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The Effect of Plyometric Exercises on the Forehand and Backhand Stroke Velocities and Hitting Percentage of Male University Student Tennis Players

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ABSTRACT

In this study, the effect of plyometric exercises on the arm and leg strength, forehand and backhand stroke velocities and percentage of hitting the targets is examined. 40 male tennis players whose ages range between 20 and 25 have participated in the study voluntarily. Participants were balanced correlatively according to their ages and classified into experimental (n=20) and control (n=20) groups by unbiased assignment method. Members of experimental group have joined to plyometric exercise program in addition to classical tennis exercises for eight weeks (2 sets on a day, 3 days in a week), and control group has only performed classical tennis exercises in this time period. Measurements of dependent variables were realized at the end of 4th and 8th weeks. Mixed between-within subjects ANOVA was used to evaluate effects of the exercising program on the dependent variables. It is seen that significant change in the average peak torque scores resulted from experimental group especially at 60^{0}/sec and 120^{0}/sec resistance velocities for lower body (right extension / right flexion) and at 60^{0}/sec resistance velocity for upper body (exterior rotation) ($p<.05$). Maximum velocity improvement in backhand and forehand parallel and cross strokes was significantly more in the experimental group, and improvement in hitting scores was observed especially in backhand cross strokes of experimental group ($p<.05$). As a conclusion, it is established that plyometric exercises applied in addition to classical tennis exercising have positive effects on the shoulder and leg power of tennis players, and improved their hitting rates besides their shooting and stroke velocities.

INTRODUCTION

Motor skill is using the power in the required way to master a particular action. This usage reflects execution of the action by means of experience and learning (Mengütay, 1999). Training is required to improve the sportive skills (Kemren, 1992). Undoubtedly, training is also required to improve the power and stroke techniques for the velocity of the ball and hitting rate of the tennis strokes (Ebben, 2002).

Motion of the tennis player is generally organized from proximate to distal (leg – body – arm – racket) for tennis stroke at high velocity. Each tennis stroke needs the power that shall come from the legs, body and arms. Muscle stress repeated in the upper and lower extremities that are required during the performance of specific tennis movements, causes development of special muscle adaptations in tennis players at elite level. Muscle imbalances may be observed when inadequate muscle strength combines with faulty biomechanical motion, thus this may cause severe injuring of the tennis player. A tennis player performed hundreds of strokes in a competition. Continuity of high muscle strength enables the player to continue his/her stroke quality even at the end of the competition.

High racket velocity is very important for a great many tennis strokes and role of the body is highly definitive in revealing the velocity of the ball. It is considered that plyometric exercises, by which a special muscle structure used in the legs is activated, is beneficial in terms of strength increase and improvement in forehand and backhand strokes. Leg muscles should be used in the same way they are used in the tennis courts.

We hope that the data we obtained for the effect of plyometric exercises on the tennis players' arm and leg strengths, forehand and backhand stroke velocities and rate of hitting the target shall light the way for the studies to be realized in the future.

MATERIALS AND METHODS

Study group consists of 40 male tennis players who are in the Turkish Tennis league, between ages 20 and 25 and in the tournament level. Population is also the sample group of the study. Tests were performed in the laboratory of Konya Selçuk University physical therapy center. All subjects were asked not to make exercises

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one day before the measurements and to come by having a light breakfast in the morning of the test day. Information was given to all subjects about test procedures and probable risks. Then, age, height, weight measurements of the subjects were recorded on the same day. Following this step, leg strength tests were made.

Research Model:

In this research intragroup and intergroup patterns that include iterative measurements (Mixed-model Ax(BxS) are utilized as one of the experimental research models. Training (experimental and control) is used as intergroup factor and time period including iterative measurements is used as the intragroup factor (pre-test, interim-test, post-test).

Anthropometric Measurements:

Survey form was issued for the participant athletes and their age, weight and height values were determined. Weight measurements were realized by using scale of which its precision degree is 100 gr. Value obtained is recorded in kg. Height measurement was made with Martin type anthropometer. Device with a precision degree of 1 cm was used for the height measurement (Zorba and ziyagil, 1995).

