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The Effects of Fatigue on Biomechanics of Heading Performance in Soccer

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THE EFFECTS OF FATIGUE ON BIOMECHANICS OF HEADING PERFORMANCE IN SOCCER

A Thesis Presented

By

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ABSTRACT

Title of Thesis: **THE EFFECTS OF FATIGUE ON BIOMECHANICS OF HEADING PERFORMANCE IN SOCCER**

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Soccer is one of the high intermittent sports, in which the athletes perform various activities of different intensities over a prolonged period. One of the most important and potentially dangerous skills in soccer is heading because it can potentially cause concussion if it is not executed correctly. Even though coaches and practitioners recognize that heading the ball is one of the factors to cause concussion, there are few studies that have examined the kinematics of head and neck motion while performing heading skill. Therefore, the purpose of this study was to examine the effects of short period fatigue on the biomechanical performance of soccer heading skill. Six competitive college male soccer players (age, 21.5 ± 3.15 years; height, 1.76 ± 0.06 m; mass, 71.38 ± 9.55 kg) participated in this study. A standard two-dimensional kinematic analysis was conducted using a high-speed video camera operated at 120 Hz during heading performance. A 90-second fatigue protocol soccer course was set up to mimic a real soccer game situation. All soccer players completed fatigue protocol five sets to induce fatigue. The mechanics of heading skills were recorded prior to the fatigue protocol and then after each fatigue protocol. Six joint reflective markers were placed on the right side of each participant's body. The statistical analysis between the baseline and after each fatigue protocol data was conducted using one-way repeated measure ANOVA at $\alpha = 0.05$ and followed up by *t*-test with Bonferroni adjustment if a significant difference was found. The result showed that there were no statistically significant differences in the heading ball velocity and acceleration, cervical spine and hip joint angle, velocity and acceleration at the time of ball contact. The results of this study suggest that heading ball velocity and acceleration, biomechanics of cervical spine and hip joint may not indicate fatigue even if athletes were fatigued during practices or games. Moreover, recreationally active male individuals may require more than five sets of 90-second fatigue protocol soccer course to induce fatigue if research or training personnel intend to use this protocol to study changes in heading ball velocity and acceleration and cervical spine and hip joint angle, velocity, and acceleration at the time of ball contact.

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Soccer is a high-intermittent sport, in which athletes perform various activities in different intensities over a prolonged period.[1] During a game, soccer players perform 1,000 to 1,400 short-period actions that change every three to five seconds including actions with ball and without ball such as dribbling, tackling, running, jumping, kicking, and heading.[2, 3] One of the most important and dangerous skills in soccer is heading because it can potentially cause concussion if it is not executed correctly. Marar indicated a large percentage of total injuries among high school soccer players (girls: 15.4%; boys: 11.1%) is from concussion.[4] Among both girls and boys, the activity most frequently related with concussion was heading performance (27.7% and 31.1%, respectively). In addition, approximately 60% of injuries sustained while performing heading skill were concussions. [4] Even though coaches and practitioners recognize that heading the ball is one of the mechanisms of concussion, there are few studies that have examined the kinematics of head and neck motion while performing the heading skill.

Fatigue during the game is one of the critical factors that could potentially affect athletic performances and movements. According to previous study, Mohr indicated that soccer players present two different fatigue patterns: a short fatigue pattern (momentary fatigue), which occurs depending on different game situations; and a long fatigue pattern related with long periods (from start of the game to finish).[5] Research studies have examined the effects of fatigue on injuries or performances on muscle strength, angles of peak torque of hamstring muscles, and ground reaction forces.[6, 7] Some research studies have evaluated the relationship between fatigue and injury in soccer players.[8, 9] However, these studies primary focused on physiological changes in the lower extremities, as opposed to mechanical differences between fatigue and upper extremities. Thus, there is a lack of understanding how fatigue can affect head and neck injuries during the heading performance even though coaches and practitioners recognize that heading the ball may potentially cause concussion. The purpose of this study was to examine the effects of short period fatigue on the mechanism of soccer heading skill. Specifically, the ball velocity and the kinematic variables of joint angle, velocity, and acceleration of the cervical spine and hip for both before and after applying fatigue protocol were examined. By comparing both pre-fatigue and post-fatigue condition, coaches and researchers would be able to obtain a comprehensive understanding of the skill of heading in soccer and the effects of fatigue on heading performance. Further, the findings could help coaches and practitioners understand the effects of short period fatigue on human body movement, so a proper strength and conditioning program may by prescribed to minimize head and neck injury for soccer players.

