KEY FACTORS INFLUENCING BACK-SPIN PERFORMANCE IN CUE SPORTS

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This study aimed to explore the key factors which influenced the performance of back-spin shots in cue sports. Nineteen male cue sports players with varied levels of playing experience were recruited. A back-spin shot test was administrated requiring participants to make the cue ball return to a specific area after potting an object ball. The performance of the back-spin test was evaluated by calculating an error distance using video analysis. The kinematics of the cue stick were determined using a 3D motion capture system. Multiple linear regression was applied to predict the performance of the back-spin shots based on selected kinematic variables of the cue stick. The results showed that the speed (p = .004) and height (p = .028) of the cue tip at impact were significant predictors of the back-spin performance. In conclusion, players should hit the lower part of the cue ball with high cue stick speed for better performance in a back-spin shot.

KEYWORDS: back swing, follow-through, speed, impact, cue tip height.

INTRODUCTION: In the game of cue sports, back spin is applied very often to position the cue ball after potting an object ball to pose the player ready for the next shot. In addition, back spin technique can also be used to obtain a "snooker" whereby the opponent is blocked from hitting a particular ball because that other ball(s) is on the way. Back spin is generated by lowering the cue tip and hitting below the midpoint of the cue ball. If the back spin is "sufficient", the cue ball will reverse its direction and travel backward after hitting the object ball (Sherman, 2009). The stronger the back spin, the longer distance the cue ball travels backward.
When executing a back-spin shot, players usually perform several practice swings before pulling back the cue stick and then hitting the cue ball at a high speed. Alongside lowering the cue tip position to generate back spin, a longer follow-through distance is also believed to contribute to good back-spin performance by inducing a longer contact time for the impact between the cue tip and the cue ball (Sherman, 2009). While aiming at the lower part of the cue ball may appear easy, it is challenging to control the exact impact position especially when players deliver the cue stick with a high speed. A previous study on professional pool players reported that the height of the cue tip at impact ranged from 1.7 to 2.0 cm (Kornfeind et al., 2015). Since all participants in their study were professional athletes, their descriptive results may serve as a reference for other players but it remains unclear how good players execute and control back-spin shots.
To date, there is no study examining the biomechanical factors influencing back-spin shot performance in cue sports. The present study, therefore, aimed to examine the relationship between the back-spin performance and biomechanical factors of the cue stick. It was hypothesised that low cue tip position and high cue stick speed at impact, alongside with long follow-through distance, would contribute to excellent back-spin performance.

METHODS: This study was approved by the Nanyang Technological University Institutional Review Board (IRB-2019-05-013). Nineteen male, active cue sports players of varied levels of playing experience [mean (standard deviation); age 26.1 (8.1) year, height 1.74 (0.06) m, body mass 72.0 (13.4) kg] provided informed consent to participate in the study. Participants were excluded if they had any injuries three months prior to the experiment or experiencing pain when playing cue sports. Participants performed shots with their own cue sticks throughout the experiment. If they could not bring their cue sticks, a standard cue stick was provided. To facilitate motion capture, retro-reflective marker or tapes were placed at the bottom, middle, and the tip of the cue stick (Figure 1). This present study only used the cue tip marker for

analysis. Eight infrared cameras (250 Hz, Vicon MX, Oxford Metrics Ltd., Oxford, UK) were used to collect kinematic data of the cue sticks when participants performed back-spin shots. A top-view Casio digital video camera (30 Hz, model EX-100, Casio Computer CO., LTD, Tokyo, Japan) was mounted on a tripod to record the ball movements on the pool table.

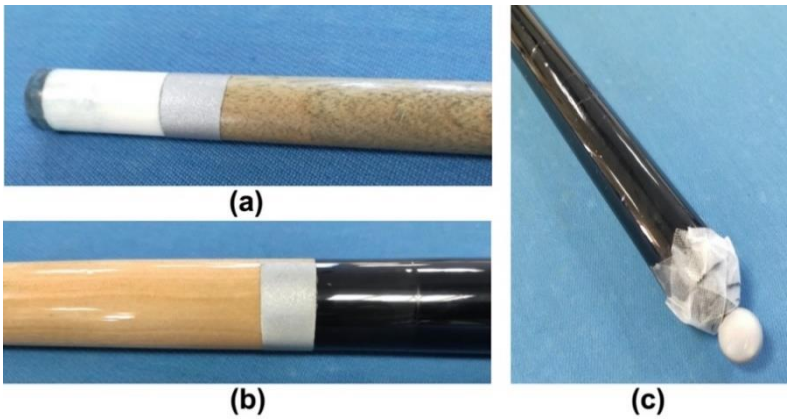

Figure 1: Retro-reflective tapes were placed at the (a) cue tip and (b) the middle of the cue stick. (c) One retro-reflective marker was placed at the bottom of the cue stick.