Tests for Measuring Ball Velocity in the Forehand and Backhand Strokes:

Forehand and backhand strokes were performed in a closed tennis court for the measurement of ball velocity. Subjects warmed up until they reach maximal forehand and backhand stroke velocity (20 minutes). 3 minutes after warm up of the subjects test stage started and 5 parallel and 5 cross forehand and backhand strokes were realized to a 3x3 m target in a specified baseline area. Strokes were applied to balls coming from Lobster ball throwing machine at 113-24 km/hour, and the fastest stroke and hitting rate were recorded by video shoot and analyzed.

Pistol radar (Sports Radar, Astro Products, CA) is used for the measurement of ball velocity. Pistol radar used for ball velocity measurement was fixed to the opposite end-line forehand and backhand area. Balls of forehand and backhand strokes falling into the net and outside of the court area are not recorded as data. Back signal of forehand and backhand strokes was informed to the players in order to provide the maximal effort. All strokes are realized in parallel and cross ways and evaluated by two tennis coaches.

Isokinetic Muscle Strength Measurement:

Isokinetic examination was performed according to standards with Biodex System 3Pro Multijoint System Isokinetic (Biodex Medical Inc, Shirley, NY, USA) dynamometer. Measurement of interior and exterior rotator shoulder muscle strengths were tested in a concentric-concentric isokinetic way when shoulder was in 90° abduction. Muscles that should work during the joint movement are shoulder internal rotation, pectoralis major, subscapular, latissimus dorsi and teres major primary muscles. These are Infraspinatus and teres minor primary muscles for external shoulder rotation. Warming up exercise was made by the athletes before testing with arm ergometer for upper extremity and with bicycle ergometer for lower extremity. Warming up loading was adjusted according to the pulse rate of the athlete and pulse rate was kept between 100 and 120 pulse/minute, in the fifth minute warming up is terminated at the pulse rate. Stretching exercises were performed for 5 minutes before and after testing with the aim to prevent probable injuries. According to the test protocol, rotation movements were made for the shoulder at submaximal strength for three times at 60-180 and 300°/sec with the aim to prepare the athletes for testing before starting recording and in terms of their adaptation, then principal protocol was applied. Procedure to be applied was explained to the athletes in detail and oral feedback was given during the exercises. Test measurements were taken by making 5 repetitions at 60°/sec as the low velocity, and 5 repetitions at 180°/sec as the medium velocity, and at last 5 repetitions at 300°/sec as the high velocity. Resting periods of 60 seconds were given between the tests. Muscle strength measurements of knee muscles were made bilaterally. Extension-flexion movements were made for the knee at submaximal strength for 3 times at 60-120 and 180°/sec with the aim to prepare the athletes for testing before starting recording and in terms of their adaptation, then principal protocol was applied. The first movement was arranged as knee extension during the test and EHA of 90° was permitted. Test measurements were taken by making 5 repetitions at 60°/sec as the low velocity, and 5 repetitions at 120°/sec, and at last 5 repetitions at 180°/sec as the high velocity. Resting periods of 60 seconds were given between the exercises.

Parameters used as the isokinetic test data; *Peak*; is the highest torque value muscle or muscle group forms in the range of motion determined. Its unit is Newton-meter (Nm).

Peak/Body weight:

It is the ratio of the highest strength value to the body weight. It makes the data specific to the individual (according to kg.). Evaluation of peak according to the body weight brings a new dimension to the interpretation of the results. Personal differences between the individuals can be evaluated by diving the peak, work and power variables to the body weight. Total body weight ratio is used more frequently in comparison to the lean body weight. Other test variables can be also normalized by diving them to the body weight.

Analysis of Data:

Independent two-tailed t test was used to analyze whether or not there is a difference between the experimental and control groups at the beginning. Two-way (training/time) mixed variance analysis was used to evaluate effects of training program on the dependent variables in every test point (two-way (2x3) Mixed ANOVA). Analyses were realized by sphericity control. When a significant interaction is found in two-way (2x3) Mixed ANOVA analyses continued, and one-way repeated measures ANOVA variance analysis was used for each group. When significant difference is found multiple comparisons were realized by Bonferroni verification. Descriptive statistics was used for each parameter (average, standard variation). At the beginning, significance level is defined as $p \leq 0.05$ for whole procedure and a statistical package program was used for statistical analyses.

Results:

Before analysis of findings concerning basic dependent variables, primary physical characteristics of participants in both of the training groups and their analyses are given. These data consist of age, height and body weight.

Findings obtained from shoulders at 60^0/sec, 180^0/sec and 300^0/sec, and from knees at 60^0/sec, 120^0/sec and 180^0/sec are established.

