Motriz, Rio Claro, v. 28, 2022, e10220000422 *DOI: http://dx.doi.org/10.1590/s1980-657420220000422*

Sports Coaching

High-intensity effort impairs basketball free-throw shooting efficiency

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Abstract - Aim: This study verified how much performance damage can high-intensity efforts cause to FT shooting efficiency. **Methods:** A sample of 13 male amateur basketball players (19.9 ± 3.2 years; 76.7 ± 8.7 kg; 182 ± 10 cm) participated in the study on three non-consecutive days. A maximum progressive exercise test determined maximum heart rate (HRMax) during the first session. On the other two days (randomly assigned), athletes performed five bouts of basketball-related exercises, intense enough to raise HR to either 65% (S65) or 90% (S90) of HR_{Max}, followed by two FT shots (totaling 10 FT). **Results:** FT performance was lower in S90 than in S65 (56.9% ± 18.9% vs 73.1% ± 12.5%, respectively; $p = 0.026$; ES = 1.01 - "large effect size"). Magnitude-based inference analysis considered shooting at S90 moderately disadvantageous and odds ratio analysis suggest that shooting FT at higher HR values represents an 11-fold chance to worsen performance (OR = 11.1; 95% CI = 1.79 to 68.9; $p = 0.01$). **Conclusion:** Basketball FT shooting efficiency is impaired after a bout of game-related high-intensity activity.

Keywords: heart rate, team sports, accuracy.

Introduction

Basketball is high activity and physiological demand intermittent sport, which arouses heart rate (HR) responses up to 190-199 bpm or 82%-95% of players' maximum heart rate (HR_{Max})[1,2]. For instance, a typical game situation such as consecutive bouts of defensive and offensive transitions could be enough to rise HR above 90% HR_{Max}[3]. This level of effort may alter the efficiency of the following plays[4], which have already been suggested for passing[5], field goals[6,7], and free throw (FT) shooting[8] accuracies. Still, surprisingly, it is not uncommon to find athletes practicing FT under resting conditions, sometimes at the beginning of the training session, or as a recovery activity, which neglects the likelihood of the FT shooting occurring right after high-intensity efforts.

FT in basketball counts for about 20% of the official match scoring points[9] and represents a key factor for determining win or loss in balanced games[10,11]. Gómez et al.[12] demonstrated that despite other game-related statistics analyses, FT increased the odds of winning by 32% in the last 5-min of the game, and 67% during overtime. Based on the notorious high value of the FT shooting during the game, it is paramount to understand to what extent high-intensity efforts can affect the efficiency of FT.

Padulo et al.[8] compared FT efficiency under three physiological conditions: resting HR, 50%, and 80% of HR_{Max}. Briefly, their results indicated that a0% of HR_{Max} players hit less FT. In addition to the very promising results, it is possible to identify some questions that remain unanswered. From a methodological point of view, some adjustments could help bridge the gap. For instance, players shot sequences of 10 consecutive FT, which is not supposed to happen in an official game since 77% of the time players go to the line for only two FT attempts[13]. It would be necessary for a defensive foul to be called in an unsuccessful 3-point shooting attempt followed by a sequence of at least seven technical fouls on the defensive team's players/coaches for a 10 FT sequence to be feasible, which is also unlikely to take place[13]. Therefore, the first two attempts' efficiency should matter more than the whole sequence of FT, but the results showed only the total FT shooting percentage. Finally, the 10 FT sequence stood approximately 50 s long, which would be enough time to increase vagal activity and reduce throughout the FT sequence[14].

Moreover, it is very unlikely that the FT shots took place immediately after the foul is called since there is a plethora of game-related events that can occur right after the foul has been called, such as the mandatory communication to the scoring table officials, players substitution, medical care, and a time-out request. Consequently, it generates a time interval between the foul calling on play and the FT shooting, favoring autonomic modulation and reducing HR before FT shooting even starts. However, to the best of our knowledge, there are no studies that have monitored how long this period lasts. Ergo, it must be determined the magnitude of HR decay due to this pre-FT interval. In addition, for ecological validation purposes, FT attempts need to be like what most happens in official matches.

To elucidate these issues, this paper presents two correlated studies. The first study was designed to identify how long the pre-FT time interval stands. The results of this study guided the methodological organization of the second study, which aimed to test the hypothesis that previous high-intensity efforts compromise FT shooting efficiency (FT%).