After warm-up and familiarisation, participants were instructed to perform shots with back spin applied. The back-spin task simulated the real game scenarios wherein players are expected to position the cue ball in a specific area preparing for the next shot (DrDaveBilliards, 2011). The cue ball was positioned at the centre of the half table aligning for a perfectly straight shot (Figure 2). Participants were required to pot the object ball and draw the cue ball back with back spin. The cue ball was expected to return to a specific target area which was represented by a quarter of a piece of a A4 sized paper (75 mm × 52.5 mm), and the centre of the target was in line with the fourth and second diamond of the top and side cushion (Figure 2). Only the shots with the object ball potted were counted as valid trials; otherwise, the participants were asked to pot again. Three valid trials were analysed in this study.

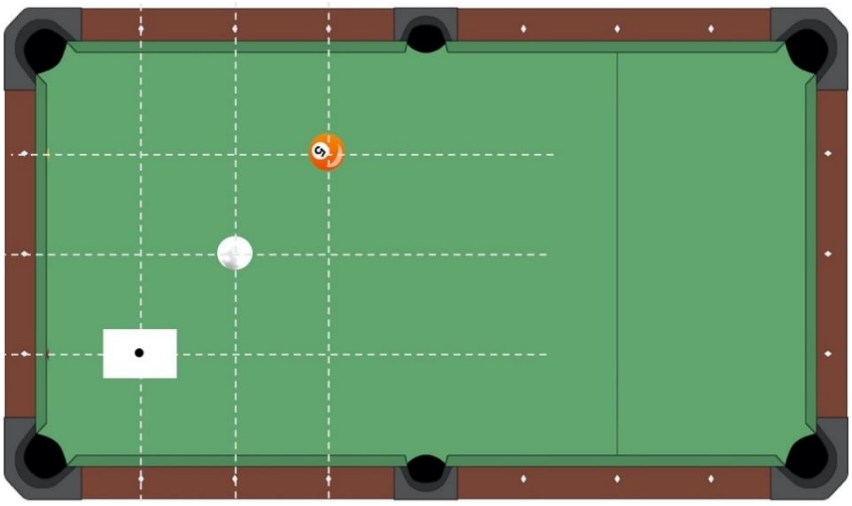

Figure 2: The positions of the object ball (orange colour), cue ball (white colour), and the target represented by a quarter of a piece of a A4 sized paper (75 mm × 52.5 mm) (Figure was modified from a photo derived from online source: https://www.facebook.com/drawshotapp/).

The video recordings of ball movement from the digital camera were analysed using a free software, Kinovea (version 0.8.27, available for download at: http://www.kinovea.org). An error distance, which was defined as the absolute distance between the end position of the cue ball

and the centre of the paper target, was measured to quantify the performance of each back-spin shot. The smaller the error distance, the better the performance of the back-spin shot.
Kinematic data of the cue stick were low-pass filtered by a fourth order Butterworth filter at a cut-off frequency of 15 Hz, which was similar to the 13.3 Hz used in a previous study on cue sports (Zhou et al., 2018). The positions and velocities of the cue tip were determined. There is primarily only one kind of stroke in cue sports, which can be divided into phases according to the positions of the cue tip. Based on existing work (Cheng et al., 2008), this study defined four key phases of a complete stroke based on the cue tip position: practice swing (feather), back swing, forward swing, and follow-through phases.
The mean value of three trial for each participant was used for statistical analyses performed using SPSS software (version 25.0, IBM Corp, Armonk, USA). Multiple linear regression was applied to predict the error distance based on the kinematic variables of the cue stick comprising back swing distance, cue tip speed at impact, cue tip height at impact, and follow-through distance. As the back swing and forward swing shared the same distance, only one phase was analysed. Results are presented by mean (standard deviation). Statistical significance was set at .05 level.

