

## CHAPTER 4

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# 4

## ACUTE EFFECTS OF A RESISTED COMPARED TO NORMAL JUMP TRAINING SESSION ON SELECTED PHYSICAL AND MOTOR ABILITY COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS

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Acute effects of a resisted compared to a normal jump training session on selected physical and motor ability components of university-level rugby players

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### **Abstract**

The purpose of this study was to determine the acute effects of a resisted compared to a normal jump training session on selected physical and motor ability components of university-level rugby players. A crossover design where players ( $n = 30$ ) were randomly selected and assigned to either a control ( $n = 15$ ) or experimental group ( $n = 15$ ) was used. On each test day the players performed the Passive-straight-leg-raise-test, the Active-straight-leg-raise-test, the Modified Thomas Quadriceps Test, the Vertical Jump Test, the speed over 5 m, 10 m and 20 m test; the Illinois Agility Run Test and the 6 Repetition Maximum Smith Machine Squat Test. After completion of the tests the experimental group was subjected to a Vertimax resisted jump training session and the control group to a normal jump training session. The entire test procedure was then repeated. The results of the nested ANOVA showed that none of the measured variables obtained significant results ( $p > 0.05$ ), which indicated that no transfer effect occurred from one testing session to the next. The main effect ANOVA found no significant differences between the effects of a resisted compared to a normal jump training session on the different physical and motor ability components. The fact that the players' neural mechanism has not yet adapted to plyometric training exercises; individual variability in players' response to the different types of plyometric exercises; the possible influence of peripheral fatigue due to the short period of rest players received between the execution of the plyometric exercises and the test battery as well as the effect of players' strength levels on the outcome of the post-activation potentiation mechanism may all serve as possible reasons for the non-significant results.

**Keywords:** plyometrics, explosive power, resisted jump training, rugby union, post-activation potentiation

## **Introduction**

Since the introduction of the professional era into rugby union, sport scientists and other sport-related professionals have been forced to investigate new conditioning techniques that would improve the training process and deliver faster results with regard to various sport-related components. One of the new training modalities that has surfaced during the last few years is resisted jump training. Resisted jump training can be described as the use of a wide range of resistive loads (for example resistance bands) while performing a plyometric exercise that requires the body's musculature to move against an opposing force (Fleck & Kraemer, 2004; Faigenbaum & Myer, 2010). Although the use of resisted jump training in the training program of athletes has been recommended (Newton & Kraemer, 1994; Rhea, Peterson, Lunt, & Ayllon, 2008a), until now researchers have not investigated the potential of resisted jump training exercises to serve as a possible post-activation potentiation intervention. According to Wilcox, Larson, Brochu, & Faigenbaum (2006), post-activation potentiation is a phenomenon that leads to an enhancement of neuromuscular function and as a consequence provides an optimal environment for explosive-force production. The studies that have thus far investigated the effects of resisted jump training have focused on the more long-term effects (6 to 12 weeks) of this type of training and made use of high school and Division 1 Collegiate athletes as well as students when investigating this training modality (McClenton, Brown, Coburn, & Kersey, 2008; Rhea et al, 2008a & Rhea, Peterson, Oliverson, Ayllon & Potenzianno, 2008b).

Loaded or resisted jump training is a plyometric-related training method (Newton & Kreamer, 1994) that utilizes the stretch shortening cycle which occurs when the active muscle is stretched rapidly (eccentric muscle action) and the body responds by causing a reflective concentric muscle action (Wilson, 2006). Research suggests that lower-body power development as a result of resisted jump training is due to the greater level of overload or increased localized stress (which is gained through the use of added resistance or bands) placed on portions of the neuromuscular system (Rhea et al., 2008a). Although no studies were found that have investigated the possible acute effects of resisted jump training on various physical and motor ability components, various studies have focused on the possible acute effects of a normal plyometric session. In this regard studies showed that an acute plyometric training session of less than an hour led to significant improvements ( $p < 0.0001$ ) in 20 m sprint time, power output (bench press throws), lower and upper-body power (explosive push-ups and 5RM (repetition maximum) bench press) among professional rugby union, college aged rugby league players and volunteers with no apparent

musculoskeletal disorders (Hrysomallis & Kidgell, 2001; Matthews, Matthews, & Snook, 2004; Baker & Newton, 2005). According to the authors of the last-mentioned studies, the changes in the named variables were possibly caused by the post-tetanic potentiation that was experienced by the subjects after participation in the plyometric session. More proposed mechanisms which may explain the positive changes due to plyometric training, are the trihasic or “ABC” pattern which occurs after certain controlled explosive movements of the limbs and the enhanced state of neurological stimulation following intense exercise to near failure (Hrysomallis & Kidgell, 2001; Matthews et al., 2004; Baker & Newton, 2005).