Methods

First study

Determining the pre-free throw period

To determine how long the pre-FT time interval stands, we analyzed 48 random official matches of a single season of the Brazilian National Basketball League (Novo Basquete Brasil - NBB). Games were previously recorded on DVD to favor stopping and rewinding the plays (if necessary) and precisely registering time. We defined the pre-FT elapsed time as the moment the referee called the foul (whistle) till the moment the player received the ball to shoot the FT. Values were recorded in seconds and rounded to the nearest whole number. We conducted a descriptive analysis using mean, median, standard deviation, and variation coefficient. As a result of 1,444 fouls analyzed, pre-FT time spanned 31.7 ± 13.2 s (median: 25 s). Since data failed normality (Kolmogorov-Smirnov test; $p < 0.001$), and the variation coefficient reached 41%, we decided to use the median to characterize the pre-FT period.

Second study

Experimental approach to the problem

In a cross-sectional design, we asked basketball athletes to attend the university facilities on three non-consecutive days 24 to 48 h apart, and at the same period of day (between 7 and 9 p.m.). On the first day, the participants performed a maximum progressive treadmill test to obtain HR_{Max}. On the next two visits, in random order, athletes performed exercises intense enough to raise HR to 65% or 90% of HR_{Max}, after that they went to the FT shooting area and waited for authorization to shoot the ball twice. On each experimental day, these procedures were executed on five bouts, to complete 10 FT (Figure 1). Heart rate was continuously recorded for further analysis.

Subjects

The sample size was determined through open access software G*POWER 3.1.9.7 (©2021 Heinrich-Heine-Universität, Düsseldorf), based on effect size (≥ 0.80), statistical significance (< 0.05), and power (≥ 0.80), and resulted in a minimum of 12 participants.

The inclusion criteria were established as 15-30 years of age (inclusive), being regularly training for championships or tournaments, and with a personal FT efficiency record of at least 70%[15]. Any participant would be excluded in case of injuries or illnesses that could hinder or limit protocol activities and consequently affect participation (none was excluded). Therefore, 13 male amateur basketball players participated in the study (Table 1). The participants should abstain from alcoholic beverages in the last 24 h before the maximum progressive test on the treadmill, and not change their eating and hydration routines on the experimental session days. In addition, they should avoid practicing physical or sports activities before the experiments.

All procedures followed the tenets of the Helsinki Declaration, and the University Research Ethics Committee previously approved the study protocol (CEP/UFS

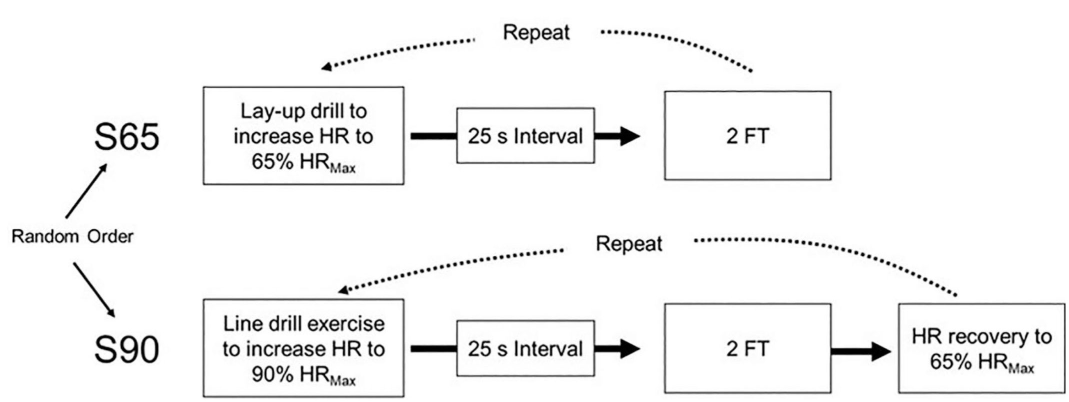

Figure 1 - Study design. S65 and S90 mean experimental sessions with heart rate increased to 65% and 90% of maximal heart rate, respectively; FT means free throw shooting.

Table 1 - Subject characteristics.

