FATIGUE DOES NOT AFFECT THE KINEMATICS OF FREE THROW SHOOTING IN BASKETBALL

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ABSTRACT

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Kinematic analysis of basketball shooting is evolving, however the effects of fatigue on free throw shooting have not been studied. Therefore the effects of fatigue on the kinematics of free throw shooting among elite male basketball players was assessed. Ten healthy male collegiate basketball players participated in the study. Resting and fatigue heart rates of the participants were measured. After a 15 minute warm-up period, markers were placed on seven locations on the shooting arm's side upper and lower extremities. The free throw shots were recorded with two digital cameras at a speed of 60 frames/s at a stereoscopic position. Data were analyzed with the photogrammetry technique. Each participant performed free throw shots (pre-fatigue condition) until the two successful and two unsuccessful shots were collected. Then participants completed a fatigue protocol, which included sprints and squat jumping, until reaching their volitional exhaustion and free throw shots were repeated (post-fatigue condition). The elbow, trunk, knee and ankle joint angles were measured. Successful and unsuccessful shots were compared for pre- and post-fatigue conditions. The results demonstrated that fatigue did not affect free throw shooting and there was no significant joint angle difference ($p>.05$) between successful and unsuccessful shots ($p>.05$). It was concluded that fatigue does not affect the kinematics of free throw shooting of healthy male collegiate basketball players and

there were no differences in the kinematics of selected joint angles for successful and unsuccessful free throw shots.

KEYWORDS: Digital photogrammetry, kinematics, motion analysis, free throw shooting

ÖZ

YORGUNLUGUN BASKETBOL SERBEST ATISININ KINEMATIGINE ETKISI YOKTUR

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Basketbol şutunun kinematik analizi çok sık çalısılan bir konu olmasına rağmen, yorgunluğun serbest atışa etkisi henüz çalışılmamıştır. Bu yüzden yorgunluğun serbest atışa etkisi elit basketbolcular üzerinde çalısılmıştır. Bu çalışmaya, on tane üniversite takımlarında oynayan basketbol oyuncusu katılmıştır. Dinlenik ve yorgunluk anındaki kalp atışı ölçülmüştür. Onbeş dakikalık ısınma süresinden sonra, şut anında kullanılan kolun tarafındaki yedi bölgeye markırlar yapıştırılmıstır. Serbest atışlar stereoskopik yerleştirilmiş, 60 görüntü/s de görüntü alabilen iki kamera vasıtası ile görüntülenmiştir. Daha sonra, elde edilen data fotogrametri tekniği ile incelenmiştir. Her katılımcı, iki başarılı iki de başarısız (yorgunluk öncesi) serbest atış kaydedene kadar serbest atış kullanmıştır. Daha sonra katılımcılar, içerisinde depar ve zıplama bulunduran yorgunluk protokolünü tükenene kadar tamamlamış ve tekrar serbest atış kullanmışlardır (yorgunluk sonrası). Dirsek, gövde, diz, ve ayak bileği açıları hesaplanmıştır. Başarılı ve başarısız atışlar, yorgunluk öncesi ve yorgunluk sonrası durumları için karşılaştırılmıştır. Elde edilen sonuçlara göre yorgunluğun serbest atışa etkisi yoktur. Hatta seçilmiş bütün eklem açıları, başarılı ve başarısız serbest atışlarda farklılık göstermemektedir ($p>.05$). Sonuç olarak, yorgunluğun, sağlıklı ünivesite seviyesindeki erkek basketbolculardaki basekbol serbest atışının kinematiğine etkisinin olmadığına karar verilmiştir. Ayrıca, başarılı be başarısız serbest atışların da kinematiğinde fark bulunamamıştır.

Anahtar Kelimeler**:** Dijital fotogrametri, kinematic, hareket analizi, serbest atış.

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CHAPTER I

INTRODUCTION

Basketball is the second most popular international sport in the world. FIBA (2006) claimed that basketball involves more than 450 million licensed basketball players registered from 200 different countries. Basketball has surpassed football as the most popular sport in areas like Asia and Australia and it is expected to surpass football in all around the world.

Jump shots, lay-ups, set shots and free throws are used by players to score on behalf of their teams in a basketball game. However, among the above mentioned scoring opportunities, free throw is the only scoring opportunity that no contestant is allowed during the execution of the action. Therefore, free throws can be a decisive element in the game. Besides practicing free throws, athletes should also take fatigue into account while performing free throws. Bompa (1999) claimed that most athletes can perform a decent skill at low velocity because it generates little fatigue. However, technical breakdown occurs under high velocities or under conditions similar to the competition. Therefore, the mechanics of the free throw action may break down when an athlete experiences fatigue.

Free throws are the penalties associated with various types of fouls (including personal, technical, and unsportsmanlike fouls), but mostly with personal fouls. A personal foul is a player's contact foul with an opponent, whether the ball is live or dead. Free throws can be used as a penalty method for above mentioned fouls. The number of free throws to be taken is determined as follows:

• If the foul is committed on a player not in the act of shooting and if the team is filled the foul limit (i.e. four fouls per quarter) in that particular quarter: two free throws will be awarded.

• If the foul is committed on a player in the act of shooting and if the player is successful in making the shot: the basket counts and, in addition, one free throw will be awarded.

• If the foul is committed on a player in the act of shooting who fails to score: two or three free throws, depending on where the shot was taken, will be awarded (FIBA 2008).

Because of the high occurrence frequency of the above mentioned conditions that results in fouls in basketball, free throw is a very common situation during the game. In 2004-2005 NBA season, mean of 26.1 free throws per game per team were attempted (ESPN 2008). From these free throws 72.9% achievement were reached by the players. Therefore, it can be assumed that free throws are the key determiners for a team to win or lose, especially in close games.

After year 2000, FIBA has introduced new rules regarding the game. According to the new rules, the offense time reduced from 30 seconds to 24 seconds, which resulted in more aggressive type of game play, increased physiological demand on players, and increased pace of the ball game. As a result, basketball became even more demanding sports for the players.

Basketball is an intermittent sport which includes walking, jogging, running, sprinting, jumping, defensive sliding etc (Bompa 1994; McInnes, Carlson et al. 1995; Ben Abdelkerim, El Fazaa et al. 2007). According to Bompa (1994) total energy used in basketball game is obtained from 80% of anaerobic alactic (ATP/CP) and 20% of lactic acid (LA) energy delivery systems. Extremely quick and explosive activities with very short time are the cause of the use of ATP/CP energy delivery system. On the other hand, events of slightly longer duration, which are still very intense in nature, are the cause of the use of LA energy delivery system. On the same manner with Bompa, McInnes (1995) stated that since basketball places considerable demands on the cardiovascular and metabolic capacities of players, physiological requirements of basketball are high. It was claimed that during the real games, not only the blood lactate level but also the mean heart rates of the players are close to their maximal values (McInnes, Carlson et al. 1995; Ben Abdelkerim, El Fazaa et al. 2007). Therefore, it can be speculated that players are expected to perform under fatigue conditions.

Fatigue has been claimed as a detrimental factor which may affect performance, coordination, and skill of an athlete (Ivoilov, Smirnov et al. 1981; Forestier and Nougier 1998; Kellis, Katis et al. 2006; Lyons, Al-Nakeeb et al. 2006). Fatigue can not be considered as a single process. It can be considered as an outcome of complex interactions of numerous different components within both central nervous system and the muscle system (McKenna 2003). Due to the above mentioned properties of the basketball game, fatigue can be claimed as an indispensible part of the game which may affect the success of a player and, therefore, requires attention to be studied.

To evaluate sports related skills and performance, sports biomechanists have been using and developing new techniques. Using multiple camera motion analysis systems along with the reflective markers, researchers are able to evaluate these movement kinematics (i.e. joint angles, angular velocities and accelerations) in 3-dimensional space. However, due to the high cost and the lack of mobilization of these high-tech systems, photogrammetric systems have been extensively used for simpler kinematic analyses. The latter system is superior in sports-related kinematic analyses since it can be used in the field and it has relatively low cost. This makes the kinematic analysis of certain movements in sports (e.g. free throw shooting in basketball) more feasible.

Since shooting in basketball is one of the most important parts of the game, basketball shooting styles have been an interesting subject for a lot of researchers. Physicists (Tan and Miller 1981; Gablonski and Lang 2005), engineers (Okubo and Hubbard 2006), and sports biomechanists (Hudson 1982; Elliot 1989; Walters, Hudson et al. 1990; Elliot 1992; Miller and Bartlett 1996; Rojast, Cepero et al. 2000; Button, MacLeod et al. 2003; Tsai, Ho et al. 2006) have dealt with various types of shooting styles in a very detailed manner. However, the kinematics of free throw shooting under the fatigue conditions, which can be claimed as a real game situation, is missing in the literature. Therefore, the findings of this study are expected to give insights to explore how the players cope with fatigue during free throw shooting. Moreover, studying the differences between successful vs. unsuccessful free throws under fatigue vs. non-fatigue conditions might provide necessary knowledge to the literature.

1.1 Hypothesis

1. Fatigue has an adverse affect on the kinematics properties of free throw action for basketball players.
2. Successful and unsuccessful free throw shots' kinematics will be different than each other.

1.2 Definitions of Terms

Fatigue: A state of discomfort and decreased efficiency resulting from prolonged or excessive exertion which may occur in any combination of the central or peripheral nervous system and the muscle system.

Free Throw: An unguarded shot taken from foul line by a player whose opponent committed a personal or technical foul which is worth one point.

Kinematics: The branch of dynamics concerned with the description of motion without considering the causes (forces) leading to the motion.

Elbow Angle: The intersection of the line that was drawn from the wrist marker to the elbow marker and from the elbow marker to the shoulder marker represented the elbow angle.

Trunk Angle: The intersection of the line that was drawn from the shoulder marker to the pelvis marker and from the pelvis marker to the knee marker represented the trunk angle.

Knee Angle: The intersection of the line that was drawn from the pelvis marker to the knee marker and from the knee marker to the ankle marker represented the knee angle.

Ankle Angle: The intersection of the line that was drawn from the ankle marker to the heel marker and from the heel marker to the metatarsal marker represented the ankle angle.

Successful Shots: Any successful free throw shot that touched neither the rim nor the backboard was claimed to be a successful shot.

Unsuccessful Shots: Any free throw shot that touched the rim or the backboard, regardless of its success, was claimed to be an unsuccessful shot.

1.3 Purpose of the Study

The purpose of this study is to explore the kinematics of free throw shooting in basketball and to compare the kinematics of free throws action before and after fatigue conditions. As a supplementary aim, this master thesis was designed to compare the possible differences between successful and unsuccessful free throw shots.

