Vertical Jumps Performance Analysis: Implementation of Novel Complex of Jumps

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Keywords: Vertical Jumps Performance Analysis, Female Athletes, Fitness Control, Motor Asymmetry.

Abstract: The proposed study was focused on justification of complex of vertical jumping tests analysis for practical applications of athletes' enhancement. Eighteen national level female athletes aged from 18 to 25 (13 basketball-players and 5 biathletes) underwent anthropometric measurements and set of vertical jumping tests on the force plate. To obtain comprehensive data on jumps performance and motor assymetry classic countermovement and squat jumps were supplemented by countermovent jump with arms swinging and single-leg jumps (on the right and left leg separately). Descriptive and comparative analysis were applied for further statistical data processing. We found that: (i) mean values of body composition variables were within the norm in both groups, meanwhile, biathletes had significantly higher relative body and leg muscle mass; (ii) there were no significant differences in countermovement jump performance between basketball players and biathletes except longer duration of squat and take-off phases in biathletes; (iii) squat jump performance analysis revealed significantly higher strength of knee extensors in female biathletes; (iv) jump height in countermovement jump with arms swinging was significantly higher in biathletes' group; (v) motor asymmetry of lower extremities was more evident in basketball players. The proposed set of different vertical jumps provides with valuable information on fitness level in athletes.

1 INTRODUCTION

Vertical jumping tests are widely used in the sports science and practice for evaluation of muscular strength and motor coordination (Lara, 2006, Van Hooren, 2017, Zakharova, 2017). These types of tests have been introduced since the beginning of XX century (Petrigna, 2019). A number of studies showed high informative value and comprehensive outcome data from this testing, as well as simplicity of its carrying-out (Newton, 2006). Due to these facts, in the modern era vertical jump tests are frequently used by coaches and strength and conditioning professionals to obtain valuable information for correct trainings planning.

Initially, jump tests were used without specific equipement and the only available information was the jump itself. Along with technical development in sport science new devices were implemented: force plates, photoelectric cell systems, contact mats, contact platforms, jump mats, accelerometer-based systems, linear position transducers, digital cameras with sensors placement for motion analysis etc. (Petrigna, 2019). These hi-tech instruments are widely used nowadays for obtaining comprehensive information not only on height of the jumps, but also on biomechanics (Ashley, 1994) and motor assymetry of lower extremities (Yanci, 2014).

Although, progressive development provided with valuable equipment for high quality research, we should keep in mind that a number of issues concerning reliability and feasibility still remains unsetteled.

One of the mentioned above problems is a lack of standartization in jump phases identification, which may affect interpretation of jump phases duration, time to peak force reaching and rate of force development (Petrigna, 2019). Among other issues is the high cost of force plates and motion analysis devises.

Numerous studies are devoted to performance analysis of vertical jumps. Biomechanical kinetic and

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kinematic variables (force, velocity, displacement, etc) are under consideration, nevertheless there is still a gap in practical applications of valueable information.

The aim of the proposed research was to justify the complex of vertical jump test analysis for practical applications of athletes' enhancement.

2 ORGANIZATION AND METHODS

The study was conducted in the laboratory "Functional Testing and Complex Control in Sports" of the Institute of Physical Education, Sports and Youth Policy, Ural Federal University (Yekaterinburg, Russia).

Eighteen qualified female athletes were recruited for the study: 13 professional basketball players (mean age – 19.5±2 years, height – 181.7±7.4 cm, weight – 72.5±10.4 kg) and 5 biathletes (mean age – 20.8±2.3 years, height – 166.8±5.5 cm, weight – 57.8±5.6 kg). Both basketball-players as well as biathletes had more than 7 years of training and competitive experience and were national leaders in their kind of sport among athletes of their age. All tested subjects had no acute traumas or injuries, were free of any neurological or muscular-skeletal disorders and were admitted to perform the proposed tests by the team medical staff. The investigation conforms to the principles of the Declaration of Helsinki of the World Medical Association. Subjects involved in the study had been provided with comprehensive information on the procedures, methods, benefits and possible risks before their written consent was obtained. The study protocol was approved by the Ural Federal University Ethics Committee (#05-2020).

2.1 Anthropometric Measurements

Anthropometric data (height and body mass) of involved in the study athletes were measured with the use of WB-3000 plus Digital Physicians Scale (Tanita, Japan).

