Relationships among repeated sprint ability, vertical jump performance and upper-body strength in professional basketball players

Carlos Balsalobre-Fernández[1], Carlos Mª Tejero-González[1], Juan del Campo-Vecino[1], Beatriz Bachero-Mena[2], Jorge Sánchez-Martínez[3]

[1]Departamento de Educación Física, Deporte y Motricidad Humana, Universidad Autónoma de Madrid. [2]Facultad de Deporte, Universidad Pablo de Olavide, Sevilla. [3]Club Estudiantes de Baloncesto, Madrid.

Recibido: 29.10.2013
Aceptado: 26.11.2013

Summary

The repeated sprint ability (RSA), counter-movement jump (CMJ) performance and upper-body strength are very important variables in high-level basketball competition. However, the relationships among these variables are poorly studied in elite basketball players. Thus, the purpose of this research is to study the relationships among the Running-Based Anaerobic Speed Test (RAST), the CMJ and upper-body strength in professional male basketball players from the highest-level competition of Spain (League Endesa). Eleven, athletes (N=11, age = 24.5 ± 5.8 yrs, height = 200 ± 10.9 cm, weight = 98.4 ± 9 kg) were tested on the RAST, the CMJ before and after the RAST and the bench press strength in one single morning. The results show, high and statistically significant correlations between the RAST fatigue index (FI) and CMJ loss (the difference between pre and post RAST measures) (r = 0.78, p <0.01), the FI and the maximum force production on the bench press (r = -0.86, p <0.01), and the CMJ loss and the load at which peak power is produced on the bench press (r = -0.77, p <0.01). Our data highlights the remarkable relationship among repeated-sprint ability, the CMJ and upper-body strength in professional male basketball players. For this, it seems clear that elite basketball players may benefit from training programs designed to improve such variables simultaneously. This may be relevant for the strength & conditioning training of such athletes.

Palabras clave:
Athletic performance.
Strength testing.
Elite players.

Relaciones entre la capacidad de repetir sprints, el salto vertical y la fuerza de miembros superiores en jugadores profesionales de baloncesto

Resumen

La capacidad de repetir *sprints* cortos, los niveles de salto vertical con contramovimiento (CMJ) y la fuerza de miembros superiores tienen una gran importancia en la competición de alto nivel de baloncesto, aunque la relación entre estas variables no está clara en jugadores de élite. Así, el objetivo de esta investigación es estudiar las relaciones entre el test anaeróbico específico de carrera (RAST), el CMJ y la fuerza de miembros superiores en jugadores profesionales de baloncesto de la liga de mayor nivel competitivo en España (Liga Endesa). Para ello, se midió el RAST, el salto con contramovimiento (CMJ) antes y después del RAST y la fuerza en *press* de banca a 10 deportistas (N=11, edad=24,5 ± 5,8 años, altura = 200 ± 10,9 cm, peso corporal = 98,4 ± 9 kg) durante una sesión de entrenamiento. Los resultados muestran correlaciones altas y significativas entre el índice de fatiga en el RAST (IF) y la pérdida de CMJ (diferencia entre la medición antes y después del RAST) (r = 0,78, p <0,01), el IF y la máxima producción de fuerza en el *press* de banca (r =-0,86, p <0,01), y la pérdida de CMJ y la carga con la que se produce la potencia máxima en *press* de banca (r = -0,77, p <0,01). Estos datos evidencian la notable relación existente entre la capacidad de repetir *sprints,* el CMJ y la fuerza de miembros superiores en jugadores profesionales de baloncesto. Por ello, la elaboración de programas de entrenamiento que incidan en estas capacidades simultáneamente parece justificada en jugadores de baloncesto de élite. Estos hallazgos pueden ser relevantes para la preparación física de dichos deportistas.

Key words:
Rendimiento físico.
Valoración de la fuerza.
Jugadores de élite.