As sports become important part in the Americans' lives, various organizations, researchers, coaches, parents, and clinicians have critical responsibilities to provide an environment that decreases the risk of injury during sports performances.[10] Athletic trainers, who are part of clinicians in the sports medicine, also should provide care and programming to prevent sports injuries and improve athletic performance. For these reasons, this study could help decrease the number of concussions with understanding of the influences of fatigue on biomechanical changes in soccer heading performance and provide practical and useful information for athletic trainers and practitioners.

LITERATURE REVIEW

Soccer is one of the most common and popular sports in the world. The International Federation of Association Football (FIFA) reported that approximately 265 million people participated in soccer worldwide in 2007.[11] There are currently 209 nations recognized for men and 177 for women listed in the FIFA World rankings process. Participation at both elite and recreational levels has increased significantly in women's soccer. Fahmy indicated that only two international matches were played in 1971 compared to over 500 competitions involving 141 countries in 2010, with almost 29 million women competing in soccer in 2011.[12] In the United States, the popularity of soccer has been increasing, and it is recognized as the primary youth participation sport. During the 2009-2010 school year, over 390,000 student athletes participated in the 11,375 authorized boys' high school soccer programs; more than 25 percent of participation has been increased in 10 years.[13] According to National Federation of State High School Associations (NFHS), the number of high school soccer programs in the U.S. has approximately doubled in the past 20 years.[13] Due to its' popularity, soccer is reported to have the third highest number of injuries in the U.S after football and wrestling.[14]

Previous researchers investigated about movement demands of men's soccer athletes.[1, 15-17] Soccer is one of the high intermittent sports, in which athletes perform various activities at different intensities over a prolonged period.[1] During the game, soccer players perform 1,000 to 1,400 short period actions that changes every three to five seconds including actions with ball and without ball such as dribbles, tackles, running at various velocities, jumps, kicks and headings, and each type of movements varies significantly in terms of physiological demand on athletes.[2, 3, 18, 19]

A typical soccer game is 90 minutes in duration (two halves with 45 minutes with a 15-minute halftime break). The effective time in the game that subtract the time such as substitution, injuries, goals, and stoppages is nearly 50 minutes or 55% of the total duration of the match.[20] In general, elite soccer players cover approximately 11 kilometers in distance with moderate intensity effort near the anaerobic threshold (80 to 90 percent of maximal heart rate) and the ratio of work to rest is 1:8 depending on teams' strategy.[1, 15, 21-24] In addition, the average time of ball possession per each player in the game is from 44.6 to 74.3 seconds.[25] According to Withers, soccer players in the Australian Professional National League perform nearly 50 high speed changes in direction during a competition.[26] Hence, the activity profile of the soccer players can be considered as high intensity, repeated, multidirectional sprint, and match specific efforts, combined with different bouts of low to moderate intensity activity for the duration of the game.