In contrast to the reported positive acute effects of plyometric training, Deutsch and Lloyd (2008) reported that sprint performance was impaired when preceded by plyometric exercises in a group of elite rugby players. Similarly, Weber, Brown, Coburn and Zinder (2008) found that squat jumps significantly decreased ( $p < 0.05$ ) mean and peak jump height and elicited no change in the average peak ground reaction force in Division I male track and field athletes. Furthermore, the findings of Esformes, Cameron and Bampouras (2010) showed that plyometric exercises which preceded counter movement jumps had no significant additional benefits compared to inactivity in competitive male athletes that were anaerobically trained. Research has provided several possible reasons for the negative or insignificant acute effects of plyometric exercise/s on various physical and motor ability components. For example, Chatzinikolaou Foutouros, Gourgoulis, Avloniti, Jamurtas, Nikolaidis, Douroudos, Michailidis, Beneka, Malliou, Tofas, Georgiadis, Mandalidis, & Taxildaris (2010) found that plyometric exercises elicited muscle micro-trauma which led to acute performance deterioration and coincided with a lack of changes in isometric and isokinetic muscle torque among healthy men. These findings were also supported by other researchers who observed that an acute bout of plyometric exercises primarily affected the fast-twitch muscle fibres by causing damage to the Z disks and a reduction in the force-velocity relationship (Macaluso, Isaacs, & Myburgh, 2012).

Considering the non-availability of research that pertains to the influence of an acute resisted jump training program on selected physical and motor ability components of rugby players, the purpose of this investigation was to examine the acute effects of a resisted compared to a normal jump training session on selected physical and motor ability components of university-level rugby players. The results of this study may possibly provide sport scientists, researchers and coaches with new information with regard to the use and benefits of acute resisted jump training sessions to

team sport participants. We hypothesized that an acute resisted jump training session will lead to significantly bigger ( $p > 0.05$ ) changes in leg explosive power, speed, agility, lower-body flexibility and muscle strength, among university-level rugby players than a normal jump training session.

## **Materials and methods**

### *Subjects*

Thirty rugby players of a rugby Institute at a university in South Africa were randomly selected to participate in the study. The players all formed part of the 1<sup>st</sup> and 2<sup>nd</sup> teams of the university's senior group. The thirty players were in turn randomly divided into two groups of fifteen players each. The competitive rugby playing experience of these players varied between 2 and 12 years with an average of  $9.03 \pm 2.80$  years. The subjects' mean ( $\pm$  standard deviation) age, height and body mass was  $21.78 (\pm 1.86)$  years,  $183.08 (\pm 6.00)$  cm and  $95.16 (\pm 10.70)$  kg respectively. Positionally, the group of players consisted of 15 backs (numbered nine to fifteen) and 15 forwards (numbered one to eight). Subjects volunteered to participate in the study and were healthy and free of any injuries during the time of testing and participation in the jump training sessions. Each subject was instructed to sleep at least 8 hours during the evening and morning prior to the different testing sessions. They also had to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or physiological responses of the body for at least 48 hours before the scheduled tests. Subjects had to maintain the same diet during the weeks of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. All subjects were participating in the same rugby conditioning program before, during and after the testing period.

At the time of the study players were following an in-season program, which was conducted by the same sport scientist to ensure consistency in coaching techniques and programming. The program consisted of field sessions once a day and resistance training sessions three times a week of which the duration was more or less 2 hours per training session each. The field sessions included skill activities, offensive and defensive drills as well as conditioning intervals. Resistance training sessions consisted of more or less 12 to 16 medium to high-intensity resistance exercises (70-100% of the 1RM) with repetitions that ranged from 1-6 (maximal strength: 85-100% of 1RM) and 8-12 (hypertrophy: 70-80% of 1RM) which were focused on the attainment of muscle hypertrophy (size with strength) and pure strength.

### *Study design*

The design of the study was a two-way, pre-post-test, randomized, crossover experimental design. The dependant variables of this study were the flexibility of the hamstrings and quadriceps muscle groups (in degrees); vertical jump test (VJT) height (in cm), power output (in Watts) and speed ( $\text{m.s}^{-1}$ ); speed over 5 m, 10 m and 20 m in seconds (sec); the Illinois Agility Run Test (IART) time (in seconds) and the 6RM (repetition maximum) Smith Machine Squat Test (6RM-SMST) value (in kilograms). The independent variables were the resistance or normal jump training sessions. Data collection took place over a period of three weeks during which players completed one session a week. The first visit to the sport science laboratory during week one was a familiarization session to familiarize the players with the apparatus (Vertimax, VertiMax Inc., Tampa, Florida) to be used and to practise the exercises of the different sessions. On this visit, players also completed an informed consent form and a general information questionnaire regarding their exercising habits, playing positions, best performances of the last two years and injury incidence. Once they had completed the last-mentioned forms, the exercises and research project were explained to each player. This was followed by the execution of the exact same warm-up that would be performed during the official testing period as well as the flexibility, VJT, speed, IART and 6RM-SMST. Players then executed the different exercises on the Vertimax. A week after the familiarization session had taken place, the first testing commenced. At the start of the session the players' body weight and height were firstly measured after which they were subjected to a thorough warm-up, followed by the execution of the flexibility, VJT, speed, the IART and the 6RM-SMST. Next, the experimental group was subjected to the resisted jump training session on the Vertimax whereas the control group executed the same exercises on the floor. Directly after the training session each of the players again completed the test battery. After the first week, a crossover design was implemented by subjecting the control group to the treatment and allowing the initial experimental group to form the control group. The identical testing protocol was repeated, at the exact same day of the week and the exact same time of day, so as to minimize the effects of circadian variations on the different metabolic responses.