Correspondencia: Carlos Balsalobre-Fernández
E-mail: carlos.balsalobre@uam.es

Introduction

Professional basketball increasingly requires higher levels of physical condition, especially in relation to anaerobic efforts[1-4]. So much so that time-motion studies have shown that repeated sprints and jumps are the commonest skills in competitive matches, as they account for more than a third of all game actions[1,5]. Therefore, the analysis of the ability to repeat such efforts both in basketball and other team sports has raised the interest of coaches and researchers[6-9].

Repeated sprint ability (RSA) has been comprehensively dealt with in many scientific studies, and its importance regarding intermittent sports performance such as basketball has been emphasized by many authors[10-14]. Although there are many protocols depending on sprint duration, recovery periods or sport specificity[9,11,14], the running-based anaerobic sprint test (RAST) is being widely used since it has been validated and proposed as an alternative to the Wingate test for measuring sprint power output more specifically[15,16]. The test, consisting of six 35-meter sprints with 10 second recovery, has been used in team sports such as basketball, football, soccer or futsal[17,18], but, to the authors' knowledge, no study has addressed the RAST performance among professional basketball players.

The counter-movement jump (from now on, CMJ) is another basic basketball skill[1,3,4]. Since vertical jumps are quite common in basketball after one or more sprints[5,19], some authors have proposed measuring the CMJ before and after a series of repeated sprints[20,21] in order to assess the endurance to these efforts in players. For example, Buchheit *et al*.[20] measured the CMJ in athletes from different team sports before and after a 6-repeated-sprint test where significant correlations among the velocity loss and the height loss in CMJ were found. This author recommends the use of these protocols both for evaluation purposes and team sports training because they are highly specific to real game situations. Finally, many basketball studies on physical condition have analyzed the upper limb force production of the players as a key factor in the development of modern basketball competition, where strength and power are increasingly involved[3,22-24].

Consequently, the relationships among these key skills are a recurring issue in studies on physical fitness related to basketball[2,25-27]. Usually, the correlation studies analyze skills such as the countermovement jump (CMJ), short sprint (10-40 meters) and force production by lower limbs (generally isokinetic measurements), among other variables[2,25,28]. However, the relationships among sprint performance, the CMJ and force production in the upper limbs has been little studied. In fact, we don't know of any research examining the relationship among the repeated-sprint ability, CMJ and bench press strength in professional basketball players; yet, we believe that it is instrumental to better understand the determining performance factors in basketball competition and training specificities.

Therefore, the main objective of this research is to study the relationships among the RAST, the CMJ height loss, and force production, at bench press in a professional basketball team. Furthermore, this study aims to provide a physical profile of a professional basketball team. According to the studies on the literature and to our expertise in sports sciences, our hypothesis is that CMJ height loss has a close and statistically significant relationship with the velocity loss in the RAST.

Materials and methods

Participants

The sample consisted of 11 professional players from a men's team of the Premier Spanish Basketball League (ACB-Endesa), aged between 18 and 32 years (24.5 ± 5.8), heights between 186 and 214 cm (200.2 ± 10.9), weights from 81.5 to 112.5 kg (98.5 ± 8.6), BMI between 27.8 and 22.6 kg/m^2 (24.6 ± 1.7) and expertise on the ACB League between 1 and 13 years (4.9 ± 4.5). All playing positions were equally prevalent. There were no inclusion or exclusion criteria: we recruited all available players from a team in which we have full access. All players participated voluntarily with full acceptance and no counterpart. Informed consent was obtained prior to the first tests. The study was carried out in accordance with the Declaration of Helsinki, and it was approved by the ethics committee at the Autonomous University of Madrid.

Study design

A correlation and design study was carried out. Authors didn't have any conflict of interest, and any institution funded this investigation.

