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VELOCITIES AND JOINT ANGLES DURING DOUBLE BACKWARD STRETCHED SALTO PERFORMED WITH STABLE LANDING AND IN COMBINATION WITH TEMPO SALTO

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Abstract: The aim of the study was to compare the values of velocity an joint angles obtained during performance of double salto backward stretched with a stable landing and its combination with salto tempo. Seven top level acrobats (track jumpers) participated in study. Mean values of body height, mass and age had a value of: 170 cm ± 4.0 cm, 72.4 kg ± 3.6 kg, 20.4±1.7 years, respectively. The studies were conducted on a standard acrobatic path (type PTS 2000). Two digital video cameras (240 Hz) and APAS 2000 (Ariel Dynamics Inc.) were used during studies. Markers were placed in ankle, knee, hip, arm, elbow and wrist joints. All marker positions were tracked and reconstructed using the APAS system. Two sequences with the following elements were analysed: round-off - double salto backward stretched (A) and round-off - double salto backward stretched - tempo salto (B). The highest differences between the key components describing performance of presented exercises exist for joint angles during launching and landing position, and resultant velocities during touchdown. In version A the athlete created prerequisites for "gliding" double salto backward stretched by means of the body segments motions, whereas in version B he executes faster motions of the body segments accentuating his actions upon backward rotation of the body. During the final phase of double salto backward stretched in combination with tempo salto the athlete performed courbette "under himself" (almost straight feet are placed in front of vertical line), pushes directly back and in 0,1 s executes stable arm swing upward-backward to tempo salto.
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Key words: Kinematics – Technique – Tumbling - Double salto - Touchdown

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Introduction

Double salto backward stretched is an exercise of high coordination complexity. Elite athletes perform double salto backward stretched in acrobatic jumps as a “flat element” and with pirouettes at the end of combination as well as in the middle and even at the beginning, just after the round-off in combination with other salto,- tempo salto most frequently (for instance: round-off–double salto backward stretched – tempo salto – flick-flack – double salto backward stretched with pirouette of the first salto – tempo salto – flick-flack – double salto backward stretched with pirouette of the first salto and half-pirouette of the second salto).

Analysis of scientific and methodical materials and practical experience has demonstrated that deep comparative biomechanical analysis of sport techniques’ of double salto backward stretched performed with stable landing and in combination with tempo salto was never done. Biomechanical information about the connection (connecting move) between double salto backward stretched and tempo salto is not available. High level of complexity and high mastery are demonstrated by leading athletes who are, as rule, winners, prize-winners and participants of the major international tournaments and championships of those countries in which sports acrobatics is highly developed. However, analysis of phase structure of executed acrobatic jumps (both basic and competitive of various complexity) shows rather significant and even gross technical errors in exercises of many athletes. This is especially peculiar to the phase of preparatory actions of executed salto and that of concluding actions [1,2,6,9,11,13,14,16].

During the phase of preparatory actions for salto execution these technical errors include: flexed knee joints, flexed hip joints, extremely inclined to vertical line or beyond its body position during support before taking-off in salto [8,15]. Technical errors committed during the phase of preparatory actions prevent athlete from assuming technically correct body position while flying up to and thus do not allow to execute sufficient push-flying up to, so that to reach an ascending part of flight trajectory (high, high-far). While performing the jump with technical errors the subsequent motions are executed "stracossied", that is "under oneself" or with "falling onto the back" which decreases height of flight, velocity of body rotation and significantly distorts exercise techniques. Technical errors prevent the athlete from qualitative execution of the major actions during flight - the salto proper [9,10,16,18].

At the phase of concluding actions the most typical technical errors (being the consequence of preparatory actions performed with technical errors) are: the lacking untucking, which prevents trunk extension for "gliding" in the space before landing, insufficiently or excessively turned salto at the moment of landing, landing in low squat position [3,13,15,19]. Technical errors in concluding actions decrease the quality of stable landings as well as transition to another acrobatic jump.

Objective: The aim of the study was to compare the values of velocity an joint angles obtained during performance of double salto backward stretched with a stable landing and its combination with salto tempo.

Materials and Methods

Seven top level acrobats (track jumpers) participated in study. Mean values of body height, mass and age had a value of: 170 cm±4.0 cm, 72.4 kg±3.6 kg, 20.4±1.7 years, respectively.

