Journal of Physical Education and Sport ® (JPES), Vol. 23 (issue 9), Art 283, pp. 2461 - 2468, September 2023
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effects of plyometric and mixed-methods power training on ball velocity and kinematic parameters of instep kick after muscle fatigue in amateur futsal players

THANAKORN KAIMUSIK[1], SONTHAYA SRIRAMATR[2], CHAMNAN CHINNASEE[3]
[1 2] Department of Sports Science, Faculty of Physical Education, Srinakharinwirot University, Nakhon Nayok, THAILAND
[3] Department of Sports Science, Faculty of Health and Sports Science, Thaksin University, Phatthalung, THAILAND

Published online: September 30, 2023
(Accepted for publication September 15, 2023)
DOI:10.7752/jpes.2023.09283

Abstract
The purpose of this study was to compare the effects of plyometric training and mixed-methods power training on the ball velocity and kinematic parameters of the instep kick after muscle fatigue in university futsal players. The study recruited 42 futsal players with an average age of 20.2 years, weight of 66.04 kg, and height of 172.7 cm. The subjects were divided into three groups comprising a control group (regular futsal training), a plyometric training group, and a mixed-methods training group. The training program was conducted for 8 consecutive weeks, with two training sessions per week. The researchers measured ball and ankle velocities, as well as hip and knee angular velocities, before the training program, after 8 weeks of training, and after inducing muscle fatigue. Collected data were analyzed using multivariate analysis of variance (MANOVA). The results showed that after the 8-week training program, both the plyometric training group and the mixed-methods training group showed an increase in mean ball and ankle velocities, as well as hip and knee angular velocities. However, there was no significant difference between the plyometric and mixed-methods training groups. Both training groups exhibited significantly higher values compared to the control group ($p < .05$). Similarly, the study found no significant differences between the plyometric training group and the mixed-methods training group in these variables after inducing muscle fatigue. However, both training groups had significantly higher values compared to the control group ($p < .05$). In summary, the study suggests that both plyometric training and mixed-methods power training can improve the ball velocity and kinematic parameters of the instep kick in foot athletes after muscle fatigue. The findings of this study have implications for training programs aimed at enhancing the performance of futsal players.
Keywords: Ball velocity, Kinematics, Plyometric training, Mixed-methods training

Introduction

Futsal is a variation of football played indoors on a field 40x20 meters, with each team having 5 players. Competition time consists of two halves, and each half will last 20 minutes. The match time will be stopped if the ball goes out of play, a foul is committed, an athlete is injured, etc. For this reason, the duration of the match can last from approximately 40 to 85 minutes (Roxburgh, 2008). Each half-time, each team has the right to request one time-out and a 10-minute half-time break. Player changes can be made throughout the match. Matches consist of making offensive and defensive plays continuously. (Naser et al., 2017). Therefore, athletes must move in different ways with speed, such as running at a speed of more than 15 kilometers per hour (13.7%) and running at a speed of more than 25 kilometers per hour (8.9%) for the total distance (Naser et al., 2017; Spyrou et al., 2020). In addition, futsal often involves shooting goals with the back foot. In each game, athletes will undertake high-intensity exercise for approximately 3-6 minutes before changing players. Such movement activities must use energy sources from the anaerobic system that are characterized by a discontinuous pattern.

Throughout a game, athletes have a rate of oxygen consumption per minute that may be 75% of their maximum, a heart rate per minute of 90% of maximum, and circulating lactic acid of 5 mmol/l (Castagna et al., 2009; Makaje et al., 2012). This may result in muscle fatigue and reduced body performance in many aspects such as muscle contractions and running speed (Dal Pupo et al., 2014), as well as angular velocity in the movements of the knee and hip joints (Dal Pupo et al., 2016) and range of motion (Makaje et al., 2012). Particularly in the second half of a race, runners' total distance traveled per minute decreases dramatically compared to the first half (Castagna et al., 2009). Muscular fatigue from football matches results in a decrease in repetitive sprint performance (Rampinini et al., 2008), skeletal muscle, which affects the degree of contractile strength of the femoral muscles as well as sprint performance (Rampinini et al., 2011) and ball speed from instep kicks (Russell et al., 2011; Radman et al., 2016). Similarly, football players experience fatigue from simulated football games, which results in a decrease in ball velocity from the instep kicks and maximal angular velocity of the lower leg during knee extension compared to pre-fatigue (Killis & Katis, 2006; Ricardo & Roland, 2012). In

Corresponding Author: SONTHAYA SRIRAMATR, E-mail: sonthase@g.swu.ac.th

particular, higher-intensity activity during a match results in more fatigue and a reduction in ball velocity from instep kicks (Ricardo & Roland, 2015).