General procedures

The participants performed the tests in one day in the following order: (1) pre-RAST CMJ (CMJ1) (2) RAST test; (3) post-RAST CMJ (CMJ2); and (4) bench press test with increasing loads. Pre-testing was conducted after the players completed a standardized 15–minute warm-up, including jogging, a variety of movement drills, joint mobility and dynamic stretching. The players were familiarized with both the RAST and the CMJ tests. Validity and reliability of these tests were previously studied[15,29-31]. The study was carried out in the sports facilities of the High Performance Centre in Madrid (Spain) between 11 a.m. and 1 p.m., in an indoor hall with an ambient temperature of 21º C.

Measures

The following variables were analyzed: height reached in the CMJ1 (cm), height reached in the CMJ2 (cm), difference among CMJ1 and CMJ2 (CMJ loss) (%), mean power produced in the RAST (RAST_MP) (W), peak power produced in the RAST (RAST_PP) (W), RAST fatigue index (FI) (%), propulsive peak power produced at each bench press load (BP_PP) (W), propulsive peak force produced at each bench press load (BP_PF) (N), absolute propulsive peak power load at bench press (BP_PL) (kg), and one repetition maximum (RM) at bench press (kg).

Counter-movement jump (CMJ)

The athletes performed a CMJ test with arm swing[32]. The CMJ test was performed on an Optojump infrared platform[33] (Microgate Corporation, Italy). The participants were required to perform 3 trials before and after the RAST, and mean height was scored in centimeters (cm). The reliability of the measurements was very high (Intra-class correlation coefficient [ICC]=0.97-0.98).

Running-based anaerobic sprint test (RAST)

The RAST test consists of six repeated 35-meter sprints at full speed with a recovery time of 10 seconds between each sprint[16]. To time the trials, two pairs of Racetime 2 Light photocells (Microgate Corporation, Italy) based on a laser transmitter and a reflector were used. First, every player's power was calculated for each sprint, as follows[16]: Sprint Power = *(weight * distance^2) / time^3*, where *distance* is the sprint distance (in this case, 35 meters), *weight* is the load in kg used by each player, *time* the seconds it took everyone to run 35 meters. The result was the power in watts (W) for each sprint. Once every player's power was determined for each sprint, their maximum, mean and minimum power values were calculated. Finally, the RAST Fatigue Index (FI) was obtained through the following equation[16]: FI = ((RAST Maximum-Minimum power) / RAST Maximum power) * 100. The FI score was equal to the change rate (%).

Bench press test with increasing loads

The test included 4 sets of 3 bench press repetitions with 4 minutes recovery time between sets, using the following loads: 47.5 kg, 57.5 kg, 67.5 kg and 77.5 kg. For this purpose, a dynamic measurement system with a recording frequency of 1kHz (T-Force System; Ergotech, Murcia, Spain) automatically calculated the relevant kinematic parameters of the propulsive phase of every repetition[34,35]. A Smith machine (Multipower Fitness Line, Peroga, Spain) that ensures a smooth vertical displacement of the bar along a fixed pathway was used for the tests. The participants performed the bench press only in a purely concentric manner, and were told to perform the eccentric phase in a controlled manner by waiting for 1 second with the bar on their chest, and then performing the concentric phase of the movement as quickly as possible.

Statistical analysis

Variables are reported as mean ± standard deviation (SD), maximum and minimum values. The Kolmogorov-Smirnov test was applied to verify the normality of the data and correlations between changes in variables were analyzed using the Pearson correlation coefficient. The significance level was set at α=0.05. The IBM SPSS Statistics 20 software (IBM Corporation, USA) was used for all statistical analyses.

Results

Descriptive results

The athletes jumped an average of 44.3 cm (± 5.3) before performing the RAST test, and they lost 7.7% (± 3.0) after the test. Similarly, the players accumulated a fatigue index of 31.1% (± 8.2) in the RAST, losing 0.7 s (± 0.2) from first to last sprint. Moreover, the maximum force produced in the bench press test (corresponding to the load of 77.5 kg) was 1303.3 N (± 204.1). Finally, the load with which the players produced maximum power turned out to be 52.5 kg (± 5.3), and the RM to be 103.3 kg (± 12.6). Physical profiles of the basketball players who participated in this study are shown in Table 1.

