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The Effect of Fatigue on the Kinematics of Free Throw Shooting in Basketball

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Fatigue is an indispensible part of a basketball game which may affect an athlete's shooting kinematics. Although kinematic analyses of various sports related movements were extensively done, this study is the first to consider the effects of fatigue on the kinematics of free throw shooting. After measuring the resting heart rate, ten collegiate level, male basketball players (21.8±1.6 y; 192.8±3.6 cm; 84.1±8.5 kg) were asked to perform free throws. Two successful and two unsuccessful free throws were selected. Thereafter, participants were asked to complete the fatigue protocol, which included 30m sprints and 5 vertical jumps at each end, until they reached volitional exhaustion. Additional two successful and two unsuccessful free throws were collected. All shots were recorded by using two digital cameras operating at 60 Hz and placed in a stereoscopic view. The elbow, trunk, knee and ankle joint angles were measured before and after the ball release and at the ball release point. The selected joint angles were compared between successful and unsuccessful free throws, as well as before and after the completion of fatigue protocol. The results demonstrated that fatigue did not effect free throw shooting kinematics (p>0.05) and there was no significant joint angle difference between successful and unsuccessful shots (p>0.05). This study suggested that high level athletes are able to cope with the possible detrimental effects of fatigue while performing coordinated movements such as free throw shooting.

Key words: *digital photogrammetry, motion analysis, heart rate, volitional exhaustion*

Introduction

Basketball is an intermittent sport that involves both intensive short movements (e.g., jumping, sliding, sprinting) and less intensive longer movements (e.g., walking, running). Altogether, the physiological demands of basketball game on players, which requires both aerobic and an-aerobic energy delivery systems, were claimed to be high (Bompa, 1994). Moreover, not only the blood lactate levels but also the mean heart rates of the players during a competitive game were found to be close to their maximal values (Ben Abdelkerim et al., 2007; McInnes et al., 1995). As a result, fatigue becomes an indispensible part of the game that may deteriorate the performance, the coordination and the skill of a player (Forestier and Nougier, 1998; Ivoilov et al., 1981; Kellis et al., 2006; Lyons et al., 2006); and yet players are expected to perform well under fatigue conditions. It is surprising that only a handful of studies considered the effects of fatigue on the

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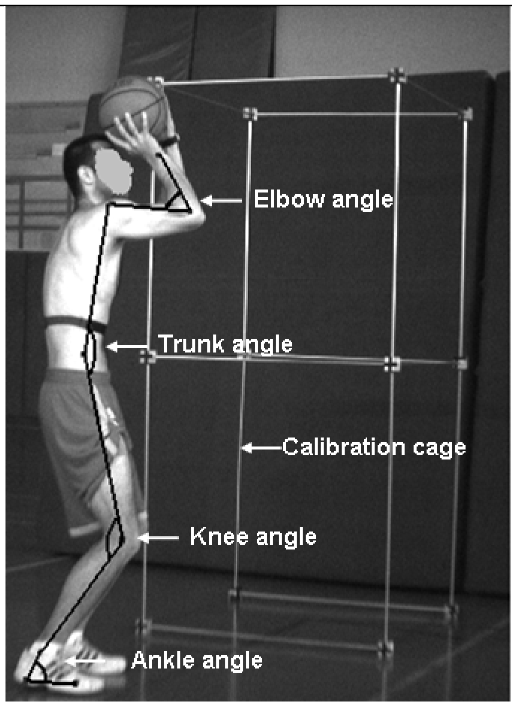

Figure 1

analyses of basketball specific movements until now (Erculj and Supej, 2009; Lyons et al., 2006).

Free throw is a considerably decisive element of a basketball game. Researchers (Button et al., 2003; Elliot, 1989; Goktepe et al., 2009; Hudson, 1982; Miller and Bartlett, 1996; Okubo and Hubbard, 2006; Rojast et al., 2000; Tan and Miller, 1981) have dealt with various types of analyses in sports, including free throws, in a detailed manner. Although most of the athletes and coaches believe that fatigue has detrimental effects on shooting performance, kinematics of free throw shooting in basketball performed under fatigue conditions have not been yet studied. The research question of the current study was to establish the effectiveness of elite basketball players in coping with fatigue during free throw shooting. Moreover, the differences between successful versus unsuccessful free throws under fatigue versus non-fatigue conditions were studied. We hypothesized that the joint angles would be different between successful and unsuccessful free throw shots in basketball and there will be significant differences between free throws performed under fatigue and non-fatigue conditions.

Material and Methods

Ten healthy male collegiate level basketball players (two guards, four forwards, and four centers; age 21.8±1.6 years; height 192.8±3.6 cm; weight 84.1±8.5 kg) volunteered for the study. All of the participants were free 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 technical problems, two of the right handed players' kinematic data were insufficient for kinematic analysis and excluded from the study. All participants signed an institutionally approved informed consent prior to data collection. The study was approved by the local ethical committee of the Middle East Technical University.

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 1.0x1.0x2.0 m containing 12 control points was used to calibrate the free throw shooting area (Figure 1). 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 by using Pictran Software (Technet GmbH, Germany). 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.

