Original Article

Effect of Fatigue on the Kinematic Variables of Jump Header Performance in Soccer

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Abstract

The purpose of this study was to examine the influence of cardiovascular fatigue on the lower and upper body kinematic and kinetic movements while performing jump heading in soccer. Kinematic and kinetic analyses consist of ball velocity, jump height, maximal leg power, vertical force, knee extension angular velocity take off, trunk flexion, trunk extension angular velocity, trunk flexion angular velocity, knee flexion, head velocity, and landing. In this study a quantitative descriptive method was used. The study involved 21 male university level players as participants. The participants had the following characteristics: a mean age 18.1 ± 2.6 years; height 1.66 ± 0.04 m, body mass 60.6 ± 4.26 kg, BMI 22.1 ± 1.2 kg/m², VO2Max 45.4 ± 3.05 m/kg/min, and mean maximum heart beats 187.0 ± 4.63 bpm. Furthermore, there were significant differences in ball velocity, jump height, maximum leg power, maximum trunk flexion, head velocity, and feet landing indicators ($p = 0.033$, $p = 0.041$, $p = 0.034$, $p = 0.042$, $p = 0.041$, and $p = 0.023$, respectively) with the p -value = $0.000 < 0.05$. We recommend that coaches and athletes strengthen their core muscles. In addition, cervical and neck muscles should become the focus in complementing exercise programs.

Keywords: Fatigue, maximum heart rate, sport biomechanics, soccer, heading.

Introduction

Biomechanics is the science of structures and functions of biological systems from the viewpoint of mechanical systems (Burkett and Carr, 2010). Sport biomechanics, a branch of biomechanics that studies physics mechanics, is implemented to analyze movements to achieve most efficient and effective performance and to reduce the risk of injury during a match (Baltzopoulos, 2008). The appropriate and accurate implementation of sport biomechanics has an impact on performance improvement, rehabilitation, and prevention of injuries as long as the athlete exercises to achieve an optimal sports performance (Bartlett, 2018).

Speed, power, agility, and technical ability are the dominant factors in soccer games. According to (Arastoo, Aghdam, Habibi, and Zahednejad, 2014), technical ability is divided into two components, i.e., movements and with ball. Movements without a ball consist of running and direction changing, jumping, and feinting, or body feinting. In addition, movements with a ball consist of kicking, ball receiving, heading, dribbling, feinting, tackling, throwing-in, and goal keeping techniques (defensive and offensive). Because heading is basic soccer techniques that is essential in a game, it is frequently used by a player for ball passing, anticipating opponent's attack, and scoring goals (Economiche, Bucci, Cubo, Scoppa, and Calabria, 2013). Heading techniques are divided into stand heading and jump heading (Mohr, Krstrup and Bangsbo, 2015). Jump heading technique is a skill that requires immense coordination, motion harmonization, and ball feeling. Several steps of jump heading techniques as follows by Marqués-Jiménez, et al (2017) jump in the ball direction, when the body reaches the highest point, it goes backwards, and neck muscles contract; eyes sight is focused on the target; the chin moves close to the neck; tighten abdominal muscles and push the pelvis and the body forward, so that the forehead impacts the ball; the body leans forward and lands with both legs explosively.

Thus, the purpose of heading is to touch the ball with the head to move the ball from one place to another, to pass it to teammates, and to score a goal. Therefore, heading motion must be done with little energy, but can produce the maximum motion. According to the athletes who have mastered the heading movement skill, efficiently movement with correct motion mechanics allow to avoid the risk of injury. Motion skills are competencies exhibited in tasks related to achieving a goal (James, Ambegaonkar, Caswell, Onate, and Cortes, 2016; Tierney et al., 2008).

Skills are a continuous series of overall body movement coordination. Meanwhile, motion coordination is influenced by skeletal muscles; this process originates from somatic motor nerve stimulation as an effort to produce responses in the body (Sunami and Maruyama, 2017). Muscles can contract and relax because of the

energy available from the muscle cells (Barte et al, 2017). Through muscle contraction, the body performs like a machine. Muscle is a machine that converts chemical energy into mechanical energy, which is represented by physical activity. Skeletal muscles are a collection of skeletal myocyte fibers located at the edge of the cell wall. Sarcolemma cell membranes can deliver impulses to all parts of the muscle, including continuing delivery along the walls of the transversal tubule (Barte, Nieuwenhuys, Geurts, and Kompier, 2018; Queen et al, 2013).