Subjects gave written informed consent after having received both a verbal and a written explanation of the experimental protocol and its potential risks. The study was conducted

according to the Declaration of Helsinki and the study protocol was approved by the university's Ethics Committee (NWU-0024-11-A1).

#### *Anthropometric measurements*

Body stature was recorded to the nearest 0.1 centimetres by means of a stadiometre (Harpenden portable stadiometre, Holtain Limited, UK.) and body mass was recorded to the nearest 0.1 kg with a portable electric scale (BFW 300 Platform scale, Adam equipment Co. Ltd., UK.).

#### *Flexibility tests*

The Passive-straight-leg-raise-test (PSLRT) was executed according to the method of Maud and Kerr (2006). Players were asked to lie on a firm plinth in the supine position, with the arms at the sides of the body and the palms facing downward. The lower limbs were extended flat on the bench, while the sacrum stayed in contact with the surface of the plinth. The tester placed one hand on the anterior aspect of the non-test thigh to ensure that it stays in contact with the plinth. The other hand was placed under the calf of the test leg. The tester lifted the test leg while the knee was kept in total extension. The foot and ankle were relaxed. The leg was lifted until the maximum amount of hip flexion concurrent with full knee extension was achieved. A standard plastic goniometer was centred over the greater trochanter of the femur, with the mobile arm pointed towards the lateral epicondyle of the femur and the fixed arm aligned with the lateral midline of the pelvis. The same measurement was taken for the non-tested leg. Each measurement was taken twice. If a difference of more than 5° was observed between the two measurements, a third measurement was taken.

The Active-straight-leg-raise-test (ASLRT) was executed in the exact same manner as the PSLRT with the difference that the player had to lift the test leg by himself while the knee was kept in total extension (Harvey & Mansfield, 2000).

The Modified Thomas Quadriceps Test (MTQT) was executed according to the method of Harvey and Mansfield (2000). The players were instructed to sit at the end of the plinth and lie back with both knees held to the chest, while the non-tested leg was held at the knee and at the same time held to the chest while the tested limb was lowered towards the floor. The players had to relax the hip and thigh muscles so that the passive end-point position could be obtained due to gravity alone. The angle of knee flexion of the tested limb which was lowered towards the floor was measured. A

standard plastic goniometer was centred laterally at the knee joint line, the fixed arm aligned with the length of the femur towards the greater trochanter of the femur and the mobile arm pointed towards the lateral malleolus of the fibula. The same measurement was taken for the non-tested leg. Each measurement was taken twice. If a difference of more than 5° was observed between the two measurements, a third measurement was taken.

#### *The Vertical Jump Test (VJT)*

The VJT was executed in accordance with the method of Harman, Garhammer and Pandorf, (2000). The VJT was performed by means of the Vertec device (Power Systems, Knoxville, Tennessee). Before commencement of the testing procedure, the height of the vertical column was adjusted so that the player could touch the movable vanes to register a standing touch height. Each player was instructed to stand with the dominant arm's shoulder and the dominant leg's foot under the coloured movable vanes. Keeping the heels on the floor, the player reached upwards as high as possible. The distance was recorded as the standing touch height to the nearest 0.5 cm. An arm swing and counter movement were used to jump as high as possible and to tap the highest possible vane. This distance was recorded and noted as the jumping distance. The difference between the standing touch height and jumping distance was calculated and recorded to the nearest 0.5 cm. The players performed a minimum of two trials with a 2-minute rest period between each trial. The better of the two trials were recorded. Power output during the VJT was measured for each jump with a Tendo™ Power Output Unit (Tendo Sports Machines, Trencin, Slovak Republic). The Tendo™ unit consisted of a transducer that was attached to the end of each player's waist and which measured linear displacement and time. Subsequently, jump velocity was calculated by means of which power was determined. Peak power output was recorded for each jump and used for the subsequent analyses. According to Hoffman, Ratamess, Kang, Rashti and Faigenbaum (2009); the test-retest reliability of the Tendo unit is  $r \geq 0.90$ .

#### *5-, 10- and 20-m Speed test*

The sprint for a specific distance is seen as an objective, reliable and valid test to determine the speed of subjects (Hetzler, 1991). According to Ellis, Gaistin, Lawrence, Savage, Shields, Stapff, Timilty, Quinn, Woolford, & Young (2000), players rarely run further than 20 m in a straight line during a game; hence the reasons for a 20-m speed test. Additionally, the last-mentioned authors also recommend that the standing start rather be used during execution of the 20-m test due to its sport specificity. Over the years numerous sports have also assessed acceleration with the 5 and

10-m split times (Ellis et al., 2000). It is against this background that the Smartspeed™ intermediate-beam electronic timing gates (Fusion Sport, QLD 4108, Australia) were set at 0, 5, 10, and 20 m intervals on a section of the rugby field. The starting (0 m) and finishing line (20 m) were marked with cones. When players were ready they started from a standing position (thereby eliminating the possible influence of reaction time) with the front foot up to the starting line. The players were requested to sprint as fast as possible through the finish line, making sure not to slow down before the finish line. The players executed the test while wearing rugby boots. Split times (at 5 and 10 m) and final time (20 m) for two trials, with a 2-minute resting period between each, were recorded to the nearest 0.01 sec. The best times for 5, 10 and 20 m were used in the final analyses.

