SHOT PERFORMANCE AND CUE STICK KINEMATICS OF TOP SPIN SHOTS IN CUE SPORTS PLAYERS OF VARIOUS PLAYING LEVELS

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This study aimed to compare the shot performance and kinematics of the cue stick in top spin shots between less-skilled and skilled players. Twenty-five cue sports players were recruited and assigned to the less-skilled (n = 12) or skilled (n = 13) groups. Ten successful top spin trials were recorded for each participant. 2D video analysis was employed to evaluate shot performance which was represented by an error distance. A 3D motion capture system was used to obtain kinematic data of the cue stick during the cueing movement. The results showed that skilled players were more consistent in their performance with lower inter-trial variability than less-skilled players (p = 0.028). No significant differences between two groups were found in the cue stick kinematics including height (p = 0.723), speed (p = 0.153), and angle (p = 0.380). The results indicated that similar cueing techniques were adopted by all participants. Further analysis of human body kinematics is in need to uncover potential technique differences among players despite achieving similar cueing movements.

KEYWORDS: error, variability, cue stick, angle, speed.

INTRODUCTION: Cue sports, such as pools, billiards, and snooker, are popular around the world among players of a wide age range. The games are usually played with a cue stick on a rectangular table with six pockets. Alongside the back spin shot that has been investigated previously (Kong et al., 2020), top spin shot is also an important technique in games to position the cue ball after hitting an object ball. By hitting the cue ball above its equator (midline) to generate top spin, the cue ball continues to travel forward after ball-to-ball impact. The greater the amount of top spin, the further the cue ball travels. Hence, during games, players should precisely control the amount of spin applied onto the cue ball to achieve desired ball position for the next shot.
In the literature of cueing movement, researchers have reported the biomechanical profiles of different groups of cue sports players. For examples, Kornfeind and colleagues (2015) reported descriptive kinematic data of elite European players. These data of elite players may serve as a reference for players and coaches to learn from. Haar and co-workers (2020) presented kinematic data along with shot performance of a group of beginners who had little or no playing experience. Due to the lack of comparison between players of different playing levels, the specific techniques adopted by skilled players and the associated performance are unknown.
This study, therefore, aimed to compare the shot performance and the kinematics of the top spin shots between cue sports players of different playing levels. It was hypothesised that the skilled players would perform better in the top spin shot compared with the less-skilled players and that the kinematics would differ between the two groups.

METHODS: This study was approved by the XX [*removed for blind review*] University Institutional Review Board (IRB-XXXX-XX-XXX *removed for blind review*). Twenty-five male, right-handed cue sports players, who were the members of the national team of xx [*removed for blind review*], local tertiary institution teams, and recreational population, were recruited in this present study. All participants were required to perform self-directed warm-up (e.g., potting ball freely, and potting balls with top spin applied) on the experiment pool table for approximately 10 min. After that, a 15-ball test without requiring any particular order, which is a common training drill, was administrated to evaluate their performance level (Pan et al., 2021). Two trials were conducted by each participant and the total number of balls potted was counted (maximum 30). According to the test results, the participants were assigned to either the less-skilled group [n = 12, who potted 6.4 (3.1) balls] or skilled group [n = 13, who potted 17.7 (5.4) balls] (Table 1).

Table 1: Participants' demographic and anthropometric characteristics.

	Less-skilled (n = 12)	Skilled (n = 13)	*p*	Effect size (*d*)	
Age [years]	25.1 (2.2)	27.0 (9.8)	0.514	-0.265	Small
Experience [years]	3.4 (3.7)	9.2 (7.6)	**0.025***	-0.961	Large
Height [cm]	172.4 (4.4)	173.8 (6.7)	0.563	-0.235	Small
Body mass [kg]	69.4 (8.8)	70.8 (13.9)	0.756	-0.126	Trivial

Data are expressed in mean (standard deviation). Significant difference ($p < 0.05$) is shown in bold text and indicated by an asterisk.

