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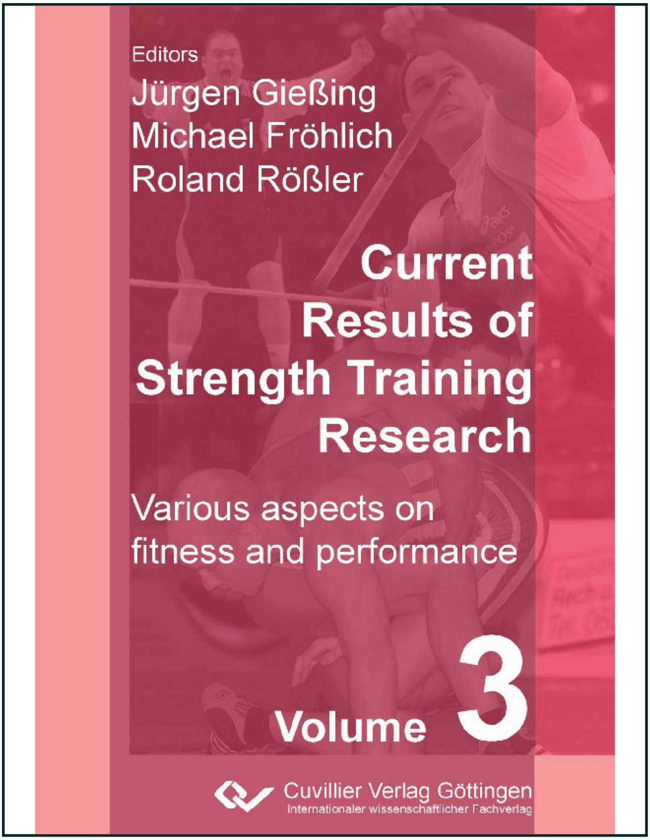
Current Results of Strength Training Research

Various aspects on fitness and performance



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Strength testing in basketball

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Introduction

Basketball is an intermittent team sport characterised by the repetition of high-intensity activities during four quarters of 10 minutes each (McKeag, 2003). Time-motion analysis of competitive matches has shown that a game involves a large number of jumps (44 to 46 in males and 35 in females), sprints (55 to 105 in males and 49 in females) and high intensity shuffle movements (63 to 94 in males and 58 in females) (Ben Abdelkrim et al., 2007; Matthew & Delextrat, 2009; McInnes et al., 1995). Although high-intensity activities only represent a small proportion of live time (15.0 % to 16.1 %), they are crucial to the outcome of a game and could potentially make the difference between winning and loosing (Ben Abdelkrim et al., 2007; McInnes et al., 1995). Consequently, most authors have highlighted that strength and power, rather than endurance, should be the main focus of physical conditioning programes for basketball players (Drinkwater et al., 2008; McKeag et al., 2003).

In contrast with other team sports, such as soccer and rugby, where a specific test has been validated and is commonly used for strength assessment, no single test has been acknowledged standard evaluation of strength in basketball, and several methods are currently used (Hoffman & Maresh, 2000). The following paragraphs aim to review the methods of the most common tests used in strength and power assessment, inspecting the relationship between strength and other aspects of performance as well as comparing strength and power of different playing positions.

Methodological considerations

The most common tests used in the strength and power assessment of basketball players include laboratory-based tests, such as the Wingate Anaerobic Power Test (WanT) and isokinetic testing of specific muscle groups, and field-based tests, such as one repetition maximum (1-RM) tests, vertical jump test and basketball chest pass. The difficulty to identify a single test as a standard tool for strength assessment mostly lies in the lack of specificity and applicability of these tests to basketball.