#### *Illinois Agility Run Test (IART)*

The players' agility was assessed using the IART. The Smartspeed™ intermediate beam electronic timing gates (Fusion Sport, QLD 4108, Australia) were used to take the players' times to the nearest 0.01 sec. When players were ready they started from a standing position and sprinted 9 m, turned, and returned to the starting line. When the players reached the starting line they zigzagged in between four markers and completed two 9 m sprints. The fastest time of the two trials was noted as the final agility time. A resting period of 2 min was allowed between trials. The players executed the test while wearing rugby boots. According to Gabbett (2002), the intra-class correlation coefficient for the test-retest reliability and technical error of measurement for the IART is 0.86 and 2.02% respectively.

#### *The 6RM (repetition maximum) Smith Machine Squat Test (6RM-SMST)*

The leg muscle strength was evaluated by making use of the 6RM-SMST as adapted from the testing method of Baechle, Earle and Wathan (2008). The players were first instructed to warm up with a light resistance that would allow them to perform 11 to 16 repetitions. After a rest period of 1 minute the load was increased by 10-20 percent to allow the players to perform 9 to 10 repetitions. Another 2-minute rest period was allowed after which another 10-20 percent increase in load took place that allowed the players to perform 7 to 8 repetitions. Players were provided with a 4-minute rest period after which they attempted to perform a 6RM with a 10-20% heavier weight. The weight was increased or decreased until the players could complete 6 repetitions with the proper exercise technique. The knee angle of each player was controlled to be 90° during the downward phase of the squat movement by centring a standard plastic goniometer laterally at the

knee joint line with the fixed arm aligned with the length of the femur towards the greater trochanter of the femur and the mobile arm pointed towards the lateral malleolus of the fibula. The Smith Machine stoppers were then set at the point where the bar position forced the players to bend their knees 90° during the downward phase of the movement.

#### *Jump training sessions*

The jumping training sessions consisted of three exercises (¼ stick jump, lunge jump and drop jump) of which two sets of six repetitions were performed. The control group performed the exercises on a normal gym floor while the experimental group executed the exercises at a resistance of level 3 on the Vertimax apparatus. The volume of the exercises was kept low in order to prevent exercise-induced fatigue and deterioration in neuromuscular performance (Komi, 2000). A rest period of 2 minutes was allowed between each set of the exercises and between each exercise. The players performed the exercises in groups of four players each.

#### *Statistical Analysis*

The Statistical Data Processing package (Statsoft Inc, 2012) was used to process the data. The descriptive statistics (averages, standard deviations, minimum and maximum values) of each physical, motor ability and anthropometric component were firstly calculated. This was followed by the calculation of differences between each of the groups' pre and post-session's values. In another step a nested design ANOVA was performed to determine whether any of the variables displayed a transfer effect from one testing session to the next. In cases where a transfer effect was identified, the researchers used an independent *t*-test to determine the statistical significance of differences between the values of the two groups' variables. Finally, a main effect ANOVA provided the researchers with answers regarding the significance of resisted compared to normal jump training sessions on the different physical and motor ability components. The level of significance was set at  $p \leq 0.05$ .

#### **Results**

Firstly, the descriptive statistics and the differences between the pre- and post-test results of the various groups of players regarding the selected physical and motor ability components are presented (Table I).

Table I. Descriptive statistics and differences between pre-post values of the various groups of players regarding the selected physical and motor ability components

