CARDIORESPIRATORY FITNESS ALLEVIATES THE EFFECT OF FATIGUE ON BASKETBALL FREE THROW SHOOTING PERFORMANCE

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Fatigue causes basketball players to change their movement patterns while shooting free throws, leading to missed shots. Cardiorespiratory fitness may moderate this negative relationship. Male collegiate basketball players completed a VO_2max test to determine their fitness. On another day, each player shot 10 free throws, then performed a basketball-specific fatigue protocol, and then shot 10 more free throws. Shot accuracy, shot consistency, and shooting kinematics were calculated from video analyses. Shot accuracy was unchanged, shot consistency worsened (p = 0.03), and peak knee flexion angle increased ($p < 0.01$) for all players following the fatigue protocol. Fitter players were more accurate ($p < 0.01$) and more consistent (p = 0.02) when shooting while fatigued. Conditioning may be an important factor in free throw training.

KEYWORDS: Basketball, Shooting, Fatigue, Fitness, Accuracy, Consistency.

INTRODUCTION: In basketball, free throw shooting performance, especially in a close game, has been identified as a determining factor in a team scoring more points and therefore winning (Csataljay, O'Donoghue, Hughes, & Dancs, 2009; Csataljay, James, Hughes, & Dancs, 2012; Kreivytė, 2014). A free throw is a set shot from a fixed distance of 4.6 meters and is the only designated uncontested shot. A free throw is awarded as a penalty for the opposing team committing a foul. Intentional fouling strategies are commonly employed in late-game situations to change possession. Performance analyses of free throws under game conditions allow coaches to generate reliable tactical information about their team and their opponents (Ibáñez, García, Feu, Lorenzo, & Sampaio, 2009). Understanding each player's ability to shoot a free throw accurately when they are fatigued, as they would be at the end of a game, therefore, is tactical information of great relevance.

Multiple factors influence free throw performance, including athletic experience, rehearsal experience, hand dominance, gender, confidence, and fatigue (Sampaio, Gonçalves, Rentero, Abrantes, & Leite, 2014). Playing an entire basketball game causes both physical and mental fatigue in a player. The high percent duration of active movements during periods of basketball play indicates a generally high physiologic demand (Narazaki, Berg, Stergiou, & Chen, 2009). The manual repetitive tasks of basketball, including guarding, dribbling, and shooting lead to local muscle fatigue (Gates & Dingwell, 2011). The fatigue a player experiences from playing a full basketball game has a detrimental effect on their free throw performance. Fatigue impairs muscle strength, reaction time, and proprioception, which causes players to change their shooting movement patterns. Unconsciously altered movement patterns are less consistent, and movement and outcome consistency are critical for the fixed skill of free throw shooting. Fatigue causes a redistribution of forces in the body (Cowley & Gates, 2017). This leads to changes in the forces the body applies to the basketball, and free throw shooting requires precise release conditions created by specific forces (Chau & Silverberg, 2008). Free throw shooting accuracy and consistency is greater in players whose shooting movement patterns have been less affected by fatigue.

Limited information exists regarding the effects of player cardiorespiratory fitness level on fatigue and free throw shooting movement patterns and performance. Winning teams tend to shoot better, which was hypothesized to be the result of higher conditioning statuses (Ibáñez *et al.*, 2009). Trained basketball players can recover from high levels of fatigue sufficiently in a short time to maintain their free throw performance (Peynircioglu, Thompson, & Tanielian, 2000). The exact relationship remains undetermined. The objective of this study, therefore, was to investigate how cardiorespiratory fitness affects the relationship between fatigue and free throw shooting performance. We hypothesized that a greater cardiorespiratory fitness level would moderate the negative effect of fatigue on free throw shooting accuracy and consistency.

