



The Relationship Between Muscle Strength, Anaerobic Performance, Agility, Sprint Ability and Vertical Jump Performance in Professional Basketball Players

by
Utku Alemdaroğlu

The purpose of this study was to investigate the relationship between isokinetic knee strength, anaerobic performance, sprinting ability, agility and vertical jump performance in first division basketball players. Twelve male first division basketball players participated in this study. The mean age was 25.1 ± 1.7 yrs; mean body height 194.8 ± 5.7 cm; mean body mass 92.3 ± 9.8 kg; mean PBF 10.1 ± 5.1 ; and mean VO_{2max} 50.55 ± 6.7 ml/kg/min. Quadriceps and hamstrings were measured at 60° and $180^\circ/s$, anaerobic performance was evaluated using the Wingate anaerobic power test, sprint ability was determined by single sprint performance (10-30 m), jump performance was evaluated by countermovement (CMJ) and squat jump (SJ) tests and agility performance was measured using the T drill agility test. Quadriceps strength was significantly correlated with peak power at all contraction velocities. However, for mean power, significant correlation was only found between the 60° left and 180° right knee quadriceps measurements. No measure of strength was significantly related to the measurements from/results of field tests. Moreover, strong relations were found between the performance of athletes in different field tests ($p < 0.05$). The use of correlation analysis is the limitation of this study.

Keywords: Isokinetic strength, anaerobic power, vertical jump, sprinting, agility

Introduction

Basketball is an aerobic-based anaerobic sport (Delextrat and Cohen, 2009; Meckell et al., 2009; Metaxas et al., 2009) which requires high intensity activities such as jumping (for rebounds, blocks and shots), turns, dribbles, sprints, screens and low intensity activities such as walking, stopping and jogging. Frequent stoppages in games allow players to recover between bouts of activity, thus allowing repeated high-intensity spells of play (Drinkwater, 2008). Aerobic capacity is positively associated with recovery during repeated high-intensity bouts (Castagna et al., 2008; Tomlin and Wenger, 2001). Moreover, the high intensity movements of basketball players are closely related to the development of strength, speed and agility (Castagna et al., 2007; Hedrick, 1993; Meckell et al., 2009). During a basketball game, professional players cover about 3500-

5000m (Janeira and Maia, 1998). Each player performs about 1000, mainly short, activities lasting around 2 seconds; time motion analysis has shown that these short activities are performed with a different frequency according to the player's position (Abdelkrim et al., 2007). Explosive strength, take-off power, speed, and agility are abilities that make an important contribution to efficient movement with and without the ball, thus play an important role in basketball technique and tactics (Erculj et al., 2010). The level of these abilities, that is, the motor potential, is most often measured using various motor tests with and without the ball (Colli et al., 1987). In basketball practice, motor tests are the most suitable and applicable because they are implemented in conditions similar to those of training or competition (Erculj et al., 2010).

¹ - Pamukkale University Schools of Sport Sciences and Technology, Denizli, Turkey

Authors submitted their contribution of the article to the editorial board.

Accepted for printing in Journal of Human Kinetics vol. 31/2012 on March 2012.

Assessment of the physical capacities of athletes is one of the most important issues in modern sports, many test used in order that selection procedures, for screening candidates, or to monitor the efficacy of training regimes (Norkowski, 2002). Despite sports performance professionals and sports scientists focus on performance assessment, there are lack of research examining the relationships between various motor skills (Vescovi and McGuigan, 2008). There are a lot of motor skills in different sports, have kinematic, biomechanical and muscular similarities (Bobbert and van Zandwijk, 1999; Zajac, 2002), but examining correlations between these skills has proved elusive (Vescovi and McGuigan, 2008).

Studies investigate relationships between sprinting and muscle strength performance have had different limitations and reported only weak and no relationships so far (Dowson et al., 1998). The examination of only one joint action or type of muscle contraction, or an incomplete investigation of the relationship between strength and sprint performance measures may be reason of this weak correlations (Dowson et al., 1998).

Sports scientists have examined lower limb strength and power are frequently using the isokinetic knee joint test and the vertical jump test; some studies have focused on the correlation between performance in these two motor skills but have reported scattered findings (Iossifidou, 2005). This scattered findings may be due to a number of differences, such as joint angular velocities and the positioning of the participants, affecting muscle length and velocity of contraction, participant characteristics and methods used for calculation power of joint in isokinetic dynamometry (Iossifidou, 2005).