The most frequently reported strength testing measure in the literature is the 1-RM test in the bench press for the upper body and squat for the lower body (Caterisano et al., 1997; Groves & Gayle, 1993; Hoffman et al., 1991, 1996; Hunter et al., 1993; Jukic et al., 1999; Latin et al., 1994; McKenzie Gillam, 1985). The aim of such tests is to reach a maximal effort within three to five attempts, as described by Knuttgen and Kraemer (1987). The specificity of these tests is acceptable because even if performed in a gym setting, they focus on the muscle groups responsible for the movements involved in real game situations (McKeag, 2003). Moreover, the squat test is weight-bearing and thus any performance improvement measured by this test potentially provides a better transfer of strength to specific actions on the court, compared to non weight-bearing tests. A very good test-retest reliability of 1-RM determinations in the squat and bench press has recently been shown in various populations, as evidenced by intraclass correlation coefficients ranging from 0.95 to 0.99 (Le-Brasseur et al., 2008). Latin et al. (1994) discussed the advantages of using the power clean rather than squat test because it integrates strength, explosive power and neuromuscular coordination and therefore represents a closer replication of movements involved in a real game situation. However, very few measurements of maximal strength in the power clean have been reported in basketball players (Latin et al., 1994). The difficulty in learning the appropriate technique for this test could be one reason responsible for the lack of data.

As an alternative to the bench press test a few authors used the performance in the chest pass to assess upper-body strength of female players (Delextrat & Cohen, 2009; Hoare, 2000). It involves throwing a basketball from the chest in a seated position against a wall, with the legs rested straight horizontally on the floor. This test is specific and more convenient for coaches to use. However Cronin and Owen (2004) highlighted that its reliability is lower than laboratory tests (coefficient of variation between test-retest of 3.47 %) and that performance in that test is highly influenced by players' anthropometric characteristics.

The last field test described in this section is used to measure power rather than strength and involves converting vertical jump height (in cm) to power (in $kg \times s^{-1}$), using the Lewis nomogram (Fox & Matthews, 1996). This conversion is classically used in the basketball literature, although the scientific bases for its use have been questioned by several authors (Keir et al., 2003). In particular, the result of the test seems to depend mostly on the effects of gravity during the descending phase of the jump, rather than the explosive power of the legs (Sayers et al., 1999).

Laboratory assessments of strength are generally described as more valid and reliable, compared to field assessments. However, their main limitations are the cost of the equipment necessary to run the tests and their specificity with regards to the movements performed in basketball. Several authors have measured the peak power, mean power and fatigue index during the 30-second Wingate anaerobic test (WanT) as an indicator of the anaerobic fitness of basketball players (Apostolidis et al., 2003; Delextrat & Cohen, 2008, 2009; Hoffman et al., 1995, 2000; LaMonte et al., 1999). This test is characterised by high reliability (correlation coefficients between test-retest higher ranging from 0.89 and 0.98, see Bar-Or, 1987). The main limitation raised regarding this test is the major difference in locomotion modes and muscle contraction patterns between cycling and running, which questions its relevance for basketball (Tharp et al., 1985). Maud and Shultz (1989) have also argued that the load limitations imposed by the test (commonly 7.5 % of body mass), although designed to maximise power output in the general population, could prevent taller and heavier subjects like basketball players from expressing their real peak power. Finally, it could be argued that variations of the Wingate test, such as the 10-s WanT or the 5 × 6-s maximal cycling repeated sprint test, could be more relevant to basketball than the 30-s WanT because they involve work durations that are closer to sprint times performed in competition (McGawley & Bishop, 2006; Zajak et al., 1999). Unfortunately, no data on basketball players has been reported using such tests.