Relationship between the RAST and CMJ loss

A statistically significant positive correlation was observed between the RAST fatigue index and CMJ loss (r = 0.78, p <0.01). Furthermore, there were also statistically significant positive correlations between the CMJ loss, on the one hand, and the propulsive mean (r = 0.64, p <0.05) and peak (r = 0.73, p <0.01) power of the RAST, on the other hand.

Table 1. Descriptive physical profile of the participants.

	M	SD	Min	Max	K-S
Body weight (kg)	98.5	8.6	81.5	112.5	1.000
Height (cm)	200.2	10.9	186	214	0.959
BMI (kg/m^2)	24.6	1.7	22.6	27.6	0.129
Years in ACB League	4.5	4.3	1	13	0.084
Vertical jump Test					
Pre-jump (cm)	45.6	5.9	36.4	54.7	0.736
Vertical jump loss (%)	9.2	4.8	2.1	18.7	0.898
RAST Test					
Fatigue index (%)	33.1	8.0	18.5	45.8	1.000
Velocity loss between 1st and last sprint (s)	0.7	0.2	0.3	1.1	0.968
Mean power (W)	772.2	126.4	551.8	947.4	0.982
Peak power (W)	956.8	193.7	613.4	1223.8	0.885
Bench press test with increasing loads					
Absolute peak power (W)	543.2	67.8	457.0	650.4	0.957
Absolute peak force (N)	1303.3	204.1	1055.0	1635.9	0.990
One Repetition Maximum (kg)	101.9	12.5	78	114	0.524
Absolute peak power load (kg)	51.9	5.3	47.5	57.5	0.204

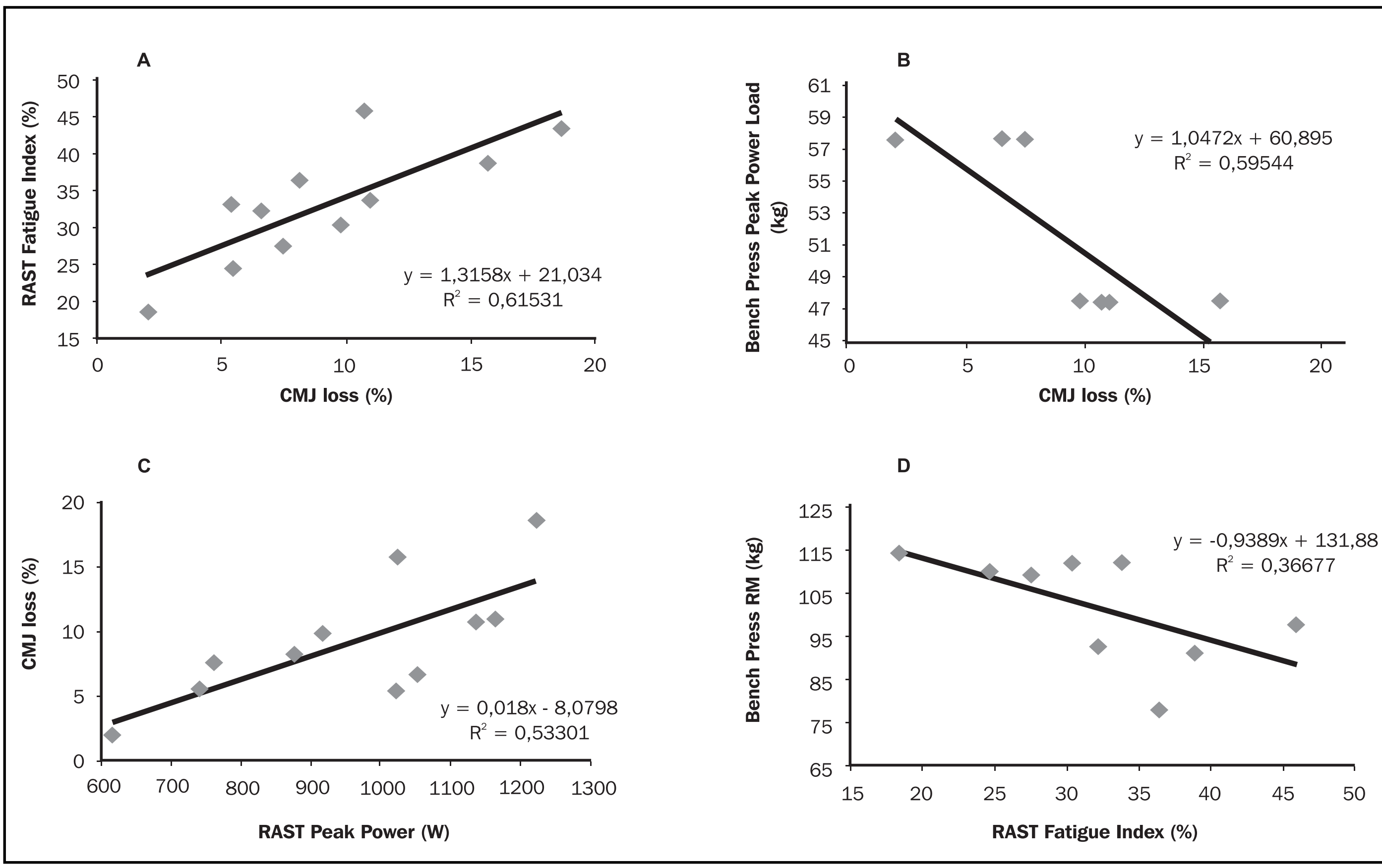
M: mean; SD: standard deviation; Min: minimum value; Max: maximum value; K-S: Kolmogorov-Smirnov test.