	Mean ± SD	Range
Age (years)	19.9 ± 3.2	15-24
Body Mass (kg)	76.7 ± 8.7	65-94
Height (cm)	182 ± 10	163-196
Maximal heart rate (bpm)	194.1 ± 8.3	176-202
Basketball experience (years)	6.9 ± 3.5	3-13

approval number: 3.304.052). Besides, after receiving information about the benefits and risks of the investigation, all participants (or their parental/legal guardian) signed an informed consent document.

Procedures

Determining maximum heart rate

The participants performed a maximum progressive exercise test on a treadmill (CENTURION 300, MICRO MED, Brazil), according to ramp protocol[16]. The initial speed was set at 6.0 km/h, with increments of 0.3 km/h every 20 s, up to the limit of volitional exhaustion despite the strong verbal encouragement to keep going. Participants wore an HR monitor (S810i, POLAR, Finland) to record HR responses continuously during the test and we considered the highest value as HR_{Max}.

Elevation of pre-free throw heart rate

We chose 65% and 90% of HR_{Max} values to simulate two different game intensities[2]. Athletes performed basketball game-like drills to raise HR. In the 65% session (S65), athletes performed a simple non-stop alternate lay-up drill. This drill starts at the elbow of the lane (restricted area), then the player drives towards the basket for a lay-up shot (right hand). Then, after grabbing his rebound, he dribbles as fast as possible towards the opposite elbow and immediately restarts the movement for another lay-up (left hand), and so on (Figure 2A). This exercise went on until the athlete reached 65% of HR_{Max}, which took approximately 30 to 60 s long.

In the 90% session (S90), athletes performed the line drill exercise, which consisted of progressive distance back-and-forth runs at maximum speed, with a 180° change of direction at FT line, half-court line, opposing FT line, and full-court, totaling 140 m, based on FIBA official pitch size regulations (Figure 2B). Athletes executed two bouts of line drill test, 1-min apart, which was enough to reach 90% of HR_{Max}. In both experimental sessions, we recorded HR responses continuously as well as stored data for later analysis using an S810i heart rate monitor (S810i, POLAR, Finland). All tests were performed on an Official-sized indoor basketball court.

Free throw efficiency protocol

On both S65 and S90, after reaching the desired HR values, athletes moved to the FT area and waited for 25 s (based on the first study results) to receive the ball and to shoot two FT. At this moment, as athletes were still using the HR monitor, we were able to determine HR pre-FT decay.

On S90, after the FT shooting, athletes sat in a chair and rested until the HR reached 65% of HR_{Max}, and then they restart the activities to increase HR to 90% of HR_{Max}. There was no need for a resting period on S65 since the HR values were already low after the FT. On both days, athletes performed the complete protocol (pre-exercises and FT) five times, totaling 10 FT.

We chose to keep a total of 10 FT as Padulo et al.[8] used to facilitate a more comprehensive analysis, however, split into five bouts to maintain FT shooting conditions similar to what happens in official matches. Besides, this shorter number of attempts was intended to avoid autonomic modulation and HR reduction throughout FT shooting. So, each of the 10 FT could be shot at the same or quite similar HR value. FT efficiency considered the entire set of 10 FT attempts to calculate shooting percentage.

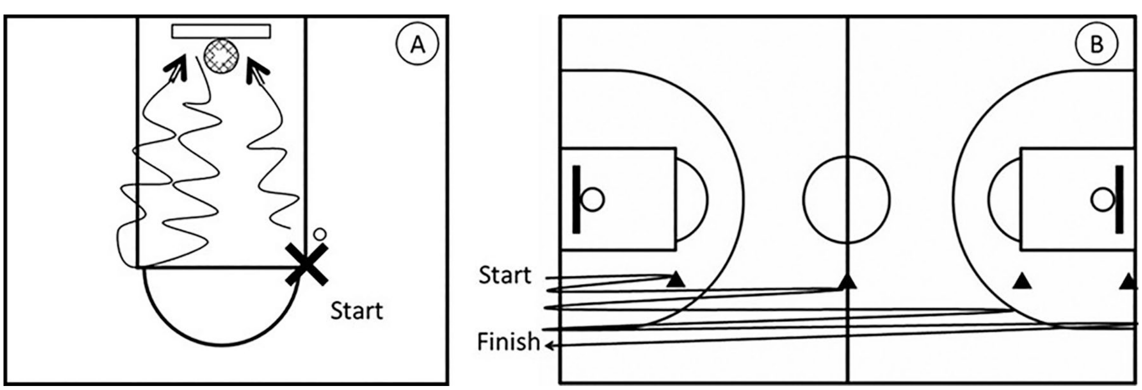

Figure 2 - Diagram of the pre-free throw shooting exercises to enhance heart rate. Panel A: non-stop alternate lay-up drill used to raise HR to 65% of HR_{Max}; Panel B: line drill test used to raise HR to 90% of HR_{Max}.

