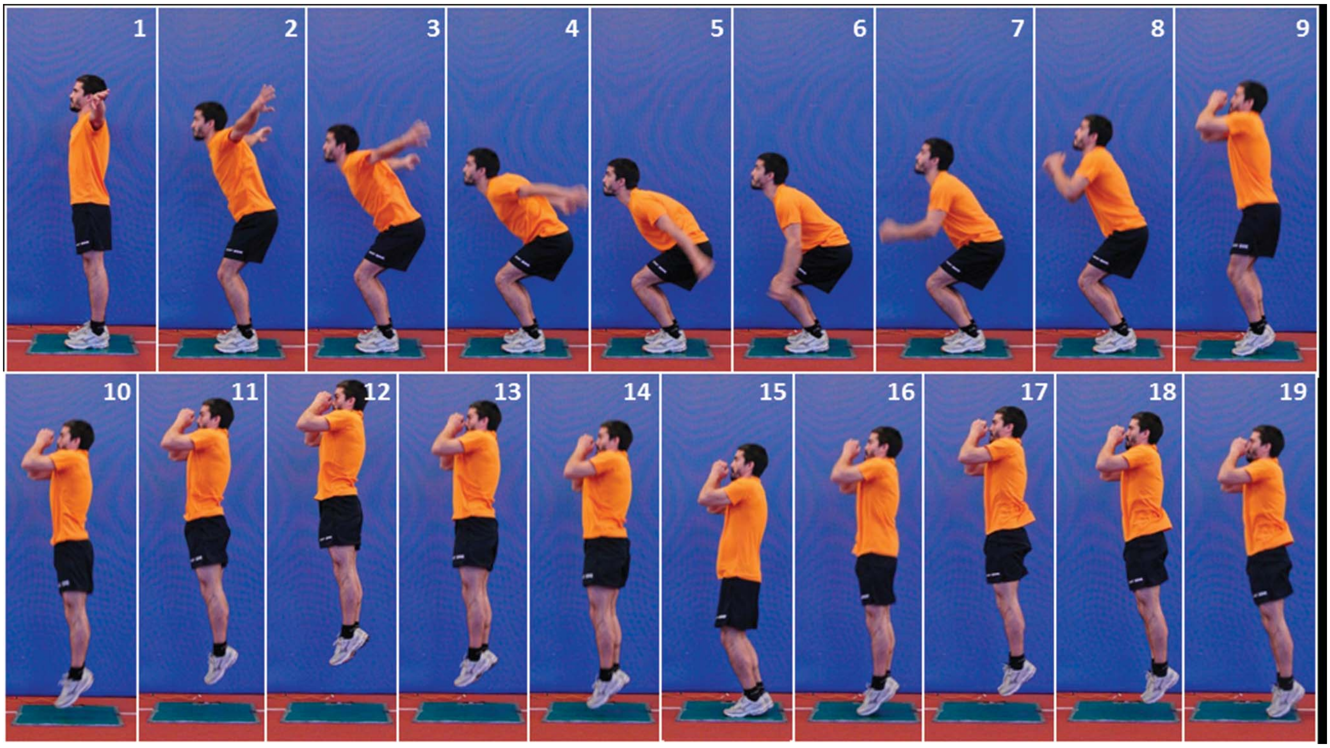

Figure 2. Countermovement jump with arm swing performed properly.