Table 2. Correlations between main variables of the study.

	CMJ loss	FI	RAST_PP	RAST_MP	BP_PP	BP_POT_LOAD	BP_PF	RM
CMJ loss	-	**0.784****	**0.730****	**0.643***	-0.097	**-772****	**-0.837****	-0.344
FI	-	-	**0.859****	**0.714****	-0.097	**-0.743***	**-0.860****	**-0.606***
RAST_PP			-	**0.967****	0.084	**-0.644***	**-0.784***	-0.313
RAST_MP				-	0.082	-0.480	**-0.668***	-0.203
BP_PP					-	-0.166	-0.086	**0.584***
BP_POT_LOAD						-	**0.671***	0.350
BP_PF							-	0.447

*p<0.05; **p<0.001

Figure 1. Correlations between (a) CMJ loss and RAST Fatigue Index (FI); (b) CMJ loss and bench press peak power load; (c) RAST peak power and CMJ loss; (d) FI and bench press.



Relationship between the RAST and bench press strength test

A statistically significant negative correlation between the RAST fatigue index and the load at which peak power was reached at bench press was observed (r = -0.74, p <0.05). Similarly, significant correlations were also observed between the load at which peak power was reached at bench press and the peak power produced in the RAST (r = -0.64, p <0.05). A statistically significant negative correlation was also observed between the RAST fatigue index and the peak force produced in the bench press test (r = -0.86, p <0.01). The peak force produced in the bench press test also showed statistically significant correlations with the mean (r = -0.67, p <0.05) and peak (r = -0.78, p <0.05) powers produced in the RAST. Finally, a statistically significant negative relationship was observed between the RAST fatigue index and the RM at bench press (r = -0.61, p <0.05).

Relationship between CMJ loss and bench press strength test

A statistically significant negative correlation was found between CMJ loss and peak power load at the bench press (r = -0.77, p <0.01). Negative and statistically significant correlations were also found between CMJ loss and peak force at bench press 77.5 kg (r = -0.84, p <0.01), 67.5 kg (r = -0.84, p <0.01) and 47.5 kg (r = -0.79, p <0.01) (Table 2).