Two digital video cameras (240 Hz) and APAS 2000 (Ariel Dynamics Inc.) were used during studies (Fig. 1). Markers were placed in ankle, knee, hip, arm, elbow and wrist joints. All marker positions were tracked and reconstructed using the APAS system. The first one video camera was placed in key position, 90 degrees to the plane of the path tumble, the second perpendicularly to the first one. Dimensions of known factors on the field and various other measured objects in the field of view were used for the calibration points. The video pictures were grabbed and the files were stored in Audio Video Interlace format (AVI).

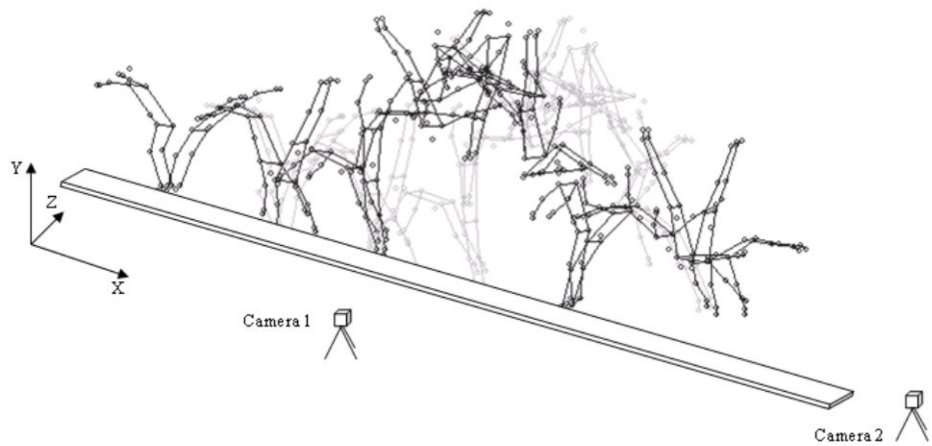

Fig. 1
The view of the system coordination and cameras localization

The data coordinate endpoints were then smoothed using a second order low-pass Butterworth digital filter with a 10 Hz cutoff frequency. Composite control cube consisting of 8 points and 17 data points were digitized and entered into the 2 dimensional linear transformation (DLT) module and converted to real displacements. The real coordinate endpoints were smoothed using a 10 Hz cutoff frequency in a low-pass digital filter. The studies were conducted on standard acrobatic path (type PTS 2000).

Two control tasks were performed by top level athletes – acrobatic jumping exercises on the track: the first one – round-off – flick-flack – double salto backward stretched with stable landing (Version A), the second one – round-off – flick-flack – double salto backward stretched – tempo salto (Version B).

Values of joint angles, velocities of the body segments, CG (center of gravity), time of exercises execution and body posture were estimated and analyzed. Error of distance measurement was estimated on 3.0%.

Structure of studied exercises has been considered as a structural and functional integrity, causal conditionality of acrobatic jumping combinations on the track. The following key elements have been subjected to analysis: preparatory phase of double salto backward stretched as well as tempo salto – launching body position (biomechanically expedient position of acrobat's body on support in the system of coordinates creating effective conditions for take-off and upward-backward flying up to with rotation); basic phase – body position changing during free of support rotation; final phase – resultant body position (peculiar for stable landing or connection with tempo salto). The opinion of each acrobat about the techniques of executing the above control tasks has been revealed during discussions with athletes. Elaborated procedure has been based upon the findings of earlier studies [2,13,14,15].

Results

Trajectories of gravity center, shoulder and ankle joints of athlete's body during execution of double salto backward stretched are presented in the Fig. 2.

In the next steps (relatively to the time execution of key elements) values of the following joint angles: knee (shank – thigh), hip (thigh – trunk) and shoulder (trunk – up-arm) were described.

Table 1 contains values of joint angles (knee, hip, shoulder) which characterize the key elements of sports techniques of double salto backward stretched with stable landing (version A) and in combination with tempo salto (version B). Direction of joint angles measurement is presented in the Fig. 3.