Some studies have attempted to correlate the results of the WAnT and isokinetic tests. Arslan (2005) found that there were significant correlations between explosive leg strength and anaerobic performance. Kin-İşler et al. (2008) reported that isokinetic concentric knee extension strength was significantly correlated with peak and mean power at all contraction velocities (60°, 150°, 240°). However, there was significant correlation only between 240° knee flexion strength and peak power for isokinetic concentric knee flexion.

While some studies have investigated the relationships between isokinetic knee strength, anaerobic performance, sprinting ability, agility,

and vertical jump performance in other athletes, an insufficient number of studies have been conducted on basketball players. Therefore the purpose of this study was to investigate the relationship between isokinetic knee strength, anaerobic performance, sprinting ability, agility and vertical jump performance in first division basketball players.

Methods

Subjects and Experimental Approach

Twelve male first division basketball players participated in this study. The mean measurements gathered were as follows: age 25.1 ± 1.7 yrs; body height 194.8 ± 5.7 cm; body mass 92.3 ± 9.8 kg; PBF 10.1 ± 5.1; and VO₂max 50.55 ± 6.7 ml/kg/min. The subjects were informed about the possible risks and benefits of the study and gave their informed consent to participate in this study, which was approved by the Clinical Research Ethical Committee of Pamukkale University. The study was conducted over a 1-week period, during which the players did not participate in any other training or matches.

On the first day, anthropometric measurements, vertical jump measurements, sprint tests, agility test and shuttle run test were performed respectively. On the third day, players underwent isokinetic leg strength tests. On the fifth day, players performed the Wingate anaerobic test.

Anthropometric Measurements

Subjects reported to the laboratory at 8:00 a.m. First, body height (cm), body mass (kg), and percentage of body fat (PBF) measurements were taken for each subject. The body height of the basketball players was measured using a stadiometer accurate to within 1 cm (SECA, Germany), while electronic scales (Tanita BC 418, Japan) accurate to within 0.1 kg were used to measure body mass and percentage of body fat (Lohman et al., 1988).

Anaerobic performance evaluation

The Wingate Anaerobic Test (WAnT) was conducted using a mechanically braked cycle ergometer (834 E, Monark, Vansbro, Sweden). Subjects were seated on the ergometer and adjustments were made to ensure an optimal cycling position. The WAnT was conducted according to the widely accepted recommendations for standardization (Inbar et al., 1996). The WAnT test was administered for 30 seconds with resistance set at 7.5 % of body mass.

The WANt session started with a standardized warm-up of 5 min of cycling at 50 rpm against no load, after which the subjects rested for 5 min. They were then instructed to pedal as fast as they could. When the pedaling rate reached approximately 160–170 rpm the resistance was applied and subjects continued pedaling as fast as possible for 30s. The subjects were verbally encouraged during the test. Peak power (PP) and mean power (MP) was calculated automatically by the Wingate Anaerobic Test computer program. A fatigue index was calculated by using the following equation (Inbar et al., 1996):

$$\text{Fatigue Index (FI)} = (\text{PP}) - (\text{MinP}) / (\text{MP}) \times 100$$

PP is the peak power, and MinP is the minimum power that was determined during the WANt test. WANt test performed according to Kin-İşler et al. (2008)

Isokinetic Leg Strength:

Before the isokinetic test, subjects performed a 5-minute warm-up on a cycle ergometer. Measurements were taken using an Isomed 2000 (Ferstl, Germany) isokinetic dynamometer. The test was performed in a seated position; stabilization straps were secured across the trunk, waist, and distal femur of the tested leg. The leg extensor and leg flexor muscle of each leg were concentrically measured at $60^\circ \times \text{s}^{-1}$ (10 repetitions) and $180^\circ \times \text{s}^{-1}$ (10 repetitions). Verbal encouragement was given to the subjects during the measurement. Before starting the test, subjects were allowed 5 trials.