Discussion

Our results show moderate to high statistically significant correlations between multiples of the variables studied. Firstly, the study of the correlations between the performance achieved in the RAST and the loss of CMJ mainly underlines the close relationship between the loss of height from the first to the second jump and the RAST fatigue index. This would demonstrate that the accumulation of fatigue in repeated sprints could be largely explained by the loss of explosive force as measured by the CMJ ($R^2 = 0.61$). Therefore, having noted that the onset of fatigue in the sprints is closely related to that in the CMJ, it would seem appropriate to use training methods combining these efforts, which are so common in professional basketball competition[5,6,20,21]. The analysis has also shown a positive and statistically significant correlation between the mean and peak powers in the RAST and the loss of height in the CMJ. This finding may lead to the conclusion that the players producing more power in the RAST also have more CMJ loss. This could be due to an increased activation of type II fibers produced by the power levels typically higher in short sprints[36,37]. Besides, these fibers can be preferably activated in the CMJ thus reverting the size principle[38,39], which could entail a greater loss in CMJ height through the accumulation of fatigue in fast fibers in the RAST. However, more research is needed to clarify this topic.

Furthermore, the analysis of the relationship between force production at the bench press and performance in the RAST has shown interesting results. Specifically, the load at which maximum power is reached at bench press has proved to be very related (r = -0.74) with the RAST fatigue index. Consequently, there is a trend whereby the higher the load at which maximum power is achieved at bench press, the lower the fatigue index in the repeated sprint test. However, since these relationships weren't studied before in such population, there is a lack of knowledge which could explain why the power production of the upper-body are so well related with the fatigue index of a lower-body task. Similarly, we see that the maximum force in the bench press test (produced with a 77.5 kg load, i.e. 76% of the RM as an average) also has a negative, high, significant correlation with the fatigue index (r = -0.86), mean power (r = -0.67) and maximum power (r = -0.78) in the RAST. No significant correlations were found with the rest of the loads used in the bench press test. According to this data, the players who produce more force with high loads and more power at the bench press are the ones who generate less fatigue and less power in the RAST. In fact, our data provides a statistically significant negative correlation between the RAST fatigue index and the RM at bench press. Moreover, negative, high, statistically significant correlations were found between the loss of CMJ and peak power load and between the loss of CMJ and peak force produced with all the loads of the bench press test (except with 57.5 kg). Thus, as with the RAST, the players who can generate more force with each load in the bench press test are the ones who suffer less fatigue (less CMJ loss). It could be argued that players with higher body weight may find it more difficult to perform repeated sprints and/or jump tasks at maximum effort[40] and, consequently, they would reach lower fatigue index. However, the analysis of the correlation shows that body weight has no significant relationships neither with the fatigue index (r=0.34, p=0.3), nor the mean (r=0.28, p=0.41) and peak (r=0.32, p=0.34) power in the RAST, nor the CMJ1 height (r=-0.32, p=0.34), nor the CMJ loss (r=0.27, p=0.42). In the light of these results, players' body weight does not significantly influence performance in repeated sprints and jumps. More research is therefore necessary to clarify the reasons of the negative relationships between force production and CMJ and RAST fatigue in professional basketball players.

In all events, our results demonstrate the existence of close relationships between performance in running-based anaerobic tests, CMJ loss and both muscle strength and the power of the upper limbs in professional basketball players. In conclusion: (a) CMJ loss of is closely related to fatigue in the RAST; (b) the players who produce more force and power in the bench press test are those who suffer less fatigue both in RAST and in the CMJ. Specifically, the evaluation of the CMJ and power production in bench press could be interesting to assess indirectly the capacity of the players to repeat short sprints. These findings may be useful to ascertain the physical profile of elite players as well as to propose training strategies that would optimize the performance of the athletes.

