INVESTIGATION OF A THEORETICAL MODEL FOR THE ROTATIONAL SHOT PUT TECHNIQUE

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This study aimed to investigate the causal relationships among biomechanical variables for achieving high release velocity in male shot putter and create a theoretical model for the rotational shot put technique. The throwing motions of 22 male shot putters were videotaped and analysed using the 3D DLT method. Path analysis was used to examine causal relationships among biomechanical variables. The examined model consisted of three kinetic and eight kinematic variables that significantly related to a higher release velocity directly or indirectly. Two key factors were identified in shot put performance with the rotational technique: (1) increasing of impulse of the shot at delivery phase, and (2) creating greater linear and angular momentum before delivery. Future research should confirm or extend this potential causal mechanism of contributors to shot release velocity.

KEYWORDS: throwing, momentum, path analysis, causality

INTRODUCTION: The velocity of release has been shown to be the most important factor in shot put performance (Hay, 1993), therefore a better understanding of how to accelerate the shot to a high velocity is a critical issue. The rotational throwing technique is becoming the mainstream among elite male shot putters in recent years (Dinsdale, Thomas, Bissas & Merlino, 2017; Dinsdale, Thomas, Bissas & Merlino, 2019; Salinero & Coso, 2021), and it can be separated into five phases with six events according to foot contacts (Figure 1) (Bartonietz, 1994). One of the characteristics of this throwing technique is that the velocity of the shot decreases during the transition phase and then increases towards the release at an accelerating pace (Hay, 1993; Bartonietz, 1994; Ohyama-Byun, Fujii, Murakami, Endo, Takesako, Gomi & Tauchi, 2008). Multiple studies have identified key biomechanical variables in shot put performance such as velocity and angular velocity of body segments such as the upper limbs, lower limbs and torso, and momentum of the athlete-shot system (Bartonietz, 1994, Ohyama-Byun et al. 2008; Lipovšek, Škof, Štuhec & Čoh, 2011; Kato, Kintaka, Urita & Maeda, 2017). Furthermore, recent review stated that optimising high release velocity is predominantly determined by the development and transference of momentum through each phase, and kinematic variables within each phase are co-dependent (Schofield, Cronin, Macadam & Hébert-Losier, 2022). However, limited knowledge exists for the causal

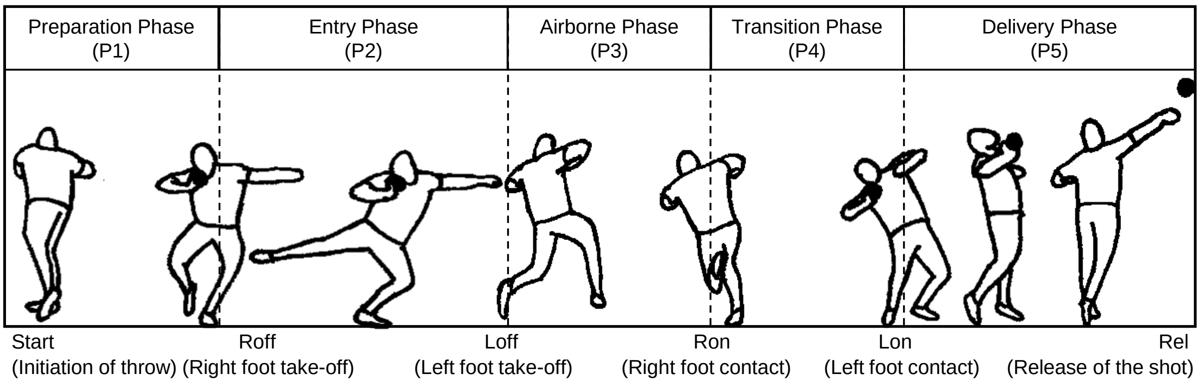

Figure1: Defined events and motion phases of rotational shot-put technique.

relationship among biomechanical variables for achieving high release velocity, and only one study indicated a deterministic model of shot put performance focused on variables at release (Hay, 1993). Therefore, the aim of this study was to investigate the causal relationships among biomechanical variables for achieving high release velocity in male shot putter and create a theoretical model for the rotational shot put technique.

METHODS: Twenty-two well-trained male shot putters (stature: 1.76 ± 0.06 m; range 1.66-1.86 m, body mass: 106.77 ± 11.95 kg; range 83.00-128.00 kg, personal best shot put record: 15.13 ± 1.72 m; range 11.45-17.90 m) participated in this study. All of them were right-handed throwers and provided written informed consent to participate in this study.
The data collections in this study were performed during official athletics competitions at national or collegiate levels in Japan. The throwing motions were recorded by two cameras (HDR-CX675, Sony, Tokyo, Japan) at 60 fps with a shutter speed of 1/1500 s. Cameras were place on the right side and backward of throwing direction at the shot put field. Before beginning of the competitions, a survey pole with 8 markers of known height was placed on 9 places around and inside of the shot put circle. A total of 72 control points were used to establish 3-D coordinate so that throwing direction was positive Y, upward was positive Z, and to the right of throwing direction was positive X.
The best recorded trial for each participant was selected for data analysis. The shot and 25 end points of each body segment were manually digitised at 60 Hz and reconstructed (Frame-Dias VI, Q'sfix, Tokyo, Japan), and three-dimensional DLT method was applied to collect coordinate data of the shot and end point of 15 body segments. A Butter worth digital filter with the cut-off frequencies ranging from 3.0 to 7.0 Hz was used to smooth the coordinate data.