1.4 Significance of the Study

Researchers who are interested in the analyses of basketball shot mostly dealt with the kinematic properties of numerous shooting styles like free throw (Tan and Miller 1981; Hudson 1982), jump shot (Walters, Hudson et al. 1990; Miller and Bartlett 1996; Spina, Cleary et al. 1996; Tsai, Ho et al. 2006), and shooting against an opponent (Rojast, Cepero et al. 2000). One can speculate that the common limitation of the above mentioned studies was the lack of simulation of a real game situation (i.e. fatigue). However, one can speculate that fatigue is an indispensible part of a basketball game that needs to be taken into account when dealing with any kind of basketball shooting studies. Therefore, investigating the effects of fatigue on the kinematics of free throw shooting would provide crucial information that may be useful for not only researches and coaches but also basketball players.

1.5 Limitations

1) The proposed onset fatigue should be simulating the real game situation. However, in order to accomplish this, there should be two courts near each other. While one court can be used for analyses and other court can be used for simulating the real game situation. However, two side by side court was not possible in Middle East Technical University.

2) Since this study will be the kinematic analyses of basketball free throw shot, markers were put on some of the joints of the subjects. It may possibly adversely affect the performance of the subject.

3) Due to the financial limitations the blood lactate level, which may be a better indicator of induced fatigue condition, could not be collected. Instead, by using polar heart rate monitors heart rate values were collected and inferences were made about the induced fatigue level.

4) Subjects were the members of the Middle East Technical University and TAI basketball teams members, who voluntarily participated in this study.

5) Kinematic analyses have been done with various ways on numerous topics. The main problem related with the kinematic analyses is the unavoidable error that might happen during getting the 3D coordinates of the markers that were placed on subjects. To minimize these errors, all digital 3D optical motion capture systems

including at least 4 cameras which can operate up to 2000 frames/s along with the required software have been used in the literature. However, due to the financial limitations, 2 cameras operating at 60 frames/s were used. Moreover, the 3D coordinates of the markers was found by using Picktran software. However, instead of using motion capture systems to find the 3D coordinates of the markers, markers had to be marked manually on each captured pictures. Therefore, the error of the calculated 3D coordinates of the markers might be higher than the more sophisticated motion capture systems.

6) Due to the tough nature of the photogrammetric analyses, only ten participants were used and, therefore, the inclusion of control group was omitted.

CHAPTER II

REVIEW OF LITERATURE

Different kinds of shooting in basketball were discussed extensively by physicians (Tan and Miller 1981), mathematicians (Gablonski and Lang 2005) and sports biomechanists (Hudson 1982; Elliot 1992; Miller and Bartlett 1996; Rojast, Cepero et al. 2000) to solve the complicated nature of it. Although those papers covered most of the important theoretical and biomechanical features of shooting in basketball, none of them dealt with the possible player adaptations caused by physiological loads in real game situations. The purposes of this literature were to address the research that have been done by using movement analyses systems, the effects fatigue of fatigue on sports related performance and skill, and the recent findings of kinetic and/or kinematic analyses of different kinds of shooting in basketball.

2.1 Physiological Loads of Basketball

According to Bompa (1994), the total energy used in a basketball game is obtained from 80% of anaerobic alactic (ATP/CP) and 20% of lactic acid (LA) energy delivery systems. Extremely quick and explosive activities done in a very short time were the cause of using of ATP/CP energy delivery system. On the other hand, events of slightly longer duration which were still very intense in nature are the cause of using the LA energy delivery system (Bompa 1994). Similarly, McInnes et al. (1995) stated that since basketball places considerable demands on the cardiovascular and metabolic capacities of players, the physiological requirements of basketball are high. They investigated the intensities of activities and movement patterns during men's basketball game by video taping the movements and monitoring the heart rate and blood lactate responses of eight elite players during a real basketball game. They used eight categories to define player activities in basketball, which includes standing, walking, jogging, running, striding/sprinting, low shuffling, medium shuffling, high shuffling and jumping. Of all strides/sprints, 51% lasted longer than 1.5 s, 27% longer than 3 s and 5% longer than 4 s. On average, about 15% of actual playing time was spent engaged in very high intensity level play. High intensity run efforts were present once every 21 s of game time, with an average duration of 1.7 s. In addition, it was stated that elite basketball players spend 75% of playing time with a heart rate greater than 85% of their maximum hear rate. The mean blood lactate concentration was 6.8 +/- 2.8 mmol/l, indicating the involvement of glycolysis in the energy demand of basketball (McInnes, Carlson et al. 1995).

The rules of the basketball game changed in May 2000. The new rules shortened the offense time from 30 to 24 s and decreased the time allowed to cross midline for 10 to 8 s. Moreover, instead of playing in two 20 min halves, the games have been played 10 min of four quarters. Therefore, the pace of the basketball game substantially increased. These changes in rules was claimed to be a factor which may affect the physiological demands of the game. Therefore, Ben Abdelkerim et al. (2006) studied the physical demands of a real competitive game which was played under the new rules. According to their findings, players spend the 16.1% of the live time in highly intensity activities such as "specific movements", sprinting, and jumping in games that were played with the new rules. The same high intensity activity percentage before the rule changes was found to be 15% in a study that were done on Australian professional players (McInnes, Carlson et al. 1995). After the rules change, the mean heart rate during the game was found to be around 171 (±4) beats/min, whereas, the mean plasma lactate concentration was claimed to be 5.49 (1.24) mmol/l (Ben Abdelkerim, El Fazaa et al. 2007).

The physiological lads of the basketball is also claimed as to be playing position (i.e., guards, forwards, and centers) specific. It was claimed that centers spent significantly lower time in high intensity activities than guards and forwards. Consequently, the heart rate for guards was found to be significantly higher than that for centers during the entire game. However, there were no differences between the heart rates of forwards and centers. Moreover, the plasma lactate levels for guards were found to be significantly higher that those for centers (Ben Abdelkerim, El Fazaa et al. 2007).

2.2 Effects of Fatigue on Sports Related Performance

In the literature, there exist two different ways of inducing fatigue and those have been used to study the effects of fatigue in a sport related performance. One of which was inducing the fatigue locally on the selected limb that would be dominantly used in the execution of selected action (e.g. locally induced arm extensor muscle fatigue in an overhead throwing action (Forestier and Nougier 1998) or inducing the fatigue only in the lower leg during shooting in soccer (Aprioantono, Nunome et al. 2006). The other major way of inducing fatigue is to induce the whole body fatigue (e.g. completing an intermittent exercise that might simulate a real game situation). Although the effects of former way of inducing fatigue has been found as more prominent, the latter way can be speculated as a better way to study the effects of fatigue in a real game situation.

In a study of Forestier and Nougier (1998), the effects of localized fatigue on the coordination of a multijoint throwing task were studied. Six right handed handball players threw ball towards one of the three targets before and after localized muscular fatigue, while researchers collected kinematic data by using one infrared camera operating at 200 Hz. Maximum voluntary contractions (MVC) of the wrist flexors of the participants were assessed and 70% of this MVC was used in fatigue protocol. Fatigue was claimed to be induced when subjects, for a given trial, were unable to maintain the 70% MVC for at least 15 s. It was found that the accuracy had decreased after fatigue condition. Before induced fatigue, subjects used summation of speed principle (proximal -shoulder- to distal –hand- joint) during throwing tasks. However, once the fatigue was induced, participants showed absence of the temporal delay between elbow and hand peak velocity, namely, increased the rigidity of the multijoint system. Therefore to compensate the detrimental effects of fatigue and to be successful in throwing task, subjects changed their motor coordination. Namely, instead of using the summation of speed principle, subjects organized their movement similar to that of a rigid system (Forestier and Nougier 1998).

Postural stability during free throw shooting can be speculated as one of the most important aspects of free throw shooting. Researchers investigated the effects of prolonged exercise and thermal dehydration on postural stability. The participants exercised for 2 hours at a power output equal to 57-63% VO_{2max} on two different occasions which ended without drinking any fluid and with an intake of 1.9 l of a carbohydrate-electrolyte solution. Before and after exercise, center of pressure locations were measured with a force plate. Researchers found that prolonged exercise without fluid ingestion causes postural instability which might decrease the stability-dependent sports performance such as free throw shooting in basketball (Derave, De Clerq et al. 1998).

It was claimed that most athletes can perform a decent skill at low velocity because it generates little fatigue. Technical breakdown occurs under high velocities or under conditions similar to the competition. The mechanics of the skill break down when the athlete experiences fatigue. In basketball, skill deterioration for shooting accuracy occurs when players are fatigued. Bompa (1999) concluded that fatigue affects the mechanics of skill. His recommendation was making corrections under fatiguing conditions similar to those the athlete experiences in competition.

Another study investigated the effects of moderate and high intensity whole body fatigue on the basketball passing accuracy of both novice and expert basketball players. Participants performed as much squat thrusts as possible in one minute which was claimed as the 100% of the maximum number of repetitions. 70% of this maximum repetition was claimed as moderate and 90% of it claimed as high intensity whole body fatigue. Players completed the AAHPERD basketball passing test at rest and after completion of moderate and high intensity whole body fatigue. It was found that although both novice and expert players' passing accuracy decreased with fatigue, expert players were better able to manage the detrimental effects of fatigue (Lyons, Al-Nakeeb et al. 2006).

Tsai et al. (2006) studied the effects of completing a high intensity fatigue protocol on the three point shooting in basketball by using 6 male colligate level players. 3P shots were recorded by using one high speed camera operating at 250 Hz. It was found that elbow, wrist, and ankle joint angular velocities decreased after fatigue, whereas the knee joint angular velocity increased. However, one should keep in mind that in this study statistical analyses were missing. It was concluded that the alterations that occurred in elbow, wrist, hip, and ankle joint angular velocities after completing fatigue protocol was compensated by the increase in the knee joint angular velocity (Tsai, Ho et al. 2006).

