

Biomechanical Analysis of Explosive Strength of Legs of Athletes

Baljinder Singh, Ashok Kumar and M.D. Ranga

Abstract

Aim: The purpose of the study was to analyze the explosive strength variables of legs of athletes of different sports. **Method:** The study was conducted on 45 male players (fifteen handball players; age: 15.80 ± 0.68 years, fifteen football players; age: 16.13 ± 0.83 years & fifteen basketball players; age: 16.40 ± 0.83 years) of Punjab State coaches in Patiala (India). **Results:** The results of the study shows that the basketball players performed better in explosive strength parameters like the squat jump flight time, squat jump height, counter movement jump height, counter movement flight time, peak power (45-60sec) and mean power (0-60sec), then the football and handball players. The least performance was recorded by the handball players. The results also indicate that there was a highly significant correlation exists among the various explosive strength variables. **Conclusion:** The explosive strength variables measurement could be used by coaches to plan or adjust the training program of athletes.

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Introduction

The explosive strength is an action that is accomplished with maximum effort in a minimum amount of time. The basis for explosive strength is in speed-strength, a physical quality displayed in many sports skills such as jumping for maximum height (Rousanoglou et al., 2008), hitting for maximum power or distance (Silvia et al., 2009), running at top speed (Sannicandro et al., 2014), throwing for maximum distance or power (Samah, 2016) and kicking for distance or power (Nurper O., 2015). Successful sporting performance at elite levels of competition often depends heavily on the explosive leg power of the athletes (Cabri et al., 1988; Bangsbo, 1994, Stølen et al., 2005, Silvia et al., 2009). Coaches and trainers are greatly interested in developing training techniques designed to improve and measure the explosive strength and power performance of the legs of the athletes (Blattner, Stuart 1978, Haff et al., 2015). Vertical Jump (VJ) has widely been used by sports performance professionals as direct assessment method to measure the explosive strength in the lower limbs (Arteaga et al., 2000, Hara et al., 2006, Sargent 1921, Bosco et al., 1983) and to know the effectiveness of training programs (Hara et al., 2006, Peterson et al., 2006, Nicole et al. 2015). The VJ performance is a complex movement including several factors i.e. the maximal force developed by the muscles, the rate of force developed and the neuromuscular coordination of the upper and lower body segments ((Brian R.1998, Hopkins 2000, Sargent 1921). Some common explosive strength measures calculated from the VJ tests are the peak power (PP) or mean power (MP). Power is the product of muscular force and velocity or as an instantaneous value during a given movement. The latter, often referred to as peak power (PP), is typically associated with

explosive strength movements such as sprinting, jumping and may be an important variable associated with success in a given sport discipline. The measurement of PP or explosive strength by strength and conditioning-coaches is an important consideration in the training process. Changes in PP throughout the annual plan may be indicative of training status or adaptation to the workload and could be used to plan or adjust the training program based on the athlete's performance. The knowledge of explosive strength components of lower extremities of athletes of selected game disciplines can be of great interest for coaches and sport scientists to optimize talent selection in many sports disciplines. Therefore, the purpose of the study was to measure, compare and find the relationship between the explosive strength variables of legs of athletes of different sports.

Materials and Methods

Forty five (n=45) male players (fifteen handball players; age: 15.80 ± 0.68 years, fifteen football players; age: 16.13 ± 0.83 years & fifteen basketball players; age: 16.40 ± 0.83 years) briefed for the purpose of the study and the experimental protocol (Bosco et al., 1983, Mcguigan et al., 2006) comprising of players training under the guidance of Punjab State coaches in Patiala (India). All the risks involved were also explained to each player and voluntary consent was taken from them. Each volunteer was first subjected to physical examination that include measurements of corporal data like date of birth, age, training age, height, body mass and sports discipline. The vertical jump test or explosive strength measurement system consisted of a portable hand-held computer unit connected to a contact mat (Swift Performance, New South Wales, Australia) (Figure 1). It has been previously reported that the system is reliable compared with a force platform (Cronin et al., 2001). Three jumps: Squat jump (SJ), Counter movement jump (CMJ) and Continuous vertical jump Test for 60 seconds (CVJT) were performed by the subjects according to the experimental protocol (Bosco et al., 1983, Mcguigan et al., 2006) (Figure 2). The participants performed an adaptation process prior to the vertical jump test so that error could be minimized. The participants were told to perform a 15-minute routine warm-up before performing the tests through stretching, running, coordination exercises and consecutive jumps (two sets of five vertical jumps). Three squat jumps (SJ) and three counter movement jumps (CMJ) were performed in random order on a jump mat connected to an electronic timer without the aid of an arm swing; this was standardized by having participants hold their hands on their hips. Two minutes rest period between attempts was established. The SJ involved the subject flexing the knee to approximately 90 degree maintaining the position for 3 seconds, and then jumping on the command "go." The CMJ was performed under the same conditions but involved flexion of the knee followed immediately by extension of the legs. Test was executed following the original protocol for both jumps (Sayers SP, et al., 1999). On the next day, again the participants performed a 15-minute routine warm-up before the tests through stretching, running, coordination exercises and consecutive jumps (two sets of five vertical jumps). The participants were told to perform the continuous vertical jump Test (CVJT) during a work performed at maximal effort, with no pauses between jumps for 60 seconds. The subjects were told to keep chest in vertical position, with no excessive advance to avoid influence in the results; as well as to keep knees in extension during the flight, remaining with hands around waist. The participants were given stimulus to jump the highest as possible during the tests.