Muscle Fatigue

Fatigue is defined as the inability to continue a desired level of intensity during task.[27] Although the effect of fatigue on injury occurrence is unclear, within the field of exercise physiology or sport, fatigue is defined as "feeling or tiredness or exhaustion or a need to rest because of lack of energy or strength."[28] According to Abbiss, different fields of sports science have described fatigue best match individual disciplines.[29] For example, biomechanists may evaluate fatigue as a decrease in the muscle force output from the breakdown of mechanical motion whereas psychologists may define fatigue as feeling of tiredness, and physiologists may measure fatigue as the failure of a particular physiological system.[29] In addition, as Abbiss explained that there are several interrelated models for exercise related fatigue such as cardiovascular/anaerobic model (decreased in function of cardiovascular function and the capacity to supply the body with rich-oxygen blood with removing metabolic by products at the same time), energy supply model (an incapability to meet energy demand for working muscle), neuromuscular model (failures in excitation-contraction coupling), muscle trauma model (macro/micro strain to the muscle fiber structure and whole muscle), biomechanical model (decreased efficiency of movement with strenuous or prolonged exercise), thermoregulation model (body's self-protection from increased temperature), psychological/motivational model (reduced motivation to maintain activity), and central governor model (overarching body safety switch against overload).

As fatigue is considered negative and an inevitable result of exercise, research has investigated effects of fatigue on exercise performance.[30-32] Evidence from previous researches studied from different sports suggest that both perceived fatigue produced by exercise and fatigue associated with muscle force are the risk factors for injury during competition and practice.[33-36] In ice hockey, a study of high school players have indicated that fatigue may increase the risk of injury.[35] In the skill of hockey department, research has shown that fatigue may change backward skating mechanism.[36] In addition, basketball players in China have reported that they believe when they experience fatigue, they are more prone to injury.[34] Hawkins indicated that the final 15 minutes of both halves in a soccer game is where the majority of non-contact injuries occur; as the duration of athletic event increases, the risk of injury increases as well. Thus, it can be concluded that fatigue can be a major risk factor for injury.[37]

There are different methods to assess and evaluate fatigue such as questionnaire or electromyography (EMG). The objective methods of measurements for fatigue include using EMG, altering muscle and body segment coordination, changing in posture and accuracy of performance.[38] Jump landing is a common test to measure of fatigue in athletic performance in a laboratory setting, and any weakness in the lower extremity muscle may result in injury to the knee or ankle joint.[38] Researchers have indicated that fatigue changes the kinematics of landing which makes the knee joint more vulnerable to injury.[39, 40] Specifically, fatigue increases hip and ankle muscle forces and the anterior knee shear force during landing.[39, 41]

Heading and Concussion

The skill of heading in soccer is first performed by extending head and trunk backward, followed by a quick forward head and truck flexion movements to strike the ball with player's forehead.[42] The heading technique requires high velocity of trunk hyperextension to generate a high impact force applied to the ball with a rigid neck musculature in order to stabilize the head during the movement. The most common heading injuries are due to improper mechanics in which the ball impacts the head with insufficient head and neck stability and the lack of flexion in the neck joint.[43] According to Marar, a large percentage of the injuries experienced by high school soccer players (girls: 15.4% and boys: 11.1%) are concussions. Tysvaer indicated that up to 22% of soccer injuries consist of head injuries including concussions.[4, 44] In addition, approximately 60% of injuries sustained by concussions experienced as a result of heading performance.[4] Sports-related concussions are often the result of an external force, which causes an impacting the skull. Sports-related concussions may result from contact with the playing surface, a part of sports equipment, or another player. The collision can produce acceleration and deceleration forces, which may cause damage to the brain's central nervous system. The degree of concussion depends on a variety of factors that include the direction of impact, anatomical structures, and distribution of forces.[45] The complexity surrounding the mechanism of head injuries and concussive symptoms, the concussion assessment and management are extremely challenging. Head injuries and concussion can potentially be ignored due to ignorance, poor information given by the athletes, and inadequately staffed sporting events. Currently, there are different types of concussion assessment include postural assessments, graded symptom checklists, neuropsychological tests, balance protocols, and mental status measurements. These concussion assessment protocol and tests are commonly used in both laboratory and field settings.[46]

