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Ashwin Phatak · Utkarsh Mujumdar · Robert Rein · Fabian Wunderlich · Marc Garnica · Daniel Memmert

Institute of Training and Computer Science in Sports, Deutsche Sporthochschule Köln, Cologne, Germany

Better with each throw—a study on calibration and warm-up decrement of real-time consecutive basketball free throws in elite NBA athletes

Free throws are a key element that determines success in competitive basketball. Previous research done on NCAA division one men's basketball games shows that 20% of all points were scored from the free throw line. The free throws scored by winning teams were significantly higher than those of the losing teams (Kozier, Vaughn, Whitfield, Lord, & Dye, 1994). During a free throw, the player is not impeded by the actions of opponents and therefore throwing success is only determined by the individual abilities of the player. However, even without interference by opponents the basketball free throw constitutes a complex sensorimotor skill as multiple biomechanical degrees of freedom are involved in the execution of the movement. Current evidence suggests that success rates for an average NBA player for free throws were between 70 and 80% (Sampaio et al., 2015). This indicates that even in professional high-performance players success rates are not perfect. This entails the question, which factors might impede throwing performance in basketball free throws?

The free throw situation in a basketball game has similarities to dart throws in the context of, multiple throws, target acquisition tasks, and repetitive motor skill execution. A study by Rienhoff et al. (2013) examined 26 basketball players of different skill levels with no experience in darts and studied the transfer of

motor and perceptual skills from basketball to darts. The results of the study showed a positive transfer from basketball to throwing accuracy in darts. However, the researchers emphasized the differences in the two sets of skills, and the need for further research. The free throw is a motor task embedded in a complex game, whereas dart throws represent the core of the game itself. It must also be considered that basketball free throws are awarded after a foul and therefore the time between consecutive sets of free throws is highly variable for each player. This may suggest that task-specific adjustments of arousal, attention, and other mental and bodily states could affect free throw performance in the present study, as suggested by Adams (1961) and later reiterated by Schmidt, Lee, Winstein, Wulf, and Zelaznik (2018).

In this respect, a related finding has been obtained in dart throwing. Wunderlich, Heuer, Furley, and Memmert (2019) showed that the first dart of a series of three was less accurate than the following throws and attributed this to fine-tune visuomotor calibration as an effect of warm-up decrement. Accordingly, the present study aims to answer the question of how calibration effects also underlie throwing performance in multiple basketball free throws.

According to the current rules of the National Basketball Association (NBA), a free throw is awarded to the player after

a foul (normal or technical). The number of free throws depends on the exact action during the foul. If the player was fouled during the shot and the shot is missed, the player receives either two or three free throws, depending on whether the shot was taken from inside or outside the three-point zone. If the player manages to score despite being fouled, only a single free throw is awarded to the player. In the NBA, every fifth foul committed by a team during the same period, regardless of it being technical or personal, leads to the awarding of two free throws to the opposing team.

Professional basketball players are accustomed to the situation of attempting to score in the presence of opposition defenders, as this scenario occurs most frequently during the game (Erčulj & Štrumbelj, 2015). Shooting jump shots, layups, dunks, and three-pointers require skill aspects such as controlling the ball, dribbling, faking, etc. before attempting the shot. These aspects are not present in a free throw situation, making free throws ideal for studying visuomotor calibration with fewer interfering factors and consistent shooting position on the court compared to jump shots. The present study adopts the methods of the study used by Wunderlich et al. (2019) and attempts to confirm the transferability of these results to a related movement of free throws in basketball.

Detailed kinematic analyses of free throws have been performed to determine the optimal player height, angle, and spin of the ball during the shot for measuring performance (Gablonsky & Lang, 2005; Mullineaux & Uhl, 2010). The study conducted by Okubo and Hubbard (2018) differentiates between the kinematic controls of set shots, like free throws, and jump shots. Furthermore, a multitude of studies have been performed to investigate possible improvements in basketball free throw performance. They explore different interventions with different underlying mechanisms such as quiet eye training, verbal instruction, self-regulation, imagery training, pre-performance routines, etc. (Cleary, Zimmerman, & Keating, 2006; Harle & Vickers, 2001; Lerner, Ostrow, Yura, & Etzel, 1996; Wilson, Vine, & Wood, 2009). Research specific to how visuomotor control influences aiming accuracy, as a function of the calibration process, seems to be limited.