Previous studies have found that the most effective training methods that show positive results in increasing muscle power and improving athletic performance are plyometric and mixed-method training. Practicing both methods could affect the development of the muscle's ability to produce large amounts of force in a short period, known as muscle power. Building muscle power depends on building maximum strength, as well as the speed of contractions and the rate of force development of muscle. By practicing plyometric training, it consists of stimulating the muscles in the same group to have an elongated contraction (eccentric) followed by a rapid shortened contraction (concentric) (Wang & Zhang, 2016). This training focuses on increasing the ability of the muscle reflex system, learning how to stretch muscles to contract rapidly and increasing the capacity of the connective tissue that surrounds muscle fibers, or muscle tendons to create elastic energy that is stored within the muscles to create a large amount of force in a short period (Wang & Zhang, 2016). Past studies found that plyometric training affected the development of muscle power in university futsal athletes (Davar & Parisa, 2011), increasing flexibility and muscle power (Naves, 2017), increasing explosive muscle power and ball speed for instep kicks (Sedano & Vaeyens, 2009), and increased running speed, vertical jump, standing long jump, maximum power and instep kick speed (Ozbar, 2015), while mixed-methods training consisting of heavy resistance training combined with plyometric training affected the development of muscle power by increasing the size of type IIa muscle fibers, leg strength, and the ability to jump vertically as well as the angular velocity of knee extension from instep kicks (Jorge et al., 2008; Manolopoulos & Papadopoulos, 2006).

One problem is that futsal athletes need to use muscle power continuously and rely on anaerobic energy systems. As a result, muscle fatigue accumulates, resulting in decreased physical and sports performance, especially in the second half of a game. This problem should be addressed to maintain proper muscle power throughout a game, especially the ability to shoot the ball with instep kicks. From the results of past studies, it was concluded that plyometric training and mixed-methods training is an effective method that has shown positive results in increasing muscle power and improving athletic performance. For this reason, the researchers were interested in investigating the effects of plyometric training, mixed-methods training and muscle fatigue on ball velocity and kinematic variables of instep kick in amateur futsal players. Three research questions were raised: 1) Can increasing muscle power increase the ball velocity of instep kicks and the kinematic variables in amateur futsal players? 2) Does muscle fatigue from futsal games affect the ball velocity and kinematic parameters of instep kicks in amateur futsal players? 3) Will increasing muscle power preserve the ball velocity and kinematic parameters of instep kicks after the onset of fatigue?

Materials & methods

Participants

The subjects comprised 42 male futsal athletes (mean age 20.2 ± 0.9 years, weight 66.04 ± 9.06 kg, and height 172.7 ± 6.41 cm) from a university. Subjects were selected using a simple random sampling method. The number of subjects was based on previous studies that had similar study characteristics (Ozbar, 2015). However, this study used 14 subjects in each group to prevent 40% of withdrawal from the study. It consisted of a control group (regular futsal training), experimental group 1 (regular futsal training and plyometric training), and experimental group 2 (regular futsal training and mixed-methods training). Before initiating the research, all subjects were informed of the study details and signed informed consent forms, which were certified by the Human Research Ethics Committee of Srinakharinwirot University (number SLUEC/&G-302/2564).

Plyometric training

The athletes practiced plyometric training 2 days per week for 8 weeks. Each training day consisted of 4 moves. In the first 4 weeks, they practiced squat jumps, single-leg vertical jumps, standing long jumps and power skipping. In each move, the athletes performed 8 reps for 4 sets in weeks 1-2 and 5 sets in weeks 3-4. In weeks 5-8, the athletes practiced repeated tuck jumps, split squat jumps, front hurdle hops and alternate leg bounding. In each move, the athletes performed 8 reps for 5 sets in weeks 5-6, and 10 reps in weeks 7-8. Athletes rested 2-3 minutes between sets and 3-5 minutes between moves. The height of the fence at weeks 1-4 was 40 cm, which was increased to 50 cm in weeks 5-8, as adapted from Ozbar (2015).

Mixed-methods training

The athletes trained in mixed-methods exercises 2 days per week for 8 weeks, consisting of power clean, back squat, jump squat, and depth jump. Athletes performed each move 5 times in 3 sets during weeks 1-2, then increased to 4 times during weeks 3-4, and 5 times in weeks 5-8, but 6 sets in weeks 7-8. Athletes rested 2-3 minutes between sets and 3-5 minutes between moves. The height of the box in the 1st-4th weeks was 40 cm, which was increased to 50 cm in the 5th-8th weeks, as adapted from Haff (2012).

