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Movement variability of professional pool billiards players on selected tasks

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Abstract

Parameter values characterizing the motion of the cue during impact in pool billiards have been determined for selected shots. 20 elite players performed 18 predefined tasks comprising follow, draw, stop shots and breaks. 3D-kinematics were obtained using a motion analysis system comprising 8 cameras operating at 250 Hz and a high speed camera capturing with 5000 Hz. Longitudinal accelerations of the cue stick were recorded with 5 kHz using an accelerometer, mounted on the butt cap of the cue. Coefficients of variation for the parameter values obtained range from 3.9 % (height of impact point of maximum follow shot) to 58.3 % (elevation angle of 10-ball break). The average cue stick motion is basically non-accelerated (-0.060 +/- 0.508 ms\(^{-2}\)) at ball impact for all of the tasks except for the breaks (3.918 +/- 0.164 ms\(^{-2}\)). Despite the high number of DOF in the input configuration the tested pool billiard players achieved very similar outcomes.

1. Introduction

The physics behind the game of billiards is well understood [1]. Biomechanical aspects have, however, rarely been considered. In pool billiards, where the focus of this particular study has been set, the object of the game is to
strike the white cue ball into the colored balls and then subsequently pocket them. Successful pool billiard players are required to have efficient fine motor skills coupled with excellent repeatability in order to handle the different challenges on the table [2]. When performing identically tasks, international top players show recognizable inter-individual differences in their playing technique. These variations are notably related to the range of motion and the sequence of segment movements, which lead to the question about the existence of a common playing technique. Hence, the knowledge of subject independent movement parameters determining a successful shot technique is of interest in order to derive general principles for coaches and youth players. It may be hypothesized that individual movement strategies are necessary to compensate differences in anthropometrics and physiological properties.

Moreover, it may be assumed that due to the physical principles governing the impact between cue stick and ball, top elite players show a similar resulting motion of the cue stick at impact. To the best knowledge of the authors, kinematic data describing this motion have not been published so far. The objective of the study described within this paper, which has been performed as part of a larger research project, is to examine this expectation.

2. Methods

All measurements were done during an international tournament in St. Johann (Austria Open, Salzburg, Austria). A group of 20 top elite players (height: 180.2 ± 6.7 cm, mass: 80.3 ± 13.5 kg), all of them ranked under the top 80 of the Euro-tour of the European Pocket Billiard Federation, 5 of them former world champions, performed 18 predefined tasks (A-R) comprising follow (A-F), draw (G-L), stop shots (M-N) and breaks (O-R). A follow shot is (normally) done by hitting the cue ball above center. The cue ball stops momentarily then follows the object ball's direction upon contact with the object ball. In a draw shot the cue ball stops momentarily then draws away from the object ball towards the player upon contact with the object ball. A stop shot occurs when the cue ball comes to a direct stop after making square contact with the object ball. The break shot is the first shot, which is used to separate the object balls which have been racked together.

Each predefined position of the balls has been previously marked on the table’s cloth to guarantee identical conditions for all participants (see Figures 1-6).
All players had to succeed in one given task within up to three attempts and were allowed to use their own sports equipment (shooting cue, break cue). 3D-kinematics were captured at 250 Hz using a motion analysis system comprising 8 cameras (Vicon, Oxford). Longitudinal accelerations of the cue stick were recorded with 5 kHz using an accelerometer, mounted on the butt cap of the cue. In addition, video imaging of the cue tip and the cue ball were done at 5000 Hz with a high speed camera (IDT, Tallahassee) positioned perpendicular to the shot direction.

The following parameters were analyzed:

1. $v_{\text{impact}}$...Velocity of the cue at ball impact
2. $\phi_{\text{impact}}$...Elevation angle of the cue at ball impact
3. $h_{\text{impact}}$...Height of impact point
4. $t_{\text{impact}}$...Contact time between cue and ball during impact
5. $a_{\text{impact}}$...Acceleration of the cue at ball impact

$v_{\text{imp}}$ is defined as the 3D-velocity of a marker point attached near the top of the cue, $h_{\text{imp}}$ is the height of the first contact point between cue and ball, $a_{\text{imp}}$ as the acceleration into the longitudinal direction of the cue at impact. $v_{\text{impact}}, \phi_{\text{impact}}$ and $h_{\text{impact}}$ were determined using the motion analysis system, $t_{\text{impact}}$ from the high speed video recordings and $a_{\text{impact}}$ from the accelerometer data. It was assumed that all parameters follow a normal distribution. In order to find out, if there is evidence against this assumption Shapiro-Wilk tests were performed (significance level: 0.05). Mean values, standard deviations and coefficients of variation were calculated.