Vertical Jump Measurements

Vertical jump performance was measured using a portable force platform (Newtest, Finland). Players performed countermovement (CMJ) and squat jumps (SJ) according to the protocol described by Bosco et al. (1983). Before testing, the players performed self-administered submaximal CMJs and SJ (2-3 repetitions) as a practice and specific additional warm-up. They were asked to keep their hands on their hips to prevent any influence of arm movements on the vertical jumps and to avoid coordination as a confounding variable in the assessment of the leg extensors (Bosco et al., 1995). Each subject performed 3 maximal CMJs and SJs, with approximately 2 minutes' recovery in between. Players were asked to jump as high as possible; the best score was recorded in centimeters (Bosco et al., 1995).

10-30m Sprint Test

The subjects performed 2 maximal 30 m sprints (with 10 m split times also recorded) on the basketball court. There was a recovery period of 3 minutes between the 30 m sprints. Prior to each sprint test, players performed a thorough warm-up consisting of 10 minutes of jogging at 60–70% of HRmax and then 5 minutes of exercise involving fast leg movements (e.g., skipping, cariocas) over short distances of 5 to 10 m and 3–5 single 15 m shuttle sprints with 2 minutes of passive recovery. Times were measured using an electronic timing system (Prosport TMR ESC 2100, Tumer Engineering, Ankara, Turkey).

T-Drill Agility Test:

Four 22.86 cm collapsible agility cones were arranged as outlined in Semenick (Semenick, 1990) (Figure 1). At the tester's signal, subjects sprinted forward 9.14 m and touched the tip of the cone (B) with their right hand. Then they performed a lateral shuffle to the left 4.57 m and touched the tip of the cone (C) with the left hand. Subjects then changed direction and shuffled 9.14 m to the right to touch the tip of the cone (D) with their right hand.

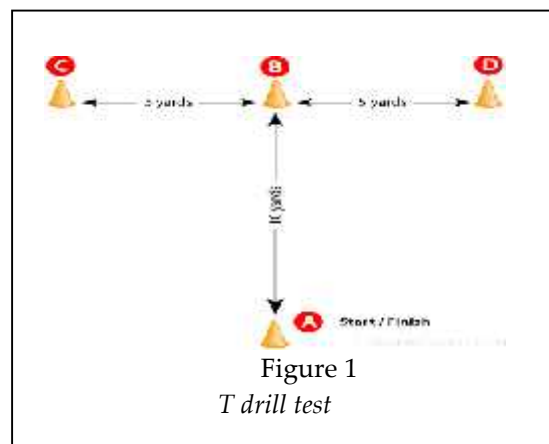


Figure 1
T drill test

They then shuffled 4.57 m to the left to touch point (B) with their left hand. Finally, the subjects back-peddled 9.14 m, passing through the finish at point A (Patterson et al., 2008). Times were measured using an electronic timing system (Prosport TMR ESC 2100, Tumer Engineering, Ankara, Turkey).

Multi-Stage 20m Shuttle Run Test

Subjects' maximal oxygen uptake (VO_2 max) was indirectly obtained using a multi-stage 20 m shuttle run test. This consisted of shuttle running between two parallel lines set 20 m apart, running speed cues being indicated by signals emitted from a commercially available pre-recorded audiocassette tape. The audiocassette tape ensured that subjects started running at an initial speed of $8.5 \text{ km} \times \text{h}^{-1}$ and that running speed increased by $0.5 \text{ km} \times \text{s}^{-1}$ each minute. This increase in running speed is described as a change in test level. The speed of the cassette player was checked for accuracy in accordance with the manufacturer's instructions before each application. All subjects performed a 10-minute warm up that included the prescribed jogging and stretching. Test results for each subject were expressed as a predicted VO_2 max obtained by cross-referencing the final level and (completed) shuttle number at which the subject became exhausted with that of the VO_2 max table provided in the instruction booklet accompanying the multi-stage 20 m shuttle run test. Only fully completed 20 m shuttle runs were considered (Léger and Gadoury, 1989).

Statistical Analyses

The relationships between isokinetic knee strength, anaerobic performance, sprinting ability, agility and vertical jump performance were evaluated using Pearson Product Moment Correlation analysis. All analysis were executed in SPSS for Windows version 17.0 and the statistical significance was set at $p < 0.05$.