2.3 Kinematic analyses of movement

Motion capturing systems have been used extensively in the area of biomechanics for more than three decades (Winter 2005). With the increasing demand from the academia and video game industry, the capabilities of a real-time multisensory 3D optical system have been increasing. Commercial systems (hardware and software) with at least six cameras can now track more than 100 markers at frequencies up to 2000 frames/sec (Richards 1999; Shao, Fraser et al. 2001) and provide 3D coordinates of the markers. With an addition of kinetic data by using force plates to the kinematic data, researchers have been able to apply the inverse dynamics. By integrating kinematic and kinetic data, inverse dynamics provides moment of forces (torques) and powers on the selected joint, such as the hip joint moment or knee joint power. Because of the availability of capturing three dimensional kinematics and kinetics of the movement, these forces, moments, powers can be calculated in three major planes (i.e. sagittal, frontal, and transverse planes). These state of art systems are commonly used in research areas, such as gait analyses (Ferber, Osternig et al. 2002; Luepongsak, Amin et al. 2002), mechanisms of injury and its prevention in athletes (Salci, Kentel et al. 2004; Schmitz, Kulas et al. 2007), rehabilitation (Mian, Thom et al. 2007), pathological populations (Liikavainio, Isolehto et al. 2007), performance analyses in sports (Button, MacLeod et al. 2003; Kellis, Arambatzi et al. 2005; Reid, Elliot et al. 2008), locomotion (Riener, Rabuffetti et al. 2002; Nadeau, McFadyen et al. 2003; Uygur, Richards et al. 2009) and so on. Although accuracy of these digital smart cameras and real-time image-based tracking systems are superior to other systems, they are extremely costly and require large spaces. Moreover, these systems can not be mobile, namely, they are hard to use in the research areas that investigate sports related performance while simulating real game situations (e.g. effects of fatigue on free throw shooting in basketball).

Another option to capture motion is to use photogrammetric motion study systems. Generally, this system consists of a set of one or two video imaging cameras and a group of control targets. By using the computed exterior parameters of the control targets, researchers can compute the relative position of the moving targets (Chong 2004). The biggest advantage of these photogrammetric motion study systems is its drastically lower price when compared to the above mentioned sophisticated real-time multisensory 3D optical system. Moreover, these systems are also easier to use in the field. However, there are some disadvantages of using photogrammetric motion study systems. First of all, the accuracy of the movement data is highly dependent on the precision of the computed 3D coordinates of the control targets. Namely, any small error that was made in the computation of the control targets would result in errors in the 3D coordinates of the motion targets. Therefore, there exists off-the-shelf automated target-image digitizing software in order to increase the accuracy of the control targets' coordinates. Another possible source of the error may originate from the manually tracking the motion targets. As another limitation of these low cost motion study systems, the analyses of joint angles and, therefore, angular velocities and accelerations of selected joints can only be done in one plane, mostly in sagittal plane.

Due to its availability to use in the field and the low cost of the system, researchers have been using photogrammetric motion study systems in numerous sports related research areas, such as wheelchair javelin throwing (Chow, Kuenster et al. 2003), wheelchair propulsion (Koontz, Cooper et al. 2002), soccer (Barfield, Kirkendall et al. 2002; Aprioantono, Nunome et al. 2006), table tennis (Iino, Mori et al. 2008), handball (Davilla, Garcia et al. 2006), tennis (Chow, Carlton et al. 2003) and basketball (Miller and Bartlett 1996; Rojast, Cepero et al. 2000).

The effects of fatigue on the kinematics and kinetics of instep kicking in soccer was also an interest for researchers. Seven subjects participated in a study and completed knee extension and knee flexion motions on a weight training machine until exhaustion. Instep kicking motion data were captured by using two cameras operating at 500 frames/s both before and after the locally induced fatigue. It was found that after the onset of fatigue, reduced lower leg swing speed and slower peak lower leg angular velocity happened. These reductions resulted in a slower ball speed at the time of instep kicking (Aprioantono, Nunome et al. 2006).

In another study that investigated the gender differences in instep kicking in soccer, six females and two males were used for to compare their kinematics. Two video cameras, operating at 120 frames/s, captured the motion while subjects were trying to kick as hard as possible. It was found that the male subjects kicked the ball faster than the females. This superior performance of the males was due to the higher maximum toe velocity, ball contact velocity, mean toe acceleration and, mean toe and ankle velocity (Barfield, Kirkendall et al. 2002).

Kinematics of tennis serving also placed attention for research. In one study, the kinematic differences between the first and second serves in a tennis game were compared. The motion of four male and four female elite tennis players were captured by using two cameras operating at 200 frames/s. It was found that the pre-impact ball position in first serve was more in front than the position of the ball in the second serve. Moreover, the ball velocity in the first serve was higher than the first serve. Finally, it was found that in the second serves the pre-impact racquet vertical and lateral velocities were higher than the ones in the first serve. These changes in the racquets' vertical and lateral velocities were speculated to be a reason for the source of the topspin and sidespin on the ball in the second serves (Chow, Carlton et al. 2003).

Contributions of racket arm joint rotations to the racket velocity in table tennis backhands that were performed against topspin and backspin had also been studied. Eleven subjects' joint rotations were captured by using two cameras operating at 100 frames/s while they were trying to hit backhands against topspin and backspin. Researchers found that in the backhands performed against backspin, the negative contribution of elbow extension to the upward velocity was drastically less than the negative contribution of elbow extension in backhands performed against topspin. However, the contribution of wrist in backhands against the backspin was greater than the contribution of wrist in backhands against topspin (Iino, Mori et al. 2008).

2.4 Biomechanical Analyses of Shooting Action in Basketball

Jumps shots and free throw shots are two of the main long distance shooting types in basketball. Biomechanical studies about basketball mostly dealt with various aspects of those shooting types, such as shots taken from different distances, shots taken by athletes with different skill levels and the kinematic differences between genders.

2.5 Kinematic and/or Kinetic Analyses of Jump Shots in Basketball

A study was conducted to show the differences of kinetic and kinematic variables between two point (2P) and three-point (3P) jump shots for female basketball players. It was found that the ball was released earlier in relation to the peak of the jump for 3P shots when compared to two point jump shots. It was also found that mean the ball velocity for 3P jump shots (7.9 ms^{-1}) was significantly ($p<.05$) higher than mean ball velocity for 2P jump shots (6.6 ms^{-1}). According to the experimenters, this was because of the greater angular displacement of the shoulder joint (+8.8 degree) and wrist joint (+3.7 degree) in 3P shots when compared to 2P shots. Kinetic data revealed that an additional 24.6cm horizontal displacement from take off to landing occurred during the 3P jump shots when compared to the displacement for the 2P jump shots. Furthermore, the decreases in horizontal ground reaction forces for 3P and 2P jump shots were -0.5 BW and -0.3 BW respectively (Elliot 1989).

Miller (1998) argued that unsuccessful shots and their contributory factors have received little attention and his aim was to compare the kinematics characteristics and variability of successful and unsuccessful basketball shots. Thirteen elite male basketball players, who took shots from 6.40m, participated in this study. Five successful and five unsuccessful shots were recorded with two dimensional video recording techniques with a camera at 50 frames/s. Findings were supported by the recent evidence which challenges the widely-held belief that skilled performance is characterized by minimization of variability. It was concluded that variability in multi-segmental accuracy based movements may not be appropriate method of assessing inaccuracy, and that variability is apparently an integral aspect of such skills.

In another study, possible gender differences that might occur in kinematic variables during 2P and 3P jump shots in basketball were discussed. Three different distances were used to study the kinematics of shooting action for both genders. It was found that vertical displacement of the hip was greater in percentage of total vertical hip displacements in the jump for male players than for female players at the moment of releasing the ball for all shooting distances. Moreover, this percentage decreases as the shooting distance increases for both genders (Elliot 1992).

Miller and Bartlett (1996) conducted a similar study about the relationship between shooting kinematics, distance and playing positions. They used forwards, guards and centers as their participant group. Since players from different positions had a tendency to play in specific areas, researchers hypothesized that their shooting styles would be different. Three different shooting distances were used to point out the possible kinematic adaptations of the players. Participants took jump shots from 2.74, 4.57, and 6.40 m. Trials were repeated until an attempt was successful for each distance. For shots to be successful, the ball should not touch either the rim or the blackboard. Experimenters used two cameras at filming rate of 100 Hz. Vertex of the head, 7^{th} cervical vertebra, right and left glenohumeral, elbow, wrist, 3^{rd} metacarpophalangeal, hip, knee and ankle joints were the points to be digitized. After analyzing the data, they found that both guards and forwards were likely to increase their upper limb angular velocities as the shooting distance increased. Moreover, guards could maintain their center of mass velocity stable at the closest distance, which was significantly ($p<.01$) different from all groups at the furthest distance. They concluded that guards, players who take majority of their shots from long range, could easily adjust their shooting kinematics with respect to changing distance (Miller and Bartlett 1996).

Rojast and his colleagues (2000) performed a study to show the possible kinematic adjustments in basketball jump shot when the players were shooting against an opponent. Ten male professional basketball players served as a subject group for this experiment. Two cameras operating at 50 frames/s were used to record the performance of the shots. The presence of an opponent during the shot was used as an independent variable. Researchers hypothesized that the presence of an opposition during the jump shot would affect the mechanics of the shots. After analyzing the kinematic data, experimenters found that the release angle of the ball was significantly ($p<.05$) increased if the shot was opposed by an opponent. They also stated that knee angle at the beginning of the acceleration impulse phase, the shoulder angle at the ball release and the vertical velocity of ball from its lowest point until its release increased significantly ($p<.05$). They concluded that players attempted to release the ball from a greater height and more quickly by adjusting their joint angles and body positions to achieve successful shots when they were facing with an opponent (Rojast, Cepero et al. 2000).

2.6 Kinematic Analyses of Free Throw Shots in Basketball

Free throw shooting is an important decisive element in a basketball game. It provides an opportunity to score uncontested points and it can be a deciding factor in a close game or even of a championship title. Free throw shooting is a combination of co-ordination, accuracy and sub-maximal velocity. Since it requires sub maximal velocity, there are endless arrangements of segmental combinations needed to achieve a successful free throw shot (Hudson 1982).

Hudson (1982) studied the kinematics of the free throw shooting and investigated whether any differences exist among the players of different skills levels. In this experiment three groups of players (i.e., professional, moderate, and low skilled) were utilized. Researcher used angle of ball projection, accuracy, trunk inclination, and height of release as dependent variables to analyze. Analyses were made by 1 camera at 64 frames per second. It was found that highly skilled players had more balanced center of gravity than low skilled players, which enabled high skilled athletes to achieve a greater stability during free throw shooting**.** Moreover, it was found that a greater ratio of release height to the standing height of release was related to higher skill level. However, both angle and velocity of projection were not related with the skill level (Hudson 1982). Along with these findings, she defined categories that discriminates the skill as accuracy, stability, and height of release (Hudson 1985).

Skill level and movement variability during basketball free throw has also taken interest of researchers. Six female basketball players, who were representing different skill level, performed free throws while researchers captured the data with one camera operating at 60 frames/s. Researchers hypothesized that there would be a reduction in trajectory variability as the skill level increase. However, they found that as the skill level increases, there was an increase in the inter-trial movement consistency in elbow and wrist joints. Moreover, it was speculated that wrist and elbow joints compensates each other towards the end of throws compensating the changes in release parameters of the ball (Button, MacLeod et al. 2003).