METHODS: This study was conducted during a basketball season. Cardiorespiratory fitness testing was conducted at the start of the season, and free throw shooting testing was conducted at the middle and end of the season. Twenty healthy, right handed, male, division I collegiate basketball players, aged 18-25 years old were involved in this study. Participants were excluded if they were aged under 18 or over 25, currently sick, had pain or injury in the past three months, or were not a collegiate-level, competitive basketball player. All players consented to be a part of the study, which was approved by Marshall University's IRB.
Early in the season, each player performed a VO_2max test on a treadmill (Woodway Pro, Woodway, Inc., Waukesha, WI) in an exercise physiology lab. The test started with the player performing a two-minute warm up on the treadmill. During this warm-up period, the staff confirmed that the equipment was working correctly, and the player was comfortable with the equipment. For the test, the players walked at 5.5 mph starting at a 10% grade with a 1% grade increase every 60 seconds (Bruce, Kusumi, & Hosmer, 1973). The player's breathing was monitored throughout the test with a two-way valve mask (7900 Oro-Nasal, Hans Rudolph, Shawnee, KS) and a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT), which measured the fractions of oxygen and carbon dioxide in the expired air. A VO_2max test is an effort dependent test, so the players were asked to keep walking until they physically couldn’t continue. The VO_2max test ended when the player felt they could not continue and their respiratory exchange ratio had been at least 1.1 for at least 30 continuous seconds, indicating intense exercise. Each player’s VO_2max was calculated as the oxygen consumed during the final minute of the test, and normalized to body weight.
On four different days later in the season, immediately before a regularly scheduled practice, players completed a free throw shooting test in groups of three or four. One group completed the free throw shooting test per day with staggered start times among group members. These tests were conducted on a regulation indoor basketball court. Each player warmed up for 15 minutes by performing self-selected dribbling, passing, and non-free throw shooting skills. After the warm-up period, the player shot 10 free throws. They then performed a set of 10 repetitions of defensive slides while holding a basketball over their head as fast as they could as a fatigue protocol. One repetition was to start facing the baseline with their right foot on the right lane line, shuffle laterally to the left lane line and touch it with their left foot, and then shuffle laterally to the right lane line and touch it with their right foot, all the time holding a basketball above their head. The time to complete the set was measured with a hand-held stopwatch. The player then completed n subsequent sets of 10 defensive slides with no break between sets, until the time to complete the n^{th} set was 120% of the time taken for the first set. The number of sets completed varied among players due to their different fitness levels; those with greater cardiorespiratory fitness levels completed more sets. The total duration of completing the fatigue protocol was recorded as a second indicator of cardiorespiratory fitness. Following the fatigue protocol, the player then immediately shot another 10 free throws, and then joined the rest of their team to participate in their scheduled team practice.
Three high-speed, digital video cameras (RX10iii, Sony USA Inc., New York, NY) recorded the free throw shooting test from behind the player, to the right side of the player, and above the basket aiming at the top of the rim. The left-right X and front-back Y position of the center of the ball in the horizontal plane as it reached the height of the rim at the end of the shot was recorded on a diagram as points on an XY plane for every shot. Shot accuracy was calculated as the distance between the actual shot location and the optimal shot location as determined by Chau & Silverberg (2008), with greater values indicating less accuracy. Shot consistency was calculated as the distance between the actual shot location and the average shot location for a set of 10 shots, with greater values indicating less consistency. Changes in accuracy and consistency from before to after the fatigue protocol were calculated as: score before − score after, and averaged per-player. Two-dimensional knee, hip, shoulder, and elbow joint angles of the player were measured for the first three free throws before and after the fatigue protocol

using Kinovea (Kinovea.org). The maximum joint flexion angles during the shooting procedure were recorded and averaged for every player.

Changes in shot accuracy, shot consistency, and shooting kinematics following the fatigue protocol were assessed using paired-sample t-tests. The effect of cardiorespiratory fitness on changes in shot accuracy and shot consistency was assessed using linear regression, and a canonical correlation between a combination of VO_2max and fatigue protocol duration and a combination of change in shot accuracy and change in shot consistency. All statistical analyses were conducted in SPSS version 24 (IBM Corp., Armonk, NY). Statistical significance was set a priori as alpha = 0.05.

RESULTS: The players' shot consistency was worse following the fatigue protocol (pre = 4.3 ± 1.4 cm, post = 5.1 ± 1.3 cm, t_{19} = 2.122, p = 0.03) (Figure 1). There was no difference in shot accuracy when the players were fatigued (Figure 1). Players displayed minimally altered shooting kinematics following the fatigue protocol. Their maximum knee flexion angle was 5° greater when fatigued (pre = 56 ± 9°, post = 61 ± 9°, t_{19} = 4.446, p = 0.002). There were no statistically significant changes in maximum hip, shoulder, and elbow flexion angle when the players were fatigued.

VO_2max and shot accuracy and shot consistency were not linearly related. Fatigue protocol duration and change in shot accuracy were linearly related such that as fitness increased shot accuracy improved (R^2 = 0.488, $F_{1,19}$ = 10.485, p = 0.008). Fatigue protocol duration and change in shot consistency were linearly related such that as fitness increased shot consistency improved (R^2 = 0.396, $F_{1,19}$ = 7.216, p = 0.02).

A distinct canonical correlation of 0.784 was found between linear composites of fitness and shooting performance (Λ = 0.250, $F_{4,18}$ = 4.492, p = 0.008). The canonical correlation was primarily between fatigue protocol duration (β = 0.958) and a linear combination of change in shot accuracy (β = 0.829) and change in shot consistency (β = 0.288), with fitness accounting for 51.1% of the variance in shooting performance (Figure 2).