Measurement of ball velocity and kinematic parameters

Before starting the data collection, the subjects warmed up for 15 minutes, and then 22 reflective markers were attached to the plug-in gait model: PIG (Barbieri et al., 2015). Measurements were performed using a 3D motion analyzer consisting of 10 infrared cameras (Qualysis Miqus, Sweden) and recorded at a frequency of 200 Hz. The 3D kinetic analyzer was calibrated by recording the data while the subjects stood stationary in the center of the data collection area for 2 seconds (Apidech et al., 2020). To collect data, one reflective mark would be removed while kicking the ball with the instep, i.e. at the toe-distal end of the fifth metatarsal of the kicking side. The athletes performed three instep kicks, one-minute intervals each time, with the athletes prepared at a shooting point 10 m from the target. The subject will sound "Start" (The goal is 1x1 m in the middle of the door, adapted from Barbieri et al., (2015) with the highest level of intensity using radar speed detectors (Pocket Radar, Inc. California, USA). The athletes kicked the ball with the instep with maximum force toward a designated target (The goal is 1x1 meters in the middle of the door), adapted from Barbieri et al., (2015) with radar speed detectors (Pocket Radar, Inc. California, USA).

The instep kick used to make a ball travel at maximum speed was used to analyze 3D motion and kinematic parameters with Qualisys Track Manager Software motion analysis software, using Qualisys motion recording files to analyze hip and knee angular velocity by exporting all marker motion data from C3D files to file data for analysis with the program. An OpenSim package in the form of inverse kinematics analysis was used to obtain kinematic data of the hip and knee joints of subjects while instep kicking the ball. The data obtained from the 3D motion camera would be selected during the analysis. The starting point for the analysis was determined from the moment the subjects ran to the foot position. This period was defined as the Initial phase. The second phase was the backward swing. This period was defined as back swing phase. The final phase was the step that kicked the foot forward until it kicked the ball and swung the foot forward at the highest position. This period was defined as the kicking phase. The range analyzed was the kicking phase. Using the leg movement data that was determined, the marker movements were selected for analyzing the inverse kinematics procedure from Open SIM (Delp et al., 2007), and the data were analyzed further.

Stimulation of fatigue

Stimulating fatigue with sequential speed runs according to the Yo-Yo Intermittent Endurance Test Level 2 (Bangsbo, 1994) begins with the subjects running 20 meters round-trip (each trip with a 5-second rest period). The running was controlled by a tape-recorded audio signal. The subjects had to complete 2 round-trip runs at a speed of 8 km/h, then increase their speed to 10 km/h and 12 km/h, respectively. The speed of running would then be increased by 0.5 km/h. Subjects were asked to stop the test when they were unable to follow the specified sound signal and muscle fatigue was confirmed when the heart rate reached 90% of the maximum heart rate and serum lactate concentration was greater than 8 mmol/l (Howley et al., 1995). The subjects were then seated for a period of 3 minutes to recover, and the ball velocity and kinematic parameters of the instep kick were measured according to the ball velocity and kinematic parameters measurement procedure.

Heart rate measurements were monitored continuously during exercise (Polar Team System, Polar Electro, Finland), while fingertip blood sampling was performed after exercise had ended for blood lactate analysis (lactate plus, Waltham, MA, USA) The control group, the plyometric and combined training groups had mean heart rates of 184.8 ± 0.8, 188.4 ± 0.8 and 186.2 ± 0.8 beats/min, respectively, and peak serum lactate was 12.7 ± 0.8, 11.9± 0.8 and 12.3± 0.8 mmol/l, respectively, with no statistical difference found. The physiological responses of heart rate and lactic acid levels were consistent with previous studies in futsal competitions (Castagna et al., 2009; Makaje et al., 2012) and confirmation of physiological fatigue consisted of heart rate to 90 percent of the maximum heart rate and the concentration of lactate in the blood greater than 8 mmol/l (Howley et al., 1995). Therefore, it can be said that the Yo-Yo Intermittent Endurance Test Level 2 could simulate the physiological responses of futsal athletes in this study.

Data analysis

Statistics program SPSS version 17 (SPSS Inc. Chicago, IL, USA) was used to test the normal distribution of the data by using the Shapiro-Wilk Test. The mean and standard deviation of ball and ankle velocities, as well as the angular velocity of the hip and knee joints, were analyzed. All the dependent variable scores were subjected to a series of 3 (training groups) x 3 (before, after training, and after fatigue testing) between-groups multivariate analysis of variance (MANOVA) tests to evaluate the interaction and the intervention's primary effects, while Tukey was used to compare post-hoc differences. Statistical significance was set at the .05 level.

Results

The characteristics of the 3 sample groups are shown in Table 1. There was no significant difference in participant characteristics between groups at the pretest ($p > .05$). The MANOVA using Pillai's Trace showed that there was no significant interaction effect of training groups classified by testing periods on all dependent variables ($p > .05$). The results of the MANOVA found that there was no significant difference between groups on the combined variables (ball and ankle velocities, hip and knee angular velocities) at the pretest (Wilks' Lambda = 0.82 F (2, 39) = 0.74, $p > .05$). The Box's M (52.78) was not significant, $p > .05$. However, after training, there was a statistically significant difference between the three groups on the combined dependent variables (Wilks' Lambda = .58 F (2, 39) = 2.18, $p < .05$, partial eta = .24). The Box's M (121.64) was significant, $p < .001$. The post-hoc test showed that the control group was different from the plyometric training group and the mixed-methods training group ($p < .05$), but there was no difference between the plyometric training group and the mixed-methods training group. Similarly, there was a statistically significant difference between the three groups on the combined dependent variables after fatigue (Wilks' Lambda = .52 F (2, 39) =

2.73, $p < .01$, partial eta = .28). The Box's M (59.52) was significant, $p < .05$. The post-hoc test showed a difference as it did after training.