Basketball is very demanding in that most of the time during a real game, heart rates of the players have are close to its maximum values (McInnes, Carlson et al. 1995; Ben Abdelkerim, El Fazaa et al. 2007). Moreover, athletes' mean lactate level is high enough to cause the fatigue (McInnes, Carlson et al. 1995). Since physiological demands of basketball are high, most of the time players have to deal with the effects of fatigue during the game. In critical situations that may change the destiny of the game (e.g. free throws) players have to overcome the possible undesired effects of fatigue during the execution of free throw action. Recent biomechanical studies related to basketball mostly dealt with different kinds of shooting styles, namely, free throw shots, set shots, and jump shots. Researchers used various subjects group to seek some different conditions for those shooting styles. Investigators found differences in the kinematic and/or kinetic variables of different genders, skills, shooting distances and the presence of an opponent. However, participant groups that were used in these experiments were not exhausted. Studies involving the crucial element of a real game situation, such as fatigue, are missing in the literature.

CHAPTER III

METHODS

In this chapter, the methodological procedure that was followed in the study was introduced. This chapter consists of four major sections: (1) Demographic information of the participants, (2) Experimental procedures and instrumentation, (3) Data processing, and (4) Statistical analyses.

3.1 Participants

Ten highly skilled active male colligate basketball players volunteered to participate in this study. Five of the players were playing in their college teams and the other five of the players were playing in a third level league in Turkey. Moreover, the later group was also members of various college teams. All of the participants were practicing according to their team’s regular training schedule (at least 3 times per week). The mean (±S.D.) age, height and weight of the subjects were 21.8 (±1.6) years, 192.8 (±3.6) cm and 84.1 (±8.5) kg, respectively. Among the participants there were two guards, four forwards, and four centers. All of the participants were free of any kind of injuries at the time of data collection. Eight of the players were right handed shooters while two of them were left handed. Two left handed participants completed the experiment on a different day and the placement of the cameras and the calibration cage was adjusted accordingly. Due to the synchronization problems that happened during data collection, two of the right handed participants’ data was excluded from kinematic analyses. However, the rest of the analyses were completed by using 10 subjects.

3.2 Experimental Procedures and Instrumentation

All of the subjects completed the following procedures in the given order;

1. After 10 minutes of passive resting, the resting heart rate levels of the participants by using Polar Vantage NV instrument (Polar Electro, Kempele, Finland) were measured.

2. After measuring the resting heart rates, markers were placed on the dominant side of the subjects. The markers were placed on the wrist (at the pinkie side), the elbow (on the lateral epicondyle), the shoulder (on the acromion), the pelvis (on the anterior superior iliac spine), the knee (on the lateral epicondyle), the distal end of fibula (on the lateral malleolus along an imaginary line that passes through the transmalleolar axis), the heel of the shoe (on the calcaneous at the same height above the plantar surface of the foot as the phalange marker) and the 5th phalanx of the foot.

3. Subjects warmed-up according to their individual habits for 15 minutes prior to data collection.

4. Subjects performed free throw shots. Two successful and two unsuccessful free throw shots were selected for the pre-fatigue condition. Successful shots were determined when the ball did not touch the rim or the blackboard. The shots that did not follow this rule were considered as unsuccessful shots (Miller and Bartlett 1996; Rojast, Cepero et al. 2000).

5. Subjects completed a custom designed fatigue protocol to reach their volitional exhaustion (Figure 1). Subjects started this protocol with five consecutive vertical jumps and instructed to sprint 30 meters as soon as they completed vertical jumps. At each turning point, they were asked to complete five vertical jumps and sprint back to their starting point again. The subjects were instructed to touch the ground and jump as high as possible during vertical jumps. They were also instructed

to accelerate and decelerate as quickly as possible during the 30 m sprints. The fatigue protocol continued until the subject reached a state of volitional exhaustion (Chappel, Herman et al. 2005).

6. After participants reached their volitional exhaustion, researchers collected the heart rate values and immediately free throw shots were performed. After each free throw shot, participants completed the fatigue protocol for once to keep their heart rate level elevated. Heart rates were measured just before each free throw shots. Two successful and two unsuccessful shots were selected for further analyses (post fatigue condition).

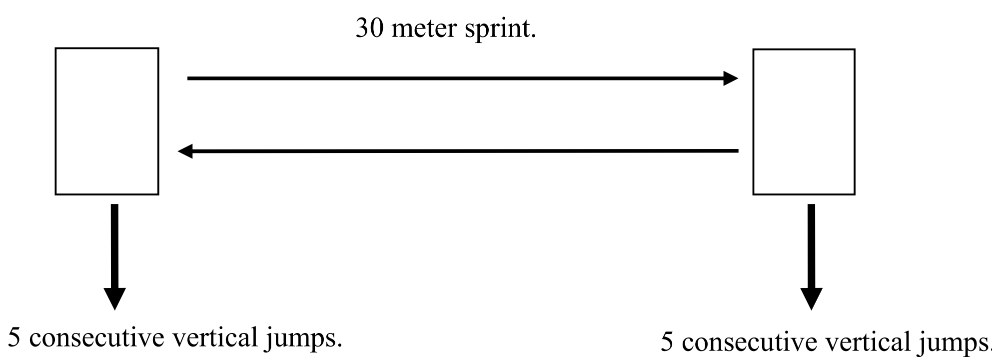

Figure 1 Set-up of the fatigue protocol.

3.3 Data Processing

The free throw shots were recorded by using two digital cameras (Dragonfly Express, Point Grey Research, 2006) at 60 frames/second in a stereoscopic view. A calibration cage of 1.0 m long, 1.0 m wide and 2.0 m height containing 12 control points was used to calibrate the free throw shooting area (Figure 2). The cameras were placed in such a way that all of the markers that were placed on subjects and the 12 control points were in sight of both cameras. Photogrammetric images were corrected and analyzed using the Pictran Software (Technet GmbH, Germany) at Selcuk University, Photogrammetry laboratory. Adjustments were made according to 6 to 8 control points assessed in a bundle. After the adjustment process, 3D coordinates of the marked points were recorded.

Four joint angles were described for the kinematic analysis (Figure 2). The intersection of the line that was drawn from the wrist marker to the elbow marker and from the elbow marker to the shoulder marker represented the elbow angle. The intersection of the line that was drawn from the shoulder marker to the pelvis marker and the line from the pelvis marker to the knee marker represented the trunk angle. The intersection of the line that was drawn from the pelvis marker to the knee marker and the line from the knee marker to the ankle marker represented the knee angle. Finally, the intersection of the line that was drawn from the ankle marker to the heel marker and from the heel marker to the metatarsal marker represented the ankle angle.

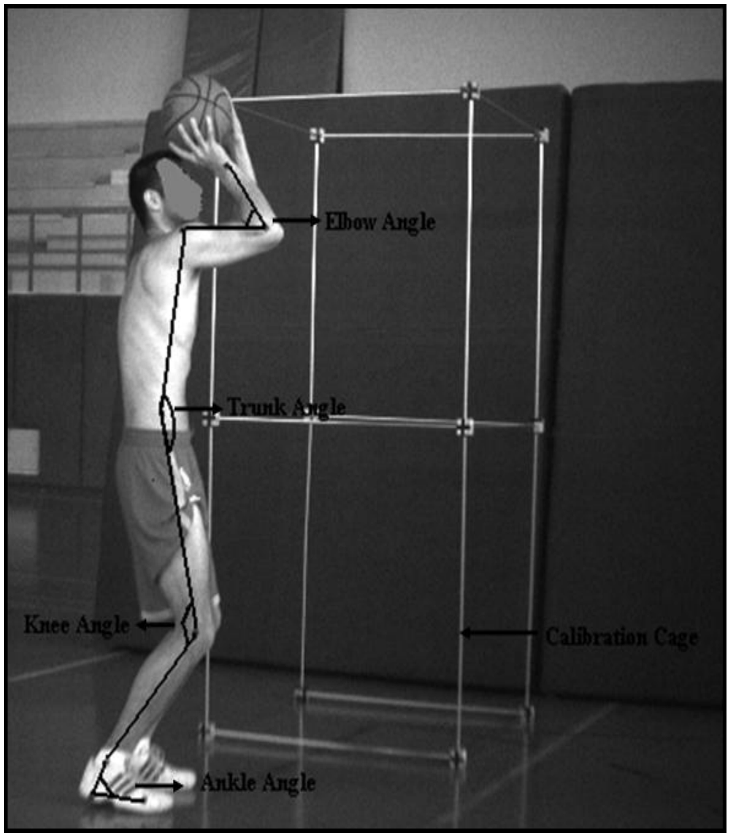

Figure 2 Definition of joint angles and the calibration cage.

A customized LabView™ program (see Appendicex) was created to calculate the elbow, trunk, knee, and ankle joints angles by using the 3D coordinates of the markers. Joint angles were found by using equation 1 and, therefore, by using equation.2;

$$\theta = \arccos\frac{u \bullet v}{|u||v|} \tag{1}$$

$$\theta = \arccos\frac{u_x v_x + u_y v_y + u_z v_z}{\sqrt{(u^2{}_x + u_y^2 + u_z^2)(v_x^2 + v^2{}_y + v_z^2)}} \tag{2}$$

where θ is the angle from u to v, $u = (u_x , u_y , u_z)$, and $v = (v_x , v_y , v_z)$.

The free throw action was divided and analyzed in 5 different frames. The ball release point was defined as Frame 0. The follow through phase was defined as Frame +5, and the preparation phases were defined as Frames -15, -10 and -5. Mean joint angles were calculated by finding the mean joint angle values during two successful and unsuccessful shots at pre- and post- fatigue conditions.

3.4 Statistical Analysis

Since the aim of the study was to examine the effects of fatigue and success on the kinematics of free throw shooting, 2-way (pre-post fatigue and successful-unsuccessful) repeated measures of analysis of variance (ANOVA) was used for the statistical tests. A value of $p<0.05$ was set to indicate significance. To compare the resting heart rate with the heart rate after completion of the fatigue protocol, a paired sample t-test was conducted. Another paired sample t-test was conducted to evaluate whether the participants were fatigued during experimental protocol or not. In this analysis, the first and the last completion of main fatigue protocol lap times were compared. To compare the heart rate after the completion of the main fatigue protocol with the heart rates after the completion of individual laps, which were completed after each free throw shots, an intra-class correlation (ICC) analyses was conducted and one-way repeated measures (RM) ANOVAs were used to detect a possible systematic bias among consecutive heart rate values that were collected after each completion of the fatigue protocol.