The calibration mechanism falls under a wider phenomenon of warm-up decrement. Warm-up decrement is a decline in performance due to a break in the specific sensory motor skill, which recovers rapidly after the specific skill is reinstated (Adams, 1961). There has been extensive research in the field of warm-up decrement. However, the underlying mechanisms seem to be complex and multifaceted. One widely accepted explanation of this effect is the set hypothesis (Schmidt et al., 2018). It refers to task-specific adjustments at attention, arousal, and other mental and physical states which may influence performance. Another theory explaining warm-up decrement is the activity-set hypothesis as described by Murry (1980). The activity-set hypothesis suggested that activity-set interpolation task is effective in reducing warm-up decrement. This study further suggests that warm-up decrement is caused by nonhabit loss of adjustment over rest periods, which seems to be crucial to the central execution systems of the performer.

Although these are possible current explanations of the potential effect observed in basketball free-throws (present study). The above study is performed

specifically in a movement balance task (Murry, 1980). The task is conducted in a vastly different scenario and the carry-over of the same effect to more complex tasks such as a free throw would be a big leap. Another study performed by Wrisberg and Anshel (1993) on tennis players suggested that task-specific warm-up activities that direct the performer's attention to 'task-relevant cues' helps reduce the effect of warm-up decrement. This situation is closer to the free throw scenario, however, due to the nature of the game of basketball the players are constantly focused on the 'task-relevant cues' such as shooting, dribbling, and defending in the game. In this present study, we propose that the visuomotor calibration may also affect the observed rapid recovery of performance. Currently, this is classified as set or activity-set hypothesis.

Another popular theory, 'Hot hand' theory initially reported by Gilovich, Vallone, & Tversky (1985) has been extensively researched by the scientific community and there seems to be disagreement about its validity (Arkes, 2010; Bar-Eli, Avugos, & Raab, 2006). Yaari and Eisenmann (2011) examined the perceived 'hot hand effect' in the game of basketball free throws. They reported that in the case of two free throws, the probability of success increased with each attempted throw in a sequence, which indicates nonstationarity. The authors did not elaborate on the underlying mechanisms to explain this effect, which they termed as "alignment gauge" and concluded that the exact physiological and psychological causes may be determined by future research. The present study further examines this "alignment gauge" and proposes warm-up decrement due to the visuomotor calibration as a possible explanation of this effect based on the analogous findings of Wunderlich et al. (2019).

It has been observed in professional, highly skilled athletes (e.g., golf players, baseball players) that there is a need to calibrate their perceptual-motor system before competing (Ajemian, D'Ausilio, Moorman, & Bizzi, 2010). The isolated nature of basketball free throws and the large data set in the present study allow us to assess this phenomenon in

NBA professional athletes over a period of ten years. Confirming the findings of Wunderlich et al. (2019), this study may provide further evidence for the necessity of warm-ups for specific visuomotor calibration, prior to, or during breaks across professional sports. These findings may prove beneficial for target acquisition sports involving breaks of varying lengths between attempts, such as biathlon, shooting, and archery.

Based on the theoretical framework and the results of Wunderlich et al. (2019) we hypothesize that in the case of two free throws, success rates for the second attempt of free throws would be greater than that of the first. Accordingly, for three free throws, subsequent attempts should show greater success rates compared to preceding attempts. This may provide evidence that calibration effect may influence warm-up decrement in high-performance basketball.

Methods

Data sources and cleansing

A total of 610,822 free throws from the NBA seasons between 2006 and 2016 (regular and playoffs) were obtained from an open source on Kaggle.com (<https://www.kaggle.com/sebastianmantey/nba-free-throws>), which is based on ESPN's scrap data. The data were automatically checked for discrepancies, missing throws, and inconsistent names with multiple prefixes or suffixes using custom python routines. The data were first aggregated player wise for each attempt in all sets of throws to account for the base rates. They were further compared with paired and ranked tests mentioned below in order to get aggregated, within player results. It was important to do so as there was a need to compare the attempts of each set of throws within each player. If the data was aggregated first then the player strengths are not controlled for and the results will depict the average effect of the throw number instead of calibration for each player. Custom routines written in Python 3.7.2 were used for data analysis and data cleaning.

Exclusion criteria

Only players who have a minimum of 20 sets of throws in case of single throws and double throws were included. Players with a minimum of 5 throws were included in case of triple sets of throws to trim off the players with 100% or 0% free throw accuracy due to low numbers of total attempts. The data were hence reduced to 72,615 single throws, 262,459 × 2 double free throws and 4172 × 3 triple free throws. The total number of players who performed single, double and triple sets of throws was 441, 284 and 242, respectively, after the above exclusion criteria were implemented. Furthermore, for the control trial, only players who attempted all single, double and triple throws were compared (■ Fig. 1). Hence the control trial was conducted on 202 players who fit this criterion. It was crucial to set different criteria for the first attempt comparison as it needed to contain players who took all sets of throws and had a high enough number in each criterion for a valid comparison.