Table 1 shows the mean and standard deviation for the characteristics of the sample

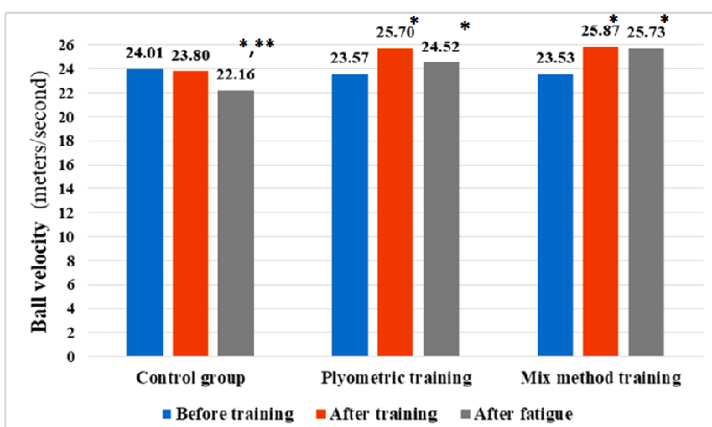
Group	Age (year)	Weight (Kilogram)	Height (Centimeters)	1 RM (Kilogram)
	$\overline{X}$ ± S.D.	$\overline{X}$ ± S.D.	$\overline{X}$ ± S.D.	$\overline{X}$ ± S.D.
Control (N=14)	20.7 ± 1.20	64.80 ± 6.20	171.4 ± 6.10	144 ± 14
Plyometric training (N=14)	19.7 ± 0.70	66.84 ± 11.26	173.79 ± 6.03	150 ± 15
Mix method training (N=14)	20.1 ± 0.90	66.47 ± 9.65	172.96 ± 7.11	153 ± 17

A comparison of before, after training and after fatigue found that the ball and ankle velocities, hip and knee angular velocities of the control group showed statistically significant reductions (Wilks' Lambda = .17 F (2, 39) **=** 6.19, $p < .001$, partial eta = .59). After fatigue was lower than after training and lower than before training (all, $p < .05$). However, before training and after training were not different ($p > .05$). In the plyometric group, the ball and ankle velocities, hip and knee angular velocities were significant different, Wilks' Lambda = .02 F (2, 39) = 6.40, $p < .001$, partial eta = .59). After fatigue was lower than after training but higher than before training (all, $p < .01$). Also, after training was significantly higher than before training ($p < .05$). Similarly, the ball and ankle velocities, hip and knee angular velocities were significant different in the mixed-methods group (Wilks' Lambda = .01 F (2, 39) = 41.59, $p < .001$, partial eta = .77). After fatigue was lower than after training but higher than before training (all, $p < .01$). Also, after training was significantly higher than before training ($p < .05$).

Table 2. Mean, standard deviation, and MANOVA results

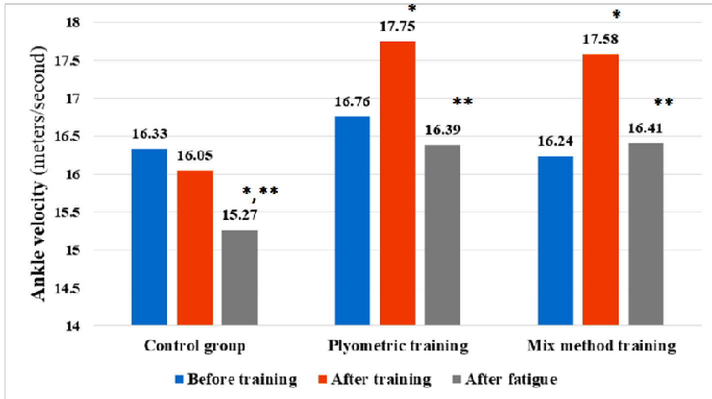
Variables	Measures	Control	Plyometric training	Mix method training	Between Group
		$\overline{X}$±SD	$\overline{X}$±SD	$\overline{X}$±SD	p
Ball velocity (meters/second)	Before training	24.01±1.80	23.57±2.25	23.53±2.30	0.805 n
	After training	23.80±1.97	25.70±1.71	25.87±1.94	0.009 *
	After fatigue	22.16±2.44	24.52±2.36	25.73±1.89	0.001 *
Ankle velocity (meters/second)	Before training	16.33±0.96	16.76±1.30	16.24±0.83	0.290 n
	After training	16.05±0.92	17.75±1.52	17.58±1.85	0.007 *
	After fatigue	15.27±1.06	16.39±1.03	16.41±0.90	0.006 *
Hip angular velocity (degrees/second)	Before training	1103.36±177.31	1207.42±260.38	1214.64±169.28	0.802 n
	After training	1187.45±229.29	1365.94±188.53	1385.45±196.02	0.027 *
	After fatigue	1089.92±185.60	1330.25±168.41	1397.04±231.23	0.000 *
Knee angular velocity (degrees/second)	Before training	1689.53±186.43	1728.74±185.05	1693.76±136.30	0.802 n
	After training	1681.62±221.01	1879.02±189.94	1827.79±204.64	0.041 *
	After fatigue	1536.92±196.07	1781.43±144.97	1724.69±181.11	0.002 *