Results

The anaerobic performance, isokinetic knee strength, sprint, agility, vertical jump and aerobic power measurements of the basketball players in the study are displayed in Tables 1, 2 and 3, respectively.

Table 4 shows the correlations between anaerobic performance and isokinetic knee strength are presented. Isokinetic concentric knee extension strength was significantly correlated with peak power at all contraction velocities. However, for mean power, a significant correlation was only found between the 60° left

There was no significant correlation between knee strength and field tests.

and 180° right knee extension strength and mean power.

Table 1

Anaerobic performance values of Basketball players

	Mean	Std
Mean Power (W)	702.81	79.26
Peak Power (W)	955.31	117.86
Fatigue Index (%)	54.67	7.34

Table 2

Peak isokinetic concentric knee extension and flexion torques of Basketball players

	Mean	Std
Hamstring Left $180^\circ/\text{s}$ (Nm)	130.36	20.94
Hamstring Right $180^\circ/\text{s}$ (Nm)	137.36	25.10
Quadriceps Left $180^\circ/\text{s}$ (Nm)	177.45	30.92
Quadriceps Right $180^\circ/\text{s}$ (Nm)	173.27	25.34
Hamstring Left $60^\circ/\text{s}$ (Nm)	159.18	36.42
Hamstring Right $60^\circ/\text{s}$ (Nm)	163.81	30.05
Quadriceps Left $60^\circ/\text{s}$ (Nm)	207.72	47.75
Quadriceps Right $60^\circ/\text{s}$ (Nm)	203.27	37.03

Table 3

Field Performance Test Results of Basketball players

	Mean	Std
$\text{VO}_{2\text{max}}$ (ml/kg/min)	50.55	6.72
CMJ (cm)	34.91	3.83
SJ (cm)	32.91	3.82
10m (s)	1.86	.30
30m (s)	4.34	.15
T Drill test (s)	9.25	.46
PBF (%)	10.01	5.10

$\text{VO}_{2\text{max}}$ = Maximal oxygen uptake,
 CMJ = Counter movement jump,
 SJ = Squat jump,
 PBF = Percentage of body fat

There was a significant but weak correlation between PP, CMJ, SJ and 10 m sprint performance (Table 5). Also strong correlations

were found between the field tests, as it can be seen in Table 6.

Table 4

Correlations between anaerobic performance and isokinetic knee Strength

	Peak Power	Mean Power	Fatigue Index
Hamstring Left 180°/s (Nm)	NS	NS	NS
Hamstring Right 180°/s (Nm)	NS	NS	NS
Quadriceps Left 180°/s (Nm)	.46*	NS	NS
Quadriceps Right 180°/s (Nm)	.55**	.40*	NS
Hamstring Left 60°/s (Nm)	NS	NS	NS
Hamstring Right 60°/s (Nm)	NS	NS	NS
Quadriceps Left 60°/s (Nm)	.57**	.51*	NS
Quadriceps Right 60°/s (Nm)	.49*	NS	NS

* $p < 0.05$.

** $p < 0.01$.

Table 5

Correlations between anaerobic performance and field test

	Peak Power	Mean Power	Fatigue Index
VO _{2max} (ml/kg/min)	NS	NS	NS
CMJ (cm)	.49*	NS	NS
SJ (cm)	.55**	.43*	NS
10m (s)	-.52**	NS	NS
30m (s)	NS	NS	NS
T Drill test (s)	NS	NS	NS
PBF (%)	NS	NS	NS

* $p < 0.05$.

** $p < 0.01$.

VO_{2max} = Maximal oxygen uptake, CMJ = Counter movement jump,
SJ = Squat jump, PBF = Percentage of body fat

Table 6

Correlations between field tests

	CMJ	SJ	10m	30m	T Dtest	BPF (%)
CMJ (cm)		.807**	NS	-.619*	-.594*	-.487*
SJ (cm)	.807**		NS	-.760**	-.473*	-.494*
10m (s)	NS	NS		NS	NS	NS
30m (s)	-.619*	-.760**	NS		.505*	NS
T Drill test (s)	-.594*	-.473*	NS	.505*		NS
PBF (%)	-.487*	-.494*	NS	NS	NS	

* $p < 0.05$.** $p < 0.01$.