RESULTS:
Descriptive results of the error distance and the kinematics of the cue stick are shown in Table 1. Multiple linear regression analysis revealed a significant regression equation [$F(4,14) = 7.206$, $p = .002$, $R^2 = .580$]. Cue tip speed ($p = .004$) and cue tip height ($p = .028$) at impact significantly predicted the value of the error distance. Back swing distance or follow-through distance were not significant predictors to the model ($p > .05$, Table 2). The error distance decreased as the speed at impact increased and the tip height decreased.

Table 1: Performance and cue tip kinematics of back-spin shots.

Variable	Value
Error distance [cm]	32.4 (20.1)
Back swing distance [cm]	17.8 (4.1)
Cue tip speed at impact [m/s]	1.51 (0.28)
Cue tip height at impact [cm]	1.7 (0.4)
Follow-through distance [cm]	14.0 (4.2)

Table 2: Regression coefficients and collinearity diagnostics for cue stick kinematics.

Variable	*r*	β	*p*	Tolerance	VIF
Back swing distance	-.456	-0.203	.881	.314	3.185
Cue tip speed at impact	-.479	-43.040	**.004***	.809	1.236
Cue tip height at impact	.607*	33.581	**.028***	.334	2.991
Follow through distance	-.213*	0.476	.571	.793	1.261

*$p < .05$. r = correlation coefficient; β = standardised regression coefficient; VIF = variance inflation factor.

DISCUSSION: This study revealed the key factors which influenced the performance of back-spin shots in cue sports. As hypothesised, the results showed that lower error distance was associated with higher cue tip speed and lower cue tip height at impact. These findings reaffirmed the anecdotal coaching guidelines that lowering the cue tip and hitting the ball with high speed would contribute to good back-spin performance.
The cue tip height at impact [1.7 (0.4) cm] was similar to the values of 1.7 to 2.0 cm reported by Kornfeind et al. (2015) on professional players. By lowering the cue tip position, participants were able to hit the lower part of the cue ball to generate a torque for back-spin rotation. The cue stick speed at impact observed in the present study [1.51 (0.28) m/s] was much slower than the results (approximately 2.5 to 4.5 m/s) revealed by Kornfeind et al. (2015). This large discrepancy was due to the fact that their participants were all elite pool athletes in Europe while the present study recruited players of varied level of experience, including recreational players with a minimum of one year's playing experience. Furthermore, Kornfeind et al. (2015)

tested both short and long draw shots (with back spin), and the latter one may require a higher cue stick speed compared with the short draw shot. A higher cue stick speed could generate more back spin in order to draw the cue ball back to a farther target.

In contrast to the hypothesis of the present study, the follow-through distance was not found to influence the performance of back-spin shots. Theoretically, a longer follow-through distance may extend the contact time of the impact and therefore generating more spin. In the present study, participants were not required to perform back spin with maximal effort but to control the amount of back spin such that the cue ball can be drawn backwards to a specific target. It is possible that participants, especially the more skilled players, can perform the sub-maximal back spin shots by controlling the cue stick speed and cue tip height alone. Future study could investigate the role of follow-through distance in long draw shot which requires a large amount of back spin and a long travelling distance. It will also be of interest to measure the contact time between the cue stick and the cue ball using high speed video cameras.

There were some limitations to the present study. First, the error distance was computed as an absolute value without taking into account the direction. While this method is simple and may be appealing to coaches, the current method is unable to differentiate whether a shot is too short or too long. Modifications of the error distance calculation to include the direction (too long / too short) and alignment of the cue ball are needed to better reflect back spin performance. Second, this study only focused on the cue tip position and velocity without considering the angular motion of the cue stick. Future studies can examine the kinematics of the cue stick and the player to offer more insights into how a good back-spin shot can be executed. Finally, we placed a piece of paper on the table to set target and this may have influenced the final trajectory of the cue ball especially for balls that were rolling at slow velocities.

CONCLUSION: This study identified that high cue stick speed and low cue tip position at impact were two key factors contributing to successful performance of back-spin shots in cue sports. These observations are consistent with anecdotal coaching guidelines that cue sports athletes should master the technique of applying high speed and maintaining low tip height when executing back-spin shots. Follow-through distance was not found to contribute to the performance of back spin, which may be attributed to the relatively short draw-back distance required for the task used in the present study.

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ACKNOWLEDGEMENTS: This project was supported by Office of Education Research Start-up Grant (SUG 12/18 KPW) from National Institute of Education, Nanyang Technological University, Singapore. The second author of this article (Jing Wen Pan) is supported by the China Scholarship Council (CSC). The authors would like to acknowledge Cuesports Singapore Academy.