American Journal of Sports Science
2014; 2(6-1): 8-13
Published online December 26, 2014 (http://www.sciencepublishinggroup.com/j/ajss)
doi: 10.11648/j.ajss.s.2014020601.12
ISSN: 2330-8559 (Print); ISSN: 2330-8540 (Online)

Differences in loaded and unloaded vertical jumping ability and sprinting performance between Brazilian elite under-20 and senior soccer players

Irineu Loturco[1, *], Ronaldo Kobal[1], Saulo Gil[1], Bruno Pivetti[1], Katia Kitamura[1], Lucas A. Pereira[1], Cesar Cavinato Cal Abad[1], Fabio Yuzo Nakamura[2]

[1]NAR, Nucleus of High Performance in Sport, São Paulo, SP, Brazil
[2]State University of Londrina, Londrina, PR, Brazil

Email address:
irineu.loturco@terra.com.br (I. Loturco)

To cite this article:
Irineu Loturco, Ronaldo Kobal, Saulo Gil, Bruno Pivetti, Katia Kitamura, Lucas A. Pereira, Cesar Cavinato Cal Abad, Fabio Yuzo Nakamura. Differences in Loaded and Unloaded Vertical Jumping Ability and Sprinting Performance between Brazilian Elite Under-20 and Senior Soccer Players. *American Journal of Sports Science*. Vol. 2, No. 6-1, 2014, pp. 8-13. doi: 10.11648/j.ajss.s.2014020601.12

Abstract: The aim of this study was to compare performance in sprint, change of direction speed, vertical jump and jump squat tests between elite soccer players from two different age categories (i.e., under-20 and senior players) from the same soccer club. Players performed sprints (average velocity at 5, 10 and 20 m), zig-zag change of direction speed (COD speed), squat and countermovement jump tests and loaded jump squats to obtain the maximum mean propulsive power (MPP) value. Senior players performed better in absolute MPP, while the relative MPP (W/kg) was higher in the U-20 players. Moreover, except for COD speed and average velocity from zero to 5 m (VEL 5 m), the senior soccer players presented superior performance in all tested variables (SJ, CMJ, VEL 10 m, VEL 20 m). In conclusion, most neuromuscular variables improve during the transition from the end of adolescence to the mature phase. However, to enhance the power abilities and sprinting capacity over very short-distances of senior soccer players, soccer fitness coaches are encouraged to increase the frequency and volume of strength/power training during the competitive season.

Keywords: Power, Football, Plyometrics, Jump Squat, Age-Categories

1. Introduction

Several fitness components are thought to be involved in high-level performance in soccer [1]. These specific fitness abilities which determine the players' soccer performance have been shown to evolve across age categories [2]. The ability to produce acceleration, maximum running speed and repeated-sprint, along with aerobic endurance as assessed by the Yo-Yo Intermittent Recovery Test, level 1 (Yo-Yo IR1) improve across the age categories from under-11 to under-19 [3-5]. Less is known about the development of fitness components in the transition between the final stages of adolescence to adulthood in high-level soccer players. Mujika et al. [5], for example, found superior performance in the Yo-Yo IR1 and Agility-15 m tests in senior (23.8 ± 3.4 years) compared to junior (18.4 ± 0.9 years) soccer players. In contrast, these authors observed that the performance in some neuromuscular specific tasks such as vertical jumping and sprinting did not differ between the soccer age categories. This suggests that power-velocity abilities may not further improve when the prospective player is transitioning to the senior category. It also indicates the necessity of considering new methods to assess lower limb muscle power in elite soccer players.

The assessment of muscular power can also be performed using power output generated during loaded vertical jumps (i.e., jump squats) [6-8]. The power output recorded in these tests is generally highly correlated with sprinting ability [9, 10]. However, its use to discriminate between soccer players of different age categories is remarkably low when compared to unloaded situations. In fact, the use of vertical jump field tests is simpler, more practical and timesaving than the use of jump squats [11]. On the other hand, jumping performance in loaded situations is highly correlated with maximum strength, and it could be crucial to characterize distinct levels of soccer players [12, 13].