References

1. Abdelkrim NB, Castagna C, Jabri I, Battikh T, Fazaa SE, Ati JE. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. *J Strength Cond Res.* 2010;24:2330-42.
2. Alemdaroğlu U. The Relationship Between Muscle Strength, Anaerobic Performance, Agility, Sprint Ability and Vertical Jump Performance in Professional Basketball Players. *J Hum Kinet.* 2012;31:149-58.
3. Delextrat A, Cohen D. Physiological testing of basketball players: toward a standard evaluation of anaerobic fitness. *J Strength Cond Res.* 2008;22:1066-72.
4. Korkmaz C, Karahan M. A comparative study on the physical fitness and performance of male basketball players in different divisions. *J Phys Ed Sport Sci.* 2012;6:16-23.
5. Bishop D, Wright C. A time-motion analysis of professional basketball to determine the relationship between three activity profiles: high, medium and low intensity and the length of the time spent on court. *Int J Perf Anal Spo.* 2006;6:1-1.
6. Buchheit M, Bishop D, Girard O. Should We be Recommending Repeated Sprints to Improve Repeated-Sprint Performance? *Sports Med.* 2012;42:169-73.
7. Christou M, Smilios I, Sotiropoulos K, Volaklis K, Pilianidis T, Tokmakidis SP. Effects of resistance training on the physical capacities of adolescent soccer players. *J Strength Cond Res.* 2006;20:783-91.
8. Delextrat A, Calleja-González J, Hippocrate A, Clarke ND. Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *J Sports Sci.* 2013;31:11-19.
9. Girard O, Mendez-Villanueva A, Bishop D. Repeated-Sprint Ability — Part I: Factors Contributing to Fatigue. *Sports Med.* 2011;41:673-94.
10. Aziz AR, Chuan TEHK. Correlation between Tests of Running Repeated Sprint Ability and Anaerobic Capacity by Wingate Cycling in Multi-Sprint Sports Athletes. *Int J Appl Sport Sci.* 2004;16:14-22.
11. Bishop D, Girard O, Mendez-Villanueva A. Repeated-Sprint Ability — Part II. Sports Med. 2011;41:741-56.
12. Caprino D, Clarke ND, Delextrat A. The effect of an official match on repeated sprint ability in junior basketball players. *J Sports Sci.* 2012;30:1165-73.