Summary

Previous research studies have investigated the relationship between fatigue and injuries or performances on muscle strength, angles of peak torque of hamstring muscles, and ground reaction forces.[6, 7] Some researchers also have examined muscle and body segment coordination, changes in posture, and changes in accuracy of performance.[38] However, there are lack of studies that evaluate biomechanical changes in head and neck (cervical spine) and trunk and hip motions. Due to the lack of empirical evidence, it is important to examine the biomechanical changes in ball velocity and the joint angle, velocity, and acceleration of the cervical spine and hip when athletes become fatigued. The results of the study could help athletic trainers, coaches and other healthcare providers better understand the effects of fatigue on soccer heading skill. A proper strength and conditioning program could be used to players to minimize chances of concussion and head and neck injuries.

METHODS

Participants

Before conducting this study, the researcher obtained approval from the University's Institutional Review Board (Case #2018090). Six healthy, competitive collegiate male soccer players (age: 21.5 ± 3.15 years; height: 1.76 ± 0.06 m; mass: 71.38 ± 9.55 kg) participated. Participants had soccer experience of at least five years, were free of injury at the time of data collection, and had no history of surgery to their back or lower extremities. Informed consent form was obtained from the participants prior to participation.

Experimental Setup

Six joint reflective markers were placed on the right side of the body (sagittal plane) including participant's top head, spine of cervical two (C2) and seven (C7), greater tubercle of humerus, greater trochanter of femur, and lateral epicondyle of the femur. A 90-second fatigue protocol soccer course was set up to induce fatigue.[47] The rationale for setting up a 90-second course was to induce fatigue based on the depletion of the anaerobic energy system.[48] This protocol consisted of shooting, running, pivoting, cutting, jumping, dribbling, and heading to mimic a real soccer game situation (Figure.1). Data collection was conducted in one session and was approximately one hour in duration for each participant. A Casio high speed video camera (Model: Ex-FH25) was used to capture the kinematic movement in the sagittal view at 120 frames per second during heading performance. Additionally, a 650W artificial light was used to assist joint marker identification.