Therefore, the aim of this study was to compare the outcomes in sprint, agility, vertical jump and jump squat tests between elite soccer players from two different age categories (i.e., under-20 and senior players) from the same Brazilian soccer club. To date, there are no studies comparing the performance of different categories of elite soccer players executing jump squats. As maximum strength level increases throughout the age categories up to adulthood [14], we hypothesized that the senior players would perform better in the loaded vertical jumps. Furthermore, as already reported in the literature, we expected to find no differences in vertical jumping ability, agility and sprinting performance between the elite U-20 and senior soccer players.

2. Methods

2.1. Participants

The study sample consisted of forty-one male Brazilian elite soccer players from two different age categories (U-20 and senior players) (Table 1). All participants were members of the same soccer club and were performing different training routines and match frequencies at the time of the study, according to their age categories (Table 2). Tests took place after a short off-season period. In the season following the tests, the senior team qualified for series A (first division) of the São Paulo State Championship, while the U-20 team finished the main national Championship within the top four. After being informed of the experimental risks, the players gave written consent to participate in this study. The research was approved by the State University of Londrina Ethics Committee.

Table 01. *Soccer players' characteristics (mean ±SD).*

	U-20 (n=23)	Senior (n=18)
Age (years)	18.2 ± 0.4	23.8 ± 3.8
Height (cm)	177.2 ± 3.4	179.8 ± 6.8
Body mass (kg)	71.8 ± 4.2	74.6 ± 6.4
Training experience (years)	± 1.6	10.2 ± 2.6

Table 02. *Training routines and match frequencies of the U-20 and senior players.*

	U-20	Senior players
Plyometrics (days/week)	1	1/2
Strength/power training (days/week)	2	1/2
Endurance (days/week)	1	1
Technical/tactical (days/week)	3	4/5
Number of matches (weekly)	1	2

2.2. Experimental Design

Prior to the assessments, the soccer players were familiarized with the experimental procedures during three non-consecutive sessions, which took place over two days, separated by at least 24 hours. The order of the assessments was as follows: day 1: unloaded vertical jump tests (squat jump and countermovement jump) and loaded vertical jump tests (jump squat); day 2: sprint and COD speed tests. Prior to the tests, the participants performed standardized warm-up protocols including general (i.e., running at a moderate pace for 5-minute followed by active lower limb stretching for 3 min) and specific exercises. The warm-up was followed by a 3-minute interval, after which the players were required to execute the actual tests.

2.3. Sprint Speed Test

Prior to the execution of the sprint speed test, four pairs of photocells (Smart Speed, Fusion Equipment, AUS) were positioned at distances of 0, 5, 10 and 20 m along the course. The soccer players sprinted twice, starting from a standing position 0.3 m behind the start line. A 5-minute rest interval was allowed between the two attempts and the fastest time realized was retained for the analyses.

2.4. Zig-Zag Change of Direction Speed (COD Speed Test)

The COD speed test course consisted of four 5 m sections marked with cones, set at 100° angles. The soccer players performed two maximal attempts, starting from a standing position with the front foot 0.3 m behind the first pair of photocells (i.e., starting line), and running and changing direction as quickly as possible, until crossing the second pair of photocells, placed 20 m from the starting line [15, 16]. A 5-minute rest interval was allowed between attempts and the best time was retained for further analysis.

2.5. Squat Jump and Countermovement Jump Heights

The players were allowed five attempts, interspersed by 15-second intervals, at each of the jumps. All the jumps were executed with the hands on the hips. In the squat jump, a static position with a 90° knee-flexion angle was maintained for 2 seconds before a jump attempt without any preparatory movement. In the countermovement jump, subjects were instructed to perform a downward movement followed by a complete extension of the lower limb joints and freely determine the amplitude of the countermovement to avoid changes in jumping coordination pattern. The jumps were performed on a contact platform (Smart Jump; Fusion Sport, Coopers Plains, Australia) with the recorded flight time (t) being used to estimate the height (h) of the rise of the body's centre of gravity during the vertical jump (i.e., $h = gt^2/8$, where $g = 9.81\ m \cdot s^{-2}$). Any given jump would only be considered valid for analysis if the take-off and landing positions were visually similar. The best attempt was retained for data analysis.