Body composition was also estimated by means of bioimpedance analysis with the use of MC-980MA Plus Multi Frequency Segmental Body Composition Monitor (TANITA, Japan) based on the advanced FDA cleared Bioelectric Impedance Analysis (BIA) technology. The following parameters were under consideration: body mass (kg), body mass index (BMI), muscle mass (kg; %), fat mass (kg; %), segmental analysis of each leg (kg; %) and muscle mass balance.

2.2 Performance Analysis for Vertical Jumps

The detailed analysis of complex of four types of jumps was performed to evaluate speed-power abilities of lower extremities as well as motor asymmetry and body posture control.

Vertical jumps were `carried out on a force plate TJ4002 (Marafon-Electro, Russia) which was mounted and carefully calibrated according to manufacturer's specifications. Original custom-designed software for ongoing analysis was used for acquisition and processing of the vertical component of the ground reaction force.

Preinstalled TJ4002 software package allowed to analyze the following parameters: duration of jumping phases (squat, take-off) (t, s); jump height (cm); maximum force for take-off (N).

Separate placement of detecting elements inside the used device (right and left parts of the force plate) provided with graphical information on movement of both legs simultaneously (Figure 1). This visualization allowed to estimate motor asymmetry of lower extremities in studied athletes.

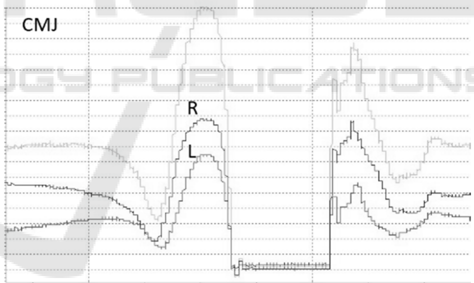

Figure 1: Example of graphs in classic vertical countermovement jump: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

Before the test each participant of the study was familiarized with the technique of each type of jump. After appropriate 5-7 min warm up to avoid any injury or healthcare issues during the test athletes were given the task to make triple jumps with short rest time between jumps:

- countermovement jumps (CMJ) with keeping hands on the waist,
- squat jumps (SJ) with hands on the waist,
- single leg jumps on the right and left legs bending hands on the waist,
- CMJs with arms swinging.

Athletes were allowed to have about 1 minute rest between the consecutive set of jumps.

Each athlete was instructed to perform the jumps with the maximum effort. It was required to jump at the highest possible speed and to attain the highest point as possible. Only the best attempt from the set of three trials of each type of jumps was further taken into consideration for the ongoing analysis.

2.2.1 Countermovement Jumps

For correct carrying out CMJ, athletes were instructed to perform a maximal vertical jump from upright position on the force plate with fully extended knees and feet shoulder-width apart. It was required to have the arms bending on the waist and avoid any release of the hands from the initial position.

No specific instructions were given regarding the depth of the countermovement. Athletes were encouraged to keep the trunk as vertical as possible.

2.2.2 Squat Jumps

Before performing vertical SJ subjects were instructed to descend into a semi-squat position with knees flexed at about 90 degrees and hold this position for approximately 3 seconds before takeoff, start jumping bending arms on the waist (Van Hooren, 2017).

It was strongly recommended to avoid any countermovement during the jump to have just the concentric action of the agonist muscles involved in the movement.

2.2.3 Countermovement Jumps with Arms Swinging

In order to perform this type of jump correctly, athletes were encouraged to carry out a maximal vertical jump from an upright position with both arms swinging simultaneously. No specific instructions were given regarding the depth of the countermovement.

Basically, ccountermovement jump with arms swinging (CMJAS) is used for comparison of the obtained data with classic countermovement jumps with keeping hands on waist (McErlain-Naylor, 2014, Lees, 2004). Some authors strongly recommended to pay particular attention to arms position during the tests and precisely describe the protocol of vertical jump (Petrigna, 2019) as the outcome data should consider different patterns of countermovement jump with and without arms swinging.

In our view, the best way was to include both types of countermovement jumps as (i) jumps with hands on the waist is a universal test, meanwhile in team sports there are no isolated movements: the whole body coordination for solving the game tasks is required; (ii) the comparison of the test results between both jumps provided with valuable information that is extremely useful in comprehensive interpretation of vertical jump tests in athletes.