Findings obtained from shoulder joint at 60^0/sec, 180^0/sec and 300^0/sec are values of interior and exterior rotation peak (60IR / 60ER, 180IR / 180ER, 300IR / 300ER) and internal and exterior rotation peak-body weight ratio (bw60IR / bw60ER, bw180IR / bw180ER, bw300IR / bw300ER).

Findings obtained from knee joint at 60^0/sec, 120^0/sec and 180^0/sec are right and left extension peak (60RE / 60LE, 120RE / 120LE, 180RE / 180LE), right and left flexion peak (60RF / 60LF, 120RF / 120LF, 180RF / 180LE), right and left extension peak-body weight ratio (bw60RE / bw60LE, bw120RE / bw120LE, bw180RE / bw180LE) and right and left flexion peak-body weight ratio (bw60RF / bw60LF, bw120RF / bw120LF, bw180RF / bw180LE).

In other findings results of ball velocity at forehand and backhand strokes and hitting rates are given.

Table 1: Basic characteristics of experimental and control groups.

	GROUP	N	Average	Sv	p†
Age (year)	Experimental	20	22.1	1.33	.822
	Control	20	22	1.45	
Height (cm)	Experimental	20	177	8.21	.499
	Control	20	178.8	8.47	
Body weight (kg)	Experimental	20	73.8	6.81	.789
	Control	20	73.1	9.39	

†P: p value of T test, Sv: standard variation

No significant difference is found between the initial values of both groups ($p>.05$). This finding shows that groups have similar characteristics at the beginning.

Table 2.1: Change in the peaks and peak body weight ratios of groups in the shoulder joint during the process (Nm).

Groups	Experimental n=20 Aver. (Sv)			Control n=20 Aver. (Sv)		
Weeks	1^{st} W	4^{th} W	8^{th} W	1^{st} W	4^{th} W	8^{th} W
60IR	56.1(13.7)	60.9 (16)	59.8 (15.8)	57.5 (16.5)	58.4 (14.3)	56.3(13.6)
60ER	49.6a(9.48)	50.7a(8.7)	52.4b(8.7)	48.9a(10.8)	49.3a(10.6)	49.5a(10.3)
bw60IR	144.3(56.1)	155.1(49)	155.5(55.4)	153.4(57.7)	156.7(57.6)	148.5(53.1)
bw60ER	117.1(35.9)	122.8(28.7)	127.2(30.2)	120.2(33.6)	122.5(31.4)	126.6(28.4)
180IR	43.8(16.8)	44(12.5)	45.6(18.6)	44.4(17.7)	44.8(18)	49.6(16.2)
180ER	38.2(9.7)	38.5(7.7)	42.1(10.5)	38.2(10.4)	36.3(10.7)	42.4(11.8)
bw180IR	112.2(50.5)	111.9(38.5)	120.8(57.3)	114.2(56.5)	123.9(54.4)	125.8(52.7)
bw180ER	102.6(39.5)	100.3(28.1)	111.8(29.7)	100.3(35.5)	103.2(41.1)	108.5(31.2)
300IR	37.1(21.5)	39.9(17)	40.6(23.6)	41.8(19.4)	42.2(19.8)	42(17.6)
300ER	31.7(10.7)	32(10)	34.4(11.2)	32.5(10.9)	31.3(11.2)	34.9(9.8)
bw300IR	95.3(54.2)	106.2(46.2)	103.2(60.3)	102.2(59.1)	111.3(54.7)	106.1(57.7)
bw300ER	89.8(41.1)	88.4(34.2)	89.5(38.3)	88.4(40.5)	94.2(44.9)	95.3(33.8)

Two-way (2x3) Mixed ANOVA results concerning 60ER are given below.

Differences in both groups are not similar, $F(1.74,66.08) = 10.041$, $p = .000$. F difference started as of 4^{th} week and originated from the experimental group.

When group factor is ignored, it is seen that there is a significant increase in 60ER in the time period, $F(1.74,66.08) = 24.683$, $p = .000$.

When group factor is ignored, it is seen that there is a significant increase in pt60ER in the time period, F (1.74,66.08) = 24.683, p = .000.

Two-way (2x3) Mixed ANOVA results concerning 180ERare given below.

Differences in both groups are similar, F (2,76) = .323, p = .725.