Eight markers were unilaterally placed on subjects as follows: wrist (styloid process of ulna), elbow (lateral epicondyle), shoulder (acromion process), pelvis (anterior superior iliac spine), knee (lateral epicondyle), distal end of fibula (lateral malleolus), the heel of the shoe (calcaneous; at the same height above the plantar surface of the foot as the phalange marker) and 5th metatarsophalangeal joint. A customized LabView™ software was used to calculate the elbow, trunk, knee, and ankle joint angles (see Figure 1) by using the 3D coordinates of the markers.

After measuring the resting heart rate, the participants were asked to perform free throws until researchers were able to collect two successful and two unsuccessful free throws. Any shot that had touched the rim or the backboard was claimed as unsuccessful (Miller and Bartlett, 1996; Rojast et al., 2000). Thereafter, participants completed the fatigue protocol (see Figure 2) until they reached volitional exhaustion. The fatigue protocol consisted of repetitive 30 m sprints and five consecutive vertical jumps at both ends of the sprints (Chappel et al., 2005). Participants were instructed to accelerate/decelerate as

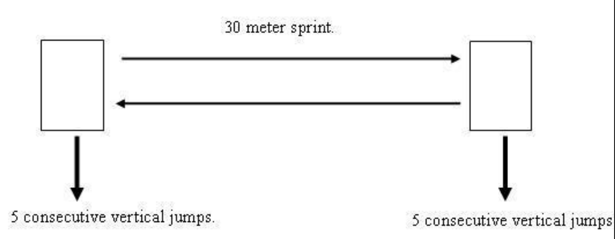

Figure 2

fast as possible during the sprints and to jump as high as possible on each end. Participants completed the fatigue protocol until they were no longer able to run or jump. As soon as participants reached volitional exhaustion, they were asked to perform free throws again until researchers were able to collect two successful and two unsuccessful free throws. However, during the free throws that were performed under fatigued state, participants were also asked to complete the fatigue protocol for only one lap (2x30m sprints and 2x5 vertical jumps) after each free throw attempt in order to keep their fatigued state elevated. Heart rate was monitored during the execution of fatigued free throws. The free throw shots were divided and analyzed in 3 different frames: the ball release point, and 83.3 ms (5 frames) before and after the ball release point.

Since the aim of the study was to examine the effects of fatigue and success on the kinematics of free throw shooting, for each selected time frame and joint angle a two-way (pre-post fatigue and successful-unsuccessful) repeated measures of analysis of variance (ANOVA) was used. A p-value of 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 in fatigue condition, an intra-class correlation (ICC) analyses was conducted. 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.

Results

Subjects reached volitional exhaustion at a mean level of 4.9 (±1.4) laps at the fatigue protocol, with a mean time of 137 s. Paired sample t-test revealed that there was a significant difference between the resting heart rate (62.3 beats/min) and the heart rate after the completion of the main fatigue protocol (175.1 beats/min) [t(9)=-29.8, p<0.01]. As a measure of induced fatigue, we also compared the completion times of the first and the last lap in the main exercise protocol. 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

Table 1

Selected joint angles for successful (suc) and unsuccessful (unsuc) shots as well as shot performed before (pre-fat) and after (post-fat) completion of fatigue protocol at selected time frames

	-83 msec		Ball release		+83msec	
	Pre-Fat	Post-Fat	Pre-Fat	Post-Fat	Pre-Fat	Post-Fat
			Elbow			
Suc	80.1 ± 15.9	86.4 ± 13.7	113.5 ± 22.8	117.5 ± 17.6	151.8 ± 10.2	147.1 ± 10.6
UnSuc	85.7 ± 14.0	83.6 ± 10.2	123.2 ± 16.1	120.1 ± 15.5	147.9 ± 14.3	148.9 ± 15.0
Trunk						
Suc	168.3 ± 2.9	166.7 ± 6.0	170.8 ± 4.6	168.9 ± 6.0	171.0 ± 5.9	169.9 ± 4.5
UnSuc	168.9 ± 3.6	168.6 ± 4.5	170.6 ± 3.5	169.5 ± 5.8	170.1 ± 4.9	169.5 ± 7.4
			Knee			
Suc	151.3 ± 11.6	152.2 ± 8.6	164.7 ± 9.7	164.3 ± 6.8	168.7 ± 7.1	167.5 ± 7.1
UnSuc	152.9 ± 12.7	151.8 ± 10.4	164.5 ± 8.6	165.8 ± 8.0	165.7 ± 5.7	169.4 ± 5.1
			Ankle			
Suc	65.7 ± 12.4	69.7 ± 5.7	70.6 ± 7.7	70.6 ± 6.7	71.2 ± 8.0	71.2 ± 7.3
UnSuc	70.1 ± 6.1	70.3 ± 6.4	70.8 ± 6.9	71.4 ± 7.0	71.0 ± 6.4	72.0 ± 7.7

elevated during the free throws performed in fatigued condition. Intra-class correlation analyses revealed that the heart rates after the initial main fatigue protocol and the subsequent completion of each individual lap, which were completed after each free-throw shot performed under fatigued condition, were comparable [ICC=.766, $F(1,9)=2.522$, $p>0.05$].