2.2.4 Single-leg Vertical Jumps

Single-leg vertical jumps (SLJ) were performed to obtain information not only about power of thigh extensors of each leg separately, but also data on symmetry/asymmetry (motor balance or imbalance) of lower extremities.

It was recommended to jump on right/left leg, standing in the center of the platform for more precise recording of the movement. It was not allowed to release the hands from the waist.

2.3 Statistical Analysis

Statistical analysis was performed with the use of statistic software package “SPSS Statistics 17.0” (IBM). Descriptive analysis was applied with calculation of mean values (M), standard deviation (SD), minimum and maximum values of the measured variables from anthropometric analysis and vertical jump tests.

Normality of distribution in groups was estimated by Shapiro Wilk test. Furthermore, obtained jump test data between groups of athletes was compared by t-test (Student criteria). Differences were significant at $P < 0.05$.

3 RESULTS AND DISCUSSIONS

Analysis of anthropometric data showed that basically all studied athletes had appropriate body composition in reference to their sports specialization. Table 1 demonstrates descriptive data from detailed analysis of body composition in studied athletes and comparison of measured variables between groups.

As one can see, there were no significant differences between mean values of right leg muscle mass and left leg muscles mass neither in basketball players nor in biathletes. At the same time, it is clear, that biathletes had higher relative muscle mass in the whole body and in both legs in comparison with female basketball players.

Table 1: Results of detailed anthropometric analysis (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Height, cm	181.7±7.4 (170-192)	166.8±5.5 ** (162-174)
Body mass, kg	72.5±10.44 (58.5-98.4)	57.8±5.6 ** (52-65)
BMI, kg/m²	21.9±1.9 (19.7-26.7)	20.1±1.1 ** (19-22)
Muscle mass, kg	53.65±5.1 (46.7-67.7)	47.4±4.1 * (43.6-53.4)
Muscle mass, %	74.7±4,3 (66.5-82)	82.2±2.9 ** (79-86)
Fat mass, %	21.8±4.2 (15-30)	13.5±2.9 ** (9.7-17.1)
Right leg muscle mass, kg	8.95±0.92 (7.6-11.4)	7.84±0.52 (7.2-8.4)**
Right leg muscle mass, %	12.4±0.7 (11-13.8)	13.54±0.73 (12.6-14.5)**
Left leg muscle mass, kg	9.1±1.01 (7.6-11.8)	7.9±0.6 (7.3-8.5)*
Left leg muscle mass, %	12.6±0.6 (12-14)	13.64±0.7 (12.7-14.5)**

** - $P < 0.01$
* - $P < 0.05$

Results of performance analysis for vertical jumps revealed no significant differences in countermovement jump performance between female basketball players and biathletes except duration of squat and take-off phases (Table 2).

Table 2: Results of countermovement jump test (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Jump height, cm	23.5±3.7 (19-29)	27.4±5.3 (20-33)
Maximum force for take-off, N	1162.5±189.8 (933-1542)	1031±123.97 (904-1233)
Relative maximum force for take-off, % body weight	161.5±21.5 (127.6-200.5)	180.5±16 (163.3-198.9)
Squat phase duration, s	0.31±0.06 (0.24-0.43)	0.3±0.02 * (0.28-0.32)
Take-off phase duration, s	0.38±0.07 (0.27-0.48)	0.41±0.03 * (0.37-0.44)

* - differences significant at $P < 0.05$

In such sport as basketball athletes require excellent sprinting performance while the competition in biathlon may be typing as endurance activity. Biathletes' tardiness in countermovement jump performance may be explained by the typical technique rhythm of skiing rather smooth than propulsive. Satisfactory average values of relative force for take-off were demonstrated by biathletes. Although 7 basketball players developed excellent relative force (more than 180 % body weight), the average value was low due to its wide variation within the group (127.6-200.5 % body weight).

Squat jump performance analysis revealed significant differences in average relative force for take-off. This means higher strength of knee extensors in female biathletes (Table 3). In comparison with countermovement jump squat jump requires less well-developed capability to co-activate muscles (Van Hooren, 2017) thus determines strength of lower limbs precisely.