The top spin test was adopted from a previous study on 9-ball (Pan et al., 2021). A cue ball (white) was set at the middle of the head string, and an object ball (red) was positioned in line with the third diamond of the left side cushion and the first diamond of the top cushion (Figure 1 a). The participant was asked to park the cue ball at the centre of the target (indicated by a quarter of a piece of a A4 sized paper, 7.5 cm × 5.3 cm). If the participant failed to park the cue ball at the target centre (indicated by the black dot, Figure 1), an error distance was measured as the distance between the centre of the cue ball and the target centre (Figure 1 b). The smaller the error distance, the better the shot performance.

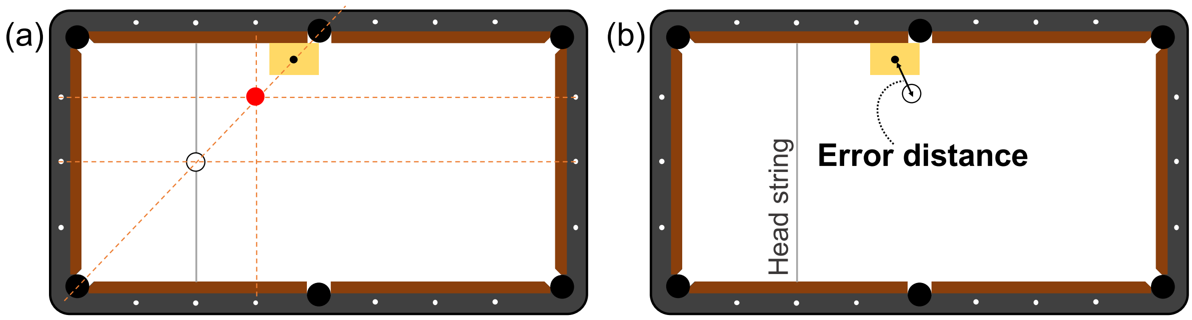

Figure 1: (a) Schematic representations of the 15-ball test and top spin test. (b) Measurement of error distance.

Ten successful trials were conducted for each participant. Ball movements on the pool table were recorded using a digital camera (30 Hz, model EX-100, Casio Computer CO., LTD, Tokyo, Japan). Three retro-reflective marks were placed on the cue tip, middle of the cue stick, and cue butt, respectively. The kinematic data of the cue stick were obtained using an eight-camera Vicon 3D motion capture system (250 Hz, Vicon MX, Oxford Metrics Ltd., Oxford, UK). Error distance was measured using the software, Kinovea (version 0.8.27, available for download at: http://www.kinovea.org) (Kong et al., 2020; Pan et al., 2021). The standard deviation of the error distances of the 10 trials was computed to represent the inter-trial variability of the shot performance within each participant. Kinematics of the cue stick were low-pass filtered by a fourth order Butterworth filter at the cut-off frequency of 10 Hz according to the results of the residual analysis (Winter, 2009). At impact, the height of cue tip and cue stick angle with reference to the pool table. Since the cue tip speed may decrease rapidly after impact, a third-order polynomial fit was also applied to the unfiltered cue tip speed data for the time interval of 20 frames (0.08 s) before impact (Kidokoro et al., 2020). The cue tip speeds obtained from the low-pass filter and the polynomial fit methods were similar (less than 0.05 m/s difference). For consistency, all kinematics data reported were processed using the low-pass filter method.
The data were imported into JASP statistical software (version 0.14.1; JASP Team, 2020) for analyses. Independent-samples *t*-tests were performed to compare the error distances and

cue stick kinematics between the less-skilled and skilled groups. Statistical significance was set at the 0.05 level. Effect size (d) was calculated from the Cohen's d and interpreted as trivial ($0.2 \leqslant d$), small ($0.2 < d < 0.5$), medium ($0.5 \leqslant d < 0.8$), or large ($d \geqslant 0.8$).

RESULTS: Table 2 shows the results of the error distances and the kinematic data of the cue stick in the top spin shots. There was no significant difference in the error distance between the less-skilled and skilled groups [$t(23) = 1.211$, $p = 0.238$]. The skilled group displayed less inter-trial variability of error distance than the less-skilled group [$t(23) = 2.342$, $p = 0.028$]. No significant difference was identified in the kinematic data of the cue stick between the two groups ($p > 0.05$).