When groups factor is ignored, there is a significant increase in 180ER scores in the time period, F (2,76) = 7.601, p = .001.

When test factor is ignored, there is no significant difference in the 180 ER scores of experimental ($\bar{X}$ =39.46) and control ($\bar{X}$ =38.99) groups, F (1, 38) = .026, p = .872.

Two-way (2x3) Mixed ANOVA results concerning 60IR / bw60IR – ER / 180IR – ER / bw180IR – ER / 300IR – ER / bw300IR – ER/ (Nm) are given below.

1- Interaction effect between group and time is not significant; this effect shows that the changes in both groups are similar.

2- Time basic effect is not significant; this effect shows that there is no significant change in the scores in time period when group factor is ignored.

3- Group basic effect is not significant; this effect shows that there is no significant difference in the scores of experimental and control groups when test factor is ignored.

Table 2.2: Differences of extension peak and peak body weight rates of groups in the knee joint during the process (Nm).

Groups	Experimental n=20 Aver. (Sv)			Control n=20 Aver. (Sv)		
Weeks	1st W	4th W	8th W	1st W	4th W	8th W
60RE	170a(47.6)	179.1b(48)	199.6c(51.1)	180.5a(50.7)	182.5a(51.5)	188.1b(51.7)
60LE	168.2(52.6)	168.9(49.8)	192.5(64)	164.7(51.4)	174.2(53.9)	172.5(52.4)
bw60RE	447a(108.5)	469.4a(97.1)	509.2b(108.6)	497.4(119.9)	481(134)	491.8(106.1)
bw60LE	440.9(114.1)	445.3(101)	486.3(131.6)	453.8(113.8)	453.6(109.6)	450.6(102.9)
120RE	128.2(49.6)	138.2(45.5)	149.5(44.9)	134.5(45.8)	128.2(49.6)	147.6(45.1)
120LE	141.3(89.4)	130(41.9)	147.4(47.6)	128.4(46.1)	128.9(48.5)	140.8(45.1)
bw120RE	285.3(119.9)	318(116.5)	346.6(131.8)	336.1(123.2)	304.5(123.4)	335.8(105.1)
bw120LE	297.5(119.7)	305.3(115.9)	347.4(137.6)	329(126.5)	311.2(119.7)	321.4(112.7)
180RE	125.6(87.9)	109.3(46.5)	145.3(78.1)	106.9(44.7)	102.4(47.6)	121.4(42.1)
180LE	105.8(45.2)	107.4(38.4)	126.1(44.1)	106.5(42.1)	103.9(44.8)	116.6(37.5)
bw180RE	236.8(118.1)	246.9(113.3)	296.4(101.5)	247.7(125)	235(106.4)	230.1(128.7)
bw180LE	233(111.1)	254.7(104.5)	279.7(130.8)	276(121.2)	257.1(119.8)	279.1(99.8)

Two-way (2x3) Mixed ANOVA results concerning 60RE are given below.

Differences in both groups are not similar, F (1.468, 55.767)=19.947, p=.000. F difference started as of 4th week and originated from the experimental group.

When group factor is ignored, there is a significant increase in 60RE in the time period, F (1.468, 55.767)=19.947, p=.000.

When test factor is ignored, there is a significant difference in 60RE scores of experimental ($\bar{X}$ =182.93) and control ($\bar{X}$ =183.763) groups, F (1, 38) = .003, p = .958.

Two-way (2x3) Mixed ANOVA results concerning 60LE are given below.

Interaction between group and time is not significant, F (2,76) =2.220, p = .116. This effect shows that differences in both groups are similar.

When group factor is ignored, there is a significant increase in 60LE in the time period, F (2,76) = 3.631, p = .031.

When test factor is ignored, there is no significant differences in 60LE scores of experimental ($\bar{X}$ =176.57) and control ($\bar{X}$ =170.51) groups, F (1, 38) = .150, p = .701.

Two-way (2x3) Mixed ANOVA results concerning bw60RE are given below.

Differences in both groups are not similar, F (2,76) =4.184, p = .019. F difference started as of 4th week and originated from experimental group.

When group factor is ignored, there is a significant increase in bw60RE in the time period, F (2,76) = 3.488, p = .036.

When test factor is ignored, there is no significant difference in the bw60RE scores of experimental ($\bar{X}$ =475.22) and control ($\bar{X}$ =490.11) groups, F (1, 38) = .203, p = .655.