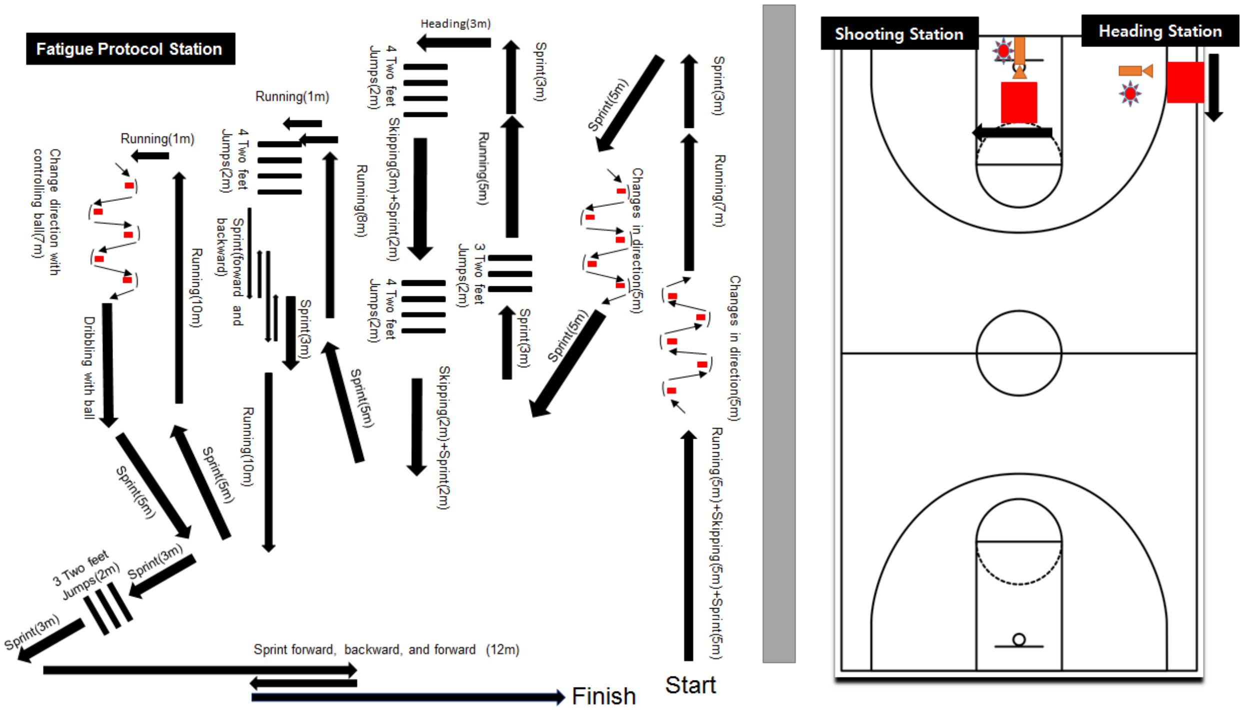

Figure 1. A 90-second fatigue protocol soccer course to induce fatigue

Procedures

All participants were asked to wear indoor soccer shoes and a soccer uniform or sweatpants to facilitate the placement of six joint reflective markers. Prior to testing, participants were asked to warm-up and stretch own their ways. The participants performed heading using a header pendulum fixed to a metal frame with a rope attached on the wall (Figure 2) above the participants with standardized ball (size 5; diameter 0.22m). The ball pendulum height was standardized to the distance of one ball diameter between head and pendulum. The participants' starting position was selected so that the ball was at the height of the forehead. The participants were instructed to perform a header from a standing position by jumping with both legs and heading the ball as forcefully as possible in a horizontal forward direction.[49] After setting the ball heights, participants performed five sets of heading and shooting for the baseline testing. After the baseline testing, participants performed fatigue protocol. Participants were asked to finish five sets of fatigue protocol in 90 seconds for each set. Five sets of heading performance were recorded at the end of each fatigue protocol.

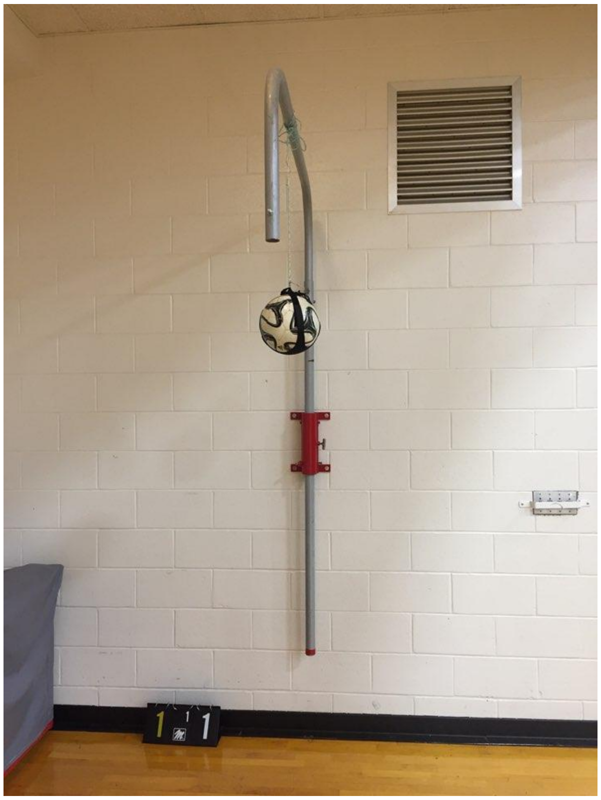

Figure 2. A header pendulum fixed to a metal frame with a rope attached on the wall

Data Processing

All video trials were transferred onto a personal laptop computer and the three best trials, determined by ball velocity, were analyzed to ensure the reliability of the data. Since each participant performed heading three times each session, baseline and five sets of fatigue protocol, a total of 108 trials (6 participants x 3 trials of heading performance x 6 different timelines) were collected in this study. A standard two-dimensional kinematic analyses were conducted with

Ariel Performance Analysis System (APAS^{TM}) software, and a digital filter function (x = 8 Hz; y = 8 Hz) was applied to reduce the noise of the data.