CHAPTER IV

RESULTS

4.1 Fatigue Protocol

Subjects reached their volitional exhaustion level at a mean of 4.9 (±1.4) laps at the fatigue protocol with a mean time of 136.97 s. Paired sample t-test revealed that there was a significant difference between the resting heart rate and the heart rate after the first completion of the fatigue protocol [$t(9)=-29.8$, $p<0.01$]. Mean heart rates were 62.3 beats/min and 175.1 beats/min before and after the first fatigue protocol, respectively. All subjects completed at least 3 and at most 6 additional laps in order to fulfill the requirements of the experiment (i.e. to complete two successful and two unsuccessful free throw shoots) (Table 1). When the completion times of the first and last laps of the main fatigue protocol were compared, paired sample t-test revealed a significant difference between the completion times. It was found that the mean first lap time of the main fatigue protocol (24.33s ± 1.70) was shorter than the mean last lap time of the main fatigue protocol (31.72s ± 3.89) [$t(9)=-6.97$, $p<.001$].

Participants were able to keep their heart rate elevated during the consequent free throws. Intra-class correlation analyses revealed that the heart rate after the initial main fatigue protocol and the subsequent completion of each individual laps in the additional fatigue protocol, which were completed after each free-throw shots, were comparable [$ICC=.766$, $F(1,9)=2.522$, $p>.05$] (Table 1).

Table 1 Individual heart rates of the subjects

Subject Number	Playing Position	Resting Heart Rate (beats/min)	Fatigue HR 1 (beats/min)	Fatigue HR2 (beats/min)	Fatigue HR3 (beats/min)	Fatigue HR4 (beats/min)	Fatigue HR5 (beats/min)	Fatigue HR6 (beats/min)	Fatigue HR7 (beats/min)	Fatigue HR Mean (beats/min)
1	Forward	60.0	167.0	168.0	168.0	167.0	168.0			167.0
2	Guard	70.0	182.0	175.0	178.0	176.0				177.75
3	Forward	57.0	168.0	170.0	168.0	170.0				169.0
4	Center	59.0	170.0	169.0	165.0	176.0	175.0			171.0
5	Center	55.0	179.0	172.0	170.0	171.0	173.0	176.0		173.5
6	Center	57.0	177.0	182.0	185.0	183.0	177.0			180.8
7	Center	62.0	180.0	178.0	175.0	178.0	180.0	176.0	174.0	177.29
8	Forward	82.0	180.0	174.0	165.0	165.0	155.0			167.8
9	Forward	59.0	193.0	190.0	191.0	189.0	190.0	188.0		190.17
10	Guard	62.0	188.0	183.0	176.0	178.0	178.0	167.0	169.0	177.0
Mean (S.D.)		62.3 (8.06)	178.4 (8.4)	176.1 (7.11)	174.1 (8.70)	175.3 (7.33)	174.5 (10.10)	176.75 (8.62)	171.5 (3.54)	175.13 (7.08)

4.2 Joint Angles

All of the selected joint angles (i.e. elbow, trunk, knee, and ankle) were analyzed separately for each selected time point (i.e., 15 ms, 10 ms, and 5 ms before ball release, at the time of ball release and 5 ms after the ball release).

4.2.1 Joint angles at 15 ms before the ball release

Two-way repeated measures (RM) of ANOVA revealed no significant main effects of fatigue [$F(1,7) = 3.628$, $p > .05$], success [$F(1,7) = .549$, $p > .05$], and fatigue*success interaction [($F(1,7) = 1.353$, $p > .05$) on the elbow angle. However, there was a significant main effect of fatigue [$F(1,7) = 8.059$, $p < .05$], but no significant main effect of success [$F(1,7) = 1.737$, $p > .05$] and fatigue*success interaction on the trunk angle [$F(1,7) = .681$, $p > .05$]. When considering the knee angle, there were no main effects of fatigue [$F(1,7) = .004$, $p > .05$], success [$F(1,7) = 2.414$, $p > .05$] and fatigue*success interaction [$F(1,7) = 2.296$, $p > .05$]. When ankle was taken into consideration, there were no main effects of fatigue [$F(1,7) = 1.075$, $p > .05$], success [$F(1,7) = .768$, $p > .05$], and fatigue*success interaction [$F(1,7) = .118$, $p > .05$] on the joint angle (Table 2).

Table 2 The joint angles (degrees) at 15ms before the ball release for pre and post fatigue and successful and unsuccessful free throws.

		Pre-Success	Pre-Unsuccess	Post-Success	Post-Unsuccess
Elbow	Mean	68.61	69.70	74.42	70.54
	(S.D.)	(13.03)	(13.40)	(13.25)	(10.79)
Trunk*	Mean	155.96	157.48	150.31	155.05
	(S.D.)	(13.99)	(14.45)	(13.96)	(15.27)
Knee	Mean	125.55	126.38	128.57	123.68
	(S.D.)	(12.73)	(14.41)	(16.08)	(12.33)
Ankle	Mean	67.66	67.79	67.00	67.57
	(S.D.)	(5.58)	(4.52)	(3.96)	(5.09)

Data averaged across participants and trials; S.D.- standard deviation
* shows significant main effects of fatigue ($p<.05$)

4.2.2 Joint angles at 10 ms before the ball release

Two-way RM of ANOVA revealed no significant main effects of fatigue [$F(1,7)= 2.275$, $p>.05$], success [$F(1,7)= .733$, $p>.05$], and fatigue*success interaction [($F(1,7)= 1.252$, $p>.05$) on the elbow angle. Moreover, there was no significant main effect of fatigue [$F(1,7)= .090$, $p>.05$], success [$F(1,7)= .073$, $p>.05$], and fatigue*success interaction on the trunk angle [$F(1,7)= 2.843$, $p>.05$]. When considering the knee angle, no main effects of fatigue [$F(1,7)=1.017$, $p>.05$], success [$F(1,7)= .921$, $p>.05$] and fatigue*success interaction [$F(1,7)= 1.113$, $p>.05$] was present. For the ankle, there was no main effect of fatigue [$F(1,7)= .032$, $p>.05$], success [$F(1,7)= .079$, $p>.05$], and fatigue*success interaction [$F(1,7)= .842$, $p>.05$] on the joint angle (Table 3).

Table 3 The joint angles (degrees) at 10ms before the ball release for pre and post fatigue and successful and unsuccessful free throws.

		Pre-Success	Pre-Unsuccess	Post-Success	Post-Unsuccess
Elbow	Mean	72.25	72.70	78.29	73.61
	(S.D.)	(14.05)	(12.59)	(14.54)	(11.14)
Trunk	Mean	163.46	154.78	150.87	163.35
	(S.D.)	(8.71)	(30.88)	(17.44)	(10.16)
Knee	Mean	134.97	134.90	138.43	134.18
	(S.D.)	(13.30)	(14.79)	(15.72)	(12.79)
Ankle	Mean	68.52	68.00	67.72	68.62
	(S.D.)	(5.42)	(6.10)	(4.98)	(5.54)

Data averaged across participants and trials; S.D.- standard deviation

4.2.3 Joint angles at 5 ms before the ball release

Two-way RM of ANOVA revealed no significant main effects of fatigue [$F(1,7)= .247$, $p>.05$], success [$F(1,7)= .254$, $p>.05$], and fatigue*success interaction [($F(1,7)= 1.209$, $p>.05$) on the elbow angle. Moreover, there was no significant main effects of fatigue [$F(1,7)= 1.050$, $p>.05$], success [$F(1,7)= 1.055$, $p>.05$], and fatigue*success interaction on the trunk angle [$F (1,7)= .308$, $p>.05$]. When considering the knee angle, no main effects of fatigue [$F(1,7)=.003$, $p>.05$], success [$F(1,7)= .048$, $p>.05$] and fatigue*success interaction [$F(1,7)= .391$, $p>.05$] were found. For the ankle, there were no main effects of fatigue [$F(1,7)= .917$, $p>.05$], success [$F(1,7)= .631$, $p>.05$], and fatigue*success interaction [$F(1,7)= .637$, $p>.05$] on the joint angle (Table 4).

Table 4 The joint angles (degrees) at 5ms before the ball release for pre and post fatigue and successful and unsuccessful free throws.

		Pre-Success	Pre-Unsuccess	Post-Success	Post-Unsuccess
Elbow	Mean	80.82	85.71	86.36	83.58
	(S.D.)	(15.94)	(13.98)	(13.65)	(10.22)
Trunk	Mean	168.33	168.93	166.64	168.57
	(S.D.)	(2.91)	(3.57)	(5.99)	(4.50)
Knee	Mean	151.34	152.85	152.19	151.78
	(S.D.)	(11.59)	(12.66)	(8.57)	(10.42)
Ankle	Mean	65.73	70.06	69.73	70.33
	(S.D.)	(12.31)	(6.05)	(5.65)	(6.38)

Data averaged across participants and trials; S.D.- standard deviation

4.2.4 Joint angles at the ball release

No significant main effects of fatigue [F(1,7)= 0.004, p>.05], success [F(1,7)= 1.613, p>.05], and fatigue*success interaction [F(1,7)= .657, p>.05] were found on the elbow angle. When considering the trunk angle, no significant main effect of fatigue [F(1,7)= 1.070, p>.05], success [F(1,7)= .006, p>.05], and fatigue*success interaction [F(1,7)= .376, p>.05] were found. On the other hand, there were no main effects of fatigue [F (1,7)= .096, p>.05], success [F(1,7)= .152, p>.05], as well as fatigue*success interaction [F (1,7)= .782, p>.05] on the knee angle. Lastly, there were no main effects of fatigue [F(1,7)= .185, p>.05], success [F(1,7)= .513, p>.05], and fatigue*success interaction [F(1,7)= .241, p>.05] on the ankle angle (Table 5).

Table 5 The joint angles (degrees) the ball release for pre and post fatigue and successful and unsuccessful free throws.

		Pre-Success	Pre-Unsuccess	Post-Success	Post-Unsuccess
Elbow	Mean	113.54	123.20	117.47	120.97
	(S.D.)	(22.81)	(16.09)	(17.63)	(15.49)
Trunk	Mean	170.84	170.06	168.89	169.48
	(S.D.)	(4.61)	(3.49)	(6.02)	(5.76)
Knee	Mean	164.72	164.48	164.32	165.81
	(S.D.)	(9.66)	(8.57)	(6.80)	(7.96)
Ankle	Mean	70.56	70.75	70.62	71.37
	(S.D.)	(7.68)	(6.90)	(6.68)	(6.99)

Data averaged across participants and trials; S.D.- standard deviation

4.2.5 Joint angles 5 ms after the ball release

Two-way RM of ANOVA suggested no significant main effects of fatigue [F(1,7)= .513, p>.05], success [F(1,7)= .305, p>.05], and fatigue*success interaction [F(1,7)= .539, p>.05] on the elbow angle. Moreover, fatigue [F(1,7)= .289, p>.05], success [F (1,7)= .398, p>.05] and fatigue*success interaction [F(1,7)= .020, p>.05] have no effect on the trunk angle. When the knee angle was considered, no main effects of fatigue [F(1,7)= 1.267, p>.05] and success [F(1,7)= .125, p>.05] were found. However, there was a significant fatigue*success interaction [F(1,7)= 12.804, p<.05] in the knee joint angle. Finally, there were no main effects of fatigue [F(1,7)= .554, p>.05], success [F(1,7)= .141, p>.05], and fatigue*success interaction [F(1,7)= .918, p>.05] if the ankle angle was considered (Table 6).