Table 2.3: Differences of flexion peak and peak body weight rates of groups in the knee joint during the process (Nm).

Groups	Experimental n=20 Aver. (Sv)			Control n=20 Aver. (Sv)		
Weeks	1st W	4th W	8th W	1st W	4th W	8th W
60RF	116.8(52.8)	118.2(43.3)	142.3(40.8)	111.4(38.9)	119(45.4)	121.4(46.5)
60LF	130.1(73.9)	123.8(64.9)	152.4(56.2)	117.7(55.8)	129.5(46.4)	118.7(54)
bw60RF	237.7(149.2)	244.8(122.9)	294.2(168.5)	245.9(105.7)	254(119.4)	239.6(85.6)
bw60LF	251.9(119.1)	246.4(118.6)	291.3(141.4)	252.3(113.7)	289(127.5)	252.4(104.9)
120RF	107.6(108.3)	92.2(28.1)	107.2(29.9)	88.1(28.3)	90.5(35.3)	93.1(33.6)
120LF	85.8(30.2)	90.4(27.5)	100.8(26.7)	83.1(30.7)	88.5(34.5)	89(29.8)
bw120RF	188.4a(78.4)	212.8ab(66.2)	240.9b(81.9)	222.3a(74.8)	221.7a(100.3)	225.1a(78.7)

bw120LF	199.2(74.8)	203.7(62.6)	227.3(73.5)	204.7(78.5)	214.8(89.7)	210.7(69.5)
180RF	83.1(46.2)	76.6(28.7)	98.4(40)	70.7(29.5)	73.4(34.8)	79.2(31)
180LF	75.1(27)	74.4(26.5)	82.4(25)	69.7(24.9)	73.7(33.2)	76.4(25.6)
bw180RF	171.5(61.3)	171.1(62.7)	204.8(57.8)	174.4(70)	173.1(81.6)	181.6(67.8)
bw180LF	168.5(58)	165.9(57.3)	181.1(53.9)	174.6(65.1)	174.5(79.7)	169.6(49.7)

Two-way (2x3) Mixed ANOVA results concerning 60RF are given below.

Differences in both groups are similar, F (2,76) =1.791, p =.174.

When group factor is ignored, there is a significant increase in 60RF scores in the time period, F (2,76) =4.861, p =.010.

When test factor is ignored, there is no significant difference in the 60RF scores of experimental ($\bar{X}$ =125.82) and control ($\bar{X}$=117.33) groups, F (1, 38) =.465, p = .499.

Two-way (2x3) Mixed ANOVA results concerning bw120RF are given below.

Differences in two groups are not similar, F (2,76) = 3.909, p = .024. F differences started from the beginning and originated from the experimental group.

When group factor is ignored, there is a significant increase in bw120RF in the time period, F (2,76) = 4.881, p = .010.

When test factor is ignored, there is no significant difference in bw120RF scores of experimental ($\bar{X}$ =214.07) and control ($\bar{X}$=223.07) groups, F (1, 38) = .148, p = .702.

In the scores of average right and left extension peak (120RE / 120LE, 180RE / 180LE), right and left flexion peak (60LF, 120RF / 120LF, 180RF / 180LE), right and left extension peak-body weight ratio (bw60LE, bw120RE / bw120LE, bw180RE / bw180LE) and right and left flexion peak-body weight ratio (bw60RF / bw60LF, bw120LF, bw180RF / bw180LE);

1- Interaction effect between group and time is not significant; this effect shows that differences in both groups are similar.

2- Time basic effect is not significant; this effect shows that there is no significant change in the scores in time period when group factor is ignored.

3- Group basic effect is not significant; this effect shows that there is no significant difference in the scores of experimental and control groups when test factor is ignored.

Table 3: Change in Backhand Parallel and Cross Maximum Velocities (km/h) and hitting numbers of groups during the process.

Groups	Experimental n=20 Aver. (Sv)			Control n=20 Aver. (Sv)		
Weeks	1^{st} W	4^{th} W	8^{th} W	1^{st} W	4^{th} W	8^{th} W
Backhand Parallel Stroke Max. Velocity(km/s)	101.6a(13.5)	106.2b(11)	115.5c(8.7)	100.9a(7.8)	103.7b(7.8)	108c(7)
Backhand Parallel Hitting number	2.55(.51)	2.65(.49)	3.50(.51)	2.60(.60)	2.85(.49)	3.35(.59)
Backhand Cross Stroke Mac. Velocity (km/h)	105.1a(13.5)	111.2b(11)	125c(8.4)	101.6a(7.6)	106.8b(7.6)	114.2c(7.7)
Backhand Cross Hitting number	2.60a(.60)	2.85ab(.49)	3.85c(.49)	2.55a(.51)	2.8ab(.52)	3.4c(.50)

Two-way (2x3) Mixed ANOVA results concerning backhand parallel average maximum velocities are given below.