Statistical Analysis

Mean and Standard Deviation (SD) values were calculated from three trials of each measurement in each time point. A one-way repeated measure analysis of variance (ANOVA) was conducted at $\alpha = 0.05$ and followed up by *t*-test with Bonferroni adjustment if a significant difference was found. All statistical analysis was conducted with SPSS (v. 24) software. Was effect size included?

RESULTS

A one-way repeated measure analysis of variance (ANOVA) was conducted at α = 0.05 for the heading ball velocity and acceleration at the time of ball contact. Using the Huynh-Feldt correction in the repeated measure ANOVA design, no statistically significant differences were found in the time effects for the ball velocity and acceleration. Table 1 and 2 show the changes in heading ball velocity and acceleration at the time of ball contact, as well as *p* values compared with the baseline.

Table 1. Comparison of heading ball velocity at the time of ball contact between baseline and each set of fatigue protocol.

Ball velocity (m/s)		Mean (SD)			
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
1.29	1.26	1.22	1.41	1.23	1.41
(0.25)	(0.18)	(0.28)	(0.29)	(0.20)	(0.23)
p	1.00	1.00	1.00	1.00	1.00

Table 2. Comparison of heading ball acceleration at the time of ball contact between baseline and each set of fatigue protocol.

Ball acceleration (m/s^2)		Mean (SD)			
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
20.00	20.40	20.96	22.83	21.50	21.72
(3.93)	(3.86)	(4.63)	(5.71)	(5.52)	(5.63)
p	1.00	1.00	1.00	1.00	1.00

A one-way repeated measure analysis of variance (ANOVA) was conducted at α = 0.05 for the joint angle, velocity, and acceleration of cervical spine and hip at the time of ball contact.

Using the Huynh-Feldt correction in the repeated measure ANOVA design, no statistical significant differences were found in the time effects for the joint angle, velocity, and acceleration of cervical spine and hip. Table 3,4,5,6,7, and, 8 show the angular displacement, velocity, and acceleration of cervical spine and hip joint at the time of ball contact and *p* values compared with the baseline respectively.

Table 3. Comparison of angular displacement of cervical spine at the time of ball contact between baseline and each set of fatigue protocol.

Displacement of cervical spine (°)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
161.20 (12.29)	164.04 (12.42)	164.91 (15.22)	162.43 (14.56)	150.29 (27.54)	162.92 (11.39)
p	1.00	1.00	1.00	1.00	1.00

Table 4. Comparison of angular displacement of hip joint at the time of ball contact between baseline and each set of fatigue protocol.

Displacement of hip joint (°)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
167.76 (9.12)	162.86 (11.28)	163.48 (13.08)	163.61 (8.25)	164.34 (10.05)	165.05 (8.61)
p	1.00	1.00	1.00	1.00	1.00

Table 5. Comparison of angular velocity of cervical spine at the time of ball contact between baseline and each set of fatigue protocol.

Cervical spine velocity (°/s)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
58.72	-5.18	-43.19	71.93	27.99	-5.19
(70.00)	(126.61)	(104.04)	(67.24)	(95.89)	(72.85)
p	1.00	0.08	1.00	1.00	1.00

Table 6. Comparison of angular velocity of hip joint at the time of ball contact between baseline and each set of fatigue protocol.

Hip joint velocity (°/s)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
-59.22	-55.34	-140.54	-92.72	-91.55	-120.75
(110.11)	(117.01)	(114.68)	(135.44)	(140.16)	(117.25)
p	1.00	0.16	1.00	1.00	1.00

Table 7. Comparison of angular acceleration of cervical spine at the time of ball contact between baseline and each set of fatigue protocol.