The piece of equipment that has undoubtedly been the most used in the past 20 years to measure lower limb strength of basketball players and record changes during the season is the isokinetic dynamometer (Delextrat & Cohen, 2008, 2009; Häkkinen, 1993; Hoffman et al., 1991; Smith & Thomas, 1991; Theoharopoulos et al., 2000). Classically, authors have tested the maximal concentric and eccentric torque of the quadriceps and hamstrings muscle groups at angular speeds ranging from $60° \times s^{-1}$ to $300° \times s^{-1}$. Two main issues have been raised regarding that test. The first one is the choice of a relevant angular speed, with higher speeds being more specific to the movements involved in basketball, and lower speeds characterised by higher test-retest reliability (Impellizzeri et al., 2008). Greater test-retest reliability has also been reported for knee extensors compared to knee flexors, and for concentric compared to eccentric contraction modes (Li et al., 1996). The second issue is the effect of speed testing order when several speeds are used. Within this context, Wilhite et al. (1992) suggested that testing slower speeds before faster speeds is preferable and leads to a higher reliability. An interesting application of isokinetic testing is assessing muscle imbalances between quadriceps and hamstrings. Authors classically calculate conventional hamstrings-to-quadriceps ratios (ratio of the peak concentric strengths of the hamstrings and quadriceps) and functional hamstrings-to-quadriceps ratios (ratio of the hamstrings peak eccentric strength to the quadriceps peak concentric strength), with values lower than 0.6 for the conventional and 0.7 in the functional representing a potential greater risk of knee injury (Aagaard et al., 1995; Gerodimos et al., 2003; Schiltz et al., 2009).

Relation between strength measurements and performance

Two main methods have been used in the literature to assess strength could be identified as a determinant of successful performance in basketball, namely correlations between strength measurements and other performance variables, and comparisons between elite-level and average-level basketball players (or between basketball players and players from other team sports of the same fitness level). Table 1 shows the correlation coefficients between strength and other performance variables established on players of different levels. Performance in basketball is multifactorial and it is therefore difficult to identify one single measurement of success. Hoare (2000) used ratings of players' performance by coaches according to several criteria (offensive and defensive skills, catch/pass skills, overall ability) to reflect successful performance. After testing the strength, power, speed, acceleration, agility and aerobic capacity, they found that the best predictors of success were power in females, and strength and power in males (Hoare, 2000). The parameter that most closely reflects basketball performance is probably the playing time. To our knowledge, only one study investigated the relationship between strength, power and playing time during four entire seasons (1998 to 1992) in 29 National Collegiate Athletic Association (NCAA) division 1 players (Hoffman et al., 1996). They showed that the variable with the greatest correlation with playing time was vertical jump height, followed by 1-RM squat performance. Interestingly, a recent study showed that 1-RM squat performance was also significantly correlated to speed (from 5-m to 20-m) (Chaouachi et al., 2009). The performance in the 1-RM bench press was not significantly correlated to playing time (Hoffman et al., 1996). Among the other parameters investigated, peak isometric torque of the knee extensors was significantly correlated to jump height in the squat jump (SJ) and countermovement jump (CMJ) (Häkkinen, 1991, 1993). An interesting finding is that stronger correlations with agility and speed were found between the mean power than the peak power achieved in the WanT (Apostolidis et al., 2003; Hoffman et al., 2000). The methodological considerations evoked in the previous paragraph could partly be responsible for these findings.

In an attempt to identify if strength was a determinant of performance in basketball, a few authors have compared basketball players and athletes from other sports with a similar fitness level (McKenzie Gillam, 1985; Zakas et al., 1995). The main results of these studies emphasise that a significantly greater explosive power rather than strength differentiates basketball players from physical education students (McKenzie Gillam, 1985).

Table 1: Correlations between strength measurements and other aspects of performance