Figure 1. Portable Contact Timing Mat System (Thermal Printer, Thermal Paper, Stop Watch, Contact Mat, Data Cable, Data Recording Unit)



Figure 2. Squat Jump Test measurement with Contact Timing Mat System

Explosive Strength Variables

The biomechanical variables of three vertical jump tests i.e. squat jump height and squat jump flight time, counter movement jump height and counter movement jump flight time, eccentric utilization ratio, elasticity index, peak power (0-15sec), peak power (45-60sec), mean power (0-60sec) and fatigue index were calculated. The Eccentric Utilization Ratio (EUR) was calculated from vertical jump height (CMJ/SJ) or peak power (CMJ/SJ) by using Sayers et al (1999) peak power formula (Mcguigan et al., 2006). Muscle Elasticity index was calculated from the jump height reached in CMJ and SJ Jumps ($CMJ - SJ * 100 / SJ$) (Francisco et al., 2010, 2011, Pradas et al., 2013, Lara et al, 2006). The explosive strength and endurance variables were power peak (PP), mean power (MP) and fatigue index (FI). Concerning the CVJT (continuous vertical jump test), the Peak Power was estimated by the mechanical power produced in the first 15 seconds of a 60-second work. The

Mean Power was estimated by the amount of work during a 60-second continuous effort. For PP and MP, the results were expressed in watts/kg (W/kg), according to the equation described by Bosco et al. (1983) (Bosco et al., 1983, Kirkendall et al., 1986, Kums et al., 2005, Jefferson et al., 2006, 2007). The fatigue index (FI) was calculated as the difference between the power peak (work produced in the first 15 seconds) and the mean power generated in the last 15 seconds of a continuous vertical jump work of 60 seconds relative to first 15 seconds peak power. The result was expressed in percentage (%) (Jefferson et al., 2006, 2007, Kums et al., 2005). The following formulas were used to calculate various biomechanical variables related to jump tests:

1. Peak Power or Mean Power (W) = $(Ft \times Ts \times g^2) / 4n (Ts - Ft)$ (Bosco et al., 1983, Kirkendall et al., 1986, Kums et al., 2005, Jefferson et al., 2006, 2007)

The average power generated (W) is calculated from the test duration (Ts) from 0 to 60 second, the number of jumps (n), total flight time (Ft) and where g is the acceleration due to gravity. The unit of mechanical power per mass unit is Watts per kg (W/kg).

2. Eccentric Utilization Ratio (EUR) = vertical jump height (CMJ/SJ) or peak power (CMJ/SJ) (Mcguigan et al., 2006)

3. Muscle Elasticity Index (EI): $[(CMJ-SJ)/SJ] \times 100$ (Francisco et al., 2010, 2011, Pradas et al., 2013, Lara et al, 2006)

4. Fatigue Index (FI): $\text{Peak Power (0-15sec) - Mean Power (45-60sec) / Peak Power (0-15sec)} \times 100$ (Jefferson et al., 2006, 2007, Kums et al., 2005)

Mean and standard deviation for all the attributes age, height, body mass and biomechanical transients related to explosive strength of legs were calculated. To observe the difference and relationship in the means of the various anthropometric and biomechanical variables among different sports, One-way Analysis of Variance (ANOVA), Scheffe Post Hoc Test and Karl Pearson's coefficient of correlation tests were applied with the help of SPSS software.

Results

Table 1 shows that the basketball players performed better in explosive strength parameters like the squat jump height, squat jump flight time, counter movement jump height, counter movement flight time, peak power (45-60sec) and mean power (0-60sec), then the football and handball players. The football players recorded the highest values in the peak power (0-15sec), which showed that this game require more explosive power at the start of the movement. The least performance in the tests was recorded by the handball players.