Data analysis procedures

Statistical analysis used SPSS 22.0 (IBM, USA). Shapiro-Wilk and the Levene tests authenticated data normality and homogeneity, respectively ($p > 0.05$ in both), for all variables. The student's paired t-test compares FT% between S65 and S90. Intraclass correlation coefficient (ICC) and one-way ANOVA verified the reproducibility of the HR values over the five bouts of each session. ANOVA 2×2 compares HR responses between the experimental sessions (S65 vs. S90) and between the moments of the protocol (post-exercise vs. pre-FT). The odds ratio of a worse FT% at S90 was also calculated. The significance level was set as 5%.

To make the results more robust, we applied Cohen's effect size adopting the following cut-off points: 0.01 (very small), 0.2 (small), 0.5 (medium), 0.8 (large), 1.2 (very large), and 2.0 (huge). We also used inference-based magnitude analysis assuming the probability of S90 causing some degree of negative, null or positive effects on FT % as: < 1% trivial (strongly reject), 1-5% (moderately reject), 5-25% (weakly reject), 25-75% (ambiguous), 75-95% (weakly compatible), 95-99% (moderately compatible), and > 99% (strongly compatible).

Results

Heart rate

Before the maximum progressive exercise test, athletes presented a resting HR of 70.5 ±10.8 bpm, and reached a maximal HR of 194.1 ± 8.3 bpm at the end of the test. There was no difference in resting HR values between the two experimental sessions (68.6 ± 8.0 bpm vs 71.7 ± 10.5 bpm, for S65 and S90, respectively, $t(12) = -1.131$, $p = 0.28$; 95%CI = -9.0 to 2.8, ES = 0.34 - small effect). HR decay between the previous activities (game-related drills) and the FT shooting was more accentuated in the S65 in relative values (11.8% ± 6.0% vs 8.5% ± 3.9% for S65 and S90, respectively, $t(64) = 4.097$, $p < 0.001$, 95%CI = 1.7% to 4.8%, ES = 0.65 - medium effect), albeit no difference was found in absolute bpm values (14.7 ± 7.5 bpm vs 14.7 ± 6.5 bpm for S65 and S90, respectively, $t(64) = -0.014$, $p = 0.99$, 95%CI = -2.2 to 2.2 bpm, ES = 0.10 - very small effect) (Figure 3).

ANOVA showed no statistical difference in HR responses amongst the five bouts of FT shooting on both experimental sessions ($p > 0.05$ for all; Figure 4). Additionally, ICC ranged from 0.86 to 0.96, meaning a high level of reproducibility (Table 2). FT shooting HR was 111.2 ± 9.1 bpm (CV = 9. 1%) in the S65, and 159.8 ± 10.7 bpm (CV = 6.7%) in the S90, which was equivalent to 56.5% and 81% of HRmax, respectively.

Free throw efficiency

FT efficiency was lower during S90 experimental session (S65: 73.1% ± 12.5%, S90: 56.9% ± 18.9%, $t(12) = 2.540$, $p = 0.026$, IC95% = 2.3% to 30.0%,

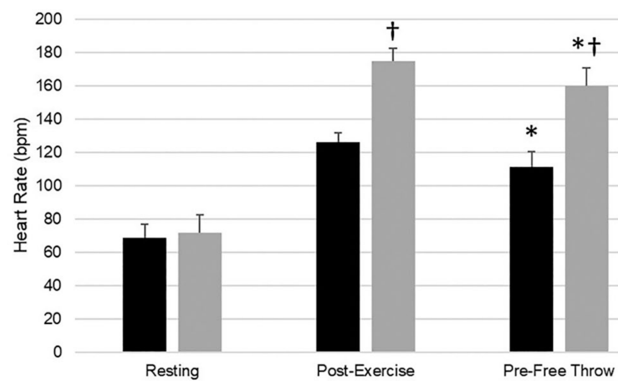

Figure 3 - Heart rate responses across phases of experimental sessions. *means $p < 0.05$ from Post-Exercise HR; †means $p < 0.05$ from S65.