Table 6 The joint angles (degrees) at 5ms after the ball release for pre and post fatigue and successful and unsuccessful free throws.

		Pre-Success	Pre-Unsuccess	Post-Success	Post-Unsuccess
Elbow	Mean	151.84	147.90	147.07	148.92
	(S.D.)	(10.20)	(14.27)	(10.63)	(15.01)
Trunk	Mean	171.03	170.17	169.89	169.47
	(S.D.)	(5.86)	(4.89)	(4.46)	(7.36)
Knee	Mean	168.68	165.69	167.45	169.35
	(S.D.)	(7.10)	(5.68)	(7.07)	(5.08)
Ankle	Mean	71.20	71.03	71.22	71.98
	(S.D.)	(7.98)	(6.37)	(7.25)	(7.70)

Data averaged across participants and trials; S.D.- standard deviation

The elbow (Figure 3), trunk (Figure 4), knee (Figure 5), and ankle (Figure 6) joint angles for successful-unsuccessful and pre-post fatigue conditions were represented below. Joint angles were shown in 5 different frames which are 15, 10, and 5 ms prior to ball release, at the time of ball release and 5 ms after the ball release.

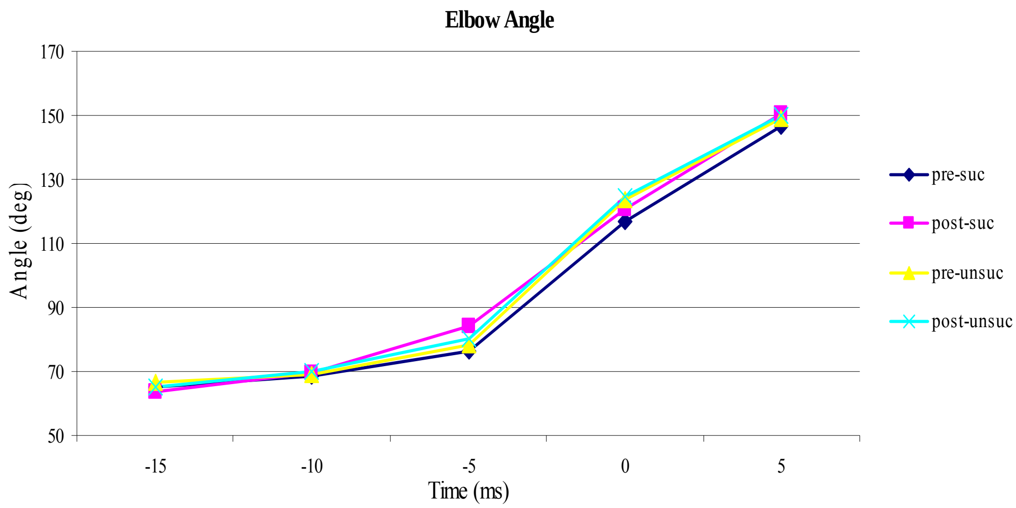

Figure 3 The elbow angle for pre and post fatigue and both successful and unsuccessful free throw shots.

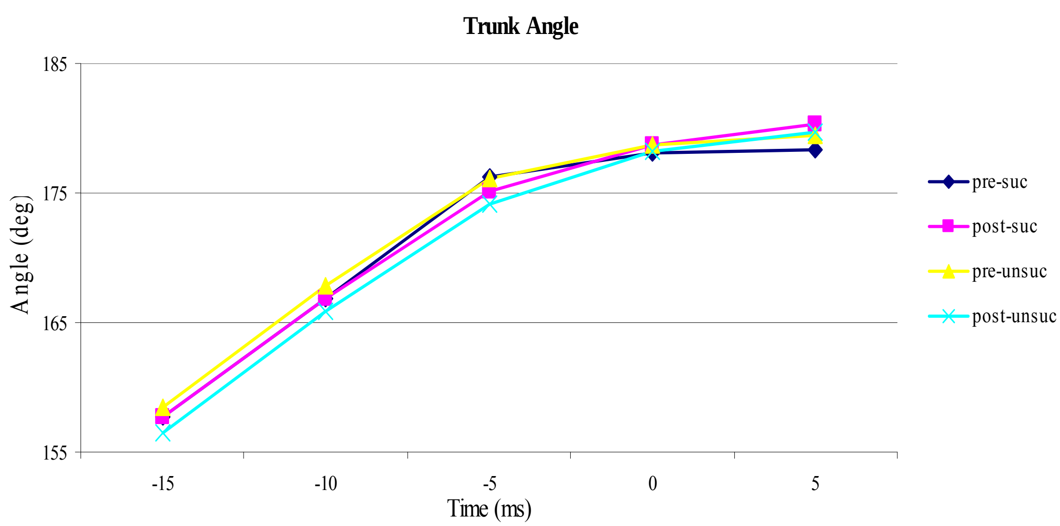

Figure 4 The trunk angle for pre and post fatigue as well as both successful and unsuccessful free throw shots.

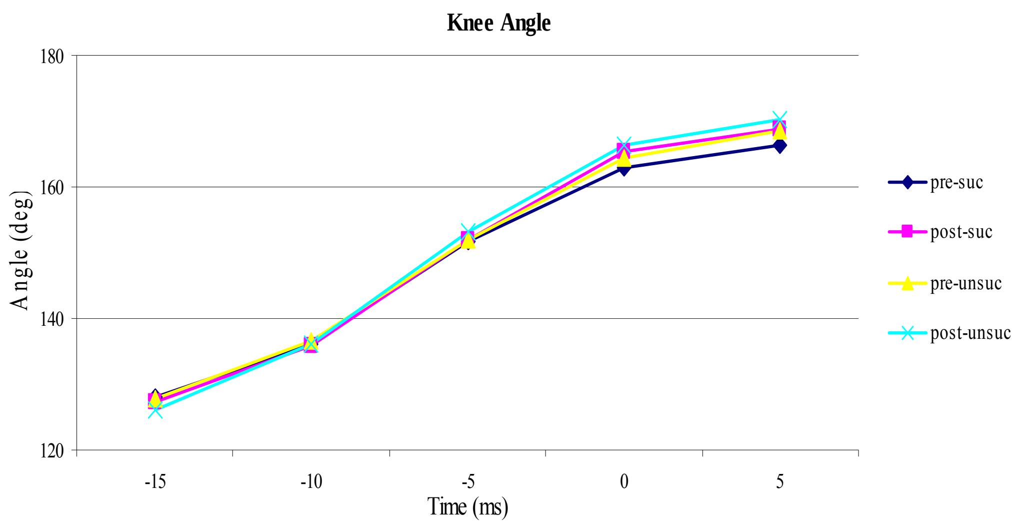

Figure 5 The knee angle for pre and post fatigue and both successful and unsuccessful free throw shots.

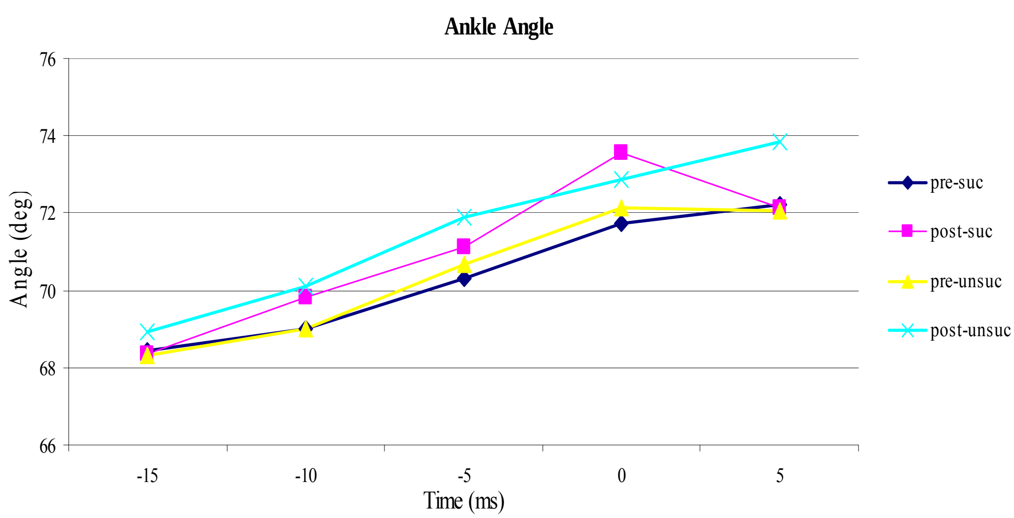

Figure 6 The ankle angle for pre and post fatigue and both successful and unsuccessful free throw shots.

CHAPTER V

DISCUSSION

This study was conducted to investigate the effects of fatigue on the kinematics of basketball free throw shooting. The kinematics of elbow, trunk, knee, and ankle joint angles were calculated. Not only were the effects of fatigue on the joint angles but also the kinematic comparisons between successful and unsuccessful free throw shots were done. Selected joint angles were analyzed at the time of ball release and 15, 10, and 5 ms before and 5 ms after the ball release.

In order to study the effects of fatigue on the free throw shooting, subjects were asked to complete a fatigue protocol until they reach their volitional exhaustion. One of the major limitations of this study was the lack of the blood lactate level measurement, which was claimed as to be one of the best indicators of the level of induced fatigue (Sinclair, Rebecca et al. 2009). However, due to the financial limitations, this could not be accomplished. Instead, the heart rate levels following each completion of fatigue protocol were monitored. Heart rate level during physical exercise along with exercise period was claimed to be another way to measure the intensity of exercise (Boulay, Simoneau et al. 1997).

The mean heart rate value of 178.4 beats/min (85-90% of maximum heart rate) that was collected right after the completion of main fatigue protocol can be speculated to be similar with the ones that can be seen in fatigue situations. Moreover, participants were able to keep the level of heart rate similarly elevated throughout the additional fatigue laps. Aside from the heart rate, participants reached their volitional exhaustion in the main fatigue protocol with a mean time of 137s. Taking the mean heart rate, intensity, type, and the period of the exercise together, it can be claimed that participants were eager to force themselves as hard as possible before they reach their volitional exhaustion. Moreover, the brief communication among the researcher and the participants after the experiments revealed that participants could no longer run or jump once they stopped continuing in the fatigue protocol.