Differences in two groups are not similar, F (1.39,52.79) =18.664, p = .000. F difference started as of 4^{th} week and originated from the experimental group.

When group factor is ignored, there is a significant increase in Maximum Velocity in the time period, F (1.39, 52.79) =167.620, p = .000.

When test factor is ignored, there is no significant difference in Maximum Velocity of experimental ($\bar{X}$ =107.783) and control ($\bar{X}$=104.233) groups, F (1,38) =1.435, p = .238.

Two-way (2x3) Mixed ANOVA results concerning backhand parallel average hitting numbers are given below.

Differences in both groups are similar, F (1.54,58.41) =1.682, p = .200.

When group factor is ignored, there is a significant increase in the hitting number in the time period, F (1.54,58.41) =43.955, p = .000.

When test factor is ignored, there is no significant difference in hitting number scores of experimental ($\bar{X}$ =2.90) and control ($\bar{X}$=2.93) groups, F (1,38) =.069, p = .795.

Two-way (2x3) Mixed ANOVA results concerning backhand cross average maximum velocities are given below.

Differences in two groups are not similar, F (1.21,46.06) =16.919, p = .000. F difference started as of 4^{th} week and originated from the experimental group.

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When group factor is ignored, there is a significant increase In Maximum Velocity in time period, F (1.21,46.06) =289.163, p = .000.

When test factor is ignored, there is a significant difference in Maximum Velocity scores of experimental ($\bar{X}$=113.78) and control ($\bar{X}$=107.55) groups, F (1,38) =4.516, p = .040.

Two-way (2x3) Mixed ANOVA results concerning backhand cross average hitting numbers are given below.

Differences in two groups are not similar, F (2,76) =3.150, p = .048. F difference started as of 4th week and originated from the experimental groups.

When group factor is ignored, there is a significant increase in the hitting numbers in the time period, F (2,76) =71.078, p = .000.

When test factor is ignored, there is no significant difference in hitting number scores of experimental ($\bar{X}$ =3.10) and control ($\bar{X}$=2.91) groups, F (1,38) =2.131, p = .153.

Table 3.1: Change in Forehand Parallel and Cross Maximum Velocities (km/h) and hitting numbers of groups during the process.

Groups	Experimental n=20 Aver. (Sv)			Control n=20 Aver. (Sv)		
Weeks	1st W	4th W	8th W	1st W	4th W	8th W
Forehand Parallel Stroke Max.Velocity (km/h)	107.3a(16)	114.3b(14.3)	122.3c(12)	101.7a(8.3)	107.5b(6.9)	111.8c(7.1)
Forehand Parallel Hitting number	3.00(.65)	3.10(.55)	3.90(.45)	2.75(.55)	3.00(.56)	3.55(.51)
Forehand Cross Stroke Max. Velocity (km/h)	106.1a(13.5)	111.8b(9.7)	127.1c(6.7)	100.4a(5.6)	104.4b(6.3)	110.1c(4.4)
Forehand Cross Hitting number	2.75 (.64)	2.90 (.45)	3.70 (.47)	2.70 (.47)	2.90 (.55)	3.30 (.47)

Two-way (2x3) Mixed ANOVA results concerning forehand parallel average maximum velocities are given below.

Differences in two groups are not similar, F (1.40, 53.04) = 5.642, p = .013. F difference started as of 4th week and originated from the experimental group.

When group factor is ignored, there is a significant increase in the Maximum Velocity in the time period, F (1.40, 53.04) = 135.365, p = .000.

When test factor is ignored, there is a significant difference in Maximum Velocity scores of experimental ($\bar{X}$=114.68) and control ($\bar{X}$=107.00) groups, F (1,38) = 4.838, p = .034.

Two-way (2x3) Mixed ANOVA results concerning forehand parallel average hitting numbers are given below.

Differences in both groups are similar, F (2,76) = .887, p = .416.