Data analysis

Normality test and homogeneity of variance

Free throw success rates (total successful shots/total attempted shots) for every individual player were obtained for all attempts and tested for normality using the D'Agostino–Pearson's test (D'Agostino, 1970). Furthermore, success rates for each separate attempt were obtained and tested for normal distribution across athletes (each attempt of double and triple free throw sets). Levine's test was used to check for homogeneity of variance between throws for both double and triple sets of throws.

Wilcoxon test

The success percentages for the first and second attempts of double free throw sets were analyzed. The free throw percentages of each player were averaged across all available seasons and success rates of each of the players were treated as separate data points. A Wilcoxon test was used to account for unequal variances and to test for significant differences between

the percentages of the two attempts. The same procedure was used as for testing all attempt combinations of the triple throw sets.

Friedman's test

The success percentages for the first, second and third throw were obtained as described above and Friedman's test was used to assess significant differences between the three groups. Furthermore, Friedman's test was also used to analyze the first attempt of the single, double and triple free throws to control for the base rate of all the first attempts. The data were aggregated over each player in order to account for different base rates after the implementation of the exclusion criteria. Pearson's R values were calculated to depict the effect sizes for all sets of tests (■ Table 1).

Results

The data for all throws showed normal distribution but failed the homogeneity test for variances in each of the separate free throw sets. Hence, the choice to use the nonparametric Wilcoxon and Friedman's test was made. All the first attempts of the single, double and triple sets of free-throws were compared using Friedman's test as a control and no significant differences ($p = 0.2994$) were observed between them as shown in ■ Fig. 1.

■ Table 1 shows the results of the Wilcoxon and Friedman's tests for double and triple set of free throws. The Wilcoxon test showed that free throw success percentage for the second throw was significantly higher than that of the first throw ($p < 0.001$, $r = 0.6205$) (■ Fig. 2). Friedman's test showed a significant difference in the success percentages of all three throws ($p < 0.001$, $r = 0.3273$). The post hoc Wilcoxon test confirmed the results of Friedman's test for the triple sets of free throws, where the subsequent throws in a triple throw have a significantly higher success rate than the prior ones (■ Fig. 3).

Discussion

This study aimed to investigate the calibration effect, previously shown in darts

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Better with each throw—a study on calibration and warm-up decrement of real-time consecutive basketball free throws in elite NBA athletes

Abstract

Calibration and warm-up decrement seem to influence performance in sensorimotor skills that are repeatedly performed in succession. Current evidence suggests that error rates are greatest for the first of multiple attempts when performing the same sensorimotor task repeatedly. The aim of the present study is, therefore, to study the calibration effect in sets multiple free throws for National Basketball Association (NBA) players by analyzing single, double and triple sets of free throws and their success rates for each of the respective attempts. We hypothesized that the success rate of subsequent free throws is greater compared to immediately preceding throws. To this end, data from the NBA seasons between 2006 and 2016 totaling 610,049 shots and 1098 players were obtained. For a set of double free throws, the success rate of the second throw was greater compared to the first throw. For triple free throws the success rate increased with each successive throw. The results demonstrate differences between consecutive throwing percentages. In conclusion, the current study supports previous findings in darts that calibration effects may explain the underlying increases in performance during repetitive execution of complex sensorimotor skills. Therefore, the present study extends the previous findings to full body movements involving many biomechanical degrees of freedom.

Keywords

Free throw · Calibration · NBA · Basketball · Warm-up decrement

(Wunderlich et al., 2019). The same phenomenon may occur during the more complex, whole-body action of the basketball free throw. Accordingly, we expected that successive attempts would elicit greater success rates compared to immediately preceding trials. The statistical analysis provided support in this regard. The results show that the suc-

Fig. 1 ▲ Comparison between the first attempt of single, double and triple sets of free throws. *ns* no significant differences

Fig. 2 ▲ Comparison between the first and the second free throw success rates for double free throws ($n = 2 \times 262,459$; Wilcoxon: $p < 0.001$ ****), where the number of * indicates the level of significance

Fig. 3 ▲ Comparison between the first, second and third free throw success rates for triple free throws ($n = 3 \times 4172$; Friedman's: $p < 0.001$ ****), where the number of * indicates the level of significance

cess rate of the first attempt is lower than that of the second attempt in a double free throw. This trend was also exhibited in triple free throws, where the success rates increased from the first to the third attempt. Therefore, the results add to the findings of Wunderlich et al. (2019) regarding basketball free throws and suggest that calibration effects might be a broader phenomenon in underlying motor control processes.