| Group                                | Pre-test         | Post-test        | Difference between pre- and post-tests |
|--------------------------------------|------------------|------------------|----------------------------------------|
| L: PSLRT (°)                         |                  |                  |                                        |
| Control group (n = 20)               | 83.83 ± 9.05     | 78.03 ± 10.98    | -5.80 ± 10.19                          |
| Experimental group (n = 20)          | 83.20 ± 10.97    | 80.17 ± 12.34    | -3.03 ± 8.84                           |
| R: PSLRT (°)                         |                  |                  |                                        |
| Control group (n = 20)               | 83.43 ± 8.35     | 77.67 ± 9.91     | -5.77 ± 9.52                           |
| Experimental group (n = 20)          | 81.23 ± 11.37    | 77.57 ± 11.62    | -3.67 ± 7.58                           |
| L: ASLRT (°)                         |                  |                  |                                        |
| Control group (n = 20)               | 97.47 ± 10.45    | 94.83 ± 8.88     | -2.63 ± 8.43                           |
| Experimental group (n = 20)          | 97.53 ± 8.65     | 96.77 ± 9.40     | -0.77 ± 7.86                           |
| R: ASLRT (°)                         |                  |                  |                                        |
| Control group (n = 20)               | 95.43 ± 7.29     | 94.00 ± 7.90     | -1.43 ± 6.83                           |
| Experimental group (n = 20)          | 98.43 ± 10.20    | 97.03 ± 8.65     | -1.40 ± 8.65                           |
| L: MTQT (°)                          |                  |                  |                                        |
| Control group (n = 20)               | 62.47 ± 8.53     | 66.83 ± 10.33    | 4.37 ± 8.26                            |
| Experimental group (n = 20)          | 62.30 ± 8.10     | 65.10 ± 10.92    | 2.80 ± 8.62                            |
| R: MTQT (°)                          |                  |                  |                                        |
| Control group (n = 20)               | 63.53 ± 10.36    | 66.33 ± 10.44    | 2.80 ± 7.69                            |
| Experimental group (n = 20)          | 63.60 ± 8.93     | 67.13 ± 9.05     | 3.53 ± 8.01                            |
| VJT height (cm)                      |                  |                  |                                        |
| Control group (n = 20)               | 53.18 ± 7.91     | 52.68 ± 7.82     | -0.50 ± 3.66                           |
| Experimental group (n = 20)          | 53.12 ± 4.40     | 53.80 ± 5.12     | 0.68 ± 2.52                            |
| VJT Tendo peak power (W)             |                  |                  |                                        |
| Control group (n = 20)               | 2894.87 ± 335.54 | 2915.97 ± 281.55 | 21.10 ± 169.04                         |
| Experimental group (n = 20)          | 3111.13 ± 317.07 | 3091.80 ± 289.76 | -19.33 ± 146.25                        |
| VJT Tendo speed (m.s <sup>-1</sup> ) |                  |                  |                                        |
| Control group (n = 20)               | 3.25 ± 0.25      | 3.25 ± 0.21      | 0.00 ± 0.18                            |
| Experimental group (n = 20)          | 3.23 ± 0.19      | 3.23 ± 0.19      | -0.01 ± 0.07                           |
| 5m Speed (s)                         |                  |                  |                                        |
| Control group (n = 20)               | 1.11 ± 0.07      | 1.08 ± 0.07      | -0.03 ± 0.08                           |
| Experimental group (n = 20)          | 1.11 ± 0.06      | 1.10 ± 0.07      | -0.01 ± 0.07                           |
| 10m Speed (s)                        |                  |                  |                                        |
| Control group (n = 20)               | 1.87 ± 0.09      | 1.83 ± 0.09      | -0.03 ± 0.09                           |
| Experimental group (n = 20)          | 1.84 ± 0.15      | 1.85 ± 0.09      | 0.01 ± 0.14                            |
| 20m Speed (s)                        |                  |                  |                                        |
| Control group (n = 20)               | 3.17 ± 0.13      | 3.17 ± 0.13      | -0.00 ± 0.09                           |
| Experimental group (n = 20)          | 3.16 ± 0.15      | 3.17 ± 0.15      | 0.01 ± 0.09                            |

Values presented as mean ± SD; L = Left; R = Right; PSLRT = Passive-straight-leg-raise-test; ASLRT = Active-straight-leg-raise-test; MTQT = Modified Thomas Quadriceps Test; VJT = Vertical jump test

Table I (cont.). Descriptive statistics and differences between pre-post values of the various groups of players regarding the selected physical and motor ability components

| Group                                                     | Pre-test       | Post-test      | Difference between pre- and post-tests |
|-----------------------------------------------------------|----------------|----------------|----------------------------------------|
| Illinois agility (s)                                      |                |                |                                        |
| Control group ( <i>n</i> = 20)                            | 15.60 ± 0.78   | 15.54 ± 0.74   | -0.05 ± 0.50                           |
| Experimental group ( <i>n</i> = 20)                       | 15.48 ± 0.66   | 15.47 ± 0.65   | 0.01 ± 0.28                            |
| 6RM SMST weight (kg)                                      |                |                |                                        |
| Control group ( <i>n</i> = 20)                            | 127.00 ± 25.82 | 125.42 ± 24.23 | -1.58 ± 7.84                           |
| Experimental group ( <i>n</i> = 20)                       | 133.00 ± 17.20 | 133.17 ± 16.94 | 0.17 ± 3.82                            |
| Relative 6RM SMST weight (6RM.body.weight <sup>-1</sup> ) |                |                |                                        |
| Control group ( <i>n</i> = 20)                            | 1.39 ± 0.29    | 1.37 ± 0.26    | -0.02 ± 0.09                           |
| Experimental group ( <i>n</i> = 20)                       | 1.36 ± 0.17    | 1.36 ± 0.17    | 0.00 ± 0.05                            |

Values presented as mean ± SD; 6RM SMST = Six repetition maximum Smith Machine Squat Test

An analysis of the tabulated results (Table I) showed that all the flexibility-related components showed improvements in both the groups from pre- tot post-testing. Despite the fact that the experimental group displayed a small increase in the VJT height due to the resisted jump training session, the VJT Tendo peak power showed a rather large decrease and the VJT Tendo speed a negligible change. Dissimilarly, the control group experienced a rather large increase in VJT Tendo peak power even though the VJT height showed a decrease and the VJT Tendo speed no change after a normal jump training session. Both groups displayed negligible or no acute changes in the speed, Illinois agility times and the 6RM SMST relative weight due to the different jump training sessions. The control group did, however, experience a small decrease in 6RM SMST absolute weight, whereas the experimental group experienced a negligible increase in the last-mentioned value.