It was claimed that the decrease in performance in the task of interest is a good indicator of fatigue (Chappel, Herman et al. 3005). In this study participants were instructed to sprint as fast as possible and at each end to jump as high and quick as possible. Therefore, to better explain whether the participants were fatigued at the end of the fatigue protocol or not, the completion times of the first and last laps were compared. This comparison revealed that the completion times of the last lap of the fatigue protocol (31.72s ± 3.89) were significantly higher than the initial completion times (24.33s ± 1.70). In other words, the fatigue protocol in this study was effectively created and participants experienced the whole body fatigue at the end of the fatigue protocol.

Fatigue can not be considered as a single process. It can be considered as an outcome of complex interactions of numerous different components within both central nervous system (i.e., central fatigue) and the musculoskeletal system (peripheral fatigue) (McKenna 2003). Due to the complexity of these systems and their interactions with human, the effects of fatigue can be dependent on the individual's physical, mental, physiological and psychological characteristics (Asmussen 1979). In other words, each individual may show different responses as a reaction to the similarly applied fatigue protocols. Therefore, applying and quantifying fatigue protocols have been a hassle for the researchers. To resolve this individualism issue, researchers have been commonly using fatigue protocols that allow participants to reach their volitional exhaustion (Chappel, Herman et al. 2005, Derrick, Dereu et al. 2002, Nikolopulos, Arkinstall et al 2004, Kyparos, Salonikidis et al. 2007).
Although lactate measurements were missing, speculations can be made by using the similarities between this study and the previous research. In a study of Janssen (2001) the blood lactate and heart rate of a sprinter during series of sprint workout were presented. In this workout series, sprinter run 50m for five times and there were

two minutes rest period between each sprint. It was found that the maximum heart rate reached during this workout was 178 beats/min whereas the lactate reached up to 12.8 mmol/l. Moreover, the author speculated that if the rest periods were shorter, the lactate accumulation would have been higher. In our study, participants completed 30 m repetitive sprints and they also complete 5 vertical jumps at each end of sprints. Therefore, if the comparisons between this study and the above mentioned study were made, it can be speculated that higher lactate accumulation, which would cause fatigue, might happened in our study.

The effects of fatigue on sports related performance and skill have been reported in the literature. Lyons et al. (2006) reported that fatigue had an adverse effect on the passing accuracy in basketball. Forestier and Nougier (1996) showed that fatigue adversely affected the accuracy and the multi-limb coordination of handball players in overhead throwing. Aprioantono et al. (2006) have found that fatigue reduced lower leg swing speed and peak lower leg angular velocity at the time of kicking. However, in aforementioned studies the researchers used fatigue protocols that induced only localized fatigue to the selected joints. Moreover, the devices or protocols that were used in above mentioned studies (e.g. isokinetic muscle testing devices or push ups) were far away from being representing the original fatigue conditions that happen in the real game situations. Therefore the effects of fatigue on skill or performance that was found in above mentioned studies might be misleading. On the other hand, the fatigue protocol that was used in this study consisted of sprinting, jumping, accelerating, and decelerating. These short duration and highly demanding movements were reported to be an indispensible part of a real basketball game (McInnes, Carlson et al. 1995; Ben Abdelkerim, El Fazaa et al. 2007). Therefore, it can be speculated that the participants used in this study were accustom to these movements.

This study failed to show the differences in joint angle kinematics for successful and unsuccessful shots. Same as with the previous studies (Miller and Bartlett 1996; Rojast et al. 2000), during data collection, the successful shots were defined as the successful ones that did not touch the rim or the backboard. In order to quantify the successful and unsuccessful shots, we tried to eliminate the chance factors which might result from the bounce of the ball from the rim or the backboard. By doing so, even if the ball barely touched the rim, we needed to claim that the shot was unsuccessful. This assumption might have disabled us to find significant differences between successful and unsuccessful shots. Moreover, the analyses of joint kinematics were done in the sagittal plane and only on the shooting arm of the subjects. This is one of the major limitations of using a photogrammetric system to analyze movement. However, some other actions that might happen outside the primary plane such as, movement of the elbow laterally or medially with respect to shoulder, supination or pronation of the hand, the involvement of the non-shooting hand to the shooting, and the rotations of the hip or shoulder (Hudson 1985) might be other crucial factors that might have affected the shots and become the reason for the unsuccessful shots. To resolve whether these factors contribute a shot to be successful or not, more sophisticated experimental tools (e.g., 3D optical system with multiple digital cameras) should be used in future studies.

This study also failed to show the effects of fatigue on the selected joint angles of participants during the free throw action. McInnes et al., (1995) stated that elite basketball players spend 75% of playing time with a heart rate greater than 85% of maximum. We found that the mean heart rate during fatigue protocols was 175.1 beats/min (85-90% of the maximum heart rate) and this value was clearly in the range of an actual basketball game (McInnes, Carlson et al., 1995). It was claimed that free throw shooting requires minimum strength and places submaximal demands for the elite players when compared to jump shots (Hudson 1982). It seems that elite basketball players are able to cope with the adverse effects of fatigue in submaximal performances that requires relatively less strength such as free throw. Therefore, the possible effects of fatigue on the shooting might be more prominent when the shooting requires explosive movements, such as 3 point shots or jump shots. This inference should be tested in the future kinematic studies.

Coordination is a more required skill than the strength in free throw shooting for elite level basketball players. Hudson (1982) defined free throw as a task which requires accuracy and endless combinations of segmental contributions. Moreover, stability in the required planes of action, good balance, high ball release point, better accuracy, and consistency in performance regardless the physical state have been claimed as the skills that is more common in highly skilled basketball players (Hudson 1982). Since the participants that were used in this experiment were elite basketball players, the effects of fatigue on free throw shooting might not seen on the kinematics of action due to the aforementioned properties of elite players. The inclusion of the control group (i.e., recreational basketball players) might have provided better understanding of the effects of fatigue on free throw shooting. Moreover, it was shown in the literature that the detrimental effects of fatigue on sports related performance were more prominent in lower skilled athletes when compared to elite level athletes (Lyons, Al-Nakeeb, et al. 2006). However the inclusion of the control group was not possible due to the difficulties in the data analyzing process.

Rojast et al. (2000) studied the kinematic adjustments of players when they were executing a jump shot against an opponent**.** In the shots taken without the opponent, researchers found that the mean elbow angle at the ball release was 123.8^0 and the mean of the trunk angle was 172.7^0. In the study of Miller and Bartlett (1996), researchers studied the relationship between playing positions and shooting distance. They found that during the middle distance (same as the free throw line) jump shots, the mean angle of elbow for guards was 136^0 and the mean angle of trunk was 172^0 at the time of ball release. There seems to be a small difference between the findings of our study and those of the previously ones. However, the shots in the studies of Rojast et al. (2000) and Miller and Bartlett (1996) were jump shots. In jumps shots, the players have to arrange their body positions not only in horizontal plane but also in the frontal and vertical planes. These additional degrees of freedom in jump shots might be the reason for this discrepancy in joint angles that was found in this current study and the literature.

In successful free throw shooting, one of the most important aspects is to maintain the body as stable as possible in the horizontal direction at the time of ball release (Hudson 1985). By constraining the whole body movement mainly in the vertical direction, players are able decrease the movement variability that might adversely affect the performance. In this study the mean trunk angle values for pre-fatigue successful condition was 170.8 degrees, while mean values for the post-fatigue successful condition was 168.9 degrees. This small decrease in trunk angle seemed to be compensated by the increase in elbow angle (113.5 vs. 117.5 for pre-fatigue successful and post-fatigue successful respectively). Being the largest body part, fatigue might affect the participants to keep a stable upright trunk position. The more flexed trunk angle values during post-fatigue free throw shooting might be an indicator of an inability to have a more stable upright position at ball release and, therefore, tendency to move in the horizontal direction. This tendency was also seen in players that have relatively lower skills (Hudson 1982), which might result in an additional step forward right after ball release. However, by increasing the elbow angle at the ball release, participants were able to compensate this undesired effect.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions about this study and recommendations for further research topics.

6.1 Conclusions

The results of this study suggested that in basketball free throw shooting there were no effects of fatigue on shooting kinematics and there were no differences in the kinematics of successful and unsuccessful shots. Although this experiment was carefully designed and the data were cautiously collected, couple of unavoidable limitations might be the reason of the lack of finding significant differences between successful vs. unsuccessful and pre- and post-fatigue shots.

6.2 Future Recommendations

1) Although the major plane that free throw shooting happens is the sagittal plane, there exist a curiosity whether the movements in other planes (e.g. frontal or transverse) can explain the reasons that determines the success of the shots. To be able to complete such analyses, future studies have to use more sophisticated 3D motion capture systems and not only the shooting side but also the whole body kinematic analyses should be done.

2) Free throw shooting is a submaximal activity in which the elite athletes can still perform well under fatigued state. Whereas, the 3-point jump shots requires

more strength than the free throws. The possible effects of fatigue on shooting kinematics are expected to be more prominent in more dynamic shooting types.

3) Inclusion of control group in this study might have provided crucial information to better understand whether elite players are able to cope with the adverse effects of fatigue better than the novice players. This study design might also provide the necessary information about which joint angles are affected more with the onset of fatigue during the execution of free throw shooting.

4) To better simulate the fatigue conditions that happen in real game, two separate but side by side basketball courts should be used. While one court can be used for an ongoing real game, the other court can be used for data collection.

5) Although the hear rate along with the exercise time can provide some insights to the degree of induced fatigue, collecting blood lactate level prior to free throw shootings would be more appropriate measurement of the induced fatigue.