IBM SPSS (ver. 21) was used to test for normal distribution.

3. Results

Mean values and standard deviations (SD) for all parameters and shot types are depicted in Figures 7 to 11. Coefficients of variation (CV) are given for the ratio-scaled variables (all but $a_{\text{impact}}$) and are written into the respective bars. The asterisk (*) indicates a significant difference to normal distribution.
Fig. 7. Cue velocity at impact.

Fig. 8. Cue elevation angle at impact.

Fig. 9. Height of impact point. The horizontal line indicates the vertical central line of the cue ball.
It should be noted that the accuracy of the contact time is limited by the temporal resolution of the recording high speed camera (5000 Hz).

CV for \( v_{\text{impact}} \) were lowest (8 % on average) whilst largest CV values were observed for \( \varphi_{\text{impact}} \) (33 % on average). For \( h_{\text{impact}} \) CV was 9 % on average. The lowest \( t_{\text{impact}} \) values were observed for the breaks. This well corresponds to the highest \( v_{\text{impact}} \) values. The mean CV for \( t_{\text{impact}} \) for all types of shots was 21 %. The average cue stick motion was basically non-accelerated (-0.060 +/- 0.508 ms\(^{-2}\)) at ball impact for all of the tasks except for the breaks (3.918 +/- 0.164 ms\(^{-2}\)).

4. Discussion

Because of the high skill level of the participants, the collected data may serve as a reference for coaches and athletes as well as for future studies. Main differences between the parameter values characterizing the shot types can well be inferred from Figures 7 to 11. Short follow shots, for example, show larger values for \( h_{\text{impact}} \) than long follow shots, short draw shots lower values for \( v_{\text{impact}} \) than long draw shots and draw shots lower values for \( h_{\text{impact}} \).
than follow shots. These differences follow physical principles of the tasks to be performed and will not be discussed in more detail, here.

The values of $v_{\text{impact}}$ for maximum follow and draw shots were almost identical (~4.5 m/s). Also $h_{\text{impact}}$ showed quite similar values for all types of draw shots (~17.4 mm). The occurrence of these values may be caused by physical boundary conditions during the interaction between cue stick and ball (e.g. static friction). Higher cue stick velocities or lower vertical impact positions on the cue ball may result in a bad shot and are probably limiting factors in pool billiards.

The distribution of $t_{\text{impact}}$ significantly differs from a normal distribution in almost all cases. This may partly be reasoned by the insufficient timely resolution of the high-speed system used for recording the motions. Respective results have therefore to be interpreted with care. Different properties of the material used for the cues’ tip might also have influenced these results.

Significant deviations to the normal distribution of $a_{\text{impact}}$ were mainly caused by one outlier. Whereas players basically hit the ball with a non-accelerated cue stick for all the tasks but the breaks, one player showed a different behavior in accelerating the cue before impact. $a_{\text{impact}}$ was negative in most cases revealing a deceleration before impact. Nevertheless, a non-accelerated motion of the cue stick during impact is clearly prevalent. Comparable observations have been made for hitting devices in other sports, e.g. in tennis [3].

Concerning inter-individual variability of the players, $v_{\text{impact}}$ and $h_{\text{impact}}$ show average CVs below 10 %. Although CV for $\phi_{\text{impact}}$ is comparatively high, the mean SD of this parameter for all types of shots is 1.2 deg. The distributions of $h_{\text{impact}}$ and $\phi_{\text{impact}}$ do not significantly differ from normal distributions for all types of shots, those of $v_{\text{impact}}$ only in cases, where SD is very small (see Figure 7). It may therefore be concluded that top elite players do not basically differ in their cue stick motion at impact. The mean values of $v_{\text{impact}}$, $h_{\text{impact}}$ and $\phi_{\text{impact}}$ might well characterize the playing behavior of top elite players.

5. Conclusion

Despite the high number of DOF in the input configuration the tested pool billiard players achieved very similar outcomes even though individual players selected a different strategy for some tasks.

References