2.6. Jump Squat Test

Mean propulsive power (MPP) was assessed through jump squats, being performed on a Smith machine (Technogym Equipment). The participants executed a knee flexion until the thigh was parallel to the ground and, after the command to start, jumped as fast as possible without their shoulder losing contact with the bar. The players were instructed to execute 3 repetitions at maximal velocity for each load, with a 5-minute interval between sets. The test started with a load of 40% of BM and 10% of BM was progressively added at each set until a decrease in mean propulsive power was observed. To determine mean propulsive power, a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) was attached to the Smith machine bar. The bar position data were sampled at 1,000 Hz using a computer. Finite differentiation technique was used to calculate bar velocity and acceleration. Mean propulsive power rather than peak power was used since Sanchez-Medina et al. [17], demonstrated that mean mechanical values during the propulsive phase better reflect the differences in the neuromuscular potential between two given individuals. This approach avoids underestimation of true strength potential as the higher the mean velocity (and lower the relative load), the greater the relative contribution of the braking phase to the entire concentric time. The relative values of mean propulsive power (MPPREL) were obtained by dividing the MPP by the subjects' body mass (W/kg). We considered the maximum MPP value collected for data analysis purposes.

2.7. Statistical Analysis

Data are presented as mean ± standard deviation. The Shapiro-Wilk test was initially used to test the normality of the data. Comparisons between the elite U-20 and senior soccer players were performed using the differences based on magnitudes [18]. This method was chosen in place of traditional null-hypothesis testing methods based on an arbitrary p value as it allows the emphasis of effect magnitudes and estimate precision, focusing on non-effect interpretation rather than on absolute effect [19]. In addition, the traditional method does not deal with the real world significance of an outcome [18], whilst the magnitude-based method defines the practical effect, allowing the researcher to qualify and/or quantify the probability of a worthwhile effect with inferential descriptors to aid interpretation [19]. Whereas traditional inferential statistics can be misleading, depending on the magnitude of the statistic, error of measurement, and sample size [18], magnitude-based inferences recognize sample variability, and provide scientists and professional coaches with an indication of the practical meaningfulness of the outcomes.. Using a confidence interval of 90%, the quantitative chances for the U-20 or senior outcomes having better or poorer values were assessed qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, almost certain. If the chances of having better and poorer results were both >5%, the true difference was assessed as unclear. The spreadsheet made available by Hopkins [20] was used. Intraclass correlations (ICCs) were used to determine the relationship within vertical jumps (i.e., loaded and unloaded conditions) for height and mean propulsive power. The ICC was 0.94 for the SJ, 0.92 for the CMJ and 0.92 for the loaded squat jumps.

3. Results

Table 3 shows the results of the vertical jump, COD speed and sprinting tests in the U-20 and senior soccer players. In the jump tests (SJ and CMJ), VEL 10 m and VEL 20 m, the senior players were very likely better than the U-20.

Table 03. *Performance in vertical jump ability, COD speed and sprint tests in U-20 and senior soccer players.*

	U-20	Senior	Chance %-/Trivial/+	Qualitative Inference
SJ (cm)	36.8 ± 4.0	40.5 ± 3.4	00/01/99	Very Likely
CMJ (cm)	37.3 ± 3.6	40.3 ± 3.0	00/02/98	Very Likely
COD speed ($m.s^{-1}$)	3.4 ± 0.1	3.5 ± 0.1	05/29/66	Unclear
VEL 5 m ($m.s^{-1}$)	4.6 ± 0.3	4.6 ± 0.3	08/33/59	Unclear
VEL 10 m ($m.s^{-1}$)	5.4 ± 0.2	5.6 ± 0.2	00/03/97	Very Likely
VEL 20 m ($m.s^{-1}$)	6.4 ± 0.2	6.6 ± 0.2	00/04/96	Very Likely

The MPP of jump squat was very likely higher in senior players (Figure 1, panel A). In contrast, when the MPP was normalized by the body mass (MPPREL), the U-20 players were likely better than the senior soccer players (Figure 1, panel B).