Before interpreting the above-mentioned results, the researchers first needed to determine which of the above-mentioned changes were statistically significant. A cross-over study design was used in this study, which compelled the researchers to consider the existence of a transfer effect from one testing session to the next, which may have influenced the results of this study. For this purpose, a nested design ANOVA was performed. The results of this analysis are presented in Table II.

Table II. The nested ANOVA results of the selected physical and motor ability components

| Variables                                            | Treating order |         |
|------------------------------------------------------|----------------|---------|
|                                                      | F-value        | P-value |
| L: PSLRT (°)                                         | 2.30           | 0.14    |
| R: PSLRT (°)                                         | 1.21           | 0.28    |
| L: ASLRT (°)                                         | 1.71           | 0.20    |
| R: ASLRT (°)                                         | 0.05           | 0.83    |
| L: MTQT (°)                                          | 0.36           | 0.55    |
| R: MTQT (°)                                          | 0.58           | 0.45    |
| VJT height (cm)                                      | 0.18           | 0.67    |
| VJT Tendo peak power (W)                             | 0.18           | 0.67    |
| VJT Tendo speed (m.s <sup>-1</sup> )                 | 0.00           | 0.96    |
| 5m Speed (s)                                         | 0.79           | 0.38    |
| 10m Speed (s)                                        | 1.35           | 0.25    |
| 20m Speed (s)                                        | 0.84           | 0.36    |
| Illinois agility (s)                                 | 2.49           | 0.12    |
| 6RM SMST weight (kg)                                 | 1.73           | 0.19    |
| Relative 6RM SMST weight (6RM.weight <sup>-1</sup> ) | 1.44           | 0.23    |

Values presented as mean  $\pm$  SD; L = Left; R = Right; PSLRT = Passive-straight-leg-raise-test; ASLRT = Active-straight-leg-raise-test; MTQT = Modified Thomas Quadriceps Test; VJT = Vertical jump test; 6RM SMST = Six repetition maximum Smith Machine Squat Test

The results of the nested ANOVA (Table II) show that none of the measured variables obtained significant results which is an indication that no transfer effect occurred from one testing session to the next. Therefore, all the variables were included in the main effect ANOVA as to provide the researchers with answers regarding the significance of a resisted compared to a normal jump training session on the different physical and motor ability components. The results of this analysis are provided in Table III.

Table III. Results of the main effect ANOVA of the different physical and motor ability components

| Variables                             | Treating order |         |
|---------------------------------------|----------------|---------|
|                                       | F-value        | P-value |
| L: PSLRT (°)                          | 3.70           | 0.06    |
| R: PSLRT (°)                          | 1.87           | 0.18    |
| L: ASLRT (°)                          | 1.65           | 0.21    |
| R: ASLRT (°)                          | 0.07           | 0.80    |
| L: MTQT (°)                           | 0.51           | 0.48    |
| R: MTQT (°)                           | 0.86           | 0.36    |
| VJT height (cm)                       | 0.26           | 0.61    |
| VJT Tendo peak power (W)              | 0.33           | 0.57    |
| VJT Tendo speed (m.s <sup>-1</sup> )  | 0.00           | 0.96    |
| 5m Speed (s)                          | 0.76           | 0.39    |
| 10m Speed (s)                         | 1.37           | 0.25    |
| 20m Speed (s)                         | 1.06           | 0.31    |
| Illinois agility )                    | 2.04           | 0.16    |
| 6RM SMST weight (kg)                  | 1.77           | 0.19    |
| Relative 6RM SMST weight (6RM/weight) | 1.48           | 0.23    |

Values presented as mean  $\pm$  SD; L = Left; R = Right; PSLRT = Passive-straight-leg-raise-test; ASLRT = Active-straight-leg-raise-test; MTQT = Modified Thomas Quadriceps Test; VJT = Vertical jump test; 6RM SMST = Six repetition maximum Smith Machine Squat Test

The tabulated results (Table III) show that none of the test components obtained significant results when the acute effects of a resisted and a normal jump training session were compared.

## Discussion

The use of the VertiMax apparatus as a resisted jump training apparatus to obtain improvements in explosive power and speed over longer periods of time is being widely proclaimed through the internet (VertiMax Inc, 2013). Several researchers have also shown that a more long-term (12 weeks) combined resisted jump training program was significantly better ( $p \leq 0.05$ ) in improving lower-body peak power than a combined program which did not involve Vertimax training (Rhea et al., 2008a; Rhea et al., 2008b). It is, however, still unknown whether these benefits can be extended to the acute use of the apparatus. To the researchers knowledge this is the first study to investigate the effects of a resisted compared to a normal jump training session on selected physical and motor ability components of university-level rugby players. Although the researchers expected an acute resisted jump training session to lead to significantly bigger ( $p \leq 0.05$ ) changes in leg explosive power, speed, agility, lower-body flexibility and muscle strength, among university-level rugby players than a normal jump training session, no significant differences were obtained for any of the measured components. These results are similar to other studies which