Muscle fiber cytoplasm contains a contractile structure that plays a role in the main function of skeletal muscles. The amount of muscle mass reaches 40-50% of the body weight. In addition, among muscle fibers, there are muscle spindles, which function as stretch receptors that help to control muscle tone and soften muscle contractions (Bangsbo, Iaia, and Krstrup, 2017). Muscle fibers are served by motor nerves, which originate from motor neuron spinal cord and brain stem. The main function of skeletal muscles to provide a contraction, which produces a change in the movement of one portion of skeleton against another (i.e., motor segment movement). Body segment movements are difficult to control and are less effective when fatigue occurs (Marqués-Jiménez et al., 2017; Gu, 2016). Fatigue defined as the loss of ability to produce maximum strength during muscle contraction. It is the major factor responsible for a decrease in athlete's performance. Fatigue is a natural effect of an overload exercise. A rapid increase in the anaerobic exercise is followed by an increase in the aerobics. Anaerobic increase is needed to produce energy, which is used to archive high performance. However, overload performance also produces lactic acid (Maher, Hutchison, Cusimano, Comper, and Schweizer, 2014).

The production of lactic acid, which exceeds the consumption by the anaerobic threshold, results in fatigue. Activities at the anaerobic threshold are usually achieved by individuals at 60% of the maximum oxygen consumption (Dezman, Ledet, and Kerr, 2013). Physical activity must be maintained at high intensity for two to three minutes, which happens in a soccer game. Based on the processes, muscle fatigue can be divided into muscle fatigue and cardiovascular fatigue. Muscle fatigue is a decrease in muscle performance after an overload of physical work, which lowers the ability to control body movements and weakens the coordination of motion system harmonization. Muscle fatigue occurs after an overload of muscle contractions, i.e., the muscle is no longer able to contract in a certain period of time that is controlled by the central brain. In the central nervous system, there are parasympathetic activation and inhibition systems (McCrory, 2003). Fatigue may result in the lack of energy reserves and an increase in metabolic waste, which cause a decrease in muscle efficiency. Chemical changes that occur result in the delivery of nerve stimulation through sensory nerves to the brain (Shewchenko, Withnall, Keown, Gittens, and Dvorak, 2005; Requena et al., 2014).

The aim of this study was to examine the influence of muscle fatigue on the lower and upper body kinematic and kinetic variable movements of the headers while performing jump heading in soccer.

Materials and Methods

Participants

The subjects of this study were 21 university level male soccer players (18.4 ± 2.6 years of age with an average height of 1.68 ± 0.12 m, body mass of 60.8 ± 3.7 kg, and BMI of 22.1 ± 1.21). None of the participants sustained an injury when heading a soccer ball. In addition, none of the participants had previous serious head injuries.

Method

A quantitative descriptive method with the "one group pretest-posttest design" was used in this study. The participants had a pre test before receiving a fatigue treatment. After the fatigue protocol was given, the participants had a post test.

Instruments

The instruments used in this study were a AMTI 3D force platform device, 2 Panasonic handycam HC-V100 Full HD video camera, a high speed camera unit (Phantom USA), 3D calibration set, 3D motion software analysis (Frame DIAZ IV, Japan), Cosmed direct gas analyzer system, and speed radar gun. The data collection process was carried out in the sports science laboratory at the Faculty of Sport and Health Education, Universitas Pendidikan Indonesia (figure 1).

Fig. 1. Sport Science Laboratory at the Faculty of Sport and Health Education

Fatigue Protocols

The maximum physical capacity is represented by the maximum oxygen consumption value (VO₂Max) and the maximum heart rate (HR Max), which provide information about the limit of the athlete's maximum physical ability to perform physical activity. The measurement of maximal oxygen consumption is an assessment of individual capacity during the performance. Typically, during the measurement of VO₂Max, an ergometer treadmill is used, which provides a load on the lower body muscles. An ergometer treadmill makes the body maintain its position on the sole foot because the foot stands at the treadmill elevation angle, which increases the load. The equipment used included a set of Fitmate MED physiology system (COSMED srl-Italy), which consisted of a heart rate transmitter, a heart rate receiver, a V mask (Hans Rudolph inc), and a Cosmed pulmonary exercise testing @ 60 treadmill. The treadmill maximum test system protocol was used. The maximum method required the subject to exert all of his ability to achieve maximum oxygen consumption. Meanwhile, the maximum heart rate value measurement used the age variable with the maximum heart rate value of experimental results (maximal heart rate = 220_Age).