When group factor is ignored, there is a significant increase in the hitting numbers in the time period, F (2,76) =45.143, p = .000.

When test factor is ignored, there is no significant difference in the hitting number scores of experimental ($\bar{X}$=3.33) and control ($\bar{X}$=3.10) groups, F (1,38) = 2.994, p = .092.

Two-way (2x3) Mixed ANOVA results concerning forehand cross average maximum velocities are given below.

Differences in two groups are not similar, F (1.51, 57.19) = 14.315, p = .000. F difference started as of 4th week and originated from the experimental group.

When group factor is ignored, there is a significant increase in the Maximum Velocity in the time period, F (1.51, 57.19) = 94.960, p = .000.

When test factor is ignored, there is a significant difference in the Maximum Velocity scores of experimental ($\bar{X}$=115.05) and control ($\bar{X}$=105.02) groups, F (1,38) = 19.395, p = .000.

Two-way (2x3) Mixed ANOVA results concerning forehand cross average hitting numbers are given below.

Differences in two groups are not similar, , F (2,76) = 2.188, p = .119.

When group factor is ignored, there is an increase in the hitting number in the time period, F (2,76) =30.438, p = .000.

When test factor is ignored, there is no significant difference in the hitting number scores of experimental ($\bar{X}$=3.12) and control ($\bar{X}$=3.97) groups, F (1,38) = 1.907, p = .175.

Discussion and Conclusion:

Today, plyometric has become a training technique utilized in all kinds of sports and by all athletes in order to increase the general strength and explosive strength. Plyometric includes stretching of a muscle rapidly (eccentric movement) and then concentric contraction of the same muscle or soft tissue. Elastic energy stored inside the muscle is utilized to produce power more than the one provided by concentric motion by itself (Miller *et al*., 2006).

Peak torque differences obtained from knee joint at 60°/sec. were the striking findings of the study realized for eight weeks. Right extension peak torque values at 60°/sec. increased in both groups in the time process, and this increase was significantly more in the experimental group as of the 4^{th} week. In a similar way, peak torque-body weight proportion values increased in both groups in the time process, and this increase was significantly more in the experimental group as of 4^{th} week. On the other hand, left extension peak torque at 60^0/sec., and right flexion peak-torque-body weight proportion values at 60^0/sec. made progress in a similar way in both of the groups.

Another striking, significant change was the right flexion differences obtained from knee joint at 120^0/sec. Right flexion peak torque-body weight proportion values at 120^0/sec. showed increase in both of the groups in the time process, and this increase was significantly more in the experimental group starting from the beginning. On the other hand, right extension peak torque and left flexion peak torque values at 120^0/sec. showed similar development in both of the groups. Additionally, left extension peak torque values at 180^0/sec. showed similar development in both of the groups.

By use of isokinetic findings obtained from shoulder joint, it is seen that exterior rotation peak torque values at 60°/sec. increased in both of the groups in the time process, and the increase in experimental groups was significantly more than the control group starting from the 4^{th} week. Another development related with shoulder peak torque is that exterior rotation peak torque values at 180^0/sec. developed in a similar way in both of the groups. No significant development is observed in other peak torque parameters (internal rotation at different velocities) obtained from shoulder joint.

These findings show similarity with the positive effects of plyometric training on the strength parameters. It is established in researches that plyometric training is a very advantageous method. Especially plyometric training is superior when it is combined with weight exercises (Ellenbecker *et al*., 2006). It is observed that plyometric training applied in different branches has improved jumping performance (Baktaal, 2008), agility (Miller *et al*., 2006), upper and lower extremity powers (Ateş and ateşoğlu, 2007) and anaerobic power (Sağıroğlu, 2008).

As it can be seen from the results, striking, significant differences in the peak torque values obtained from knee joint are mostly peak torques at 60^0/sec. and 120^0/sec., and , striking, significant differences in the peak torque values obtained from shoulder joint are mostly peak torques at 60^0/sec. This finding makes us think that resistances at 60^0/sec. and 120^0/sec. shall be more adequate resistances for the evaluation of peak torque parameters of tennis players; because resistances at high angular velocities such as 180^0/sec. and 300^0/sec. have a low resistance feature, and it should not be ignored that they shall serve to determine the muscular strength. From this viewpoint, it is meaningful not to see significant developments at these resistance velocities. Researchers have stated that plyometric training is a velocity-power exercises and it is composed of combination of these two factors, principle of plyometric method lies behind the difference velocity of eccentric and concentric contractions. (Stojanovic and Kostic, 2002). It can be said that resistances at 60^0/sec. and 120^0/sec. being more coercive in comparison to resistances at 180^0/sec. and 300^0/sec. reflect plyometric effect more that includes velocity and power. The reason of not observing developments expected at 180^0/sec. and 300^0/sec. in the upper body strength may be attributed to the content of the training implemented in this research.