Cervical spine acceleration (°/s^2)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
-267.10	2311.33	827.32	1051.70	2468.91	800.60
(1059.19)	(2545.99)	(3127.18)	(3329.65)	(2258.71)	(4261.01)
p	0.92	1.00	1.00	1.00	1.00

Table 8. Comparison of angular acceleration of hip joint at the time of ball contact between baseline and each set of fatigue protocol.

Hip joint acceleration (°/s^2)			Mean (SD)		
Baseline	Set-1	Set-2	Set-3	Set-4	Set-5
196.71 (457.44)	346.02 (649.93)	409.71 (312.57)	69.08 (591.60)	266.02 (280.12)	277.21 (213.72)
p	1.00	1.00	1.00	1.00	1.00

DISCUSSION

This study was conducted to investigate the effects of fatigue on the biomechanics 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. In order to examine the effects of fatigue on the heading performance, participants were asked to complete five sets of fatigue protocol in 90 seconds. The present study applied the soccer fatigue protocol, which has been formerly validated and used to induce fatigue conditions.[48] The results reported by researcher showed that no significant differences were observed in heading ball velocity and acceleration, cervical spine joint angle, velocity, and acceleration, hip joint angle, velocity, and acceleration at the time of ball contact between the baseline and five sets of fatigue protocol.

With regard to ball velocity, it is typically assumed that velocity decreases when participants are fatigued and previous studies supported this idea.[50, 52] However, additional research has shown that changes in ball velocity under the condition of fatigue by extended performance may vary by individual; however, heading ball velocity and acceleration may not be an appropriate way for assessing fatigue.[51] This indirect comparison may suggest that the effects of fatigue protocol are equivalent to the previous method and this study. According to the earlier reports, effects of fatigue on performance accuracies in various sports such as throwing in team handball, water polo, and kicking in soccer are controversial.[52-54] Nuno reported that the condition of fatigue decreased throwing accuracy in team handball, but no changes in soccer and water polo under the condition of fatigue.[52-54] Despite this controversial, other studies also conducted with tennis players and soccer players had established that accuracy is affected when athletes were fatigued.[55-57] Thus, the accuracy of heading performance also can be affected by fatigue generated in this soccer fatigue protocol and future study may be examined at this variable.

Although this study showed no significant difference in cervical spine and hip joint angle biomechanics at the time of ball contact, lower extremity landing strategies and the ability to attenuate impact during landing or the muscle required for the pretension might be changed after fatigue similar to other studies.[49, 58] Moreover, since heading performance in soccer is a difficult skill, which is more complicated by performing the task during other performance (e.g., walking, standing, jumping, running forward or backward, diving, or being challenged by an opponent), measuring only two joints' movement may not be sufficient to fully demonstrate or reveal ? the effects of fatigue on heading performance.[59] this study did not place markers on the lower extremities to test this hypothesis. This study was suggested that multi-joint coordination and activity of the muscle groups should be investigated in more detail in future research. Future studies are warranted to examine the biomechanics of lower extremities and ground reaction during heading performance in soccer.

According to previous literature, the condition of fatigue decreased ball velocity in soccer kicking or angular velocity of the lower leg and lower leg swing speed at the time of kicking.[48, 60] in studies as mentioned earlier applied exercise protocols that induced fatigue to the only localized joint and found the differences in the same joints that selected. However, it is essential to highlight the fact that this specifically designed fatigue protocol also mainly included the movements related to lower extremities such as sprint, jog, and jump even though the dependent variables were related to cervical spine and hip joint biomechanics. For these reasons, there were no differences in cervical spine and hip joint angle, velocities, and accelerations even if this soccer protocol induced fatigue to the participants.

