GROUND REACTION FORCES OF DART-THROWING AT DIFFERENT TARGET HEIGHTS

Chieh- Wen Kao[1], Chieh-Yin Kao[1], Tsung-Yu Huang[1], Wen-Tzu Tang[1*]
[1]Graduate Institute of Athletics and Coaching Science,

National Taiwan Sport University, Taoyuan, Taiwan, ROC

The purpose of the study was to explore whether dart players produce different lower limb control strategies when throwing darts at spatially separated targets in the vertical direction. Eight experienced darts players (height 1.75±0.04 m, mass 83.4±19.3 kg) participated in this research. Two Multi-Axis Force Plates were used to collect GRF data on both legs and synchronized with a Motion Capture System. The participants threw darts at three targets at different heights, which were the upper section of the 20 point area, bullseye and lower section of the 3 point area. The results showed that the amplitude of anterior-posterior GRF of their front legs were significantly different when darts was thrown at the 20 zone, bullseye and 3 zone respectively. Our study found that the braking forces of the front legs were greater when a dart was being thrown at the highest target (20 points) than when it was being thrown at the lowest target (3 points).
KEYWORDS: ground reaction force, dart, throwing, aiming.

INTRODUCTION: With the promotion of the World Darts Federation, an increasing number of people participate in this precision throwing sport. According to the rules of the game, dart players are required to throw darts onto a dartboard which has 82 areas with different point scores. Therefore, an experienced player must be able to throw darts accurately at different targets. Dart throwing is usually performed in a standing position and includes three stances - basic, sideways, and frontal. The basic stance is a very common throwing stance and used by more than 90% of players (Vasiljev et al., 2017). Dart coaches often asked players to keep their lower limbs stable and only control their upper limbs when throwing darts at different targets. Previous study has shown that darts-players have regular variations in foot pressure and ground reaction forces when throwing (Vasiljev et al., 2017; Endo & Miyanishi, 2014). In a previous study by Nakagawa et al. (2015), it was mentioned that the lower limbs coordinate with the upper limbs' movements when throwing darts. When darts players throw at different height targets, the legs may produce different lower limbs control strategies. Therefore, the purpose of this study is to explore whether the ground reaction force (GRF) of the lower limbs is involved in the regulation of throwing at different heights.

METHODS: Eight right-handed male darts players (height 1.75±0.04 m, mass 83.4±19.3 kg) participated in this study. They each had over 2 years' experience of dart playing, and all used the basic stance (front and back stance). The dartboard was placed at the official competition distance (2.37m) and height (1.73M) (Figure 1). The participants were asked to stand on two AMTI force plates whose frequencies were 1000 Hz (bp 400600, Advanced Mechanical Technology Inc., USA). The right foot standing on the front plate and left foot standing on the back plate. The dart-throwing motion was capture by an eight-camera motion capture system (Eagle, Motion Analysis Corporation., Santa Rosa USA) placed to surround the participant. The motion capture sampling frequency was 200 Hz. Ground reaction force (GRF) data was synchronized with the motion capture system. The three-dimensional coordinate system was identified as X, Y and Z (Figure 1) representing anterior-posterior (X), medial-lateral (Y) and superior-inferior (Z) GRFs respectively.

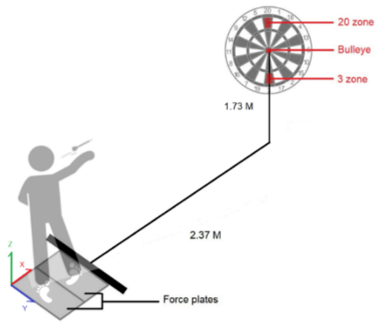

Figure 1: Experimental set-up.
Subjects stand in front of the throwing line and the distance from the throwing line to the board was 2.37 m. The height of the center of the bull's-eye was set 1.73 m above the floor.

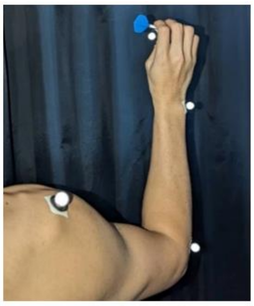

Figure 2: Location of reflective markers.