The following variables were calculated:
1. Release velocity: velocity of the shot at release.
2. Impulse of the shot: amount of change in the shot's linear momentum during P5.
3. Path length of the shot: cumulative travel distance of the shot during P5.
4. Rotation of shoulder and hip: angular velocity around long axis of upper and lower torso.
5. Trunk twist: twist angle between long axis of upper and lower torso (Figure 2-a).
6. Trunk tilt: azimuthal angular velocity of the vector from the midpoints of both hip to the midpoint of both shoulder in the sagittal plane (Figure 2-b).
7. Flexion and extension of lower limbs: velocity of change in lower limbs length (Figure 2-c).
8. Velocity of upper and lower limbs: velocity of centre of gravity of each limb (Figure 2-d).
9. Total linear and angular momentum of the athlete-shot system

Causal relationships among the variables related directly or indirectly to a higher release velocity were examined by using path analysis: multiple regression analysis using the forced imputation method was performed sequentially, and standardised partial regression coefficient (β) was obtained as the path coefficient of the independent variable for the dependent variable (Barbosa, Costa, Marques, Silva & Marinho, 2010; Barbosa, Costa, Marihno, Coelho Moreira

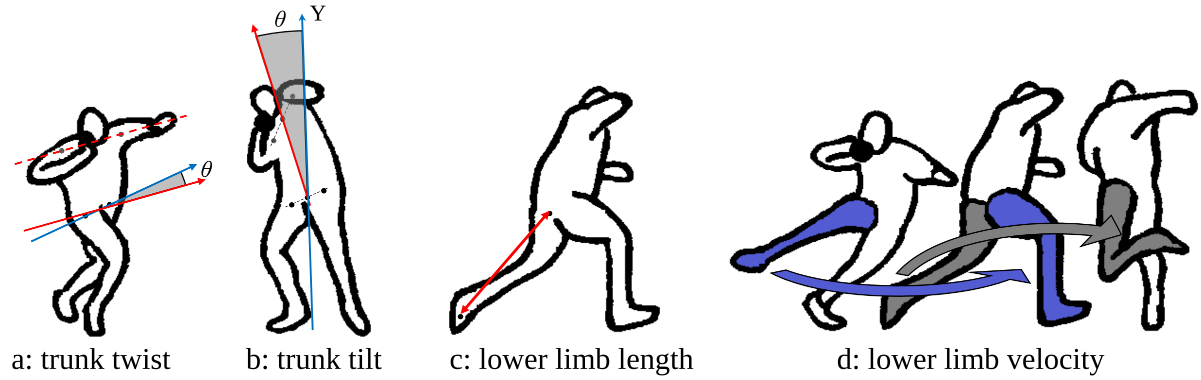

Figure2: Definition of variables

& Silva, 2010). Square root of residual contribution for each path was calculated to estimate residual effect reflected unmeasured variables. Significance level was set at < 0.05. All statistical analysis were performed by using the SPSS version 27.0 (IBM, Tokyo, Japan).

RESULTS and DISCUSSIONS: There was a significant positive correlation (r = 0.974, p < 0.01) between throwing distance (14.45 ± 1.88 m; range 11.45-17.90 m) and release velocity (11.86 ± 0.85 m; range 9.75-12.47 m/s). Therefore, release velocity was used as the end point in our theoretical model. Figure 3 shows the examined theoretical model of the rotational shot put technique in this study. The paths indicated significant causal relationships (p < 0.05) and β was shown beside the paths, respectively. There were three significant paths towards release velocity from impulse of the shot during the P5 (β = 0.474, p < 0.05), angular momentum of the athlete-shot system at Lon (β = 0.340, p < 0.05), and linear momentum of the athlete-shot system at Ron (β = 0.337, p < 0.05). These results confirmed the importance of creating a greater momentum of the system before the P5 and accelerating the shot during the P5 for achieving high release velocity (Ohyama-Byun et al., 2008; Lipovšek et al., 2011).
There were significant paths towards impulse of the shot from the mean angular velocity of the trunk tilt during the P5 (β = 0.401, p < 0.05), mean angular velocity of shoulder rotation during the P5 (β = 0.452, p < 0.05) and path length of the shot during the P5 (β = 0.731, p < 0.05). In addition, there was a significant path towards path length of the shot during the P5 from amount of change in the trunk twist angle during the P4 and P5 (β = 0.528, p < 0.05). Moreover, there were significant paths towards mean angular velocity of shoulder rotation during from amount of change in the trunk twist angle during the P4 and P5 (β = 0.752, p < 0.05) and mean angular velocity of hip rotation during the P5 (β = 1.156, p < 0.05). These identified variables towards impulse of the shot were consistent with previous studies reporting similar trends in the glide technique (Hay, 1993; Ohyama-Byun et al., 2008). It is also important to note that the rotational technique is characterised by a higher angular velocity of shoulder rotation than the glide technique (Bartonietz, 1994). From the kinematic chain perspective, previous study in baseball pitching reported the motion of trunk and hip influence the subsequent motion of shoulder and arm (Matsuo, Fleisg, Zheng & Andrews, 2006). Similarly, rotating the hip toward the front by untwisting the trunk would have contributed as the trigger of transmission the torque from the hip to the torso, torso to the shoulder and shoulder to the arm during the P5 in the current study. There was a significant path towards angular momentum of the athlete-shot system at Lon from maximum velocity of left lower limb during the P4 (β = 0.484, p < 0.05), which was significantly causal related with the maximum velocity of right lower limb during the P4 (β =