Table 2 shows the significant difference in the selected biomechanical variables of explosive strength after applying the Scheffe Post Hoc test among the handball, football and basketball players.

Tables 3 shows that there is a highly significant correlation exists between the various anthropometric and biomechanical variables of combined group (N=45).

Table 1. Descriptive Statistics of Anthropometric and Biomechanical Variables of Players of Different Sports

Variables	Handball N=15 (Mean±SD)	Football N=15 (Mean±SD)	Basketball N=15 (Mean±SD)	Total Sample N=45 (Mean±SD)
Age (years)	15.80±0.68	16.13±0.83	16.40±0.83	16.11±0.80
Height(cm)	175.87±5.18	174.40±4.36	181.87±6.29	177.38±6.15
Weight (kg)	58.40±6.97	56.13±4.42	64.60±8.61	59.71±7.64

SJ-JH(cm)	25.47±3.87	26.93±5.61	32.53±4.36	28.31±5.51
SJ-FT(sec)	0.46±0.03	0.47±0.04	0.52±0.03	0.48±0.04
CMJ-JH(cm)	28.80±3.12	30.00±5.79	35.00±4.28	31.27±5.19
CMJ-FT(sec)	0.48±0.02	0.49±0.04	0.53±0.03	0.50±0.04
EUR	1.10±0.06	1.09±0.05	1.06±0.04	1.08±0.05
EI	13.97±9.36	11.88±6.75	7.81±5.02	11.22±7.55
PP15(w/kg)	15.81±3.13	20.03±4.37	19.90±3.74	18.58±4.19
PP45(w/kg)	11.77±2.70	13.52±2.63	14.25±3.52	13.18±3.10
MP60(w/kg)	13.61±2.41	15.96±2.23	16.81±3.17	15.46±2.92
FI	23.57±18.66	31.16±13.87	27.99±13.76	27.57±15.56

SJ- Squat Jump; SJFT- Squat Jump Flight Time; CMJHH- Counter Movement Jump Jump-Height; CMJFT-Counter; Movement Jump Flight Time; EUR-Eccentric Utilization Ratio; EI-Elasticity Index; PP- Peak Power; MP- Mean; Power; FI - Fatigue Index

Table 2. Scheffe Post Hoc Analysis of Biomechanical Variables of Players of Different Sports

Dependent Variable	(I) Groups	(J) Groups	Mean Difference (I-J)	Sig.
SJJH	Handball	Football	-1.4667	.693
		Basketball	-7.0667*	.001
	Football	Basketball	-5.6000*	.008
SJFT	Handball	Football	-1.2800E-02	.646
		Basketball	-5.9400E-02*	.000
	Football	Basketball	-4.6600E-02*	.006
CMJH	Handball	Football	-1.2000	.770
		Basketball	-6.2000*	.002
	Football	Basketball	-5.0000*	.016
CNMJFT	Handball	Football	-9.8667E-03	.766
		Basketball	-4.9267E-02*	.003
	Football	Basketball	-3.9400E-02*	.020
PP15	Handball	Football	-4.2145*	.015
		Basketball	-4.0879*	.019
	Football	Basketball	.1267	.996
MP60	Handball	Football	-2.3582	.060
		Basketball	-3.2068*	.007
	Football	Basketball	-.8486	.680

*The mean difference is significant at the .05 level.

SJ- Squat Jump; SJFT- Squat Jump Flight Time; CMJHH- Counter Movement Jump Jump-Height; CMJFT- Counter; Movement Jump Flight Time; PP- Peak Power; MP- Mean

Table 3. Correlation Matrix of various Anthropometric and Biomechanical Variables of Players of Different Sports (N=45)

Variables	SJJH	SJFT	CMJH	CNMJFT	EUR	EI	PP15	PP45	MP60	FI
Age (years)	.187	.193	.183	.174	-.165	-.095	-.018	.004	.027	.027
Height(cm)	.449**	.464**	.459**	.451**	-.221	-.172	.030	-.134	-.031	.147
Weight (kg)	.334*	.333*	.289	.297*	-.399**	-.208	.080	-.096	-.014	.152
SJJH	-	.992**	.952**	.949**	-.515**	-.542**	.553**	.539**	.589**	-.007
SJFT		-	.950**	.952**	-.502**	-.533**	.559**	.505**	.576**	.037

CMJH	-	.991**	-.238	-.264	.539**	.472**	.535**	.047
CNMJFT	-		-.257	-.283	.527**	.457**	.528**	.061
EUR					.965**	-.244	-.353*	-.350*
EI						-.289	-.380*	-.398**
PP15						.517**	.804**	.436**
PP45							.873**	-.516**
MP60								-.102

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level.