Table 1 shows the calculated joint angles during successful and unsuccessful free throw shots before and after completing the fatigue protocol. Results revealed no significant main effects of fatigue, success, and fatigue-success interaction on any selected joint angle in any selected time frame.

Discussion

This study was conducted to investigate the effects of fatigue and success on the kinematics of basketball free throw shooting. The kinematics of elbow, trunk, knee, and ankle joint angles were calculated at ball release and 83 ms before and after ball release.

The mean heart rate value of 175.1 beats/min (85-90% of maximum heart rate), which was registered immediately after completing the main fatigue protocol, can be speculated to be similar to heart rates in fatigue situations, as well as in a competitive basketball game (Ben Abdelkerim et al., 2007; Erculj and Supej, 2009; McInnes et al., 1995). Aside from the heart rate, participants reached volitional exhaustion in the main fatigue protocol with a mean time of 137s. Taking the mean heart rate, intensity, type, and the period of fatigue protocol together, it can be claimed that participants were eager to force themselves as hard as possible until they reach volitional exhaustion. Moreover, the brief communication with the participants after the experiment revealed that participants could no longer run or jump once they completed the fatigue protocol.

The detrimental effects of fatigue on sports related performance and skills have been reported in the literature. It was found that fatigue had an adverse effect on the passing accuracy in basketball and this affect was more prominent in novice players when compared to experts (Lyons et al., 2006). Forestier and Nougier (1996) found that fatigue adversely affected the accuracy and the multi-limb coordination of handball players in overhead throwing. Moreover, fatigue resulted in a reduced lower leg swing speed and peak lower leg angular velocity at the time of kicking in soccer (Aprioantono et al., 2006). However, in the aforementioned studies, researchers used fatigue protocols that induced only localized fatigue to the selected extremities. Additionally, the devices or protocols used in the above mentioned studies (e.g., isokinetic muscle testing devices or push ups) were not exercise-specific in representing original fatigue conditions that occur in real game situations. Therefore, the effects of fatigue on skill or performance as was found in previous studies might be misleading. Paralleling sport-specific activities, the fatigue protocol that was used in this study consisted of sprinting, jumping, accelerating, and decelerating. These short duration, high demanding movements were reported to be an essential part of a real basketball game (Ben Abdelkerim et al., 2007; McInnes et al., 1995). Therefore, it can be speculated that the elite players that participated in this experiment were highly experienced in performing under fatigue conditions, as caused by these sport-specific movements.

This study failed to show any differences in joint angle kinematics for successful versus unsuccessful shots. Similar to previous studies (Miller and Bartlett, 1996; Rojast et al., 2000), we defined successful shots as successful attempts which did not touch the rim or backboard. In order to quantify successful and unsuccessful shots, we attempted to eliminate chance factors which might result from the bounce of the ball from the rim or backboard. By doing so, even if a successful shot barely touched the rim, we needed to claim that the shot was unsuccessful. This assumption might have prevented us from establishing 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, other actions which 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 and the rotations of the hip or shoulder (Hudson 1985), might be crucial factors that affect the shots and become the reasons for unsuccessful attempts. To resolve this issue, more sophisticated experimental tools (e.g., 3D optical system with multiple digital cameras) should be used in future studies.

It was claimed that free throw shooting requires minimal strength and places sub-maximal demands on elite players (Hudson, 1982). It seems that elite basketball players are capable of coping with potentially adverse effects of fatigue in sub-maximal performances that require relatively less strength but more co-ordination (i.e., free throws). Therefore, the possible effects of fatigue on shooting might be more prominent when shooting requires explosive movements, such as 3-point shots or jump shots. In line with this speculation, Erculj and Supej (2009) found that fatigued players performed the 3-point shots with decreased shoulder and wrist height, as well as decreased elbow and upper arm angle at the time of ball release, when compared with shots performed with no fatigue condition.

Coordination is more of a required skill than strength in free throw shooting for elite level basketball players. A free throw can be defined 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 of the physical state, are claimed as skill sets more commonly found in highly skilled basketball players (Hudson, 1982). Since the participants used in this experiment were elite basketball players, the effects of fatigue on free throw shooting might not be seen on the kinematics of action due to such 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 lesser skilled athletes when compared to elite level athletes (Lyons et al., 2006).

Rojast et al. (2000) studied the kinematic adjustments of players when 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 trunk angle was 172.7^0. In the study by Miller and Bartlett (1996), the relationship between playing positions and shooting distance was assessed. They found that during 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 the trunk was 172^0 at the time of ball release. There seems to be a small difference between our findings and and those from previous studies. 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 the 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 were found in this current study and the literature.

The major finding of this study-no significant fatigue-induced effects on free throw shooting--implies that coaches do not have to make substitutions with their fatigued players prior to performing free throw shots. However, one should also keep in mind that the effects of fatigue on non-elite or younger players, whose strength would be more important in free throw shooting than the co-ordination component, might be more influential during free throws.

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