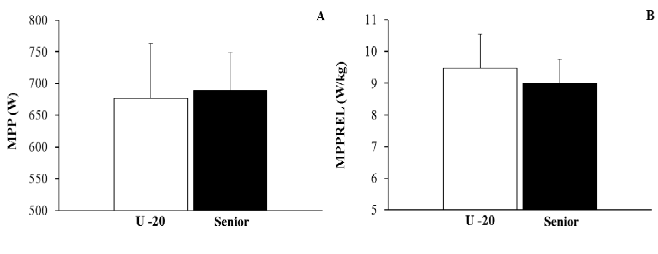

Figure 01. *Performance in the jump squat test in U-20 and senior soccer players. MPP: 00/02/98, Very likely higher in senior players. MPPREL: 83/16/01 Likely higher in U-20 players.*

4. Discussion

This is the first study that has investigated performance in loaded jumping conditions between two age categories of elite soccer players (i.e., U-20 and seniors). The main finding of this study was that, although senior players performed better in absolute power variables (MPP), the relative power values (MPPREL) were higher in U-20 players. Moreover, except for COD speed and VEL 5 m, the senior soccer players presented superior performance in all tested variables (SJ, CMJ, VEL 10 m, VEL 20 m).

Actually, we did not expect to find any differences in specific neuromuscular tasks like SJ, CMJ and sprint tests between elite U-20 and senior soccer players, since it has already been reported that these abilities do not increase during the age range studied [5, 21]. Surprisingly, in contrast to our hypothesis, the senior players in the study performed better than the U-20 in the unloaded vertical jump tests (SJ and CMJ) and in the longer distance sprinting speed tests (10 and 20 m). It is important to emphasize that our sample comprised different categories of elite soccer players from the same professional club which had a specific plyometric program that increased in frequency/volume/intensity of this type of training as the players advanced through the seniority which, in all probability, influenced the outcomes presented by the distinct categories of soccer players in the SJ and CMJ tests [22]. Finally, when considering the extensive number of studies that have found strong relationships between vertical jumping ability and sprinting speed, it was predictable that players who jump higher may sprint faster at 10 and 20 m [9, 23-25].

Despite the differences in average velocity at 10 and 20 m in favor of the seniors, both age categories performed similarly in the VEL 5 m. These results may be clarified when analyzing the sprinting kinematics at different distances. From zero to 20 m, while the velocity increases in proportion to the increase in distance, the acceleration rate decreases progressively. Starting from a zero-velocity and moving the body forward as fast as possible requires a greater capacity for applying force against the ground. However, based on the force-velocity relationship, higher acceleration rates can only be achieved if the accelerated mass represents a relatively low value, when compared to the maximum value of mass that can be moved in a given movement [26-28]. Thus, for breaking the “body’s inertial moment” and reaching higher velocities in very short distances (i.e., from zero to 5 meters), the athlete has to apply a large amount of relative force. In our results, in spite of presenting higher outcomes in absolute power variables (MPP) collected during the jump squats, the seniors performed worse than the U-20 players when these values were adjusted according to their body mass. As relative power is highly correlated with relative maximum dynamic strength [29, 30], it is conceivable that this fact hampered the seniors’ performance in the VEL 5 m.

The zig-zag COD speed tests consists of four 5 m sections (marked with cones set at 100° angles), in which athletes have to accelerate as much as possible in each section. Therefore, similar to the VEL 5 m test, performance in this specific assessment depends directly on the maximum acceleration rate achieved by the players over a very-short distance. Also in this variable, we did not find differences between the senior and U-20 categories. This could confirm the strong relationship between relative power ability and the athletes’ acceleration capacity. However, such an assumption still needs to be tested in experimental studies, since the available evidence suggests a low to moderate relationship between strength or power variables and change of direction performance [31]. Performance in COD speed tests probably involves more physical components than acceleration capability.