* = There was a statistically significant difference (p < .05)



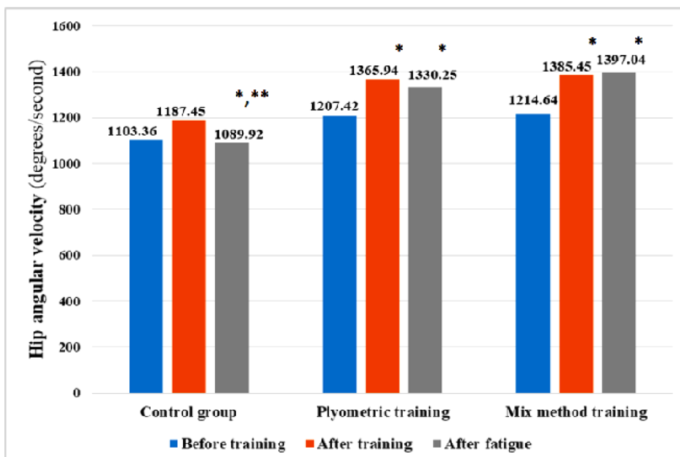
*   = Statistically significant difference from before training
** = Statistically significant difference from after training

Figure 1. The mean ball velocity before training, after training, and after fatigue for each group



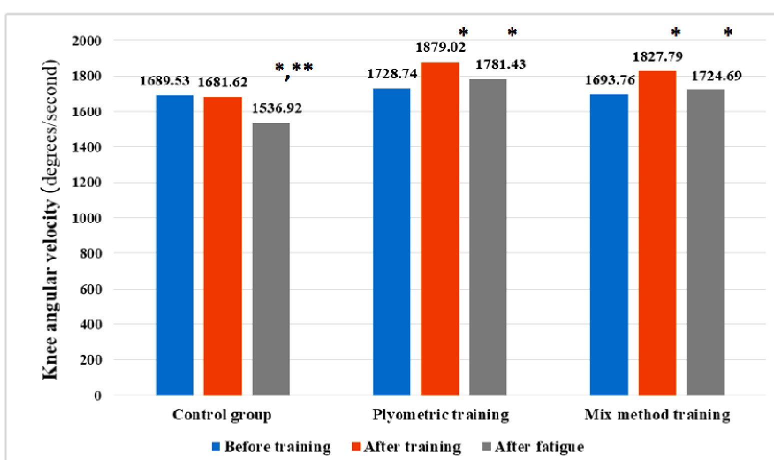
*   = Statistically significant difference from before training
** = Statistically significant difference from after training

Figure 2. The mean ankle velocity before training, after training, and after fatigue for each group



*   = Statistically significant difference from before training
** = Statistically significant difference from after training

Figure 3. The mean hip angular velocity before training, after training, and after fatigue for each group



*   = Statistically significant difference from before training
** = Statistically significant difference from after training

Figure 4. The mean knee angular velocity before training, after training, and after fatigue for each group

Discussion

Plyometric training and mixed-methods training were not significantly different for increasing ball speed, ankle speed, and hip and knee angular speed. However, both forms of training were more effective than futsal training alone. This is in line with previous studies that found that plyometric training improves leg muscle power, running speed and instep kick speed (Davar & Parisa, 2011; Naves, 2017; Sedano & Vaeyens, 2009; Ozbar, 2015). Likewise, mixed-methods training increases muscle bundle size, the number of fast contractile muscle fibers, muscle strength, jumping power, angular velocity in knee extension from an instep kick, and an increase in ball speed (Jorge et al., 2008; Manolopoulos & Papadopoulos, 2006).