have also explored the acute effects of plyometric-related exercises among semi-professional soccer, college volleyball, football and softball players as well as track and field athletes, and found no significant differences in the acceleration or sprint speed, leg strength, mean and peak jump height as well as peak power and jump performance after the execution of countermovement and squat jumps (Weber et al., 2008; Thomas, French, & Heyes, 2009; Witmer, Davies, & Moir, 2010; Chen, Wang, Peng, Yu, & Wang, 2013). What these results suggest, is that resisted jump training exercises do not provide additional stimuli to the neurological and peripheral structures of the body than normal jump training exercises. Some of the results may even suggest that this technique may have an acute detrimental effect (although not significantly so) on VJT peak power compared to normal jump training.

These results may possibly be related to the extra resistance and overload players are subjected to while performing resisted jump exercises, which may possibly lead to more stress on the neuromuscular system (Rhea et al., 2008a) and especially the proprioceptors that are involved during the execution of plyometric exercises. The resistance band-setup of the VertiMax will lead to extra tension during both the eccentric and concentric phase of the jumping movements. However, the extra load placed on the legs during execution of the jumping exercises may be detrimental to the development of explosive power due to the fact that the transition time from eccentric to concentric muscle contractions (amortisation phase) is prolonged (McClenton et al., 2008). Furthermore, the players in this study were all used to plyometric training and their muscles would, therefore, already be accustomed to land-based plyometric type of exercises. All the players had been subjected to a general rugby-conditioning program for six months prior to the intervention period. Despite the fact that they were not used to resisted jump training type of exercises, their neuromuscular systems would probably not be as sensitive and reactive to plyometric exercises as players that were untrained and not accustomed to this type of exercises. However, despite this assumption, the statements of Zatsiorsky and Kraemer (2006) and the insufficiency of the plyometric exercises to cause any significant acute changes in selected physical and motor ability components, would suggest that the players' neural mechanism has not yet adapted to plyometric training exercises. According to Zatsiorsky and Kraemer (2006), both the myotatic reflex receptors (muscle spindles) and the Golgi tendon organs play an active role during execution of stretch-shortening cycle type of plyometric movements or jumps. In this regard the muscle spindles will cause the quadriceps to contract more forcefully during a jump, while simultaneously the Golgi tendon reflex will inhibit the contraction of the quadriceps due to

the high muscle tension experienced (Zatsiorsky & Kraemer, 2006). Over time the continuous execution of plyometric exercises will lead to the inhibition of the Golgi tendon reflex and will allow athletes to improve performances in explosive power movements (Zatsiorsky & Kraemer, 2006).

Even though the researchers decided to use a cross-over design to reduce the possible influence of confounding covariates such as individual differences in the reaction to acute plyometric exercises and also to make the study more statistically efficient in view of the rather small sample size, other factors may have influenced the overall study results. For example, high individual variability in different pre- and post-test results may have “pulled” the main effect ANOVA results skew and might explain the non-significant results observed. For example, the individual left passive-straight-leg-raise pre-post-test differences for the experimental group varied between  $-32^{\circ}$  (minimum) and  $11^{\circ}$  (maximum) with a standard deviation of  $8.84^{\circ}$ , whereas the values of the control group varied between  $-28^{\circ}$  (minimum) and  $13^{\circ}$  (maximum) with a standard deviation of  $10.19^{\circ}$ . The high individual variability in different pre- and post-test results may also suggest that the physiological response of individuals to plyometric exercises is quite different, with some individuals that respond very positively, some that do not respond and others that respond negatively. It can, therefore, be concluded that the players in this study did not show any clear pattern in their response to the different types of plyometric exercises.

A similar conclusion was also drawn by Docherty and Hodgson (2007) who stated that individual variability is one of the most important factors that needs to be considered when investigating the possible effects of post-activation potentiation type of exercises on different performance measures. In this study similar post-activation potentiation exercise protocols and resistance levels were used for all the participants. A study in which the protocols are individualized according to each individual's strength and explosive power scores will offer a possible solution to the problem of individuality. This will allow each individual to perform the different exercises at a load which corresponds to a certain percentage of his maximum value. Furthermore, it would also be advisable to set up and test each player's post-activation potentiation protocol before the start of the study in order to determine the most ideal exercise load, volume and duration.

Researchers also found that players need enough recovery time between the post-activation potentiation exercises and the subsequent execution of performance-related tests (Kilduff, Bevan, Kingsley, Owen, Bennett, Bunce, Hore, Maw, & Cunningham, 2007). Their results indicated that on average 8 to 12 minutes of recovery was required to achieve a maximal post-activation potentiation effect (Kilduff et al., 2007). The low volume (3 sets of 3 exercises of which 6 repetitions were performed) of plyometric exercises used to activate the post-activation potentiation mechanism in this study as well as the long rest periods between sets and exercises (2 min) did not necessitate a long recovery period between the post-activation potentiation exercises and the execution of the physical and motor ability tests. However, in view of the non-significant effects of the plyometric exercises and the short period of rest players received between the execution of the plyometric exercises and the test battery, it is possible that fatigue may have played a role in influencing the results. Therefore, players may have experienced peripheral fatigue immediately after the preload stimulus which would inhibit the potentiation effect obtained (Jensen & Ebben, 2003).