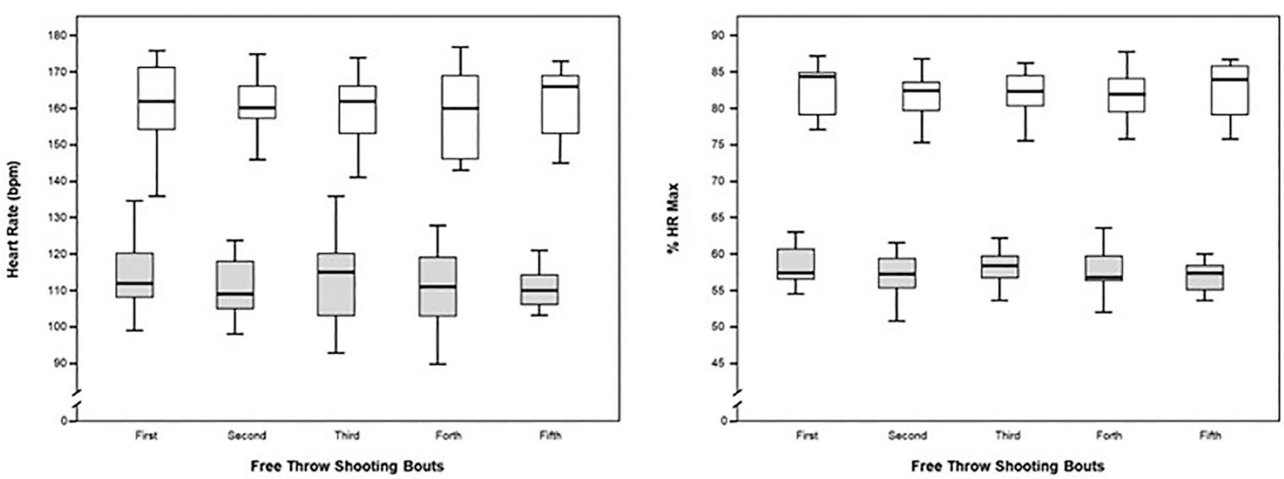

Figure 4 - Heart rate absolute (left panel) and relative (right panel) values before each bout of free-throw shooting in the S65 (grey boxes) and S90 (white boxes) experimental sessions.

Table 2 - Reproducibility indicators of heart rate recovery during the interval between the previous exercise and the collection of free throws in basketball.

	S65		S90	
HR recovery	**ANOVA (p)**	**ICC**	**ANOVA (p)**	**ICC**
Absolute	0.36	0.94*	0.77	0.96*
Percentage	0.40	0.87*	0.77	0.86*

S65: session at 65% of maximum heart rate; S90: session at 90% of maximum heart rate; All variables showed Shapiro-Wilk's normality of the distribution and Levene's homogeneity of variances ($p > 0.05$ for all); *means $p < 0.001$.

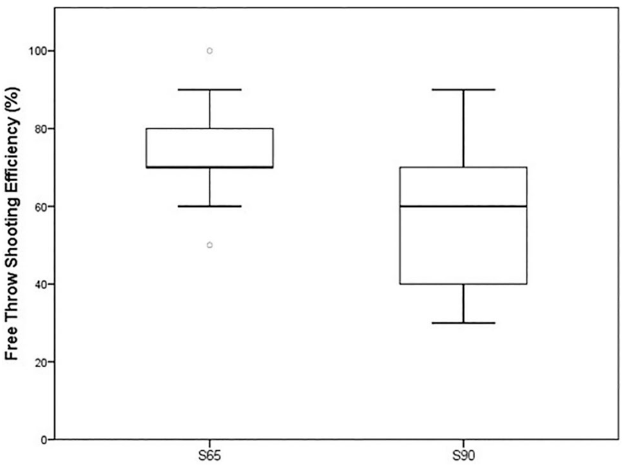

Figure 5 - Free throw shooting efficiency after heart rate was raised to 65% versus 90% of maximal heart rate. $*p < 0.05$.

Figure 5), and with a large effect size ($d = 1.01$). Odds ratio analysis suggests that shooting FT at higher HR values represents an 11-fold chance to worsen performance (OR = 11.1; 95%CI = 1.79 to 68.9; $p = 0.01$). In addition, magnitude-based clinical inference indicated moderately harmful effect of FT shooting in S90 (Difference ± 90% Confidence Limits = -16,2% ± 11%).