The present study compared the performance in loaded/unloaded vertical jumping ability and sprint performance at different distances (VEL 5, 10, and 20 m) between U-20 and senior soccer players. Our findings indicated that, although elite soccer players demonstrate enhanced performance in some neuromuscular tasks (CJ,CMJ, VEL 10m and VEL 20 m), they do not improve their capacity to apply greater amounts of relative force/power throughout the age categories, up to seniority. Given the importance of these variables in soccer performance, we consider that this information may be relevant for technical and fitness coaches involved in elite soccer training. One possible explanation for this finding is the higher exposure to training and match loads in senior players compared to their younger counterparts. Higher loading with insufficient recovery may incur signs of overreaching [32, 33], leading to impaired neuromuscular performance. Another complementary explanation could be the interference phenomenon between concurrent aerobic and strength training in soccer [34]. However, the negative effect of the specific soccer aerobic component on neuromuscular performance is not considered strong enough to cause significant impairments in either strength or power abilities of elite soccer players [35] as it is in an endurance sport [36]. Hence, a third and more likely explanation for the force/power inferiority in senior players could be a deficiency in training strategies involving adequate strength/power methods due to the congested calendar.

5. Conclusions

To conclude, this study shows that, in the transition phase from the end of adolescence to seniority, functional improvements expressed as performance in unloaded vertical jumping and sprinting tests (at 10 and 20 m) can still be observed in highly trained soccer players (SJ, CMJ, VEL 10 m, VEL 20 m). However, for reasons that need to be further clarified, relative power in the loaded jump squat is poorer in senior players compared to the U-20. This may partly explain the absence of differences in the VEL 5 m and COD speed tests. Therefore, it is highly recommended that strength and conditioning coaches involved in professional soccer target the development of power abilities in senior soccer players, increasing the frequency and volume of strength/power training throughout the competitive season. This intervention could improve their capacity to accelerate their bodies more over very short distances and to change direction more efficiently.

References

[1] Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of soccer: an update. *Sports Medicine,* 35, 501-36.

[2] Valente-dos-Santos, J., Coelho-e-Silva, M. J., Simoes, F., Figueiredo, A. J., Leite, N., Elferink-Gemser, M. T., Malina, R. M., & Sherar, L. (2012). Modeling developmental changes in functional capacities and soccer-specific skills in male players aged 11-17 years. *Pediatric Exercise Science,* 24, 603-21.

[3] Markovic, G. & Mikulic, P. (2011). Discriminative ability of the Yo-Yo intermittent recovery test (level 1) in prospective young soccer players. *Journal of Strength and Conditioning Research,* 25, 2931-4.

[4] Mendez-Villanueva, A., Buchheit, M., Kuitunen, S., Douglas, A., Peltola, E., & Bourdon, P. (2011). Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *Journal of Sports Sciences,* 29, 477-84.

[5] Mujika, I., Santisteban, J., & Castagna, C. (2009). In-season effect of short-term sprint and power training programs on elite junior soccer players. *Journal of Strength and Conditioning Research,* 23, 2581-7.

[6] Loturco, I., Ugrinowitsch, C., Roschel, H., Lopes Mellinger, A., Gomes, F., Tricoli, V., & Gonzales-Badillo, J. J. (2013). Distinct temporal organizations of the strength- and power-training loads produce similar performance improvements. *Journal of Strength and Conditioning Research*, 27, 188-94.

[7] Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2013). A rationale for assessing the lower-body power profile in team sport athletes. *Journal of Strength and Conditioning Research,* 27, 388-97.

[8] Turner, A. P., Unholz, C. N., Potts, N., & Coleman, S. G. (2012). Peak power, force, and velocity during jump squats in professional rugby players. *Journal of Strength and Conditioning Research,* 26, 1594-600.

[9] Lopez-Segovia, M., Marques, M. C., van den Tillaar, R., & Gonzalez-Badillo, J. J. (2011). Relationships between vertical jump and full squat power outputs with sprint times in u21 soccer players. *Journal of Human Kinetics,* 30, 135-44.

[10] Loturco, I., D'Angelo, R. A., Fernandes, V., Gil, S., Kobal, R., Abad, C. C. C., Kitamura, K., & Nakamura, F. Y. (2014). Relationship between sprint ability and loaded/unloaded jump tests in elite sprinters *Journal of Strength and Conditioning Research,* in Press.

[11] Castagna, C. & Castellini, E. (2013). Vertical jump performance in Italian male and female national team soccer players. *Journal of Strength and Conditioning Research*, 27, 1156-61.

