KEY FACTORS INFLUENCING THE PERFORMANCE OF THE BREAK SHOT IN CUE SPORTS

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This study aimed to explore the key factors that could influence the cue tip speed in a break shot in 9-ball. Nineteen male cue sports players at various skill levels were recruited. Each participant performed 8 break shots with maximum effort while the kinematic data were collected for the upper body joints and cue stick using a 3D motion capture system. Multiple linear regression was performed to predict the cue tip speed at impact based on selected kinematic variables of the cue-wielding arm. The results showed that the humeral elevation ROM was the only significant predictor for predicting the cue tip speed at impact (p = 0.007), while the ROM of elbow flexion/extension and wrist abduction/adduction, or peak angular velocities were not significant predictors (all p > 0.05). The cue tip speed decreased as the humeral elevation range of motion (ROM) increased. In conclusion, cue sports players were recommended to limit their humeral elevation ROM in a break shot to maximise cue tip speed for separating the racked object balls.

KEYWORDS: 9-ball, speed, range of motion, angular velocity.

INTRODUCTION: In pocket cue sports, the break shot is important as it is always the first shot in each frame. In cue sports games, such as 9-ball and 8-ball, a powerful break shot is needed to separate the racked object balls. Players take advantages of a good break shot, which allows them to pot more balls in the subsequent shots immediately after a break shot (Pan et al., 2021). A well separated ball distribution is desirable after a break shot as it is usually an easy ball pattern for the player; otherwise, extra efforts are necessary if balls are clustered before the player can continue to pot balls.

To the best of authors' knowledge, the literature on cue sports is rather sparse. Only one study revealed that the break shot had a greater acceleration at impact than other types of shots, such as top spin shots and back spin shots (Kornfeind et al., 2015). This finding is not surprising since a break shot requires great amount of power to separate the racked object balls. To generate a high cue tip speed when the cue tip contacts the cue ball, large joint range of motion (ROM) and angular velocities of the cue-wielding arm may be required. However, it is currently unclear which joint(s) would primarily influence the cue tip speed in a break shot. Therefore, this study aimed to examine the relationship between the upper limb kinematics and the cue tip speed at impact. It was hypothesised that the ROM and angular velocities of one or more upper body joints would be positively related to the cue tip speed. The research results would be expected to guide cue sports players to maximise the tip cue speed and conduct a good break shot.

METHODS: This study was approved by the Nanyang Technological University Institutional Review Board (Protocol Number: IRB-2019-06-37). Nineteen male, right-handed cue sports players [mean (standard deviation); age 25.0 (5.8) years, height 172.2 (4.8) cm, body mass 67.6 (8.0) kg, playing experience 5.4 (4.8) years] at various skill levels were recruited. All participants provided informed consent to participate in the current study. Parental consent was also obtained for minor participants who were under 21 years old. All participants were active cue sports players with at least one-year playing experience at the time of the experiment, and all were healthy without pain when playing cue sports.

Prior to the experiment, all participants were required to warm up on the experiment pool tables for approximately 10 min. They practised break shots and potted balls to familiarise themselves with the pool table and balls. Nine object balls (diameter 5.72 cm, Cyclop ZEUS Tournament

TV set, Xinzhan Co., LTD, Shanghai, China) were racked by the same researcher across the experiment sessions using a magic grid (Figure 1 a) to ensure the consistency across all frames. Each participant conducted 8 successful break shots, whereby the cue ball did not fall into the pocket or jump out of the pool table. Enough rest time was allowed between trials.

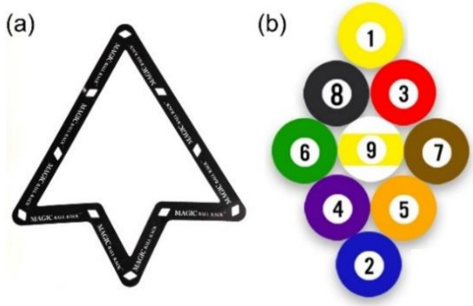

Figure 1: (a) A magic grid used to rack the 9 object balls. (b) Example of standard ball pattern with the 1-ball at the front, 9-ball in the centre, 2-ball at the bottom, and other balls randomly set in no particular order.