Stimulating athletes to fatigue by speed running according to the Yo-Yo Intermittent Endurance Test Level 2 method resulted in muscle fatigue and decreased instep kick efficiency considering the decreasing speed of the ball, ankle speed, angular velocity of the hip and knee joints due to central fatigue and peripheral fatigue. Central nervous system fatigue lowered motor activity, thereby reducing muscular maximal force (Enoka & Duchateau, 2008), decreasing the running efficiency (Eston et al., 2003; Girard et al., 2011) and kinematics of lower limb movements (Dal Pupo et al., 2014; Small et al., 2009; Pinniger et al., 2000) and reducing the contraction force of the contractile and extensor muscles during knee flexion and extension, resulting in a decrease in the angular velocity of movement of lower body joints (Dal Pupo et al., 2016). Fatigue in the extremities is caused by a decrease in energy reserves for both the phosphagen and glycogen systems in the leg muscles (Krustrup, 2003) and an increase in hydrogen ions (H^+), which causes muscle contractions to produce less force and decreases the movement of the athlete (Carroll et al., 2017). Particularly in the second half of a futsal game, it was found that the athletes' total movement distance per minute decreased compared to the first half (Castagna et al., 2009; Bueno et al., 2014; Barbero et al., 2008), which showed the increase in lactic acid level was associated with an increase in intramuscular hydrogen ion (H+) (Carroll et al., 2017). In this study, the physiological responses from the Yo-Yo Intermittent Endurance Test Level 2 of the control group showed the plyometric and mixed-methods training groups had peak serum lactate values of 11.9±2.2, 12.2 ± 2.9 and 12.3± 3.1 mmol/l, respectively, indicating that athletes were truly fatigued.

The main finding of this study was that the plyometric and mixed-methods training groups had ball and ankle velocity, as well as hip and knee angular velocities that were significantly higher than the control group after sitting down for 3 minutes; ball speed and kinematic parameters measured after muscle fatigue was applied. However, there was no difference between the plyometric training group and the mixed-methods training group. It was concluded that plyometric training and mixed-methods training resulted in no difference in muscle recovery ability after fatigue. Both forms of training resulted in faster recovery from fatigue than regular futsal training. The resulting fatigue did not cause changes in the angular velocities of the hip and knee joints (Rodacki et al., 2001; Rodacki et al., 2002; Dal Pupo et al., 2013), and the fatigue induced by simulated futsal games did not affect lower limb coordination when sprinting (Dal Pupo et al., 2016). Explosive movements of the muscles are not easily changed even with the ability of the muscles to produce explosive force around the joint changes. These may be compensatory mechanisms of the central nervous system to increase the strength and frequency of nerve impulses to muscles that have lost their force-producing properties (Bobbert & Ingen Schenau, 1988; Rodacki et al., 2001; Dal Pupo et al., 2016) and increase the ability of the muscles to recover from the central and peripheral nervous system fatigue resulting from plyometric and mixed-methods training. Coaches should consider the effects of fatigue during daily training and futsal matches. A decrease in instep kick efficiency is seen when fatigued, which indicates the need for more substitutions during the competition and underscores the importance of plyometric and mixed-methods strength training for athletes during the pre-season to reduce fatigue levels and maintain neuromuscular performance related to increasing ball speed, and angular velocity of the lower extremities during an instep kick, as well as to reduce the harmful effects of fatigue or reduce the risk of injury to the posterior thigh muscles.

Conclusion

This study found that plyometric and mixed-methods training was effective for increasing the ball, ankle and angular velocity of the hip and knee joints from instep kick, which may be due to plyometric training and mixed-methods training having a direct impact on optimizing neuromuscular function. As a result, the muscles have the ability to create more power and increase the efficiency of the skill of instep kicking in terms of the angular velocity of hip flexion, knee extension and ankle movement speed, causing the speed of movement of the ball to increase more than practicing futsal alone. In addition, both forms of training increased the ability of muscles to recover faster after central and peripheral fatigue than futsal training alone, which may result from both forms of training enabling the ability of muscles to replenish ATP-CP and accelerate the breakdown of lactic acid, thus facilitating recovery from peripheral fatigue. Fatigue does not cause changes in the angular velocity of the hip and knee joints, which is a compensatory mechanism of the central nervous system to increase the frequency of nerve impulses to muscles that have lost their force-generating properties.

Coaches and sports scientists should consider the importance of plyometric and mixed-methods training for athletes during the preseason to add strength to the muscles, reduce fatigue levels, and maintain the neuromuscular performance associated with increasing ball and angular velocity of the lower leg during instep kicks as well as reduce the harmful effects of fatigue or reduce the risk of injury to the rear thigh muscles in futsal athletes.

Conflicts of interest- The authors report that there were no potential conflicts of interest.

References:

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal Muscle Fatigue: Cellular Mechanisms. *Physiol Reviews*. 88, 287–332. https://doi.org/10.1152/physrev.00015.2007

Apidech, H., Rittiwat, W., Chinnasee, C., & Rachnavy, P. (2020). Biomechanical analysis of Instep and Toe-Poke Kicking in futsal players. *Jurnal Sains Sukan & Pendidikan Jasmani*, , 17-24. 9 DOI: https://doi.org/10.37134/jsspj.