VO_{2max} = Maximal oxygen uptake, CMJ = Counter movement jump,
SJ = Squat jump, PBF = Percentage of body fat

Discussion

One of the important findings of the present study was that there were no relation between any measure of strength and single sprint performance. Similarly, Cronin and Hansen (2005) and Kin-İşler et al. (2008) determined no relation between extension strength and knee flexion and single-sprint performance. No relation were reported between strength measures and 10 or 40 m sprint performance in rugby players by Baker and Nance (1999). On the other hand, Dowson et al. (1998) found a statistically significant relationship between concentric and eccentric knee extensor torques and 0-15 m and 30-35 m sprint times. Similarly, Alexander (1989) found a strong correlation between sprint performance, 100 m personal best sprint time and concentric knee extension torque, at 4.14 rad s⁻¹, in elite sprinters. Newman and colleagues (2004) reported a significant correlation between concentric isokinetic knee extension and flexion strength measures and single-sprint performance in football players. One of plausible explanation for the lack of association between isokinetic knee

strength and single-sprint performance could be due to the particular characteristics of the subjects (Kin-İşler et al. 2008). Body height is very important for basketball players, particularly for centers and might be one of the reasons for not finding an association between strength and single sprint performance. Another important factor may be the different distances were used in sprint tests in previous studies.

We found a significant relationship between PP and 10 m sprint ability but no significant relationship between the other Wingate test results and sprint ability. Strong negative correlations (ranges from -0.67 to -0.91) have been demonstrated between performance in the WAnT and sprint speed by previous studies (Kaczowski et al., 1982; Tharp et al., 1985; Patton and Duggan, 1987). These studies suggested that the WAnT may be used as a predictor of sprinting ability. However, the predictive ability of the WAnT may be related to the distance of the sprint, sprint times for distances of 37 or 46 m have been reported to be highly correlated with

PP, while increased sprint distances appear to be better correlated with MP (Hoffman et al., 2000).

A Further finding of this study is that of a significant relationship between quadriceps strength and PP. This result is similar to findings of previous studies. For instance, Kin-İşler et al. (2008) stated that there was a significant relationship between anaerobic power, capacity and peak isokinetic concentric knee extension strength at all contraction velocities (60°, 150°, 240°). Similarly, Baker and Nance (1999b) investigated the correlation between strength and power. They also reported a strong positive correlation between maximum strength and maximum power in rugby players. In another study, Thorland et al. (1987) found a strong significant correlation between anaerobic power and capacity and isokinetic knee strength in female middle-distance runners and sprinters. Moreover, Mayhew et al. (2001) and Arslan (2005) found that peak and mean power were correlated with explosive leg strength.

No significant relationship was found between strength and field test performances. The weak relationship in rank order of performance could be caused by the differences type of exercise (Hoffman et al, 2000). Hoffman et al, 'stated that 'differences in power produced with the legs acting simultaneously or successively, or when upper-body musculature is active or passive, may have a profound influence on power expression (Tharp et al. 1985)'.

The result of this study is that performances in a variety of field tests were correlated with each other in a group of basketball players. It can be said that either the tests assess similar attributes or performance on one test is able to predict performance on another (Vescovi and McGuigan, 2008). Cronin and Hansen (2005) reported weak negative associations between countermovement and squat jump performance and 5, 10, and 30 m sprint times. Hennessy and Kilty (2001) found countermovement jump performance was related to the times for sprint tests and that the bounce drop jump index was related with 30 m and 100 m sprint times in a group of female athletes. The relationship between linear sprinting and agility performance have been examined by few studies (Little and Williams, 2005; Paoule et al., 2000; Vescovi and McGuigan, 2008). Moderate correlation was reported between T-test performance and 37 m sprint times in a group of college-aged women by

Paoule et al. (2000). In contrast, Little and Williams (2005) found a weak correlation between acceleration (10 m) and maximum speed in a zig-zag agility test in a group of professional male soccer players. The association between agility and speed increases with longer distances and when examining agility with flying sprint times (Vescovi and McGuigan, 2008). The reason of differences between studies could be the use of different agility tests (Vescovi and McGuigan, 2008)..