Table 1

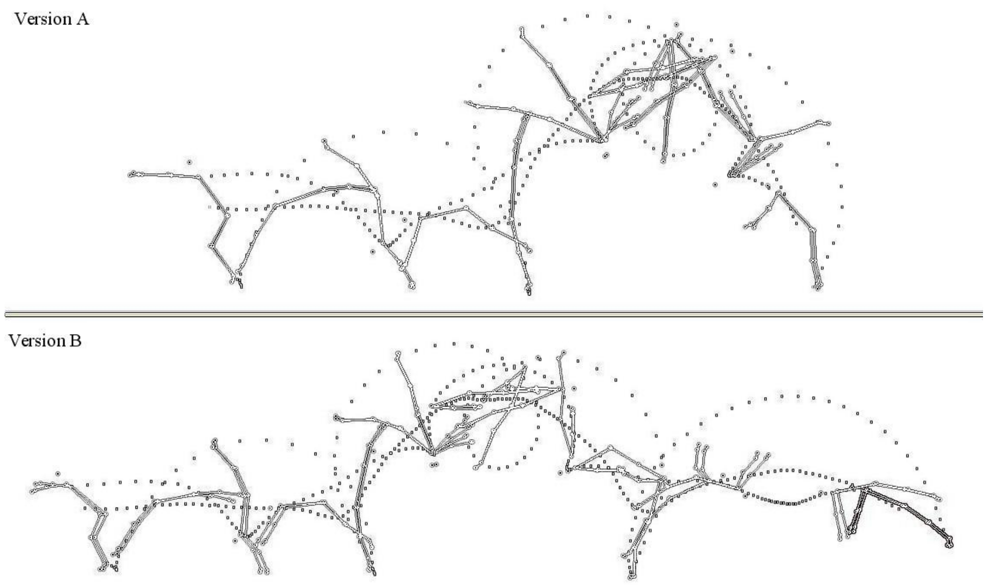

Fig. 2
Trajectories of gravity center, hip joint and center of left foot for booth type of exercises: Version A - double backward stretched salto with touchdown, Version B - double backward stretched salto with salto tempo

During the phase of preparatory action the value of hip joint angle were analyzed when the athlete assumed the launching body position (0.600 s). The knee joint angle during performance of double salto backward stretched with stable landing (version A) for the best jumper had a value of 165.9° and 159.5° while performing double salto backward stretched in combination with tempo salto (Fig. 4A) (the difference is equal to 6.4°).

The shoulder joint angle (0.600 s) in version A is equal to 194.9±1.18°, whereas in version B – to 206.0±1.00 °; knee joint angle is equal to 173.2±1.70° and 170.2±1.58° in version A and B, respectively. In version B backward stretched position of the body in support creates prerequisites for accentuated backward – upward movement of the body. Analysis of the parameters of the body launching positions in all subjects (7 athletes) demonstrates that in version B the key element of sport technique – body launching position is characterized by elasto-rigid sagged (195-206°) position of the body in support behind vertical line. Assumption of the body launching position in version A and version B had a positive effect on performance of the basic phase of double salto backward stretched – multiplication of rotation body position at ascending portion of the flight. The athlete passes from sagged body position during flight – 0.783 s to straight one – 0.850 s and then to bended body position – 1 s (Fig. 3B).

Fig.3
Direction of joint angles measurement

Figure 4C illustrates the positions of the hip joint marker during athlete's displacement from the first salto to the second one (1.183 s) when he is in vertical position with head up. In version A the angle constitutes 160.9° whereas in version B : 163.6°. One may notice backward body deviation from vertical position (by 23°). The shoulder joint angle constitutes 36.5±0.78° and 38.0±0.8° however the knee joint angles were: 169.4±2.5° and 163.7±1.93° respectively.

Biomechanical analysis of joint angle values of all 7 athletes indicates that bending (or sagging) of the body during displacement from the first salto to the second one (1.183 s) is necessary for keeping up value of the velocity of body rotation during second one salto.

Athlete's preparation for landing during the final phase is characterized by body bending in hip joints (1.533 s). The hip joint angle was equal to 141.76±3.18° in version A, whereas in version B body in the hips was bended by 23.0° more (118.8±1.13°).