Discussion

The explanation of the results of this study can be sought from the different mechanical behaviour of the leg extensor muscle variables involved during the vertical jump tests performed by players of different sports disciplines. The power output recorded during the jumping test does not measure only the power of the chemo-mechanical conversion but also use the mechanical energy stored in the elastic elements of the body (Cavagna et al. 1971, 1972; Asmussen and Bonde-Petersen 1974a, 1974b; Thys et al. 1972, 1975; Komi and Bosco 1979; Bosco et al. 1981b, 1981c). The findings of the present study revealed that there is a significant difference exists in the various biomechanical variables of vertical jump tests conducted on football, basketball and handball players. Differences obtained in the variables of vertical jump tests could be due to genetic factors and acute or prolonged effects of training regimen (Ostojic et al., 2010). Francisco et al., (2010) observed that the average squat jump height 15.8±4.2cm, flight time 357±44.4msec, counter movement jump height 16.9±4.8cm, flight time 369.0±49.9msec and elasticity index 7.1±3.2 for male table tennis players (age 11.32±1.82 years). Whereas in the present study the highest values of SJ and CMJ were registered by the basketball players i.e. squat jump height was 32.53±4.36cm, flight time 520±30msec and mean counter movement jump height 35.00±4.28cm, flight time 530±30msec was observed. The Eccentric Utilization Ration (EUR) has been suggested as a useful indicator of power performance in athletes. A high EUR means that an athlete has a high capacity to store potential energy in the elastic components of the tendons and muscle and then release this energy when the tendon and muscle is shortened. McGuigan et al., (2006) observed the average value of Eccentric Utilization Ration (EUR) 1.03±0.20 for male soccer players, 1.00 ±0.17 for softball male players, 1.03±0.20 for football male players & 1.01±0.20 for rugby male players. In the present study the highest values of EUR and elasticity index were registered by the handball players i.e. EUR was 1.10±0.06 and EI was 13.97±9.36. Additional data by McGuigan et al (2006) demonstrated a significant difference between the EUR measured during the off-season and the EUR measured during the pre-season period for field hockey players. Coaches could quickly and easily conduct the necessary jump tests to determine an athlete's EUR and predict the athlete's readiness for competition. Francisco et al., (2010) observed that the elasticity index was higher in female players than in male players. The highest values of average Peak Power (0-15sec) in CVJT was registered by the football players i.e. 20.03±4.37W/kg, highest average Mean Power (0-60sec) was registered by the basketball players i.e. 16.81±3.17W/kg and highest fatigue index value was registered by the handball players i.e. 23.57±18.66. Bosco et al. (1983) found that average Mean Power (0-60sec) for school going Boys (age 17.3±0.8 years) was 22.2±1.8 W/kg. Jefferson et al., (2007) found the average Peak Power (0-15sec) 27.76±3.78w/kg, Mean Power (0-60sec) 19.56±2.59w/kg & fatigue index (%) (FI) 48.60±7.01 for male volleyball players (age 19.01±1.36 years). In another study by Jefferson et al., (2006) of the Intermittent vertical jump tests (IVJT) observed the average Peak Power was (0-15sec) 24.68±2.70w/kg, Mean Power (0-60sec) 18.79±2.23w/kg & fatigue index (%) 57.50±9.51 for the male handball and basketball players (age of handball players 25.74±4.71years

& basketball players 18.60±0.77years). Jefferson et al., (2006, 2007) found the similar results of mean power, peak power in two studies conducted on volleyball, handball and basketball players. These results are in accordance with a study conducted by Viitasalo et al., (1987) which showed that the mechanical power, as well as power related to body weight, increased with calendar and skeletal ages. Similar studies were conducted by the researchers to find out the relationship among the different mechanical and explosive strength variables of legs (Bosco et al., 1983, Hoffman et al., 2000, 2002, Purvi et al., 2012, Veeramani S., 2015, Ana et al., 2015, Gorostiaga, et al., 2002).

Conclusion

In conclusion, based on the above considerations, the reported jumping test might offer the possibility of evaluating the explosive strength or mechanical power of the leg extensor muscles during explosive stretch-shortening type exercises, which involve both metabolic and mechanical behavior of skeletal muscles. The knowledge of explosive strength components of lower extremities of athletes of different game disciplines will help coaches and sport scientists to optimize talent selection for different sport disciplines. Very few studies have done on the measurement and comparison of explosive strength of legs of players of same age of different sports disciplines of Indian athletic population so far. Therefore the results of this study will serve as guidelines for coaches, trainers, players and other sports scientists working with athletes for monitoring the effect of sports training, adaptation to workload and recovery.

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