Variables	Significant correlations with performance	Subjects and authors
Vertical Jump (VJ)	Playing time ($r = 0.68$, $p < 0.05$)	29 NCAA division 1 male players (Hoffman et al., 1996)
Squat Jump (SJ)	Peak isometric torque of the knee extensors ($r = 0.69$, $p < 0.05$)	10 national level female players (Häkkinen, 1993)
Countermovement Jump (CMJ)	Peak isometric torque of the knee extensors ($r = 0.81$, $p < 0.01$)	11 male and 9 female national level players (Häkkinen, 1991)
Explosive power balance*	Distance covered in the Yo-yo test ($r = 0.62$, $p < 0.05$)	22 regional level male players (Castagna et al., 2009)
1-RM squat	Playing time ($r = 0.64$, $p < 0.05$)	29 NCAA division 1 male players (Hoffman et al., 1996)
	5-m sprint time ($r = -0.63$, $p < 0.05$) 10-m sprint time ($r = -0.68$, $p < 0.05$)	14 international level male players (Chaouachi et al., 2009)
Mean Power in the Wingate anaerobic test (WanT)	Agility ($r = -0.58$, $p < 0.05$) 20-m sprint with the ball ($r = -0.62$, $p < 0.05$) Line drill with the ball ($r = -0.73$, $p < 0.05$) and without the ball ($r = -0.56$, $p < 0.05$)	13 international junior male players (Apostolidis et al., 2003)
	15-s anaerobic Jump test ($r = 0.76$, $p < 0.05$) Line drill time ($r = 0.61$, $p < 0.05$)	9 international junior male players (Hoffman et al., 2000)
Peak Power the Wingate anaerobic test (WanT)	15-s anaerobic Jump test ($r = 0.59$, $p < 0.05$)	9 international junior male players (Hoffman et al., 2000)
Peak isometric torque of the knee extensors	Squat Jump ($r = 0.69$, $p < 0.05$) Countermovement Jump ($r = 0.68$, $p < 0.05$)	10 national level female players (Häkkinen, 1993)
	Squat Jump ($r = 0.80$, $p < 0.01$) Countermovement Jump ($r = 0.81$, $p < 0.01$)	11 male and 9 female national level players (Häkkinen, 1991)
	Countermovement Jump ($r = 0.52$, $p < 0.01$)	33 national male junior players (Ugarkovic et al., 2002)
Peak isometric torque of the hip extensors	Countermovement Jump ($r = 0.38$, $p < 0.05$)	33 national male junior players (Ugarkovic et al., 2002)

*: Explosive power balance was calculated as (stiff leg Jump height / CMJ height), (McClymont et al., 2004)

Secondly, peak torque of the knee flexors and extensors was significantly higher in basketball players compared to soccer players of the same level (Metaxas et al., 2009; Zakas et al., 1995). These authors suggested that these differences could be mainly explained by the specific demands induced by basketball, in particular the many physical contacts experienced in a smaller pitch to get into a strategic position in the key or box-out in defence, for example. However, when torque was expressed relative to body weight, no significant differences were revealed between basketball and soccer players (Zakas et al., 1995). This suggests that the differences observed could be partly attributed to the greater body size and mass of basketball players, compared to soccer players.

Comparison of players of different levels can also contribute to the identification of successful parameters of performance. Again, it seems that overall parameters, such as peak torque of the knee extensors as well as explosive power differentiate elite players from players of lower levels (Delextrat & Cohen, 2008; Hoare, 2000; Zakas et al., 1995). Contrasting results were reported regarding the 1-RM performances, while the different parameters recorded during the WanT do not seem to discriminate between players of different levels (Caterisano et al., 1997; Delextrat & Cohen, 2008).

Table 2: Strength performances of basketball players of different levels and other athletes

13 male college basketball players *vs.* 14 physical education majors (McKenzie Gillam, 1985)		Basketball	Physical education
	1-RM bench press (kg):	76.3 ± 11.3	82.4 ± 19.2
	1-RM squat (kg):	15.3 ± 18.0	104.2 ± 21.0
	Push ups (reps):	23.2 ± 7.9	27.1 ± 7.8
	Squat thrust (reps):	58.5 ± 31.2	38.1 ± 17.6*
	Power (kg × m/s from VJ):	154.1 ± 16.4	135.2 ± 24.9*