Barbieri, F. A., Gobbi, L. T. B., Santiago, P. R. P., & Cunha, S. A. (2015). Dominant- nondominant asymmetry of kicking a stationary and rolling ball in a futsal context. *Journal of Sports Sciences.* 33(13), 1-9. DOI: 10.1080/02640414.2014.990490

Bangsbo, J. (1994). *Physiological demands*, (pp. 43-58). In B. Ekblom. ed. Handbook of Sports Medicine and Science Football (Soccer). Blackwell Scientific Publication, London.

Barbero-Alvarez, J. C., Soto, V. M., & Granda-Vera, J. (2008). Match analysis and heart rate of futsal players During competition. *Journal of Sports Sciences*. 26(1), 63-73. DOI:10.1080/02640410701287289

Bobbert, M. F., & Ingen Schenau, G. J. van. (1988). Coordination in vertical jumping. *Journal of Biomechanics*, 21(3), 249–262. DOI:10.1016/0021-9290(88)90175-3

Bompa. (2009). *Periodization:* Theory and Methodology of Training (5th edition). Champaign, Illinois: Human Kinetic.

Bueno, M. J. D. O., Caetano, F. G., Pereira, T. J. C., De Souza, N. M., Moreira, G. D., Nakamura, F. Y., Cunha, S. A., & Moura, F. A. (2014). Analysis of the distance covered by Brazilian professional futsal players during official matches. *Sports Biomechanics*. 13(3), 230-240. DOI: 10.1080/14763141.2014.958872

Carroll, T. J., Taylor, J. L., & Gandevia, S. C.(2017). Recovery of central and peripheral neuromuscular fatigue after exercise. *Journal of Applied Physiology*. 122(5),1068-1076. DOI: 10.1152/japplphysiol.00775.2016

Castagna, C., D'Ottavio, S., Vera, J. G., & Álvarez, J. C. B. (2009). Match demands of professional Futsal: A case study. *Journal of Science and Medicine in Sport*. 12(4), 490-494. DOI:10.1016/j.jsams.2008.02.001

Dal Pupo, J., Dias, J. A., Gheller, R. G., Detanico, D., & Santos, S. G. (2013). Stiffness, intralimb coordination, and joint modulation during a continuous vertical jump test. *Sports Biomechanics.* 12(3), 259-271. DOI: 10.1080/14763141.2013.769619

Dal Pupo, J., Detanico, D., & Santos, S. G. (2014). The fatigue effect of a simulated futsal Match Protocol on isokinetic knee torque production. *Sports Biomechanics*. 13, 332-340.

Dal Pupo, J., Detanico, D., Ache-Dias, J., & Santos, S. G. (2016). The fatigue effect of a simulated futsal match protocol on sprint performance and kinematics of the lower limbs. *Journal of Sports Sciences*.7, 1-8. http://dx.doi.org/10.1080/02640414.2016.1156727

Davar, R., Parisa, A., & Soheil, S. (2011). The effect of a 4 week plyometric training period on lower body muscle EMG changes in futsal players. *Procedia Social and Behavioral Sciences.* 15, 3138–3142. DOI:10.1016/j.sbspro.2011.04.260

Delp S. L.,Frank C. Anderson., Allison S. Arnold., Peter Loan., Ayman Habib., Chand T. John., Eran, Guendelman., & Darryl, G. Thelen. (2007). OpenSim: Open-source Software to Create and Analyze Dynamic Simulations of Movement. *IEEE Transactions on Biomedical Engineering*. 54(11), 1940 – 1950. DOI: 10.1109/TBME.2007.901024

Enoka, R. M., & Duchateau, J. (2008). Muscle fatigue: What, why and how it influences muscle function. *The Journal of Physiology*. 586(1), 11 –23. DOI: 10.1113/jphysiol.2007.139477

Eston, R., Byrne, C., & Twist, C. (2003). Muscle function after exercise induced muscle damage: Considerations for athletic performance in children and adults. *Journal of Exercise Science and Fitness.* 1(2), 85 –96. https://www.researchgate.net/publication/30068033

Girard, O., Micallef, J. P., & Millet, G. P. (2011). Changes in spring-mass model Characteristics during repeated running sprints. *European Journal of Applied Physiology*. 111(1), 125-134. DOI: 10.1007/s00421-010-1638-9

Haff, G., (2012). Training Principles for Power. *National Strength and Conditioning Association*. 34(6), 1-12. DOI:10.1519/SSC.0b013e31826db467

Howley, E. T., Bassett, D. R., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *Journal of Medicine and Science in Sports and Exercise*. 27(9), 1292-1301.

Julien, S. Baker., Marie Clare, McCormick., Robert, A. Robergs. (2010). Interaction among Skeletal Muscle Metabolic Energy Systems during Intense Exercise. *Journal of Nutrition and Metabolism.* 1-13. DOI: 10.1155/2010/905612

Jorge, P. G., Hugo, O., Safira, D. G., Ignacio, A. R., German, V. R., Rafael, A. O., & Javier, C., Jose, A. L.