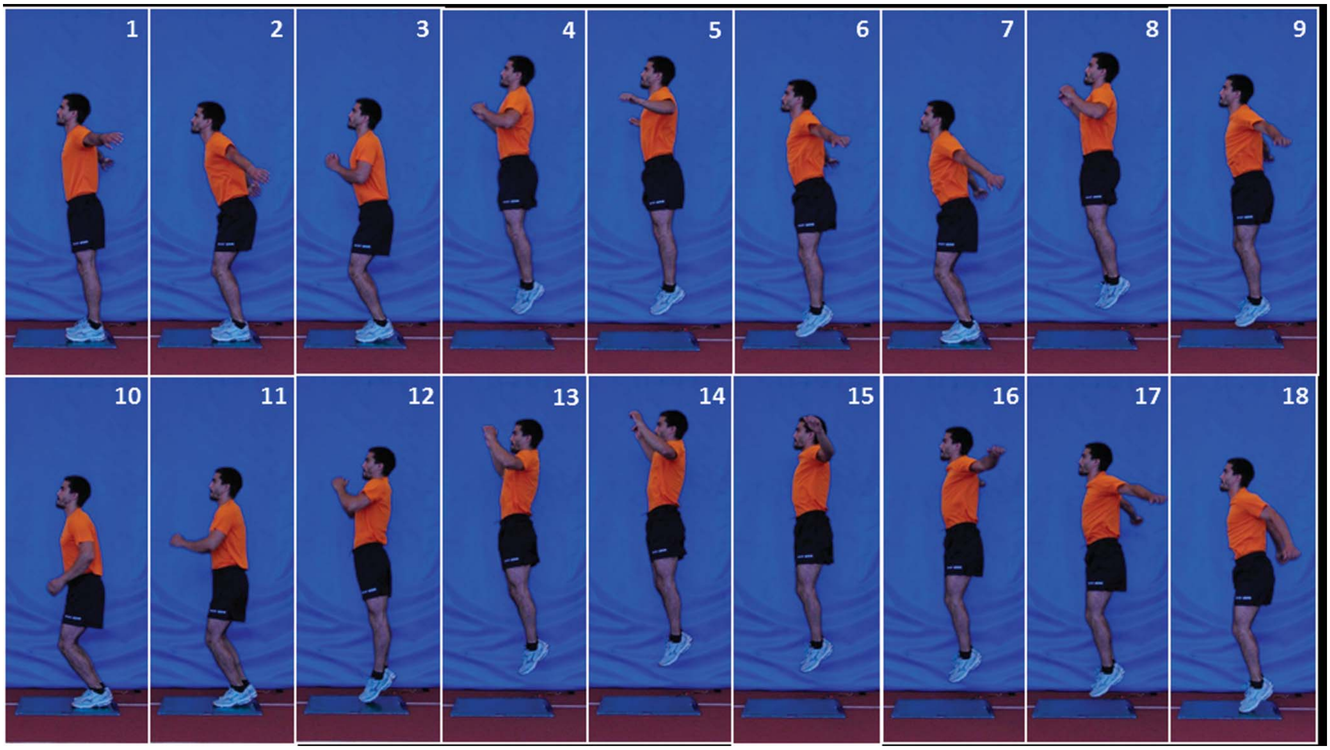

Figure 3. Reactive jump with arm swing performed properly.

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side of the body. First, do 2 or 3 progressive small jumps with the knees straight and with the help of the arm swing. There is some flexion of the knees, but the idea is communicating the performance of a reactive jump. Then, jump progressively higher during 5 or 6 seconds to achieve 2 or 3 maximum height jumps. After each of the jumps, the landing is with extended feet and knees, the same position as during the takeoff (adapted from Vittori-Bosco, 1983, in Bosco (6)). This extension helps to reduce the contact time, and therefore, facilitates the involvement of the reflex pathway and increasing of stiffness.

Of each test, the flight time and the contact time will be recorded in milliseconds of 4 jumps done properly because Bosco et al (7) obtained a high correlation test–retest with 3 attempts ($r = 0.95$) in a study with adult subjects. The highest jump with the contact time between the temporal criterions limits 249 milliseconds (maximum) and 119 milliseconds (minimum) will be selected. The temporal limits have been established to criterion of the authors from published data and empirical experience to ensure the involvement of the reflex pathway.