61 basketball players *vs.* 51 soccer players from different divisions (Zakas et al., 1995) (in this study, division 1 includes international players)			Basketball	Soccer
	Peak torque of quadriceps at 60° × s^{-1}	Division 1	284 ± 30	246 ± 43*
		Division 4	271 ± 35	226 ± 34*
	Peak torque of quadriceps at 180° × s^{-1}	Division 1	170 ± 23	154 ± 30
		Division 4	165 ± 30	142 ± 21*
	Peak torque of hamstrings at 60° × s^{-1}	Division 1	201 ± 21	168 ± 33*
		Division 4	188 ± 21	150 ± 20*
	Peak torque of hamstrings at 180° × s^{-1}	Division 1	130 ± 25	122 ± 22
		Division 4	122 ± 23	105 ± 14*

61 basketball players from different divisions (Zakas et al., 1995) (in this study, significant differences were reported only between international players and players of lower divisions)		Quadriceps		Hamstrings	
		60° × s^{-1}	180° × s^{-1}	60° × s^{-1}	180° × s^{-1}
	International	314 ± 37	195 ± 28	210 ± 19	147 ± 26
	Division 1	255 ± 22*	146 ± 18*	192 ± 23	112 ± 24*
	Division 2	271 ± 21*	165 ± 28*	186 ± 18*	117 ± 18*
	Division 3	271 ± 45*	159 ± 34*	197 ± 21	122 ± 25*
	Division 4	271 ± 35*	165 ± 30*	188 ± 21*	122 ± 23*

9 starter players (playing time of at least 30 min per game) vs. 8 reserve players (playing time of less than 10 min per game) from a Division 1 university team (Caterisano et al., 1997)	Start of the season:	Starters	Reserves
	1-RM bench press (kg)	112.7 ± 11.5	111.3 ± 19.2
	1-RM leg press (kg)	272.1 ± 41.1	252.2 ± 16.4
	End of the season:		
	1-RM bench press (kg)	104.2 ± 10.0	98.0 ± 10.6
	1-RM leg press (kg)	234.0 ± 33.0	241.4 ± 27.4

260 junior male and female players divided into "best" and "rest" players (8 best and 8 weakest players in each position, as determined by coaches) (Hoare, 2000)	VJ (cm)	"Best"	"Rest"
	Female point guards	52.6	44.8*
	Female power forwards	50.5	40.2*
	Male shooting guards	68.6	60.6*
	Chest pass (m)		
	Female power forwards	8.48	7.41*
	Male point guards	11.80	9.99*
	Male shooting guards	11.13	9.81*
	Male centres	11.63	10.02*

8 players from division 1 university league vs. 8 players from division 3 university league (Delextrat & Cohen, 2008)		Division 1	Division 3
	VJ (cm)	56.6 ± 4.4	51.6 ± 3.3*
	1-RM bench press (kg)	101.3 ± 26.9	82.5 ± 24.0*
	PP in WanT (W × kg^{-1})	10.2 ± 0.9	10.0 ± 0.9
	MP in WanT (W × kg^{-1})	8.2 ± 0.9	7.8 ± 1.2
	Peak torque of the quadriceps at 60° × s^{-1} (Nm):	167 ± 25	133 ± 15*
	Peak torque of the quadriceps at 180° × s^{-1} (Nm):	127 ± 25	102 ± 18*

61 basketball players vs. 100 soccer players (Metaxas et al., 2009)		Basketball		Soccer	
	Peak torque of quadriceps at	180° × s^{-1}	300° × s^{-1}	180° × s^{-1}	300° × s^{-1}
	Division 1	209 ± 40	151 ± 30	179 ± 21*	129 ± 15*
	Division 4	195 ± 33	152 ± 26	176 ± 25*	123 ± 18*
	Peak torque of hamstrings at	180° × s^{-1}	300° × s^{-1}	180° × s^{-1}	300° × s^{-1}
	Division 1	113 ± 27	80 ± 21	104 ± 13	77 ± 15
	Division 4	100 ± 27	82 ± 23	102 ± 18	74 ± 16

*: Significant differences between groups, $p < 0.05$