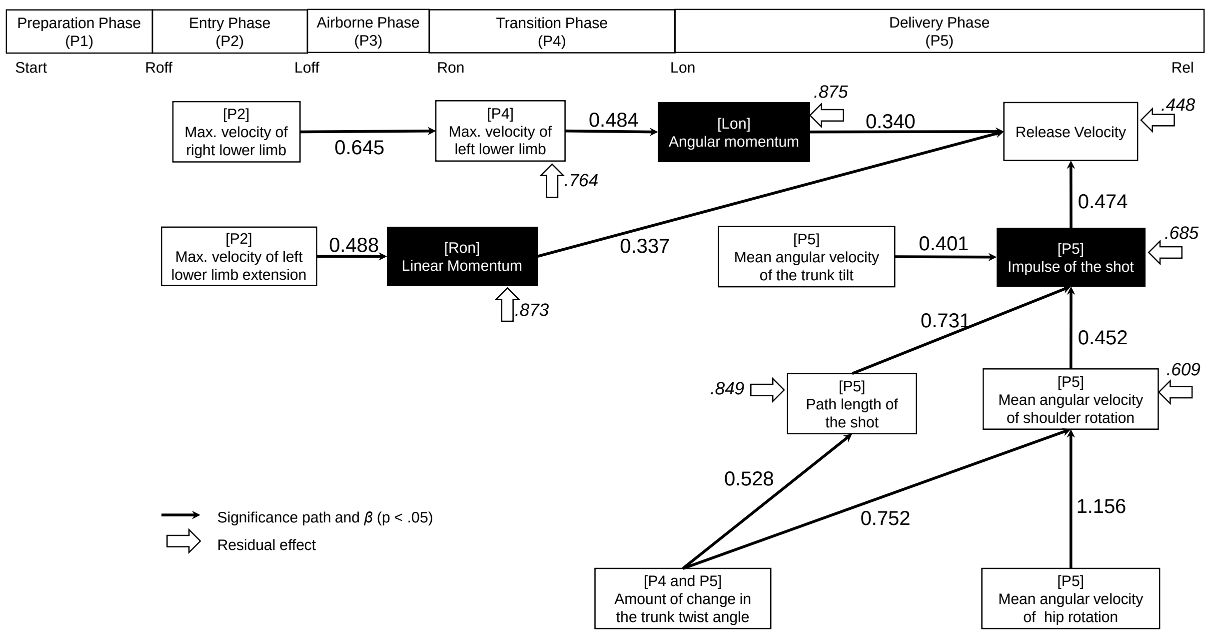

Figure 3: Examined theoretical model for rotational shot put technique.

645, $p < 0.05$). Kato et al (2017) pointed out that the swinging motion of the right lower limb during the P2 and the swinging motion of the left lower limb during the P4 lead to an increase of angular momentum of the athlete-shot system. Therefore, the swinging motion of right lower limb during the P2 and subsequently the higher velocity in the swinging motion of left lower limb during the P4 and P5 would have led to the increase of angular momentum of the athlete-shot system. There was a significant path towards the linear momentum of the system at Ron from maximum velocity of extension in left lower limb ($\beta = 0.488$, $p < 0.05$). McGill (2009) described the left leg motion during the P2 as “Shot sprint action”, which was similar motion to walking, running, and jumping. In the current study, this left leg motion may have led to create the greater linear momentum of the athlete-shot system as previously stated by Ohyama-Byun et al. (2008).

CONCLUSION: This study attempted to create a theoretical model for the rotational shot put technique by investigating the causal relationship among biomechanical variables for achieving high release velocity in male shot putter. The developed model was characterised by three kinetic and eight kinematic variables significantly related for higher release velocity directly or indirectly. Main identified factors for the higher release velocity were a greater momentum before the delivery phase and a greater impulse of the shot during the delivery phase. Future research should investigate further potential contributors to shot release velocity.

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