(2008). Effects of weight lifting training combined with plyometric exercises on physical fitness, body Composition and knee extension velocity during kicking in football. *Applied Physiology, Nutrition, and Metabolism* 33(3), 501–10. doi: 10.1139/H08-026

Kellis, E., Katis, A., & Vrablas, I. S. (2006). Effect of an intermittent exercise fatigue protocol on biomechanics of soccer kick performance. *Scandinavian journal of medicine and science in sports.* 16(5), 334-344. DOI: 10.1111/j.1600-0838.2005.00496.x

Krustrup, P. 2003.The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise*. 35(4),697-705. DOI: 10.1249/01.MSS.0000058441.94520.32

Mary, C,. & McKenna.(2012). *Energy Metabolism of the Brain* (Eighth Edition). Arne Schousboe, in Basic Neurochemistry.200-231. https://doi.org/10.1016/B978-0-12-374947-5.00011-0

Manolopoulos, E., Papadopoulos, C., & Kellis, E. (2006). Effect of combined strength and Kick coordination Training on soccer kick biomechanics in amateur players.*Scandinavian journal of medicine and science in sports.* 16(2),102-10. DOI: 10.1111/j.1600-0838.2005.00447.x.

Makaje, N., Ruangthai, R., Arkarapanthu, A., & Yoopat, P. (2012). Physiological demands and activity profiles during futsal match play according to competitive level. *Journal of Sports Medicine and Physical Fitness*.52(4), 366-374.

Naser, N., Ali, A., Macadam, P. (2017). Physical and physiological demands of futsal. *Journal of Exercise Science and Fitness*. 15(2), 76-80. doi: 10.1016/j.jesf.2017.09.001

Naves, (2017). Effects of short-term plyometric training on physical fitness parameters in female Futsal athletes. *Journal of Physical Therapy Science.* 9(5), 783–788. DOI: 10.1589/jpts.29.783

Ozbar, N., (2015). Effects of Plyometric Training on Explosive Strength, Speed and Kicking Speed in Female Soccer Players. *Anthropologist*. 19(2), 333-339. DOI:10.1080/09720073.2015.11891666

Pinniger, G., Steele, J., & Groeller, H. (2000). Does fatigue induced by repeated dynamic efforts affect hamstring muscle function?. *Medicine & Science in Sports & Exercise*. 32(3), 647-653. DOI: 10.1097/00005768-200003000-00015

Rampinini, E., Impellizzeri, F. M., Castagna, C., Azzalin, A., Ferrari Bravo, D., & Wisloff, U. (2008). Effect of match-related (fatigue on short-passing ability in young soccer players. *Medicine & Science in Sports &Exercise.* 40(5), 934–942. DOI: 10.1249/MSS.0b013e3181666eb8.

Rampinini, E., Bosio, A., Ferraresi, I., Petruolo, A., Morelli, A., & Sassi, A. (2011). Match- related fatigue in soccer players. *Medicine & Science in Sports & Exercise*. 43(11), 2161-2170. DOI: 10.1249/MSS.0b013e31821e9c5c

Ricardo, F., Roland V. D. T., & Mario, C. M. (2012).The Effect of Fatigue on Kicking Velocity In soccer players. *Journal of Human Kinetics*. 35, 97-107. DOI: 10.2478/v10078-012-0083-8

Ricardo, E., Roland van den, T., & Mario, C. (2015). The influence of different exercise intensities on kicking accuracy and velocity in soccer players. *Journal of sports andHealth science*. 6(4), 462-467. DOI: 10.1016/j.jshs.2015.10.001

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2001). Multi-segment coordination: Fatigue effects. *Medicine and Science in Sports and Exercise.* 33(7), 1157–1167. DOI: 10.1097/00005768-200107000-00013

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: Fatigue effects. *Medicine and Science in Sports and Exercise*. 34(1), 105–116. DOI: 10.1097/00005768-200201000-00017

Roxburgh, A. (2008).The technician futsal. Newsletter for coaches, *UEFA*.

Sedano, C. S., Vaeyens, R., Philippaerts, R. M., Redondo, J. C., De Benito, A. M., & Cuadrado, C. (2009). Effects of lower limb plyometric training on body composition, explosive strength and kicking speed in female soccer players. *Journal of Strength and Conditioning Research*. 23(6), 1714 -1722. DOI: 10.1519/JSC.0b013e3181b3f537

Small, K., McNaughton, L. R., Greig, M., & Lovell, R. (2009). Soccer fatigue, sprinting and hamstring injury risk.*International Journal of Sports Medicine*. 30(8), 573–578. DOI: 10.1055/s-0029-1202822

Spyrou, K., Freitas, TT., Marín-Cascales, E., Alcaraz. PE. (2020). Physical and Physiological match- play demands and player characteristics in futsal: a systematic review. *Front Psychol*. 11:569897. doi: 10.3389/fpsyg.2020.569897

Wang and Zhang. (2016) Effects of plyometric training on soccer players (Review). *Experimental and Therapeutic Medicine*. 12: 550-554.