For each break shot, a 3D motion capture system with eight infrared cameras (250 Hz, Vicon MX, Oxford Metrics Ltd., Oxford, UK) was used to record the kinematics of the cue sticks and participants' upper body. Twenty-four passive retro-reflective markers (14 mm) were placed on the upper body of each participant, including bilateral acromion process, 6 markers on the right arm, 4 on the left arm, 4 on the head,4 on the trunk, and 4 on the hip. In addition, one marker was fixed on the cue butt, and two retro-reflective tapes were placed on the cue tip and middle of the cue stick, respectively.

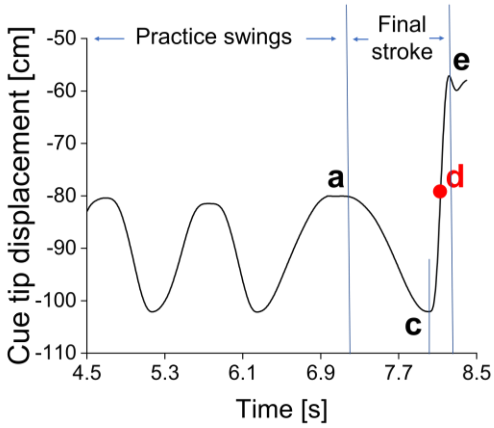

Figure 2: Several practice swings and a final stroke of a break shot determined by the anteroposterior displacement of the cue tip and four key moments [a (start of back swing), c (end of back swing and start of forward swing), d (impact), and e (end of follow-through)] of the final stroke.

Raw kinematic data were low-pass filtered by a fourth order Butterworth filter at a cut-off frequency of 10 Hz. Similar to other types of shots in cue sports (Kong et al., 2021), the break shot movement can be divided into few phases based on the anteroposterior displacement of the cue tip (Figure 2), including practice swings and a final stroke. In addition, a final stroke is consisted of the back swing (Figure 2, key moment a to c), forward swing (Figure 2, key moment c to d), and follow-through phases (Figure 2, key moment d to e). The impact (key moment d) was identified as the moment of peak cue tip speed in the anteroposterior direction. This study investigated the duration from the start of forward swing to the end of follow-through (Figure 2, key moment c to e) since this duration is directly related to the generation of cue tip speed. Kinematics were obtained using Visual3D (v2021.09.1, C-Motion, Germantown, MD, USA). The cue tip speed was identified at the key moment d. Joint angles were defined and calculated following the recommendations of the International Society of Biomechanics (ISB) (Wu et al., 2005). The cue-wielding arm kinematics were calculated, comprising the ROM and peak angular velocities of the humeral elevation (Gates et al., 2016), elbow flexion/extension,

and wrist abduction/adduction since the upper limb movements in these planes could directly contribute to the cue stick delivery.
Data are presented as mean (standard deviation, SD). Statistical analyses were performed using SPSS software (version 21.0, IBM Corp, Armonk, NY, USA). After homoscedasticity and normality of residuals were checked, multiple linear regression was performed to predict the cue tip speed at impact based on the kinematic variables of the cue-wielding arm. Statistical significance was set at 0.05 level.

RESULTS: Descriptive results of the cue tip speed at impact and the kinematics of the cue-wielding arm are shown in Table 1. The results of multiple linear regression analysis revealed a significant regression equation [$F(6,12) = 3.754$, $p = 0.024$], with an R^2 of 0.479. Humeral elevation ROM was identified as the only significant predictor for predicting the cue tip speed at impact ($p = 0.008$). The cue tip speed decreased as humeral elevation ROM increased. Specifically, the cue tip speed would decrease by 0.022 m/s with every 1 degree increase in humeral elevation ROM (Figure 3). The other kinematic variables were not statistically significant predictors to the model (all $p > 0.05$, Table 2).

Table 1: Results of the cue tip speed and cue-wielding arm kinematics.