The pre-analysis results showed that the success rate of the first attempt during double throws was lower than that of the first attempt during triple throws and the single throw when the data was not aggregated player-wise. This might be due to differences in free throw skills of different players. This phenomenon is also

evident when you compare the means of the first attempt in Fig. 1 with the first attempt in Fig. 2. The data in Fig. 1 include only the players who attempted all single, double and triple throws while Fig. 2 has players who only attempted double throws. Triple free throws are awarded when a player is fouled attempting a three-point shot while single shots are due to foul committed during an attempted and successful shot. In the NBA, athletes with the highest number of three-point shot attempts (point guards and shooting guards) and foul-count attempts have better shooting ability than the average NBA player (Erčulj & Štrumbelj, 2015). The pre-analysis seems to provide further evidence that athletes who at-

tempt three-point shots also have higher free throw accuracy.

The athletes investigated in this study were highly trained elite athletes. However, they also seem to show the calibration effect in their free throw performance. This effect may be even greater in non-elite or novice athletes, as they show greater movement variability in their inertial movement during a free throw attempt compared to highly trained athletes (Button, Macleod, Sanders, & Coleman, 2003). This may be the result of novice players actively exploring different motor patterns to achieve greater success, whereas the experts may have already progressed past the exploration phase of development (Handford, Davids, Bennett, & Button, 1997; Shmuelof, Krakauer, & Mazzoni, 2012). Although the present study is analogous to the Wunderlich et al. (2019) study, it should be noted that the nature of the basketball free throws is different from the darts scenario in the sense that free throw data is largely binary and darts data is not. Furthermore, the ceiling and the floor effect (0% and 100% accuracy) which is seen in free throw situations is not present in the case of dart throws.

Based on the current findings, it may be advisable to revisit the warm-up routines of different athletes and teams

Table 1 Results of the Friedman's and Wilcoxon tests

Test	Throw	Set	P-value	R-value
Friedman's	1st vs. 2nd vs. 3rd	Triple	< 0.001	0.3273
Wilcoxon	1st vs. 2nd	Triple	< 0.001	0.2227
	2nd vs. 3rd	Triple	0.024	0.1557
	1st vs. 3rd	Triple	< 0.001	0.3166
Wilcoxon	1st vs. 2nd	Double	< 0.001	0.6205

across multiple sports. The warm-up routines used prior to competition or during training may benefit from being closely related to the specific sensorimotor tasks' athletes are required to perform in their respective sports and positions. The requirement of recalibrations seems to be particularly relevant to highly trained athletes and the results seem to be in line with the findings of Ajemian et al. (2010) in regards to the necessity of prolonged, task-specific warm-ups for highly trained athletes before competition. In terms of basketball, the warm-up could include a series of tasks-specific training session designed to the requirements of each player and position (e.g. three-point shots, free throws, dunks, rebounds) (Shoenfelt, Snyder, Maue, & Mcdowell, 2002).

The subjects of the study were elite NBA athletes. It is safe to assume that they had high levels of endurance and were used to short recovery periods from intermittent bouts of intense basketball-specific activity. Furthermore, previous research suggests no significant effect of fatigue on free throw, jump shot or three-point shooting performance, when comparing moderate (50% Max-HR) and high (80% Max-HR) levels of fatigue (Ardigò, Kuvacic, Iacono, Dascanio, & Padulo, 2018; Padulo et al., 2015; Uygur, Goktepe, Ak, Karabörk, & Korkusuz, 2010).

The underlying calibration mechanism may be extended to a wide set of skill acquisition along with various other sports. Developing higher accuracy on the first try while performing closed motor skills may be valuable across various sports (Adams, 1971). In soccer, set plays are one such example where the player must deliver the free kick or corner precisely on the first attempt. A training method mimicking the real-game time gaps and switches in sensorimotor tasks

may prove beneficial for improving in-game set piece delivery performance. There seems to be potential for further research following the results of the present study.