Discussion

Our main objective was to verify whether previous high-intensity efforts compromises FT shooting efficiency, and the results confirmed the findings of the Padulo et al.[8] study. After performing a basketball-related high-intensity effort, the FT shooting efficiency dropped from the percentile 40 to lower than the percentile 10, according to the Brazilian's professional basketball reference values[9].

We seek to advance the knowledge by following in their footsteps but aiming at addressing some methodological aspects in a more ecological approach. First, there is no reason to deny that after a referee calls a foul there is a time lag till the player is allowed to shoot the FT. Our first study indicated that this interval can be as long as 25 s, which represents enough time for vagally mediated HR decaying[14]. Thus, in the moment players shoot FT, HR is lower than the values reached now the foul happened.

Another strategy used in our study was splitting the FT sequence into five bouts of two shots instead of 10 shots in a row. The objectives of this protocol were two-fold. First, Padulo et al.[8] indicated an average of 50 s span to complete the 10 shots. Based on our HR decay results, it was very likely that the first two or three FT may have been shot with the HR around 10% higher than the last two or three of that sequence, especially after a moderate intensity effort, when HR recovery is faster due to a lower sympathetic activity[17]. Therefore, by shooting only two shots on each bout we were able to avoid large autonomic modulations of HR.

Our results showed that pre-FT HR responses were reliable amongst all five bouts of FT shooting, regardless of the intensity of the previous effort. This means that players very likely shot all FT under the same personal HR value in each bout. Although HR values during FT shooting have reduced in comparison to the ones achieved during the previous exercises, HR remained approximately within the range of 60%-85% of HR_{Max}, which is close to what is typically found in an official basketball game[2].

The second reason for splitting the FT shooting attempts into five bouts was to resemble a real-game environment. Based on current basketball official rules, one can assume that the odds of any given player shooting 10 FT in a row are quite low. That would require a very unorthodox game situation such as a player being fouled in an unsuccessful 3-point shot followed by seven technical fouls on the fouling team. One must consider that technical fouls are a rare event in a game of basketball[13,18]. Besides, a fouled player goes to the FT area to shoot the ball twice in at least three out of four times he/she goes to the foul line[13]. Plus, Chang[19] suggested that players might be able to self-correct their shot mechanics even in a brief sequence of FT. Hence, it seems clear that the longer the FT shooting sequence is, the more feasible would be to use previous shot results as feedback to adjust body movement and improve the following shot performance. One should still consider the eventual influence of the "hot hand belief"[20] that could boost a player's self-confidence for the following sequence after a hitting streak in the previous shots[21]. Therefore, those methodological adjustments were necessary to preserve the ecological validity of the study.

Wilson et al.[22] used a 6-point scale scoring system based on FT result (hit/miss) and the quality of the shot (touching/not touching the ring or the backboard) to analyze players shooting sequences of 10 FT (7 s apart) after performing three intensities of exercise. We preferred to use a simple point/no point system for made/missed shots, as a more game-like situation. Results revealed a loss of shooting efficiency post-high (76% HR_{Max}) and severe intensity (86% HR_{Max}) exercises. Despite the different measurement scales between the studies, these findings are similar to our results, since the performance was impaired after high metabolic demand efforts by 19% and 16%, respectively.

There are a few possible explanations for this loss of performance on FT post-high intensity effort. Wilson et al.[22] found a decrease of 45% in aiming accuracy after a bout of severe exercise. Aiming accuracy depends on visual and motor systems that could be affected after performing high-intensity efforts[23], which could reduce quiet eye duration[22]. Vickers et al.[24] showed that the quiet eye is a key ability for a high-level FT performance. In fact, expert players have earlier offset target fixation, which also lasts longer while shooting FT[25].

The quiet eye phenomenon is responsible for setting the parameters of the shot, such as target location/distance, optimal ball trajectory, body/limb movement control, and coordination that are needed during the shot[26]. Klostermann[27] suggests that prolonged quiet eye durations provide a shield through inhibitory mechanisms against sub-optimal or ineffective task solutions, an ability that differentiates skilled players from others. Hence, impairment of this visual control as a result of physical exertion is expected to weaken FT shooting efficiency[23]. However, several pieces of evidence support the premise that acute high-intensity exercise improves inhibitory control[28], although these findings are not consensual[29]. As we did not analyze gaze behavior in the present study, we are not able to determine whether quiet eye disturbances were responsible for FT performance loss.