The total amount of time for exercise has been associated with increased risk of injury. Previous studies investigated the effects of 90 minutes' fatigue protocol on lower extremities' kinematics and muscle strength.[8, 61] Small indicated that 90 minutes of fatigue protocol made the correlation between increased sprint time and reduced stride length, and Greig found the eccentric strength in hamstrings decreased as a function of time and after the halftime interval.[8, 61] Since the participants in this study accomplished the fatigue protocol in 90 seconds, most participants used a significant amount of anaerobic component rather than used all three different systems (ATP-PC, Glycolysis, and Oxidation) efficiently during this protocol. The previous study by Ortiz also reported that the condition of fatigue developed by the 30 seconds of Wingate anaerobic test did not affect dynamic knee joint stability and neuromuscular activation in recreational population.[62] Although the researcher in the previous study that applied similar protocol indicated that participants reached the level of fatigue according to the soccer fatigue protocol, the rapid recovery and time for collecting data between each set of the protocol may have played a factor prohibiting differences between each set.[48] In addition, as long-lasting but low-intensity fatigue protocols have shown that in more significant and more persistent reductions in quadriceps muscle force-generating capacity than the shorter bout of exercise with external resistance, the results could be varied if this study's protocol was more focused on simulating real soccer game time than exercise intensity.[63]

This study has several limitations that should be considered. One of the limitations of this study was the lack of available tools that are commonly used for the assessment of fatigued condition during physical exercises such as blood lactate level, heart rate level in relation to physiological symptoms, or the Borg scale Rating of Perceived Exertion (RPE) for subjective symptoms. Although measuring blood lactate level was claimed as to be the most accurate indicator for measuring and monitoring fatigue, this study followed a similar approach that was presented by Ferraz induced condition of fatigue with five sets of 90 second protocol.[64, 65] The rationale was to maximize the ecological validity in this research study; hence, this study used a fatigue soccer course protocol with less equipment on the field, not in the laboratory settings, to mimic the game situation on the field which coaches or practitioners do not measure blood lactate level during practices or games at the sideline. In addition, from the short communication with the participants after five sets of fatigue protocol, it revealed that participants did experience fatigue at the last set of protocol and could no longer sprint or jump as hard as they would be able to after they had completed the fatigue protocol. Furthermore, condition of fatigue cannot be evaluated in a single process. Multiple process of evaluating fatigue can be determined as a result of complicated interactions of various components within both peripheral nervous system (e.g., musculoskeletal fatigue) and the central nervous system (e.g., central fatigue).[66] Because of the complication of these systems, the effects of fatigue can be affected by the participants' psychological, physical, physiological and mental characteristics.[67] Each participant may demonstrate different reactions as a response to the same fatigue protocol. Therefore, using this fatigue protocol with an objective tool or method for assessing fatigue may resolve this individual issue and help achieve participants' intended exhaustion in a future study. Another limitation of this study is that the participants were recreationally active collegiate male students, so the results may be different if a research study was conducted on different levels of soccer players or different gender participants. In future studies, different levels of soccer player or different genders of population should be recruited when examining the effects of fatigue on biomechanics of heading performance in soccer.

CONCLUSION

This study was carried out to observe the effects of fatigue in ball velocity and acceleration, cervical spine and hip joint angle, velocity, and acceleration in six recreationally active collegiate male students. The results are summarized as follows.

Heading ball velocity and acceleration at the time of ball contact were not changed by five sets of 90-second 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 90-second fatigue protocol soccer course to induce fatigue.

The results of this study were suggested that (1) ball velocity and acceleration may not be used exclusively as the signs of fatigue even if athletes have condition of fatigue during the practice or game, (2) cervical spine and hip joint angle, velocity, and acceleration may not be the only indicators for fatigue even if athletes have condition of fatigue during the practice and game, (3) if research or training personnel adopts this protocol to study changes in 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 completing more than five sets of 90-second fatigue protocol soccer course to fully induce fatigue.

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