Conclusion

One possible reason for the lack of correlation between tests performance may be the different energy systems that each measure needs. In isokinetic knee strength, sprint tests and vertical jump test do not last more than 5 seconds. Therefore the phosphagen system (ATP-PC) contributed to the energy need for these tests. On the other hand the Wingate test glycolytic system is dominant to the energy production. Different energetic pathways used during the tests could be the reason for the lack of association between these measures (Kin-İşler et al;2008)

Acknowledgments

The author would like to extend his thanks to Yusuf KÖKLÜ and Gülin FINDIKOĞLU for their help with data collection and to the coaches and athletes for their willingness to participate in this study.

References

- Abdelkrim N, Fazaa S, Ati J. Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *British Journal of Sports Medicine* 2007; 41: 69-75
- Arslan C. Relationship between the 30-second Wingate test and characteristics of isometric and explosive leg strength in young subjects, *Journal of Strength and Conditioning Research* 2005; 19(3) 658–666.
- Alexander M. The relationship between muscle strength and sprint kinematics in elite sprinters. *Canadian Journal of Sports Science*, 1989; 14, 148± 157.
- Baker D, Nance S. The relation between strength and power in professional rugby league players, *Journal of Strength and Conditioning Research* (1999); 13(3) 224–229.
- Baker D, Nance S. The relation between running speed and measures of strength and power in professional rugby league players, *Journal of Strength and Conditioning Research* (1999b); 13(3) 230–235
- Bobbert M, van Zandwijk, J. Dynamics of force and muscle stimulation in human vertical jumping. *Medicine and Science in Sports and Exercise*, 1999; 31, 303 – 310.
- Bosco C, Belli A, Astrua M, Tihanyi J, Pozzo R, Kellis S, et al. A dynamometer for evaluation of dynamic muscle work. *European Journal of Applied Physiology and Occupational Physiology* 1995; 70: 379–386.
- Bosco C, Luhtanen P, Komi P. A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology* 1983; 50: 273–282
- 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. *Journal of Strength and Conditioning Research* 2008; 22(3): 923–929
- Castagna C, Chaouachi A, Rampinini E, Chamari K, Impellizzeri F. Aerobic and explosive power performance of elite Italian regional-level basketball players. *Journal of Strength and Conditioning Research* 2009; 23(7): 1982–1987
- Castagna C, Manzi V, D’Ottavio S, Annino G, Padua E, Bishop D. Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. *Journal of Strength and Conditioning Research* 2007; 21(4):1172–1176.
- Colli, R, Faina, M, Gallozi, C, Lupo, S, and Marini, C. Endurance training in sport games. *Mag Sport Educ* 1987; 8: 78–86.
- Cronin B, Hansen T. Strength and power predictors of sports speed, *Journal of Strength and Conditioning Research* 2005; 19(2), 349–357.
- Delextrat A, Cohen D. Strength, power, speed, and agility of women basketball players according to playing position. *Journal of Strength and Conditioning Research* 2009; 23(7): 1974–1981
- Dowson M, Nevill M, Lakomy H, Nevill A, Hazeldine R. Modelling the relationship between isokinetic muscle strength and sprint running performance. *Journal of Sports Sciences*, 1998; 16, 257± 265
- Drinkwater E, Pyne D, McKenna M. Design and interpretation of anthropometric and fitness testing of basketball players. *Sports Medicine* 2008;38 (7): 565-578
- Erculj F, Blas M, Bracic M. Physical demands on young elite European female basketball players with special reference to speed, agility, explosive strength, and take-off power. *J Strength Cond Res* 2010; 24(11): 2970–2978,