During the first test, after 10 min of a general warm up, the subjects were asked to do maximum jump heading 8 times without break. Furthermore, during the second week, the subjects were asked to do maximum jump heading 8 times after the maximum fatigue test program using a heart rate zone monitor integrated with a treadmill ergometer. To measure the ball speed, speed radar gun was mounted perpendicular to the subject behind the goal. To analyze movement, a slow motion video recording system integrated into the 3D motion analysis software (Diaz IV frame, Japan) was used.

Fig. 2. VO₂Max data collection using the direct gas analyzer system

Statistical Analyses

The data collected are expressed as the mean $\pm$ standard deviation. To determine pre post effects, the t-test for dependent samples was applied. The normal distribution of the data was verified by the Kolmogorov-Smirnov test. The significance level was set to $p < 0.05$. Statistical evaluation was conducted by IBM SPSS (SPSS Version 20.0 for Windows, Chicago, IL, USA).

Research Design Scheme

The research was conducted in the sport science laboratory at the Faculty of Sport And Health Education, Universitas Pendidikan Indonesia. The placement of AMTI 3D force platform devices was parallel to the goal, while the computer software application was on the right side of the subject area. To measure the ball speed, a radar speed gun was placed perpendicular to the subject area behind the goal. Furthermore, the jump heading technique data collection process used 2 video cameras (Panasonic HC-V100 Full HD camera) and a high speed camera. The hanging ball pole was placed on the left side of the force platform.

Fig. 3. Field data collection scheme (top image view)

The series of motion mechanics of jump heading skills were divided into four phases, which included 1) the loading leg preparation phase; 2) the takeoff movement phase; 3) the impact ball phase; and 4) the follow through phase (Naunheim et al, 2013). The kinetic and kinematic data variable indicators consisted of ball velocity (m/s), jump height (cm), maximal leg power (W), vertical force (N), knee take off flexion (deg), knee angular velocity extension take off (deg/s), trunk flexion take of (deg), trunk extension angular velocity take of (deg/s), maximal flexion in air (deg), trunk angular velocity flexion (deg/s), knee flexion at air bone (deg), head velocity (m/s), and feet landing (N).

Fig. 4. Analysis of the mechanics of jump heading movement in soccer; A. Loading leg preparation phase B. Take off movement phase C. Ball impact and follow through phase (source image: personal data).

Results

The results of this study are illustrated in the table 1 – 3 and figure 1 – 8 shown below. The table shows the average values and standard deviations. Table 1 shows the anthropometric data of the subjects including their age (years), height (m), body mass (kg), and BMI (kg/m^2). Table 1 shows that the average age of the players is 18.1 ± 2.6 years, the average height is 1.66 ± 0.04 m, the average body mass is 60.6 ± 4.26 kg, and the average BMI is 22.1 ± 1.2 kg/m^2 . In addition, Table 1 shows that the result of the BMI measurement analysis indicates that the average BMI of the players is in the normal category.

Table 1. Data on the participants (age, height, body mass, and BMI)

Subject	Height (m)	Body Mass (kg)	BMI (kg/m^2)
1	1.73	69.2	23.1
2	1.65	59.7	21.9
3	1.64	58.6	21.8
4	1.67	55.4	19.9
5	1.68	68.3	24.2
6	1.69	60.8	21.3
7	1.64	58.9	21.9

8	1.59	55.5	22.0
9	1.69	67.9	23.8
10	1.65	57.4	21.1
11	1.67	59.8	21.4
12	1.66	62.7	22.8
13	1.61	61.6	23.8
14	1.63	56.9	21.4
15	1.75	66.9	21.8
16	1.71	55.6	19.2
17	1.62	60.9	23.2
18	1.62	55.4	21.1
19	1.63	57.6	21.7
20	1.65	62.3	22.9
21	1.64	60.4	22.5
Mean	1.66	60.6	22.1
SD	0.04	4.26	1.21

Table 2 shows the results of the VO2Max test using the ergometer treadmill. Table 2 shows that the average VO2Max of 45.4 ± 3.05 , while the average maximum heart rate is 187.0 ± 4.63 . The obtained data indicate that the subjects used their maximum ability during the test. This conclusion was clearly confirmed by the maximum heart rate (HR Max) result, which showed that significant fatigue occurred.