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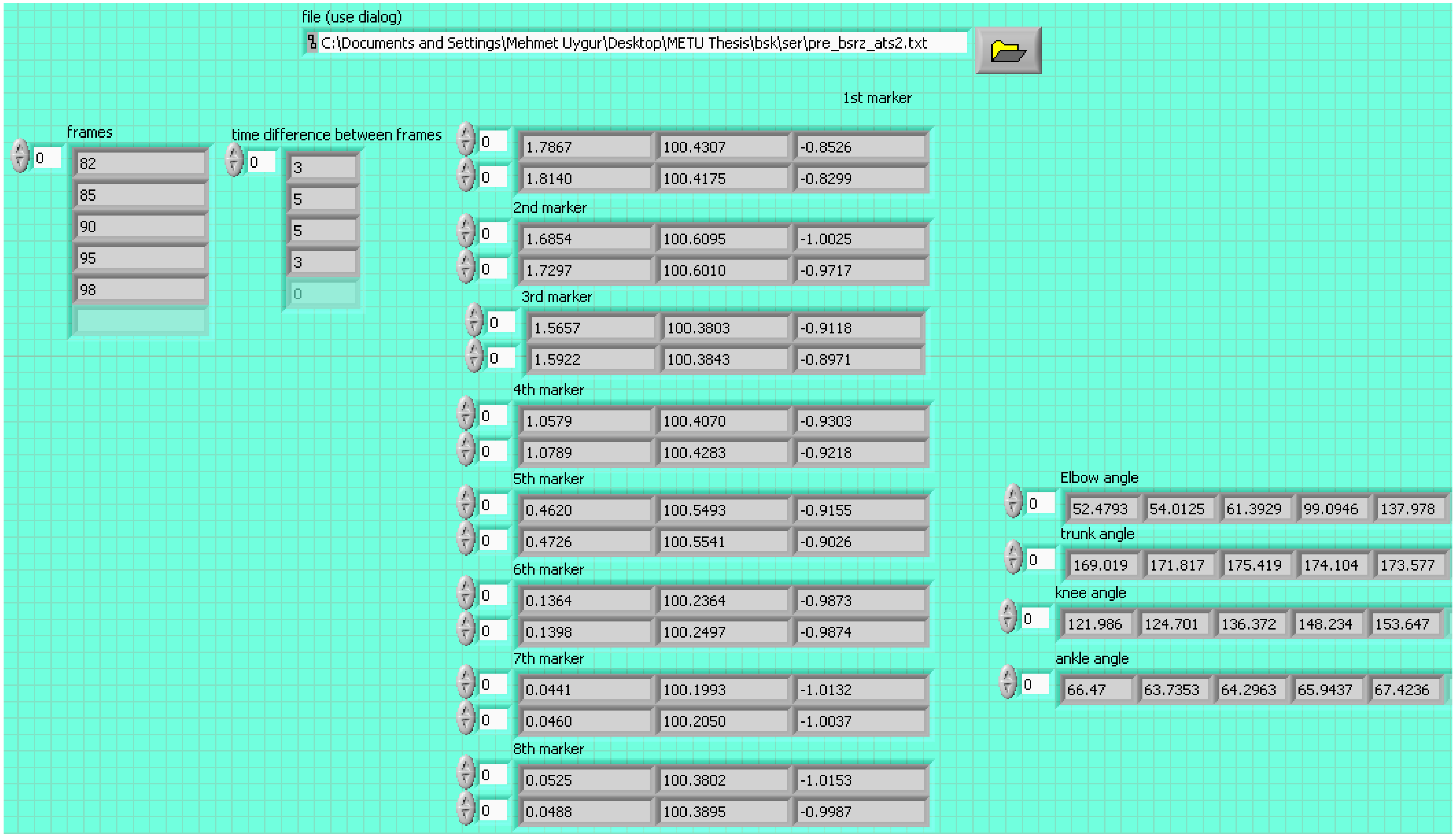
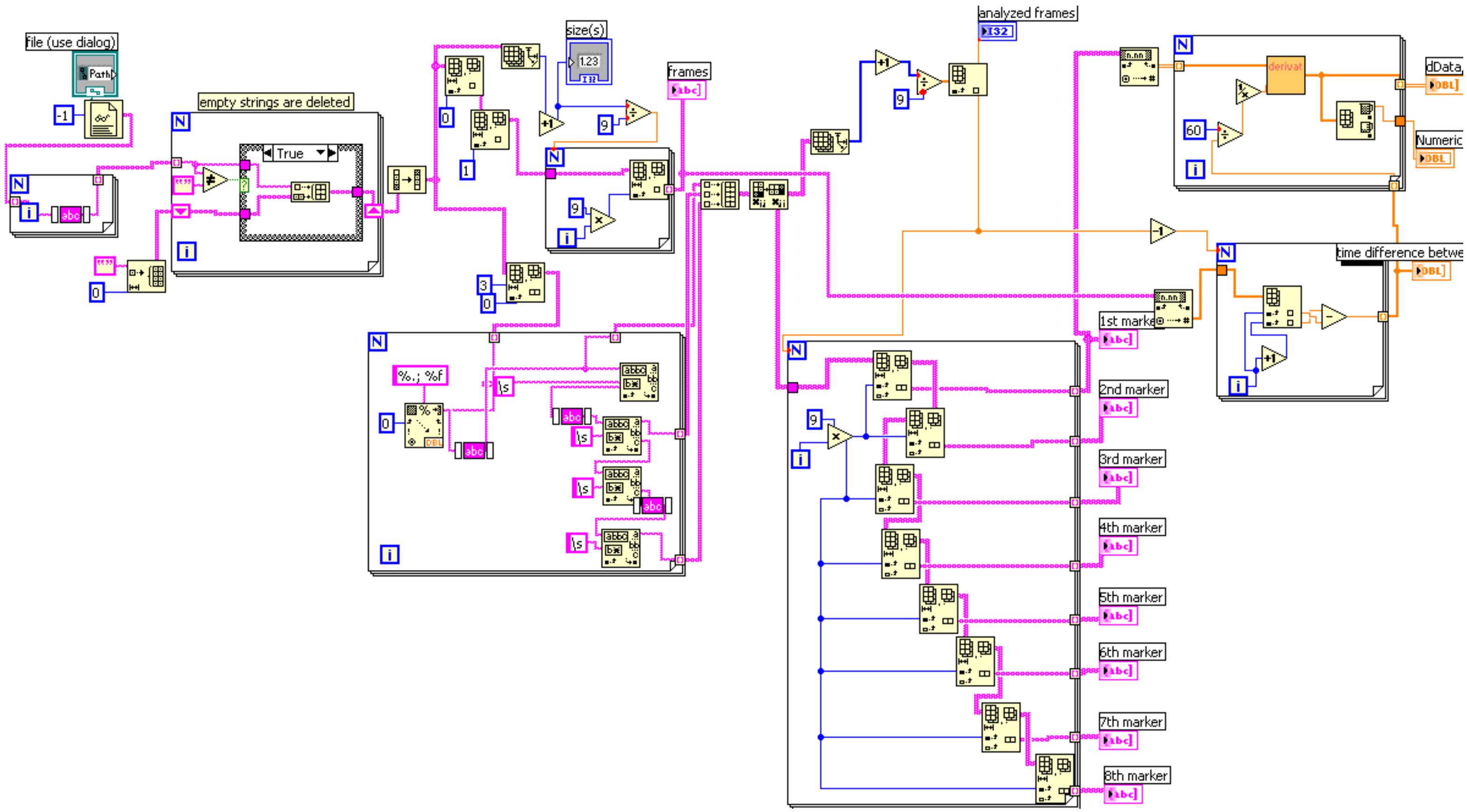
APPENDICES

APPENDIX A

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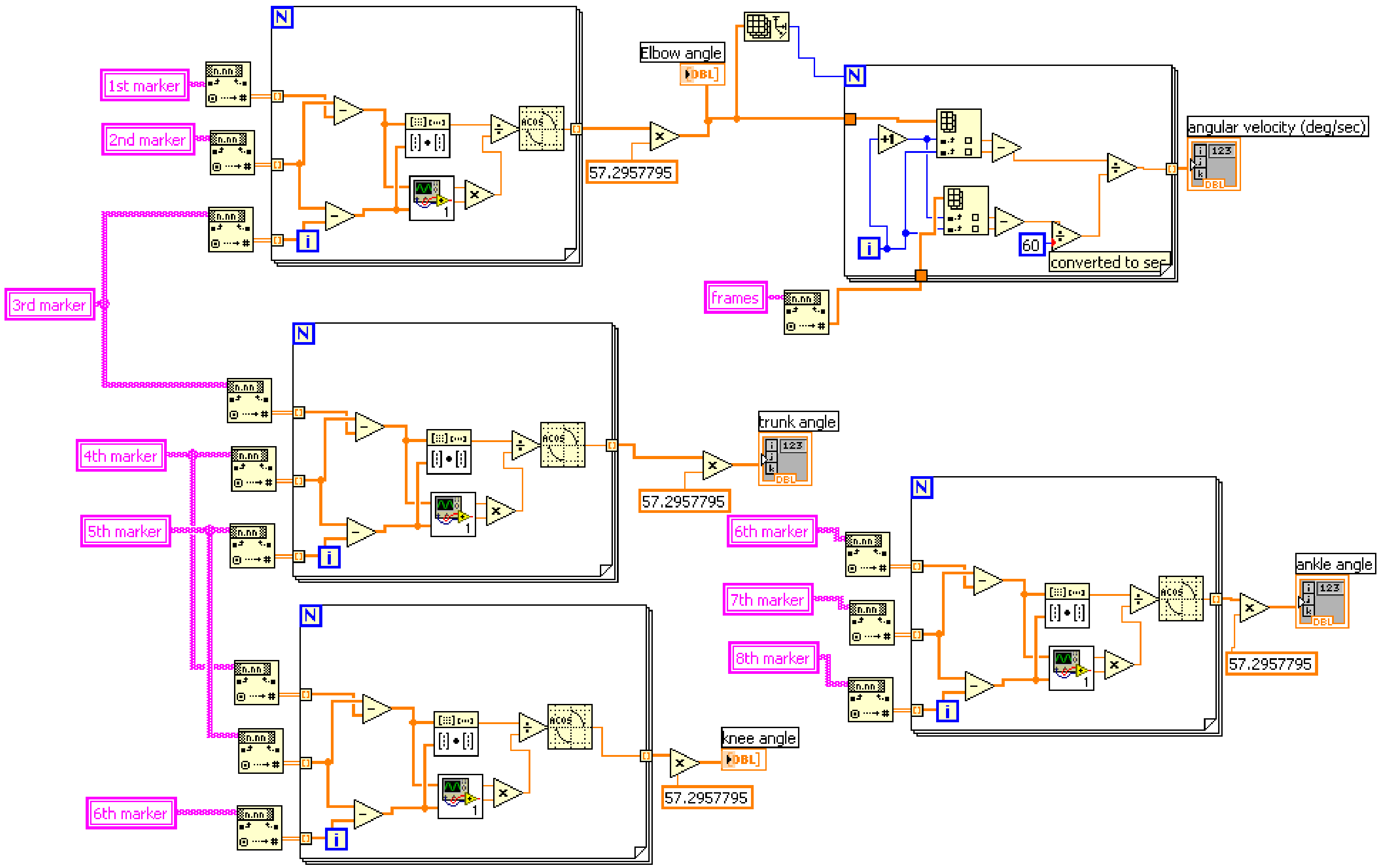
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