- Hedrick A. Strength and power training for basketball. *National Strength & Conditioning Association Journal* 1993;15: 31–35
- Hennessy L, Kilty J. Relationship of the stretch – shortening cycle to sprint performance in trained female athletes. *Journal of Strength and Conditioning Research*, 2001; 15, 326 – 331.
- Hoffman R., Epstein S, Einbinder M, Weinstein Y. A Comparison Between the Wingate Anaerobic Power Test to Both Vertical Jump and Line Drill Tests in Basketball Players *Journal of Strength and Conditioning Research*, 2000; 14(3), 261–264
- Inbar, O. Bar-Or, Skinner J, The Wingate Anaerobic Test, Human Kinetic, Champaign, IL, 1996, 41–71.
- Iossifidou A, Baltzopoulos V, Giakas G, Isokinetic knee extension and vertical jumping: Are they related? *Journal of Sports Sciences*, October 2005; 23(10): 1121 – 1127
- Kaczkowski W, Montgomery DL, Taylor AW, Klissouras V. The relationship between muscle fibre composition and maximal anaerobic power and capacity. *J. Sports Med.* 1982; 22: 407–413.
- Kin-İşler A, Ariburuna B, Ozkana A, Aytarb A, Tandogan R. The relationship between anaerobic performance, muscle strength and sprint ability in American football players *Isokinetics and Exercise Science* 2008, 16: 87–92
- Léger L, Gadoury C. Validity of the 20 m shuttle run test with 1 min stages to predict VO₂max in adults. *Can J Sport Sci.* 1989;14(1):21-6.
- Little T, Williams A, Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research.* 2005; 19, 76 – 78.
- Janeira MA, Maia J. Game intensity in basketball. An interactionist view linking time-motion analysis, lactate concentration and heart rate. *Coaching and Sport Science Journal* 1998; 3:26-30.
- Lohman TG, Roche AF, Marorell R. (Eds.). Anthropometric Standardization Reference Manual. Human Kinetics Books, Champaign: IL. 1988
- Mayhew J., Hancock K., Rollison L., Ball T. and Bowen J. Contributions of strength and body composition to the gender difference in anaerobic power, *Journal of Sports Medicine and Physical Fitness.* 2001; 41: 33–38.
- Meckell Y, Casorla T, Eliakim A. The influence of basketball dribbling on repeated sprints. *International Journal of Coaching Science* 2009; 3(2): 43-56.
- Metaxas T, Koutlianos N, Sendelides T, Mandroukas A. Preseason physiological profile of soccer and basketball players in different divisions. *Journal of Strength and Conditioning Research* 2009; 23(6): 1704–1713
- Newman M, Tarpenning K, Marino F. Relationships between isokinetic knee strength, single sprint performance and repeated-sprint ability in football players, *Journal of Strength and Conditioning Research* (2004); 18(4) 867–872
- Norkowski H. Anaerobic power of handball players representing various sport levels *Journal of Human Kinetics* 2002; 7
- Patterson S, Udermann B, Doberstein S, Reineke D. The effects of cold whirlpool on power, speed, agility, and range of motion. *Journal of Sports Science and Medicine* 2008;7: 387-394.
- Patton JF, Duggan A. An evaluation of tests of anaerobic power. *Aviat. Space Environ. Med.* 1987; 58: 237–242.
- Paoule K, Madole K, Garhammer J, Lacourse M, Rozenek R. Reliability and validity of the t-test as a measure of agility, leg power, and leg speed in college-aged men and women. *Journal of Strength and Conditioning Research.* 2000; 14, 443 – 450.
- Semenick D. The T-Test. *National Strength & Conditioning Association Journal* 1990;12(1): 36-37.

- Vescovi, Jason D. and Mcguigan, Michael R.(2008) 'Relationships between sprinting, agility, and jump ability in female athletes', *Journal of Sports Sciences*, 26: 1, 97 – 107
- Tharp G, Newhouse R, Uffelman L, Thorland W, Johnson G. Comparison of sprint and run times with performance on the Wingate anaerobic test. *Res. Q Exerc Sport*. 1985; 56:73–76.
- Thorland W, Johnson G, Cisar C, Housh T, Tharp G. Strength and anaerobic responses of elite young female sprint and distance runners, *Medicine and Science in Sport and Exercise* 1987; 19(1): 56–61.
- Tomlin D, Wenger HA. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Medicine* 2001; 31:1–11.
- Zajac F. Understanding muscle coordination of the human leg with dynamical simulations. *Journal of Biomechanics*. 2002; 35, 1011 – 1018.

Corresponding author:**Utku Alemdaroğlu**

Pamukkale University Schools of Sport Sciences and Technology, Denizli, Turkey

Phone: +90 258 296 29 05

Fax: +90 258 296 29 41

E-mail : utkualendaroglu@yahoo.com ; ualemdaroglu@pau.edu.tr