HIGHEST QUALITY RECORDS: CONTROL OF EXTRANEOUS VARIABLES

CONTROL OF EXTRANEOUS VARIABLES RELATED TO THE DESIGN OF THE TESTS

The possibility of adjusting the angle of knee flexion to between 90 and 120° has been included in the CMJA protocol to facilitate the highest result of jumping ability in each trial, as proposed by Baker et al (5) from a study by Bosco and Viitasalo (8). These studies found that the elastic energy reused during the positive work of muscle contraction varied depending on the eccentric phase. Different flexion angles of the knee were studied, small angles (from 124.7 to 128.7°) and big angles (from 92.7 to 90.8°), and the result was that the subjects who had a lower percentage of fast muscle fibers (37.4 ± 8.4) achieved a height almost the same with a small flexion angle of the knee (approximately 120°) as with one bigger (approximately 90°). However, the subjects with a greater percentage of fast muscle fibers (56.1 ± 9.0) achieved a higher jump through a low knee flexion and jumped considerably less with greater knee flexion.

The possibility of setting an individual adjustment of the drop height has been included in the 1RJA protocol to select the higher jump after a brief contact time on the floor. This facilitates the highest result of jumping ability in each trial (2).

The drop height of the jump has always been established in the vertical jump protocols to determine the parameters of neuromuscular tension, the strength or the height reached in stiffness conditions with a contact time of less than 250 milliseconds. Thus, for example, the subjects could perform a jump dropping from 40 cm (DJ40) being the same fixed external load for all subjects. It is very likely that this load does not offer enough stimulation for some people and excessive for others. Therefore, the application of the same load for all subjects does not allow for a proper comparison by age and gender.

Schmitbleicher (18) reported on the differences between subjects adapted and not adapted to the realization of jumps. Untrained subjects showed maximum electromygraphic activity before the impact on ground (reflex inhibition). On the contrary, at the same time, there was a neural facilitation for the vertical jump on the trained subjects.

Vittori and Bosco (1983) cited by Bosco (6) presented a different approach to the DJ: perform 5 jumps over 5 obstacles with a 50 cm height, located from each other at a distance of 1 m (5RJA) (Figure 1). The jumps must be performed with straight knees, with arm momentum trying to get as high as possible, and with the shortest contact time. From the 5RJA test, we have adapted a new protocol for the 1RJA test. With the 1RJA test, we estimate that women will achieve higher records in the jumps and the analysis of the results and application of the conclusions are different, especially during pediatric age. It is known that women have a different landing pattern than men after a drop (1), and also significant differences were found between girls (8–11 years) and adult women, which are attributed to maturation (14).

CONTROL OF EXTRANEOUS VARIABLES RELATED TO THE TESTER

To participate as a tester, the subjects must demonstrate a high competence to assess the jump test; hence, the subjects should reach a high intraobserver and interobserver reliability after a systematic process of formation and training. Control mechanisms will be established such as the agreement and consensus on certain points of the protocols (3), experiences in all of the roles (subject tested, observer, and tester) and the evaluation of the tester as a part of the final assessment to demonstrate competency.

The tester will select each jump trial according to the following categories: "correct" or "incorrect" depending on whether the jump is to be used for analysis or not. If the trial jump is correct, the jump height will be recorded in centimeters to the nearest millimeter. A jump will be considered correct when the criteria, established in Tables 1 and 2, are met. For each trial the subject should try and jump over the center of the platform.

RECOMMENDATION FOR THE PRACTICAL APPLICATION OF THE TEST: CMJA AND 1RJA

When the CMJA or 1RJA are going to be used for research, an intrasubject

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Table 1
Criteria established to consider the performance of a countermovement jump with arm swing (CMJA) as correct (see Figure 2, number in parentheses corresponds to the frame of figure)