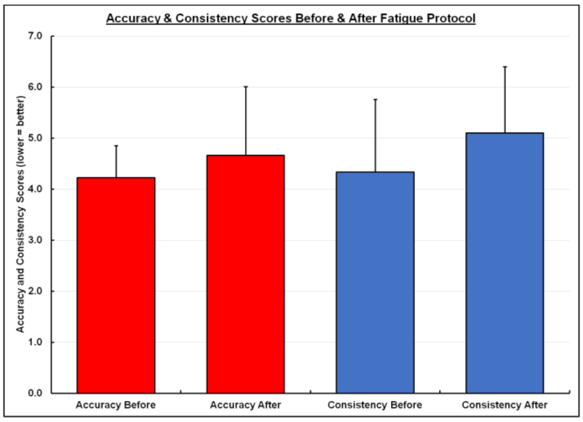

Figure 1: Accuracy Scores and Consistency Scores Before and After a Fatigue Protocol. A greater value for accuracy means the shots were further away from the ideal point, so were less accurate. A greater value for consistency means the shots were further away from each other, so were less consistent.

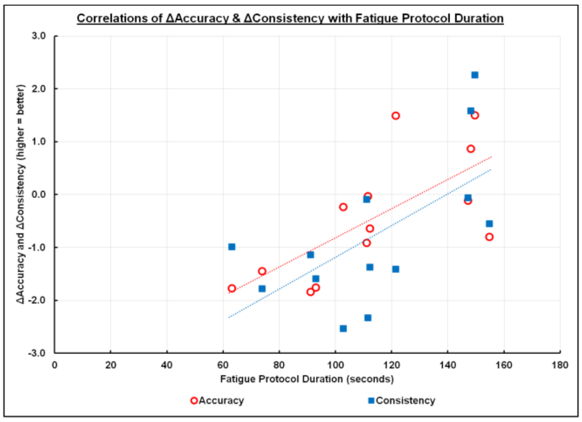

Figure 2: Bivariate Correlations of Change in Accuracy Score and Change in Consistency Score with Fatigue Protocol Duration. A greater value for Δaccuracy means the shots were more accurate after the fatigue protocol. A greater value for Δconsistency means the shots were more consistent after the fatigue protocol.

DISCUSSION: We hypothesized that cardiorespiratory fitness would moderate the negative effect of fatigue on free throw shooting accuracy and consistency. Our hypothesis was partially supported by our results. The players free throw shots were less consistent following the fatigue protocol, indicating that fatigue affects free throw shooting performance negatively. VO_2max was not related to shot accuracy or shot consistency, however, players who took longer to complete the fatigue protocol were more accurate and more consistent when shooting free throws while fatigued. These results together suggest that the fitter players' free throw shooting performance was less affected by fatigue.

The basketball players in this study demonstrated accurate free throw shooting throughout. This maintenance of accuracy is probably due to free throw shooting being an especial skill that is robust to the effects of fatigue (Keetch, Schmidt, Lee, & Young, 2005). There were also minimal changes in their shooting movement patterns. The players probably increased their knee flexion to generate additional force from the lower extremities to counteract upper extremity muscle fatigue. The fittest players were even able to improve their free throw shooting accuracy and consistency following the fatigue protocol. This may be because the fatigue protocol acted like an intense, sport-specific warm-up between the sets of 10 free throws.

Basketball is a game of repeated sprints and explosive skills. The VO_2max values may not have been related to variance in shot accuracy or consistency because it is an aerobic test. The duration of the fatigue protocol was linearly related to shot consistency and shot accuracy. Sport-specific tests may be needed to measure a basketball player's cardiorespiratory fitness appropriately.

There were limitations to this study. All testing performed in this study was effort dependent, and we cannot be certain that all participants gave maximum effort. The VO_2max test was conducted during the start of the season while the remaining testing was performed during the middle and end of the season, so the players' VO_2max scores could have changed in that time. Creating a real-life situation that would fatigue a player to the extent they would be in a game in the short testing time allowed by the team was unrealistic. The actions performed during the fatigue protocol created local muscle fatigue in the player's extremities, and all players reported feeling tired as they started to shoot their second set of free throws.

CONCLUSION: Free throw shooting consistency decreased following fatigue. Players with greater cardiorespiratory fitness levels had a longer fatigue protocol duration; fitter players took longer to fatigue. Players with longer fatigue protocol durations were more accurate and consistent. Basketball players with greater cardiorespiratory fitness levels took longer to fatigue, and were more accurate and consistent at shooting free throws while fatigued.

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