In view of the possible negative influence of fatigue on the effects of post-activation potentiation exercises, a better approach to studies of this nature will be to determine each player's most ideal recovery time before the start of the study and then use these individualized recovery times in the study protocol. Furthermore, a study protocol which allows researchers to monitor the intensity and quality of the post-activation potentiation exercises will ensure that optimal benefits are derived with regard to performance enhancement. In this regard the use of electromyographic recordings during and after the execution of the post-activation potentiation exercises will allow researchers to evaluate and monitor the post-activation potentiation effect for each individual. This will also ensure that a potentiation response is triggered.

The strength levels of participants is another factor which seems to influence the outcome of post-activation potentiation exercises, with stronger participants that benefit more from post-activation potentiation exercises (Duthie, Young, & Aitken, 2002; Kilduff et al., 2007). To test this hypothesis the correlation coefficients between the changes in the different pre- and post-tests results and the average absolute and relative six repetition maximum SMST weight were determined. However, only the PSLRT values of both legs ( $r = 0.27$  and  $0.27$ ,  $p < 0.05$ ), right leg MTQT ( $r = 0.27$ ,  $p < 0.05$ ), 5-( $r = -0.27$ ,  $p < 0.05$ ) and 10 m speed test ( $r = -0.32$ ,  $p < 0.05$ ) changes displayed significant correlation coefficients with average relative six repetition

maximum SMST weight. Vertical jump height change was the only test variable that obtained a significant correlation coefficient ( $r = 0.40$ ,  $p < 0.05$ ) with average absolute six repetition maximum Smith Machine Squat Test weight. Therefore, although significant relationships were observed between the indicators of subjects' lower-body strength values (absolute and relative) and changes in some of the flexibility, lower-body explosive power and speed-related values following the post-activation potentiation exercises, only between 7% ( $0.27^2 \times 100$ ) and 16% ( $0.40^2 \times 100$ ) of the variance in changes due to the exercises could be explained by differences in strength levels. Other studies reported much higher correlations ( $r = 0.63$ - $0.73$ ,  $p < 0.05$ ) between subjects' relative and absolute lower-body strength values and changes in lower-body performances following post-activation potentiation exercises (Young, Jenner, & Griffiths, 1998; Duthie, Young, & Aitken, 2002; Kilduff et al., 2007).

Differences in the relationships between strength and lower-body performances due to post-activation potentiation between this and other studies may possibly be related to the fact that all the last-mentioned studies made use of 1-5RM tests to determine participants' strength values and correlated these values to jumping exercise performances (loaded countermovement jump – Young et al., 1998; jump squats – Duthie et al., 2002; countermovement jumps – Kilduff et al., 2007). Furthermore, one study made use of a general population of men between the ages of 18 and 31 years (did not specify activity or sport participation level) (Young et al., 1998); one study made use of women hockey and softball players between the ages of 19 and 31 years (Duthie et al., 2002) and the most recent study made use of twenty-three professional rugby players with an average age of 24 years (Kilduff et al., 2007). These differences in test protocols and subject characteristics between this and other studies may explain dissimilarities in the relationships between the strength and lower-body performances following post-activation potentiation exercises. Despite these differences, our and other study results suggest that lower-body relative and absolute muscle strength values of subjects need to be considered when compiling and implementing post-activation potentiation strategies.

In conclusion, researchers allege that exercises or exercise sessions must meet the following requirements to produce post-activation potentiation: the exercises must be static or dynamic in nature, must involve high-intensity muscle contractions (Ebben, Jensen, & Blackard, 2000; Smilios, Pilianidis, Sotiropoulos, Antonakis, & Tokmakidis, 2005) and the exercise volume must be low enough not to induce too much fatigue and inhibit the potentiation effect (French, Kraemer,

& Cooke, 2003). Although the acute resisted and normal jump training exercises in this study met all these requirements, the results show that these exercise sessions did not lead to any significant acute changes in the physical and motor ability components of university-level rugby players. The fact that the players' neural mechanism has not yet adapted to plyometric training exercises; individual variability in players' response to the different types of plyometric exercises; the possible influence of peripheral fatigue due to the short period of rest players received between the execution of the plyometric exercises and the test battery as well as the effect of players' strength levels on the outcome of the post-activation potentiation mechanism may all serve as possible reasons for the non-significant results. However, more experience in plyometric training; individualized post-activation potentiation exercise sessions that are compiled according to each player's response to these exercises; the determination of the most optimal recovery period between the execution of the plyometric exercises and the test battery for each player and the evaluation of players' initial strength levels will assist researchers in developing and implementing more effective acute post-activation potentiation exercise sessions. These recommendations may also help practitioners in the field of sport science to develop post-activation potentiation exercise sessions that can be incorporated into athletes' training program and competition warm-ups.

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