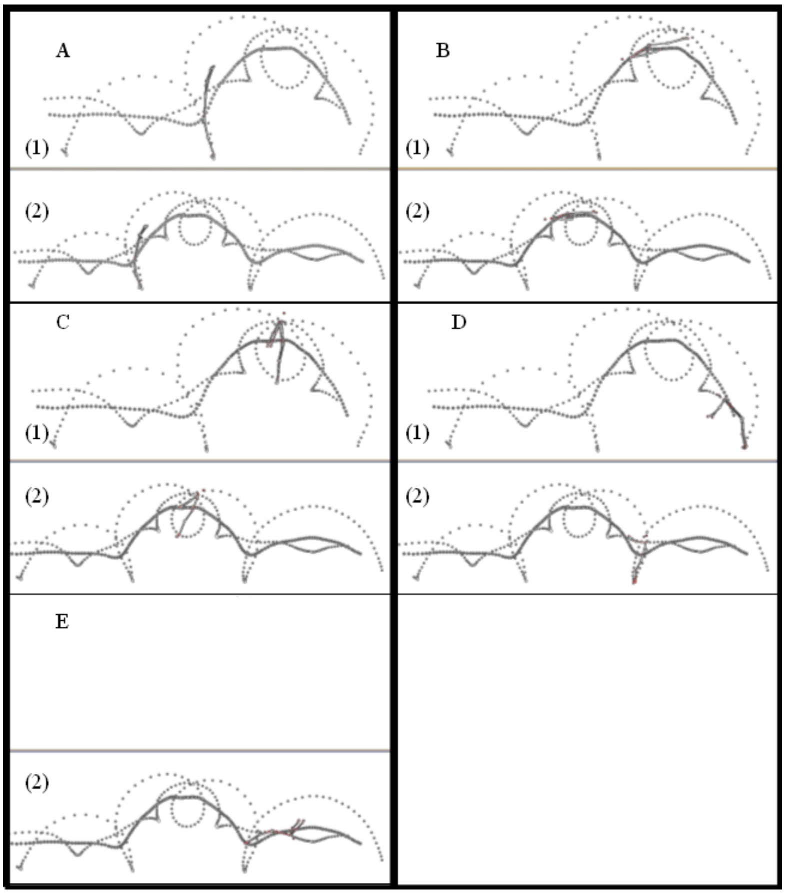

Fig. 4
Positions of hip and foot joints of the left body side during double salto backward stretched with stable landing (1) and in combination with tempo salto (2) during different time of body positions: A – 0.600 s, B – 1.000 s, C – 1.183 s, D – 1.700 s, E – 1.850 s

Analysis of presented values of the hip joint angle is indicative of various actions fulfilled by athlete within the time limits of 1.183-1.533 s. In version A the athlete "brakes" the trunk motion during the flight, thus preparing for landing by means of gliding. In version B the athlete begins to "attack" the track with specific courbette for subsequent elasto-rigid feet placement at the support "under oneself", i.e. in front of the trunk (in front of the vertical line), so that to cross the vertical line with the trunk in due time, keeping feet on the support (1.700 s) (Fig. 4D).

In version A the athletes are in front of the vertical line, the hip angle constitutes 139.1±4°, whereas in version B he is behind the vertical line, and the angle is equal to 166.5±6°.

In the process of executing double salto backward stretched upper extremities take an active part in regulation of body position which is in airborne position. For instance, at 0.78 s the shoulder joint angle had a values 127.57±1.38° and 132.5±1.28° in version A and B, respectively, whereas at 0.850 s – 68.69±0.3° and 69.9±1.1°, respectively; 0.150 s later (1.000 s) the joint angle significantly decreased – 27.92±0.85° (version A) and 28.1±0.73° (version B).

From 1 to 1.7 s the arms are close to the trunk, and the acrobat performs motions of short amplitude, being more expressed in version B (for instance, at 1.533s the shoulder angle had a value of 21.5±0.8° and 37.7±0.75° in version A and B, respectively. By the moment of landing (1.700 s) the shoulder joint angle significantly increases and constitutes 70.3±1.13° and 82.6±0.9° in version A and B, respectively.

During execution of double salto backward stretched in combination with tempo salto (1.783 s) (version B), the launching position of athlete’s body in tempo salto is characterized by such position of segments in which there occurs a directed loss of balance backward and pushing off “in the back” with extension (the hip joint angle constitutes 196.3±2.40°, that of shoulder – 76.6±0.78° and that of knee – 163.1±1.48°.

It has been established that at the instant when the athlete moves the trunk backward the arms “brake” their movement whereas in 0.100 s they “catch up” with the trunk correcting the body position multiplication during the basic phase of tempo salto.

From 1.8 s to 2.0 s the hip joint angle has the following values: 1.8 s–196.3±2.40°; 1.850 s –215.7±2.45° (Fig. 4E); 2.0 s –163.9±2.20°.

The shoulder joint angle has increased to the following values: 1.8s–76.6±0.78°; 1.850 s – 102.4±0.93°; 2.000 s – 101.1±0.73°.