On the other hand, developments observed in the external rotation of shoulder not being seen in the internal rotation may be associated with shoulder imbalance. In another study, it is observed that tennis players exhibited a higher dominant shoulder internal strength in the bilateral concentric and eccentric isokinetic tests, and also male players had more dominant external strength improvement (Saccol *et al*., 2007).

Additionally, different strength gains and different performance results are achieved in upper and lower extremities in other researches. For example; they determined strength increase in the lower extremities, but no strength increase is specified in the upper extremities after plyometric trainings for eight weeks (Wilson *et al*., 1993). They stated that this difference originated from upper extremity muscle mass being smaller than the lower extremity muscle mass, and also from not performing loading on upper and lower extremities in the same intensity and strength. They indicated that loading can be made to lower extremity muscles eight times more in comparison to upper extremity muscles. Nature of plyometrics and its place in the training periodizing are other factors that should be considered. Since plyometric trainings use explosive movements to develop muscle strength, attention should be paid that there is traumatization risk because of strong forcing during training and performance and that stress shall be build on the body before combining trainings with plyometrics (Salonikidis and Zaferidis, 2008).

Salonikidis and Zafeiridis (2008) have pointed out that plyometric exercises should be done only by good trained athletes who reached a high level of strength and flexibility. Additionally, tennis court and tennis shoes should not be utilized for these exercises, because it shall be very hard and shall increase the risk of injury; ideally comfortable running shoes should be put and training should be realized on the lawn.

In this study, it is possible to express that obtaining better strength values for upper body rotation and lower body right and left extension / flexion motions is a result that is suitable with the nature of tennis game; because it is established that higher dominant forearm extension, flexion and pronation strengths are normal for young elite tennis players (Ellenbecker *et al*., 2006).

Other findings we obtained in our research are related with backhand / forehand cross and parallel stroke velocities and hitting rates of these strokes. Maximum velocity at backhand parallel and cross strokes showed development in both groups during the process, while difference in experimental group was significantly higher than the control group as of the 4th week. When average difference in the backhand cross strokes is examined at the end of the process, improvement recorded by experimental group that is higher than the control group is another finding obtained. Increasing hitting rates in the backhand parallel stroked has been similar in the groups. Hitting rates of backhand cross strokes also showed improvement, however improvement in the experimental group varied as of 4th week and it was higher.

Maximum velocity in forehand parallel and cross strokes showed development in both groups during the process, while differences in the experimental group was significantly higher than the control group as of the 4th week. Also; when we examine average change at the end of process, it is observed that experimental group recorded more improvement in comparison to the control group. Hitting rates in forehand parallel and cross strokes have showed similar increase in both groups.

These findings imply that plyometric exercises make important contributions to the stroke velocities and hitting rates of the athletes. When we consider that today about 75% of all strokes is forehand shots, and upper extremity has a significant role in the shots, these improvements become crucial (Ellenbecker *et al*., 2006).

It is possible to explain this development in stroke velocity and hitting rates in parallel to the improvements in strength by means of shoulder strength; because plyometric exercises include very fast eccentric and concentric powerful muscle contractions and it is certain that they influence nervous system. Plyometric causes nervous system to react very rapidly by forcing the muscle to stretch rapidly and contract with the maximum strength. This process is known as stretching-contracting cycles as one of the most rapid reflex of the human body (http://www.donchu.com/articles, Access date: 08 November 2011).

In a study, showing stroke performance increases in parallel to the increasing upper extremity strength, it is informed that plyometric training caused increase in the strength of shoulder internal rotator muscles, and plyometric training performed for upper extremity has also improved the performance in shooting and throwing correspondingly (Fortun *et al*., 1997).

As a result, it is established that plyometric exercises implemented in addition to classical tennis training have positive effects on shoulder and leg strengths of tennis players, and also shooting and stroke velocities are improved together with the hitting rates.

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