Table 2: Comparison of the shot performance and cue stick kinematics between the less-skilled and skilled groups.

	Less-skilled (n = 12)	Skilled (n = 13)	p	Effect size (d)	
Error distance [cm]	13.1 (4.9)	10.9 (4.0)	0.238	0.485	Small
Inter-trial variability [cm]	6.5 (2.4)	4.7 (1.5)	**0.028***	0.937	Large
Cue tip height [cm]	3.9 (0.7)	3.8 (0.6)	0.723	0.144	Trivial
Cue stick speed [m/s]	1.3 (0.7)	1.0 (0.1)	0.153	0.592	Medium
Cue stick angle [^{o}]	3.2 (1.0)	3.9 (2.2)	0.380	-0.358	Small

Data are expressed in mean (standard deviation). Significant difference ($p < 0.05$) is shown in bold text and indicated by an asterisk.

DISCUSSION: This study presented the shot performance as well as kinematic data of the cue stick in top spin shots in cue sports players of various playing levels. The shot performance, represented by the error distance, did not differ between less-skilled and skilled players. The skilled group performed more consistently as indicated by the lower inter-trial variability of the error distances than the less-skilled group. The cue stick kinematics were similar between the two groups (Table 2), indicating that all participants adopted similar techniques to deliver the cue stick during the cueing movement.

It is somewhat surprising to observe similar error distances between the two groups, as one would expect the skilled players to perform better than the less-skilled players. One possible reason could be that all participants were cautious and purposely holding back in applying spins onto the cue ball to prevent it from falling into the middle pocket (Figure 1 a). Insufficient top spin would make the cue ball stop before reaching the pre-set target. Future researchers could extend the present protocol by setting the target at various distances from different pockets of the table. This may allow a more in-depth analysis of how players control the top spin shots. Across the ten trials, the skilled players showed less variability of the error distances compared with their less-skilled counterparties. In other sports such as golf, less performance variability could represent better performance (Bradshaw et al., 2009). The smaller inter-trial variability of the error distances observed in the present study implied the skilled players' ability to control the cue ball more consistently than the less-skilled players. Collectively, while the skilled players did not execute the top spin shots with smaller error distances, they exhibited more stable performance than the less-skilled players.

Interestingly, the kinematic data of the cue stick were similar between the two groups. In order to generate top spin, players need to hit the cue ball above its midline, hence the bridge hand should form a high arch to support the cue stick. In this study, the height of the cue tip was nearly 4 cm, which was much higher than 1.7 (0.4) cm reported in a previous work on back spin shots (Kong et al., 2020). Learning from coaches' experience, one should not elevate the cue stick butt in either top spin or back spin shots. The current study reported that the cue stick angle at impact was less than 4^o for all participants. The results revealed that the cue stick was almost parallel with the pool table, confirming that the cue stick butt was indeed not much elevated. Based on the empirical results observed in this current study and anecdotal coaching guidelines, players are advised to maintain the cue stick levelled to the pool table when applying top spins to the cue ball. The lack of differences between groups may be due to the fact that players in both groups had already mastered the basic top spin techniques. Future studies are warranted to investigate human body movements during the cueing movement, such as the upper limb joint angles and angular velocities. Having additional kinematics data of the human body would help identify the key techniques associated with excellent shot performance.

CONCLUSION: This study compared the shot performance and the kinematics of the cue stick in top spin shots among cue sports players of various playing levels. The skilled players were more consistent in their performance than the less-skilled players. All players showed similar cue stick kinematics when executing the top spin shots, hitting the cue ball above its midline while not elevating the cue stick butt. These techniques are in line with anecdotal coaching guidelines. Players are advised to maintain the cue stick levelled to the pool table when applying top spins to the cue ball. Future studies should investigate if players adopt different body movement patterns to deliver the cue stick when performing the cueing movement.

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