Phase	No.	Criteria established as correct
Starting position (1)	1	Be located, approximately, over the center of the platform
	2	Soles on the platform
	3	Feet parallel at a distance equal to the width of the shoulders. Good balance
	4	Knees are as straight as possible (approximately 180°)
	5	Trunk remains as vertical as possible. Upright position
	6	Head up. Frontal view. Look straight ahead
	7	Arms horizontally outstretched in cross form
	8	Hands facing down and back (slightly pronated) to the level of the shoulders, without swinging
	9	Keep the starting static position during 2–3 s
Action phase (2–9)	10	Down fast: fast flexion of legs, bend the knees to an angle between 90 and 120° (2–5)
	11	The downward shoulders circumduction when the eccentric phase of the lower limbs is beginning (2–4)
	12	Elbow in extension during downward movement (2–6)
	13	The highest knee flexion coincides with the lowest position of the hands (6)
	14	Nonstop, concentric phase. Vertical jump with simultaneous flexion of shoulders and elbows (7–9)
	15	Arms and forearms are thrown forward and upward
	16	Takeoff with the metatarsus (9)
Flight phase (10–14)	17	Keep the trunk in an upright position
	18	Shoulders locked in 90° and elbows flexed at right angle too when the jump maximum height has been reached. See the hands in front of the face (12)
	19	Hips, knees, and ankles fully extended and aligned during the upward and downward phase
	20	Maintain flexion of the elbow, checking that hands remain around the level of face during downward phase
Landing phase (15–19)	21	Keep the trunk in an upright position
	22	Knees at an angle of around 180° at the time of the ground contact
	23	Feet in extension, stretched. First contact with the metatarsus
	24	Bounce on the tip of toes after first contact on the platform (16–19)

reliability analysis of the trials, as well as a reproducibility analysis, should be incorporated into the research design after 3 or 4 sessions. Moreover, the familiarization process with the tests, the criteria for control of extraneous variables (e.g., protocols and quality criteria for the implementation of the tests) and training and accreditation of testers should be reported.

A guide is recommended to control the sources of variation in both strength training and physical conditioning as in any research (2).

1. Subject status
   a. Full domain of the test performance.
   b. Maximum motivation.
2. Tester
   a. With systemized formation.
   b. High intratester reliability.
   c. High intertester reliability.
3. Imperfection of the tests
   a. Check the vertical direction of the jump.
   b. Check the jump phases: starting position, action, takeoff, flight and landing.

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Table 2
Criteria established to consider the performance of a 1RJA as correct (see Figure 3, number in parentheses corresponds to the frame of figure)

Phase	No.	Criteria established as correct
Starting position (1)	1	Be located, approximately, over the center of the platform
	2	Remaining criteria of "starting position" as the CMJA test
First progressive jumps (2–9)	3	Coordinate 2–3 small jumps (low intensity) with momentum of the arms (2–6)
	4	Knees are as straight as possible during the impulse, flight, and contact phases in the course of the repetitive small jumps
	5	Height of the jumps is increased gradually
Phase	**No.**	**Last progressive jumps (10–18)**
General information	6	Repetitive jumps on platform for a limited time (5–6 s)
	7	Jumping, steadily ever higher to achieve two or three jumps of maximum height
	8	Always keep the trunk straight, during all phases
	9	Landing on both parallel feet and in good balance (10)
Action phase (10–12)	10	Arms are thrown forward and upward (10–11)
	11	Takeoff with the metatarsus and knees straight as much as be possible ($\approx 180°$) (12)
Flight phase (13–17)	12	Hips, knees and ankles locked and entirely extended (12–17)
	13	Shoulders locked in 90° and the elbows flexed during upswing phase during each jump. See the hands in front of the face (12)
	14	The backward shoulders circumduction before beginning the body descent (13–14)
	15	The downward movement of the arms must be done symmetrically to avoid the imbalance of the body (14–17)
	16	Arms should be behind the frontal plane of the body during downward phase of the jump (15–17)
Landing phase (18)	17	Knees angle during the ground contact around 180°: extended
	18	Feet in extension
	19	Landing with the metatarsus
	20	Hips, knees, and ankles locked and extended
	21	Arms tense are near the body and behind the frontal plane still
Start of a new jump	22	Arms begin swing forward (10)
	23	Lower extremities soften the landing slightly (10)
	24	Short contact time between jumps (criterion limits: between 249 and 119 ms)
	25	Repeat the phases: action, flight and landing

CMJA. countermovement jump with arm swing; 1RJA, reaction jump with arm swing.

4. External conditions and materials
   a. Wide and nonslip surface
   b. Specify in detail the sensitivity, precision, and error of measurement of signal recording instruments (contact platform, force platform, video recorder, etc.).
5. Comparison with results from other studies
   a. Consider the differences among recording instruments
   b. Consider the differences among protocols of the vertical jump tests.

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