Variable	Mean (SD)
Cue tip speed at impact [m/s]	4.63 (0.43)
ROM [deg]	
Humeral elevation	20.5 (12.9)
Elbow flexion/extension	110.6 (45.7)
wrist abduction/adduction	30.1 (10.4)
Peak angular velocity [deg/s]	
Humeral elevation	176.0 (55.0)
Elbow flexion/extension	400.6 (114.2)
wrist abduction/adduction	356.3 (83.3)

Table 2: Collinearity diagnostics of tolerance, variance inflation factor (VIF), and regression coefficients for the cue-wielding arm kinematics.

Variable	r	β	*p*	Tolerance	VIF
ROM [deg]					
Humeral elevation	-0.735	-0.022	**0.008***	0.651	1.536
Elbow flexion/extension	0.428	0.003	0.163	0.710	1.409
wrist abduction/adduction	0.161	0.007	0.578	0.320	3.124
Peak angular velocity [deg/s]					
Humeral elevation	-0.076	0.002	0.261	0.745	1.343
Elbow flexion/extension	0.299	<0.001	0.787	0.781	1.280
wrist abduction/adduction	0.374	<0.001	0.979	0.317	3.151

r denotes correlation coefficient; β denotes standardised regression coefficient; VIF denotes variance inflation factor.

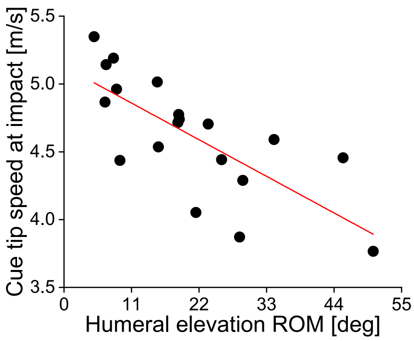

Figure 3: Negative relationship between cue tip speed at impact and humeral elevation range of motion (ROM).

DISCUSSION: This study explored the upper limb kinematics that could influence the cue tip speed in a break shot. The hypothesis that the greater joint ROM and angular velocities of the cue-wielding, the higher the cue tip speed at impact is not supported by the results of this present study. Among the three joints investigated, it was observed that only the humeral elevation ROM was a significant predictor for predicting the cue tip speed, and the cue tip speed decreased as humeral elevation ROM increased.

The cue tip speed was 4.63 (0.43) m/s for all participants in this study. As expected, the cue tip speed for a break shot found in both Kornfeind et al. (2015) and the present study was higher than all snooker shots (1.2 to 4.0 m/s) revealed by Kong and co-workers (2021). The results of this study reassured that great cue tip speed was required in a break shot which is very different from other types of shots. However, it should be noted that the cue tip speed at impact was lower than that (around 6 m/s) reported by Kornfeind et al., (2015). This may be explained by their participants all being top players in Europe, while the current study recruited players at relatively lower skill levels. It is unknown whether the top European players exhibited greater upper body joint ROM and angular velocities than those observed in the current study. In this study, the elbow and wrist ROM together with the peak joint angular velocities seemed to not influence the cue tip speed. This suggests that elbow and wrist movements should not be limited in order to accelerate the cue stick.

The participants in this study possessed various skill levels from recreational to national team players. The observed cue tip speeds ranged from 3.77 to 5.35 m/s with a small SD of 0.43 m/s across all participants. This indicated that all participants could deliver the cue stick at an appropriate speed to separate the racked object balls. Humeral elevation ROM should be limited, as the increased humeral elevation ROM was related to the decreased cue tip speed. However, the similar cue tip speeds among the 19 participants might have limited the regression analysis. Future studies are recommended to include also novice players who have yet to develop the ability to perform a good break shot. Additionally, instead of investigating the joint kinematics in isolation, further, in-depth studies should explore other variables such as joint coordination and coupling strategies.

CONCLUSION: This study identified in a 9-ball break shot, the humeral elevation ROM as a significant predictor for predicting the cue tip speed at impact, indicating that players should limit their humeral elevation ROM to maximise cue tip speed at impact.

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