Table 3: Results of squat jump test (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Jump height, cm	22.6±4.4 (16-29)	25.4±4.3 (21-32)
Maximum force for take-off, N	1065.7±197 (828-1428)	967±153 (827-1182)
Relative maximum force for take-off, %body weight	134.22±41.94 (118.2-166.04)	168.4±13.4 * (154.9-190.6)

* - differences significant at $P < 0.05$

Jump test with arms swinging results were contrary to expected ones: jump height by biathletes was significantly higher than by basketball players. In basketball tackling manoeuvre with arms swinging is essential, so we hoped that jump height would be better.

Table 4: Results of countermovement jump test with arms swinging (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Jump height, cm	29.3±3.8 (22-36)	34.8±5.2* (27-39)
Maximum force for take-off, N	1065±147 (864-1329)	1025±58 (936-1069)
Squat phase duration, s	0.3±0.03 (0.26-0.35)	0.29±0.03 (0.25-0.31)
Take-off phase duration, s	0.4±0.06 (0.33-0.48)	0.39±0.06 (0.3-0.43)

* - differences significant at $P < 0.05$

The inclusion of an arms swinging increased jump height by approximately 8-10 cm (McErlain-Naylor, 2004). Notably, in basketball players arms swinging increased the average jump performance only by 5.8 cm above the classic countermovement jump result (Table 2 and Table 4).

Comparison of vertical countermovement single-leg jump test (female basketball players vs female biathletes) revealed statistically significant better results in biathletes' right single-leg jumps (height and force) but long and smooth (Table 5) as it was found in countermovement jumps (Table 2).

Meanwhile, results of left single-leg jump showed the only significant difference in value of maximum force for take-off between the groups (Table 6).

Table 5: Results of countermovement single-leg (right) jump test (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Jump height, cm	13.3±3.7 (10-23)	17.2±3.1 * (13-20)
Maximum force for take-off, N	935±122 (731-1222)	806±72.2 * (725-883)
Relative maximum force for take-off, %body weight	120.45±76.3 (118.4-143.93)	141.14±78.4** (131.8-151.5)
Squat phase duration, s	0.29±0.05 (0.21-0.37)	0.34±0.07 * (0.27-0.43)
Take-off phase duration, s	0.42±0.08 (0.36-0.62)	0.5±0.06 * (0.45-0.56)

* - differences significant at $P < 0.05$

Table 6: Results of countermovement single-leg (left) jump test (M±SD (min-max)).

Parameters	Basketball-players (n = 13)	Biathletes (n = 5)
Jump height, cm	13.5±2.7 (10-21)	15.8±3.03 (13-19)
Maximum force for take-off, N	927±118 (748-1166)	804±87.6 (703-895)*
Relative maximum force for take-off, %body weight	128.65±11,15 (106.5-146.58)	140.63±90* (127.8-153.3)
Squat phase duration, s	0.3±0.08 (0.22-0.52)	0.32±0.05 (0.27-0.37)
Take-off phase duration, s	0.44±0.1 (0.35-0.61)	0.53±0.11 (0.43-0.69)

* - differences significant at $P < 0.05$

Comparison of vertical countermovement single-leg jump test – right leg vs left leg – revealed no significant differences. Although, a healthy person may jump slightly higher on one leg relative to the other, the magnitude of the difference is assumed to be relatively small (Lawson, 2005).

For determination of motor asymmetry in lower extremities more attention must be paid to single-leg jump height but not force or use different field tests: no significant differences between the dominant and non-dominant legs were found in the vertical jumps tests (Newton, 2006, Yanci, 2014).

Determination of motor asymmetry is onerously or expensive. For example, vertical jump forced test (Impellizzeri, 2007) consists of countermovement jumps with both legs simultaneously: one on a single force platform, the other on a leveled wooden platform. Kistler Co– the global leader in dynamic measurement technology for measuring pressure, force, torque and acceleration in sport science– suggested to use two force platforms for the asymmetry research. Contrary to above mentioned options Marathon-Electro force plate TJ4002 allows to determine three force graphs: each leg separately and their sum (Figure 1).

Graphical data from jump tests increased the value of the obtained results. It was possible to compare the movement of both legs and suggest the amendments to athletes' trainings.

Basically, asymmetry was assessed by determining vertical or horizontal differences between right and left curves with respect to axes, indicating time and space asynchrony.