During the final phase of tempo salto (2.250 s) the hip joint angle constitutes 159.4±1.93°, shoulder – 95.8±1.00° and that of knee – 173.7±1.28°.

Presented values of joint angles at the final phase of tempo salto allow to suggest that prerequisites for performing courbette of tempo salto have been created by the athlete.

Table 2

Selected body joints were also described by velocities of its motion. Table 2 contains resultant velocities equaled from vertical and horizontal components for selected joints and CG during performance of double salto backward stretched with stable landing (Version A) and in combination with tempo salto (Version B).

During launching posture assumption (0.600 s) rather close velocities of motion of ankle, knee, hip, shoulder, elbow joint and GCM have been recorded. Velocity of hand motion (wrist joint) in version A is 2.5 m/s greater. From 0.078 s to 1.000 s the athlete performs an active "entry" into the first salto and whipping foot movement "behind the head". In version A the following velocities of ankle joints were recorded: 14.4±0.32 m/s, 15.9±0.40m/s and 12.0±0.37 m/s at the time: 0.783 s, 0.850 s and 1.000 s, respectively, whereas in version B: 15.1±0.37 m/s (0.783 s), 17.0±0.45 m/s (0.850 s) and 10.6±0.40 m/s (1.000s). Velocity of GCM constitutes 4.6±0.19 m/s (0.783 s), 4.1±0.17m/s (0.850 s) and 3.6±0.17m/s (1.000 s) in version A, and 4.5±0.24 m/s, 4.2±0.25 m/s and 3.3±0.21 m/s, in version B. Velocity of shoulder joint movement in version A is equal to 3.3±0.18m/s at the 0.783 s, 0.9±0.13m/s at the 0.850 s and 5.3±0.27m/s at the 1.000 s, whereas in version B the values are as follows: 2.7±0.23m/s, 1.7±0.20m/s and 6.1±0.30 m/s.

Among 1.400 s and 1.483 s motions of the athlete are characterized by increased prerequisites for further combination of double salto backward stretched and tempo salto. During final phase of double salto backward stretched (1.533 s) velocities of shoulder and ankle joint as well as that of GCM are rather close in both versions (Table 2). However, at the 1.700 s (landing) in version A velocity of shoulder joint had a value of 6.1±0.15m/s, whereas in version B it had been higher by 2.64 m/s. Higher velocity of wrist joint (11.6±0.23m/s) has been also noted, whereas the velocity of ankle joint has dropped to zero (0.6±0.20m/s) but at 0.8 s increased to 6.4±0.40m/s in version B. In version A it was 4.9±0.17 m/s – the so-called phenomenon of elastic deformation in the process of landing was possible by this velocity.

During the phase of tempo salto preparatory actions (1.783 s) velocity of wrist joint had a value: 13 m/s, shoulder: 7.2 m/s, ankle: 6.4 m/s and GCM: 6.3 m/s. (Table 2, Fig. 3). At 1.850 s velocity of following joints were changed to: 10.2 m/s, 5.8 m/s, 10.2 m/s, CG: 5.6 m/s, respectively. During the final phase (2.250 s) the abovementioned values had values: 1.9m/s, 5.6m/s, 11.3m/s and 6.0m/s, respectively.

Discussion

Kinematical analysis of the structure of acrobatic jumps were made based on the key elements theory. Three key elements were selected to the analysis: launching body posture (LP), straight posture and its multiplication (MP) and final posture (FP). The main emphasis of this paper were put on the body position, joint angles and velocities after final posture which should prepare acrobat to the next salto tempo.

Previous authors identify, so-called, key elements to describe body position and its motion. Different names of main body positions during acrobatic performance were used: junction sequences [14,15], conducted links [17], and key elements [4,7,12]. The significance role of acrobatic jumps were attributed to phase of take off and flight [2,5,13]. However, Gervais and Dunn [6] emphasizes special ‘feeling of border’ as an element of proper training construction when the complex form of exercises were trained. Above-mentioned information was concluded in the King and Yeadon papers, therefore, body positions, linear velocities and joint angles have significance higher role then maximal force applied during take off in our paper as well [8,9,12].