Insufficient recovery time impairs technical efficiency[30]. Maybe this is the case for FT shooting after a high-intensity effort, separated by only 25 s apart. In the present study, players shot FT in S90 with HR near 160 bpm (or 80% of HR_{Max}), meaning that they were very likely under a high adrenergic stimulation[31], and still on recovery from an above ventilatory threshold intensity effort[32]. If the recovery time was not enough, FT shooting occurred under an increased ventilatory rate, and consequently, under a wide movement of the chest and shoulder girdle, making it difficult to stabilize the shoulders and control the movement while shooting the ball. Besides, players must focus on controlling ball release to improve and/or hold on to shooting performance, since FT efficiency strongly correlates to the release velocity variability[33] and muscle activation time variability[34].

Likewise, Verhoeven and Newell[35] and Mullineaux and Uhl[36] stressed the importance of synchronization between postural control coordination and ball release, while Tran and Silverberg[37] presented a set of conditions for an optimal ball release in free throw shooting, such as no more than 3 Hz of backspin on the ball. This wrist movement control could be impaired by changes in afferent feedback processing due to the high-intensity effort previously executed[38]. In addition, there is a variability increase in coordination as players perceive technique errors and try to adjust the movement during FT shooting[36]. In summary, one can argue that the typical intermittent high-intensity basketball match activities could impair FT shooting performance in several ways[39]. Although Barbieri et al.[40] found no compromise in FT accuracy after a repeated sprint ability test, our odds ratio analysis showed 11-fold more chances to worsen FT performance after a high-intensity effort, which adequately represents the magnitude of this negative effect.

Padulo et al.[7] and Ardigò et al.[6] also found a lower field goal performance post-high intensity effort in basketball players. Nonetheless, it is important to understand the differences between FT and field goal shooting, as only FT is a self-paced kind of shot[25], that is not contested by opposing players, nor relies on teammates passing skills. Therefore, FT is a highly steady, reliable, and controlled kind of basketball shot, which makes it more feasible to investigate. Still, some limitations regarding the interpretation of our results must be brought up.

Despite all the methodological care taken to respect the ecological validity of the investigation, we failed to mimic some official match context. It is not possible to clarify how much the absence of referees, opposing team, and fans, as well as game score, remaining time, or even importance of the game, avoided increasing anxiety and influencing players' performance[41]. Besides, our sample consisted of amateur basketball players, limiting extrapolation of the present results for elite or sub-elite athletes' performance. However, as sports science has already provided plenty of evidence on elite-level athletes in a lot of different fields, this study adds new information to be useful for more than 24 million amateur basketball practitioners, only in the US[42].

Also, while shooting FT in the final moments of a close game, players may face lots of adversity, such as time pressure (sometimes with no time remaining), fatigue, and frustration, which can be also associated with the feelings of last chance for winning the game[12]. Toma[43] found a slight reduction in FT performance in the last 30 s of college and professional basketball games. This performance loss was observed for players of all positions, but especially for centers[3]. As we determined a minimum of 70% FT shooting efficiency as participation criterium, our sample was constituted only by guards and forwards. On the other hand, this criterium was necessary to dodge confusion results from bad FT shooters, that would have poor performance regardless of the previous effort intensity.

It is well established, high-intensity efforts are somewhat frequent during basketball games, and our results showed a performance reduction of great magnitude when shooting FT right after this kind of effort. Considering the importance of FT shooting on match results, teams cannot miss these scoring opportunities, especially in close games. Thus, we found our results robust enough to recommend that FT training occurs at different moments of the training session, after distinct effort intensities, including high-intensity ones when athletes are at a high level of activity and with a high HR, i. e., closer to the real-game conditions. We also recommend that after high-intensity efforts coaches should not allow long sequences of FT shooting. This approach may keep players more aware of the usefulness of body and mind control during FT shooting. Long FT shooting may be ideal for technique learning and correction, but short sequences may require more focus on performance.

Conclusion

We conclude that basketball players worsen their FT shooting efficiency after performing high-intensity efforts by at least 16%, which is as high as 11-fold the chances of impairment. This represents a 30-percentile position difference in the player's performance evaluation.

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Manuscript received on January 12, 2022
Manuscript accepted on May 5, 2022