Table 2. VO2Max and HR Max data for the of subjects

Subject	VO2Max (ml/kg/min)	HR Max (bpm)
1	43.3	193
2	45.2	182
3	44.2	178
4	48.1	191
5	50.5	190
6	48.5	179
7	41.2	192
8	49.1	184
9	43.2	186
10	44.4	193
11	47.3	185
12	47.6	192
13	44.4	184
14	44.3	191
15	42.4	181
16	40.2	188
17	50.7	192
18	48.1	189
19	40.2	183
20	45.2	184
21	46.2	189
Mean	45.4	187.0
SD	3.05	4.63

Fig. 5. Image of the subject impacting a ball while performing jump heading

Table 3 shows the data for normal (non-fatigue) and fatigue conditions. The analysis of kinetic and kinematic data variable indicators consists of the ball velocity (m/s), jump height (cm), maximal leg power (W), vertical force (N), knee take off (deg) flexion, knee angular velocity extension take off (deg/s), trunk flexion take off (deg), trunk extension angular velocity take off (deg/s), maximal flexion in air (deg), trunk angular velocity flexion (deg/s), knee flexion in air (deg), head velocity (m/s), and feet landing (N).

Table 3. Kinetic and kinematic variables during under fatigue and non-fatigue condition

Variable Kinematic Analysis	Mean and SD	
	Fatigue	Non fatigue
Ball velocity (m/s)*	19.3 ± 5.7 *	11.8 ± 3.5
Jump height (cm)*	41.9 ± 6.8	47.6 ± 5.1 *
Maximal leg power (W)*	1231.6 ± 4.2	1455.3 ± 4.8 *
Vertical Force (N)	243.4 ± 3.2	253.4 ± 4.1
Knee flexion take off (deg)	42.1 ± 3.5	38.4 ± 4.2
Knee extension angular velocity take off (deg/s)	247.4 ± 1.2	251.6 ± 1.4
Trunk flexion take off (deg)	63.6 ± 0.83	65.4 ± 0.96
Trunk extension angular velocity take off (deg/s)	211.4 ± 1.1	216.2 ± 1.3
Trunk maximal flexion in air (deg)*	78.4 ± 2.1	62.7 ± 2.4 *
Trunk flexion angular velocity (deg/s)	185.6 ± 3.5	199.3 ± 3.1
Knee flexion in air (deg)	49.3 ± 1.4	48.1 ± 1.6
Head velocity (sec)*	0.52 ± 0.08	0.43 ± 0.05 *
Feet landing (N)*	432.1 ± 5.2 *	378.2 ± 5.8

* Shows significant differences at 0.05

The analysis of thirteen variable indicators showed that six items had significant differences when players performed maximal jump heading under fatigue and non-fatigue conditions. The mean comparison of ball velocity, jump height, maximal leg power, trunk maximal flexion in air, head velocity, and feet landing under fatigue and non-fatigue condition, which were analyzed by an independent sample t-test, showed considerable differences under the fatigue condition ($p = 0.033$, $p = 0.041$, $p = 0.034$, $p = 0.042$, $p = 0.041$, $p = 0.023$ respectively). A significant differences in the ball velocity ($p = 0.033$) when the players performed under fatigue (19.3 m/s) and non-fatigue (11.8 m/s) conditions.

Fig. 6. Differences in the maximal leg power and jump height under non-fatigue and fatigue conditions.

Figure 7 shows significant differences in the maximal leg power ($p = 0.034$) and jump height ($p = 0.041$) under fatigue and non-fatigue conditions. The result shows that when the leg power decreases, the power loss of vertical force also decrease. Accordance to third law of Newton, if an object receives a force, the object will transfer energy in the opposite direction with the same magnitude (Small, McNaughton, Greig, Lohkamp, and Lovell, 2009).

Fig. 7. Differences in the trunk flexion in air and head speed under non-fatigue and fatigue conditions.

Figure 8 shows that there are significant differences in the maximal trunk flexion indicator variable, trunk flexion ($p = 0.042$), and head velocity ($p = 0.041$). Fatigue causes changes in the body movement mechanism, which results in uncontrolled movements and in the lack of body movement concentration (Himanshu et al., 2017). Concentration is the ability to maintain attention on the relevant match environment (M. Mohr et al., 2010). Concentration is needed when players conduct heading skills that will produce the speed and accuracy of the ball direction towards the target. Therefore, because attention may be distracted by opponent's movements, players must possess high the level of concentration, the ability to anticipate the moving ball direction, and the ability to direct the ball to the opponent's goal.