Figure 2 demonstrates an optimal pattern of squat jump – knee extensors and core muscles were extremely efficient, no signs of imbalance were registered.

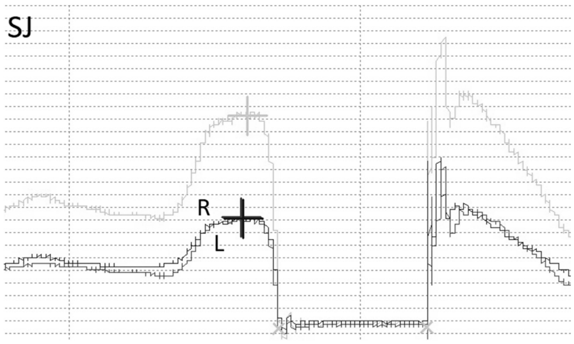

Figure 2: Example of an optimal vertical squat jump: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

Figure 3 detected both time asynchrony in the phase of knee extension, as well as a lower input of the left leg in the phase of take-off. Potentially, these may be the consequence of the previous or chronic injury or incomplete rehabilitation in the past. Apart from this, we may turn our attention to low peak in the take-off phase in both legs that is the evidence of insufficient speed-power trainings.

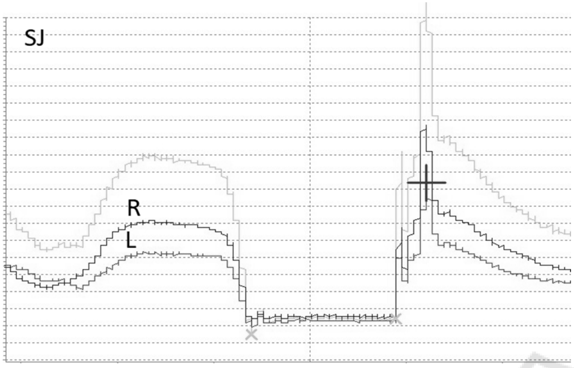

Figure 3: Vertical squat jump: signs of chronic knee injury or incomplete rehabilitation: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

Figure 4 is a typical demonstration of motor asymmetry of knee extensors in playing sports athletes. Despite of normal distribution of muscle mass in both legs, neuromuscular transmission is inefficient which results in inability to recruit all muscle fibers of the left leg.

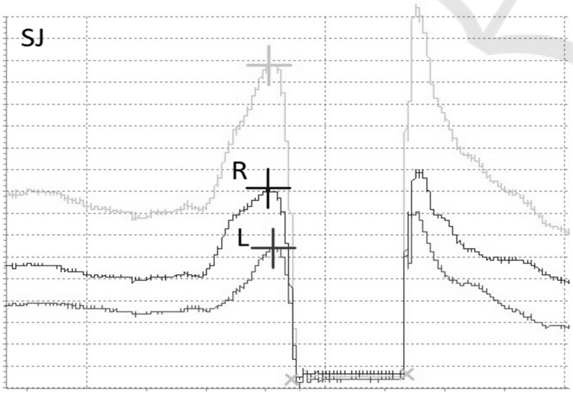

Figure 4: Vertical squat jump: motor asymmetry of knee extensors: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

Figures 5 and 6 show motor asynchrony in countermovement jump performance. Noteworthy, Figure 5 is an illustration of asymmetry in the final of take-off phase, while Figure 6 shows asynchrony both in phase of knee extension, as well as take-off phase.

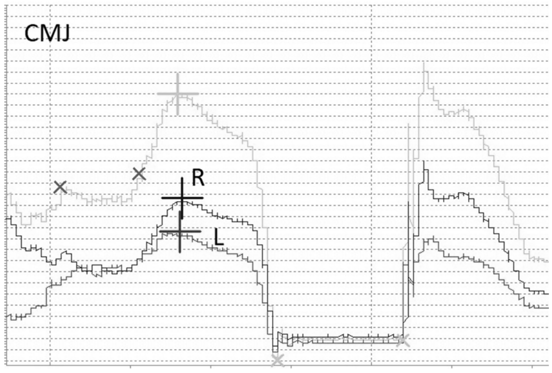

Figure 5: Countermovement jump: motor asymmetry in the take-off phase: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