Body position was the most significant differences of the parameters of body segments movements during perforation of double salto backward stretched with stable landing and in combination with tempo salto. During the final phase of double salto backward stretched in combination with tempo salto the athlete performed courbette “under himself” (almost straight feet are placed in front of vertical line), pushes directly back and in 0.1 s executes stable arm swing upward-backward to tempo salto. Moreover in version A the athlete created prerequisites for “gliding” double salto backward stretched by means of the body segments motions, whereas in version B he executes faster motions of the body segments accentuating his actions upon backward rotation of the body.

Analysis presented above confirm the fact that feet do not fall behind the trunk movement but fulfill the leading movement as well as the fact that in version B in individual elements of techniques the motion velocities of the joint are higher. The above may be necessary for the athlete to create the “reserve” of the motion velocities of the body segments for the subsequent combination of double salto backward stretched with tempo salto. In version B the athlete assumes vertical body position with head down and executes the travel from the first salto to the second earlier. At the time 1.183 s acrobat’s obtained position during his travel to the second salto. The athlete assumes a slightly bended position so that to maintain the speed of rotation. He deflects his shoulders and head backwards in order to execute a ceaseless “entry” in the second salto which allows him to accelerate movement of feet (from athletes’ answers: … “at that time an elastic rigidity of the body is maintained”).

Biomechanical analysis of the parameters of double salto backward stretched with stable landing (version A) and combination with tempo salto (version B) has become possible on the basis of determining, for sport technique, key element functioning: launching body position (rational from the angle of biomechanics position of the body segments on support), multiplication of body position (arched-straight-bent) during rotation in flight, resultant body position of stable landing, transfer of resultant body position of double salto backward stretched to launching body position of tempo salto.

Summary and conclusion to sport practice

Based on the biomechanical analysis of the technical structure of the double salto backward stretched with the tempo salto combination an algorithm of teaching for acrobatic exercises was work out (Fig.5).

Four levels of the motion expressions and motion habits were experimentally established and adopted to teaching process and system of training for Polish acrobats and coaches.

The first level (P1.1–P1.4) is composed of auxiliary task. The aim of the first level is to teach key links among the following elements existed on this level in the consecutive points:

P1.1 – launching body position in the last phase of the flick-flack,
P1.2 – multiplication of the body during flying,
P1.3. – courbette in the last phase of the double salto backward stretched
P1.4. – interlink between double salto backward stretched and salto tempo.

The second level (P2.1–2.8) is composed of psycho-functional and sensomotorical basis. The aim of the second level is enhanced levels of force and speed abilities, improvement of body sense and stability and sensitivity regulation by vestibular organ.

The third level (P3.1–P3.9) is composed of technical task. The aim of the third level is enhanced of execution key elements existed on the first level in automation manner. Improvement of body direction sense during touch down and flaying? is the main training method of this level.

The fourth level (K(P.1.1) – K(P1.4)) is the sublevel of the result of teaching. The aim of the fourth level is to appreciate feedback between competitor’s performance of the double salto backward stretched with the tempo salto combination and coach method of training and information transmission.

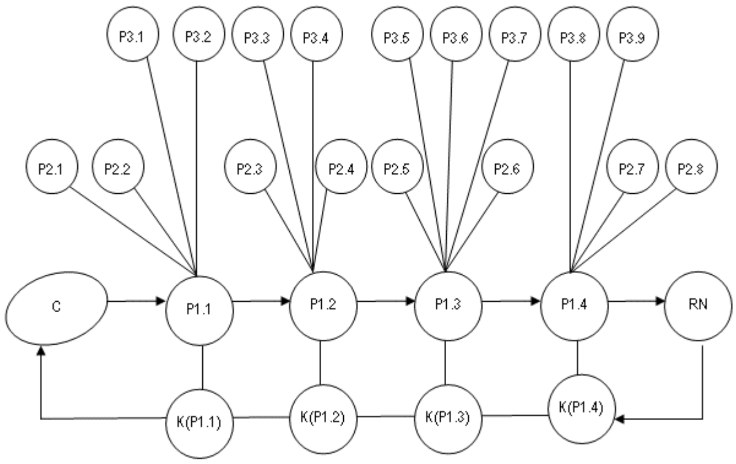

Fig. 5
The linear branched algorithm of the double salto backward stretched with the tempo salto combination teaching; RN – result of teaching, C – the principal aim of the training, additional symbols explanation shown in the paper

In our opinion the presented linear branched algorithm could improve identification of key elements existed in acrobat technique and explains connection between motion expressions and motion habitats. The linear connection among presented above levels should enhanced transmission of information between coach and acrobat and between ourselves.

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