13. Castagna C, Abt G, Manzi V, Annino G, Padua E, D'Ottavio S. Effect of recovery mode on repeated sprint ability in young basketball players. *J Strength Cond Res.* 2008;22:923-9.
14. Dawson B. Repeated-Spring Ability: Where Are We? *Int J Sport Physiol Perform.* 2012;7:285-9.
15. Kaminagakura EI, Zagatto AM, Redkva PE, Gomes EB, Loures JP, Kalva-Filho CA, *et al.* Can the Running-Based Anaerobic Sprint Test be used to Predict Anaerobic Capacity? *J Exercsie Phys.* 2012;15:90-9.
16. Zagatto AM, Beck WR, Gobatto CA. Validity of the running anaerobic sprint test for assesing anaerobic power and predicting short distance performance. *J Strength Cond Res.* 2009;23:1820-7.
17. Gwacham N, Wagner DR. Acute Effects of a Caffeine-Taurine Energy Drink on Repeated Sprint Performance of American College Football Players. *Int J Sport Nutr Exe.* 2012;22:109-16.
18. Keir DA, Thériault F, Serresse O. Evaluation of the Running-Based Anaerobic Sprint Test as a Measure of Repeated Sprint Ability in Collegiate-Level Soccer Players. *J Strength Cond Res.* 2013;27:1671-8.
19. Abdelkrim NB, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*. 2007;41:69-75.
20. Buchheit M. Performance and physiological responses to repeated-sprint and jump sequences. *Eur J Appl Physiol.* 2010;110:1007-18.
21. Buchheit M, Spencer M, Ahmaidi S. Reliability, Usefulness, and Validity of a Repeated Sprint and Jump Ability Test. *Int J Sport Physiol Perform.* 2010;5:3-17.
22. Burnham TR, Ruud JD, McGowan R. Bench press training program with attached chains for female volleyball and basketball athletes. *Percept Mot Skills.* 2010;110:61-8.
23. Caterisano A, Patrick BT, Edenfield WL, Batson MJ. The effects of a basketball season on aerobic and strength parameters among college men: starters vs. reserves. *J Strength Cond Res.* 1997;11:21-4.
24. Gašic T, Bubanj S, Živković M, Stanković R, Bubanj R, Obradović B. Difference in the explosive strength of upper extremities between athletes in relation to their sport activity, type of engagement in sport and gender. *Sport Sci*. 2011;4:63-7.
25. Gerodimos V, Giannakos T, Bletsou E, Manou V, Ioakimidis P, Kellis S. The Relationship between Vertical Jumping Performance and Isokinetic Strength of the Knee Extensors and Ankle Plantar Flexors in Basketball Players of Developmental Ages. *Inq Sport Phys Ed.* 2006;4:449-54.
26. Hoffman JR, Tenenbaum G, Maresh CM, Kraemer WJ. Relationship between athletic performance tests and playing time in elite college basketball players. *J Strength Cond Res.* 1996;10:67-71.
27. Stojanovic MD, Ostojic SM, Calleja-Gonzalez J, Milosevic Z, Mikic M. Correlation between explosive strength, aerobic power and repeated sprint ability in elite basketball players. *J Sports Med Phys Fitness.* 2012;52:375-81.
28. Delextrat A, Trochym E, Calleja-Gonzalez J. Effect of a typical in-season week on strength jump and sprint performances in national-level female basketball players. *J Sports Med Phys Fitness.* 2012;52:128-36.
29. Bosco C, Luhtanen P, Komi PV. Simple method for measurement of mechanical power in jumping. *Eur J Appl Physiol.* 1983;50:273-82.
30. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res*. 2004;18:551-5.
31. Ziv G, Lidor R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. *Sports Med.* 2009;39:547-68.
32. Souissi S, Wong DP, Dellal A, Croisier J-L, Ellouze Z, Chamari K. Improving functional performance and muscle power 4-to-6 months after anterior cruciate ligament reconstruction. *J Sport Sci Med*. 2011;10:655-64.
33. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *J Strength Cond Res.* 2011;25:556-60.
34. Gómez-Piriz PT, Sánchez MET, Manrique DC, González EP. Inter-machine Reliability (T-Force & Myotest) in strength assessment. *Rev Int Cienc Dep.* 2012;8:20-30.
35. Loturco I, Ugrinowitsch C, Roschel H, Lopes Mellinger A, Gomes F, Tricoli V, *et al.* Distinct temporal organizations of the strength- and power-training loads produce similar performance improvements. *J Strength Cond Res.* 2013;27:188-94.
36. Alev K, Kaasik P, Pehme A, Aru M, Parring AM, Elart A, *et al.* Physiological role of myosin light and heavy chain isoforms in fast- and slow-twitch muscles: effect of exercise. *Biol Sport.* 2009;26:215-34.
37. Klaver-Król EG, Henriquez NR, Oosterloo SJ, Klaver P, Kuipers H, Zwarts MJ. Distribution of motor unit potential velocities in the biceps brachii muscle of sprinters and endurance athletes during prolonged dynamic exercises at low force levels. *J Electromyogr Kines.* 2010;20:1115-24.
38. Ebben WP, Simenz C, Jensen RL. Evaluation of plyometric intensity using electromyography. *J Strength Cond Res.* 2008;22:861-8.
39. Chalmers GR. Can fast-twitch muscle fibres be selectively recruited during lengthening contractions? Review and applications to sport movements. *Sport Biom*. 2008;7:137-57.
40. Gabbett TJ, Jenkins DG, Abernethy B. Relative importance of physiological, anthropometric, and skill qualities to team selection in professional rugby league. *J Sports Sci.* 2011;29:1453-61.