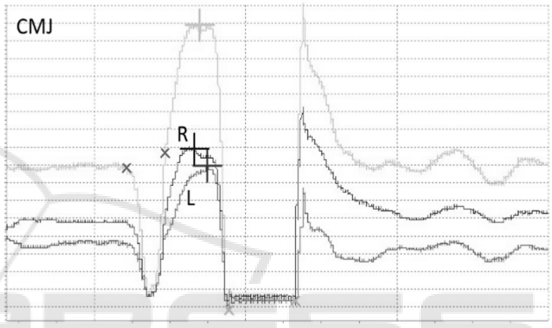

Figure 6: Countermovement jump: motor asymmetry in the phase of knee extension and take-off: the upper graph – sum of both legs, R – right leg, L – left leg, x-axis – time (ms), y-axis – force (N).

Our numerous undertaken research with the use of force plate allowed to define the following statements for fitness control in athletes:

i) Relative maximum force for take-off in the countermovement jump should be equal to 180 % of body weight in female athletes and 200 % - in males.

ii) Countermovement jump performance should be better than squat jump. If not, it is strongly recommended to devote more time to high-quality jumping, plyometric motor tasks in order to use effectively the elastic energy of the muscles and tendons.

iii) The arm swinging jump should be 8-10 cm higher than countermovement jump (hands on the waist). If not, then learn to coordinate the actions of the arms and legs in different jumping.

iv) Height of a single-leg vertical jump on right and left legs should be approximately equal and not less than 60 % of the double-leg countermovement jump height. If the countermovement jump performance is good, but single-leg jump is poor, then check the core muscles strength and pay more attention to the core muscles development (deep back and abdominals).

So presented interrelations between jumps height may reveal weaknesses in an athlete in particular case (Table 6). For example, basketball player #1 (weight 86 kg) produced 1542 H of maximum force for take-off in the countermovement jump. So her relative maximum force for take-off in the countermovement jump was equal to 179,3 % that was close to desirable 180 % of body weight in female athletes. Jumps heights were in necessary balance between each other (CMJ>SqJ, CMJAS > CMJ and SLJ Right = SLJ Left) but heights of a single-leg vertical jump on right and left leg (12 cm) were less than 60 % of the double-leg countermovement jump height. This may be the evidence of poor core muscles in basketball player #1.

Table 7: Height of vertical jumps in athletes, cm.

Type of jump	Basket ball-player #1	Basket ball-player #2	Biathlete # 1	Biathlete # 2
CMJ	24	19	32	27
SqJ	22	17	32	27
CMJAS	32	22	39	39
SLJ R	12	10	18	15
SLJ L	12	13	19	13

Basketball player #2 (weight 74 kg) produced 1109 H of maximum force in the countermovement jump. Relative maximum force for take-off in the countermovement jump was only 150 % of body weight, that was lower than necessary in female athletes. Jumps heights were in necessary balance between each other (CMJ>SqJ, CMJAS > CMJ) but arm swinging doesn't prolong the height for 8-10 cm. So different exercises must be included in training to coordinate the actions of the arms and legs in jumping or other mutual movements. There was also asymmetry in legs as SLJ Right was not equal to SLJ Left leg.

Biathlete #1 (weight 49 kg) demonstrated good leg strength with relative power for take-off 200 % of body weight. The only problem in her fitness was an inaptitude to use the elastic energy of the muscles and tendons as her countermovement jump height was equal to squat jump. Plyometrics was recommended for improvement.

As the biathlete #2 is concerned there were following aspects for fitness enhancement: legs strength, elastic energy utilization, asymmetry in legs (left leg was weaker than right one) and core muscles.

For more detailed information or in case of doubt it is recommended to review the vertical jumps graphs.

4 CONCLUSIONS

The detailed analysis of proposed set of different vertical jumps provides with valuable information on fitness level in athletes. It is essential to follow the correct technical requirements when performing each type of jump (countermovement jump, squat jump, single-leg jumps and countermovement jump with arm swinging) for reliable data collecting. Inclusion of this set of jumps on the whole could be useful for sports professionals and coaches in assessing the speed-power abilities of lower extremities, strength of the core muscles, posture and motor balance. Information on inter- and intramuscular coordination of lower extremities is available from analysis and comparison of movement graphs.

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