Fig. 8. Differences in feet landing under non-fatigue and fatigue conditions.

Figure 9 shows a significant difference in the feet landing variable indicator [432.1 ± 5.2 N ($p = 0.003$)]. Under fatigue conditions, landing will be less controlled owing to the lack of coordination and harmonization of body segment movements (Kristensen et al., 2004). The incorrect feet position while landing may increase the risk of injury to the knee and ankle joints. From 1990 to 2014, the number of injuries in football each year increased by 78% in the professional league. The injuries occurred in the knee (34%) and ankle (21%) joints (Bauer, Thomas, Cauraugh, Kaminski, and Hass, 2001). These injuries can be prevented by applying proper training patterns. An appropriate program and continuous efforts to improve the players' physical condition may also minimize the risk of injury.

Discussion

This study was conducted to investigate the effects of fatigue on the kinematics of heading performance in soccer. The biomechanics of cervical spine, hip joint, heading ball velocity and acceleration were calculated. Both cervical spine and hip joint angles were analyzed at the time of ball contact. To examine the effects of fatigue on the heading performance, participants were asked to complete the maximum oxygen consumption value (VO2Max) and the maximum heart rate (HR Max) tests, which provide information about the limit of the athlete's maximum physical ability to perform physical activity. This present study applied the soccer fatigue protocol, which has been formerly validated and used to induce fatigue conditions (Terrados, 2017). A significant difference of ball velocity ($p = 0.033$) was observed when the players performed under fatigue and non-fatigue conditions. Owing to the muscle fatigue that occurred after a long muscle contraction, the muscle is no longer able to contract within a certain period of time. Muscle fatigue refers to a process that approaches the actual physiological definition of reducing response to incoming stimulation (Kristensen, Andersen, and Sørensen, 2004). When there is fatigue, the player will have difficulties controlling the ball, especially during jump heading. Defender and attacker players frequently use heading techniques in a match. In one match, on average, players can perform jump heading, 35 times for the defender and 27 times for the attacker (Becker, Fröhlich, Kelm, & Ludwig, 2017; Moir, 2008).

In term of ball velocity, it is typically assumed that velocity decreases when participants are fatigued and previous studies support this assumption. However, additional research has shown that changes in ball velocity under the condition of fatigue owing to extended performance may vary by individual; however, heading ball velocity and acceleration may not be an appropriate way for assessing fatigue. This indirect comparison may suggest that the effects of fatigue protocol are equivalent to the previous method and this study. According to previous reports, the effect of fatigue on performance accuracy in various sports (e.g., throwing in team handball, water polo, and kicking in soccer) are controversial. Small et al, (2009) have reported that the condition of fatigue decreased throwing accuracy in team handball, however, no changes were observed in soccer and water polo under the condition of fatigue. Despite this discrepancy, studies tennis and soccer players showed that accuracy was affected when athletes were fatigued. Thus, the accuracy of heading performance can be also affected by fatigue, which is generated by the soccer fatigue protocol used. A future study may be conducted to examine this variable.

Conclusions

Fatigue clearly affects the quality of a header's motor performance. Thus, it is essential to counteract changes in the kinetics and kinematics of the headers when they experience fatigue. Heading ball velocity and acceleration at the time of ball contact were not changed by five sets of 90s fatigue protocol soccer course to induce fatigue. In addition, cervical spine joint and hip joint angle, velocity, and acceleration at the time of ball contact were not changed by five sets of the 90s fatigue protocol soccer course to induce fatigue. The results of this study showed that the 1) ball velocity and acceleration may not be used exclusively as the signs of fatigue even if athletes have the condition of fatigue during the practice or game; 2) the cervical spine and hip joint angle, velocity, and acceleration cannot be the only indicators of fatigue even if athletes have the condition of fatigue during the practice and game; 3) research or training personnel should adopt this protocol to study changes in the ball velocity and acceleration and cervical spine and hip joint angles, velocities, and accelerations. It is important to recognize that recreationally active male individuals may require to complete more than five sets of 90s fatigue protocol soccer course to fully induce fatigue. We recommend that coaches and athletes strengthen their core muscles. In addition, cervical and neck muscles should become the focus in complementing exercise programs.

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