[12] Loturco, I., Ugrinowitsch, C., Tricoli, V., Pivetti, B., & Roschel, H. (2013). Different loading schemes in power training during the preseason promote similar performance improvements in Brazilian elite soccer players. *Journal of Strength and Conditioning Research,* 27, 1791-7.

[13] Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine,* 38, 285-8.

[14] Sander, A., Keiner, M., Wirth, K., & Schmidtbleicher, D. (2013). Influence of a 2-year strength training programme on power performance in elite youth soccer players. *European Journal of Sport Science,* 13, 445-51.

[15] Little, T. & Williams, A. G. (2006). Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *Journal of Strength and Conditioning Research,* 20, 203-7.

[16] Sekulic, D., Spasic, M., Mirkov, D., Cavar, M., & Sattler, T. (2013). Gender-specific influences of balance, speed, and power on agility performance *Journal of Strength and Conditioning Research*, 27, 802-11.

[17] Sanchez-Medina, L., Perez, C. E., & Gonzalez-Badillo, J. J. (2010). Importance of the propulsive phase in strength assessment. *International Journal of Sports Medicine,* 31, 123-9.

[18] Batterham, A. M. & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, 1, 50-7.

[19] Rowlands, D. S., Rossler, K., Thorp, R. M., Graham, D. F., Timmons, B. W., Stannard, S. R., & Tarnopolsky, M. A. (2008). Effect of dietary protein content during recovery from high-intensity cycling on subsequent performance and markers of stress, inflammation, and muscle damage in well-trained men. *Applied Physiology, Nutrition, and Metabolism,* 33, 39-51.

[20] Hopkins, W. G. (2004). How to interpret changes in an athletic performance test. *Sportsci,* 8, 1-7.

[21] Lehance, C., Binet, J., Bury, T., & Croisier, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine & Science in Sports,* 19, 243-51.

[22] Hoff, J. & Helgerud, J. (2004). Endurance and strength training for soccer players: physiological considerations. *Sports Medicine,* 34, 165-80.

[23] Comfort, P., Stewart, A., Bloom, L., & Clarkson, B. (2014). Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *Journal of Strength and Conditioning Research,* 28, 173-7.

[24] Jovanovic, M., Sporis, G., Omrcen, D., & Fiorentini, F. (2011). Effects of speed, agility, quickness training method on power performance in elite soccer players. *Journal of Strength and Conditioning Research,* 25, 1285-92.

[25] Lockie, R. G., Murphy, A. J., Knight, T. J., & Janse de Jonge, X. A. (2011). Factors that differentiate acceleration ability in field sport athletes. *Journal of Strength and Conditioning Research,* 25, 2704-14.

[26] Cormie, P., McCaulley, G. O., & McBride, J. M. (2007). Power versus strength-power jump squat training: influence on the load-power relationship. *Medicine and Science in Sports and Exercise,* 39, 996-1003.

[27] Cormie, P., McCaulley, G. O., Triplett, N. T., & McBride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. *Medicine and Science in Sports and Exercise,* 39, 340-9.

[28] Moss, B. M., Refsnes, P. E., Abildgaard, A., Nicolaysen, K., & Jensen, J. (1997). Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *European journal of Applied Physiology and Occupational Physiology,* 75, 193-9.

[29] Baker, D. & Nance, S. (1999). The Relation Between Running Speed and Measures of Strength and Power in Professional Rugby League Players. *Journal of Strength and Conditioning Research,* 13, 230-5.

[30] Young, W., Benton, D., & Pryor, J. M. (2001). Resistance training for short sprints and maximum-speed sprints. *Strength & Conditioning Journal,* 23, 7.

[31] Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine,* 38, 1045-63.

[32] Coutts, A., Reaburn, P., Piva, T. J., & Murphy, A. (2007). Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players. *International Journal of Sports Medicine,* 28, 116-24.

[33] Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology,* 99, 313-24.

[34] Docherty, D. & Sporer, B. (2000). A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. *Sports Medicine,* 30, 385-94.

[35] Helgerud, J., Rodas, G., Kemi, O. J., & Hoff, J. (2011). Strength and endurance in elite football players. *International Journal of Sports Medicine,* 32, 677-82.

[36] Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: a meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength and Conditioning Research,* 26, 2293-307.