Another important point that arises is the time frame of warm-up decrement. The longitudinal effect of detraining is well known in the field of sports science, but warm-up decrement or calibration seems to result in similar acute effects in a shorter period. The findings of the present study are in line with previous findings regarding fast time scale processes which explain the gain of competency (warm up-increment) in the initial part of a new training session (Joseph, King, & Newell, 2013). Although the tasks specified by Joseph et al. (2013) were mechanically simpler to a free throw, both studies may still point at similar underlying mechanisms. Further research is required on the effects of calibration, with time gaps of varying length between a familiar and highly trained sensorimotor activity. The possibility of error may seem highest during the first attempt of a familiar and highly trained sensorimotor activity. This is demonstrated by the results of the current study and the findings of Wunderlich et al. (2019) in regards to darts. Further research in the fields of stair climbing may provide interesting insights and possibilities for practical interventions.

The real-world situation of climbing consecutive flights of stairs is similar to the present and Wunderlich et al. (2019) studies, in the cyclic nature of the task. Climbing a set of stairs every day at different times of the day is analogous to the darts and basketball free throw scenario in the sense that both skills are closed skills with small pauses. The review concerning stairway falls by Jacobs (2016) suggests identification of strategies or stairway environments that lead to

falls may be useful for further research in avoiding falls. The findings of the present study suggest investigations on falls occurring on the first attempt of climbing a set of stairways or even the first stair of a stairway as error rates seem to be high especially during the first attempt. The current study along with previous research may provide enough evidence to further investigate the calibration effect in stair climbing.

Although our results display a high degree of significance, it is still too early to claim that the observed results can suggest reliable training methods. A free throw is a motor task embedded in a complex game, whereas dart throws represent the core of the game itself hence transfer is limited. It must also be considered that basketball free throws are awarded after a foul and therefore the time between consecutive sets of free throws is highly variable for each player. This may suggest that task-specific adjustments of arousal, attention, and other mental and bodily states could affect free throw performance in the present study, as suggested by Adams (1961) and later reiterated by Schmidt et al. (2018).

Previous research by Shoenfelt et al. (2002) for variable training methods seems promising, but the underlying mechanisms are still unclear. The present results in combination with Wunderlich et al. (2019) could prove to be the first step in exploring underlying mechanisms of the calibration effect and exploring possible training interventions for reducing the error rates of first attempts when revisiting a trained sensorimotor action. One particular area of interest would be internal vs. external focus of attention. A study by Perreault and French (2015) showed that an external as compared to an internal focus of attention was significantly better in improving free throw performance in children ($n = 28$). This study was done with recreational child athletes but observing the effect of a change of attentional focus on elite athletes could be interesting, too, regarding changes on warm-up decrement.

The dataset used within this study was of considerable size, including more than 610,000 free throws from more than ten NBA seasons, and therefore allows highly

valid inferences. However, it is limited by the level of detail, as only a binary result (hit/miss) of each throw was available and no additional information regarding player behavior between two throws was given. Subsequent studies should use more detailed information, in order to gain a better understanding of reasons for and impact of the calibration process. This could include the analysis of continuous error measures based on ball tracking systems instead of binary results, as well as the analysis of player behavior (change of position, body language or interaction with other players) between throws by evaluating additional video material. Moreover, investigation of free throws and related motor tasks in experimental setups could help to gain a better understanding of the reasons for calibration effects.

Conclusion

The results of the present study confirm that, for the average NBA player, the shooting accuracy of the second attempt is significantly higher than that of the first when examining a set of double free throws. It was also found that sets of triple free throws follow the same trend, with shooting accuracy of the third attempt being higher than that of the second, and that of the second being higher than that of the first. We, therefore, conclude that the present study seems to show a calibration effect of the first throw on the shooting rates of consecutive free throws for a set of double and triple throws in NBA games.

This effect of calibration and warm-up decrement was observed in previous studies and seems to be a factor in basketball free throws at the elite level. Warm-up decrement and long-term detraining effects are well known in the scientific community, but the findings of the current study may suggest calibration effects as an explanation for warm-up decrement. This area of research needs to be expanded to find further evidence of the existence of calibration effect in other sports.

The implications and practical applications of the findings of the current study may provide further justification in

sports-specific variable training, warm-up routines and exploring mechanisms relating to accidents in elderly populations.

Corresponding address

Ashwin Phatak
Institute of Training and
Computer Science in Sports,
Deutsche Sporthochschule
Köln
Cologne, Germany
Ashwin.phatak@gmail.com

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Compliance with ethical guidelines

Conflict of interest. A. Phatak, U. Mujumdar, R. Rein, F. Wunderlich, M. Garnica and D. Memmert declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

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