To capture the dart throwing motion, four reflective markers (12 mm diameter) were attached to the right shoulder, elbow, wrist and thumb, and a reflective tape attached to the dart shaft (Figure 2). All participants were asked to throw the dart to 3 different height target positions, which were the 20-point area (higher position), the bullseye (center position) and the 3-point area (lower position) respectively. The participants threw a dart 15 times at each different target position. Force signals were analyzed from three throws (selected for throw accuracy and signal clarity) for each subject, and these data were subsequently averaged. Ground reaction force (GRF) data for both legs were recorded and processed by the AMTI force plates throughout the throwing phase, which was defined as starting at the point of maximum angle of flexion of the elbow joint until the moment that the dart was released as recorded by the motion capture system. This study analyzed the antero-posterior, medio-lateral, and vertical components of GRF. We calculated the maximum and minimum GRF values and the amplitude of GRF (the maximum value - the minimum value) during the throwing phase. And GRF was calculated at dart release.

SPSS 20.0 statistical software was used for statistical analysis. According to the purpose of the study, the GRFs of three groups were compared through one-way repeated measure analysis of variance. The significance level is set at $p < .05$.

RESULT: The result shows the relationship of ground reaction forces of the front and back legs during the throwing period (Figure 3). There was no significant difference of GRF components when darts were thrown at the three different zones (Table 1). However, the amplitude of anterior-posterior front leg GRF (Table 2) had significant differences when darts were thrown at the 20 zone (-7.20±3.59N), bullseye (6.56±3.96), and 3 zone (5.63±3.32) respectively, but no significant differences were found on the other axes.

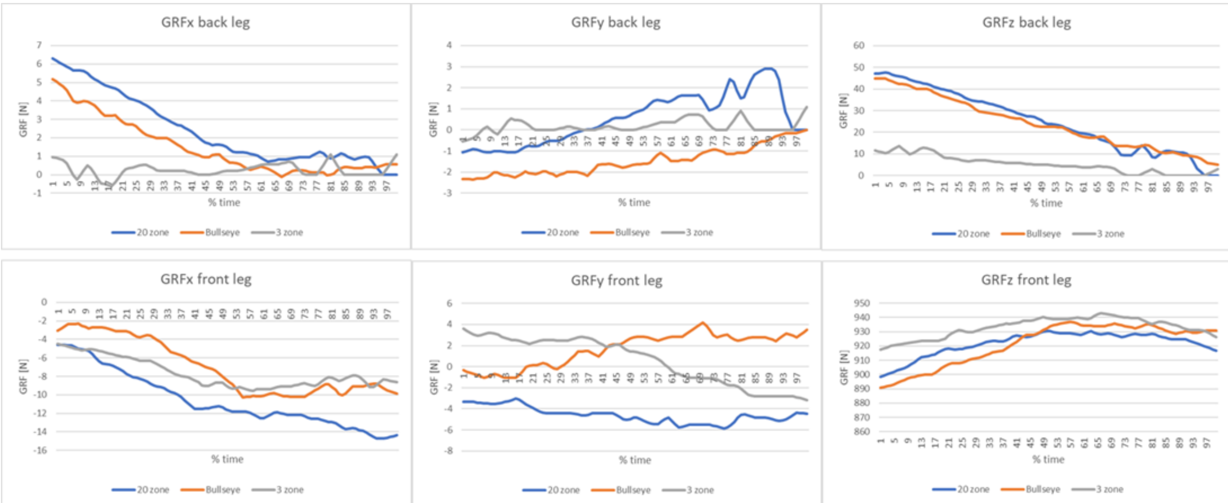

Figure 3: Antero-posterior (GRFx), horizontal (GRFy) and vertical (GRFz) Ground Reaction Forces(N) of front and back leg during throwing at three different zones. The positive and negative force of GRFx are as follows: the driving force (+) and the braking force (-) for Antero-posterior ground reaction force, the GRFy are as follows: the right component (+) and the left component (-) for horizontal ground reaction force. The force of GRFz is the gravity force (+) for vertical ground reaction force.

Table 1: GRF (anterior-posterior component GRFx, medial-lateral component GRFy and superior-inferior component GRFz) at dart release.

	The 20 zone		The bullseye		The 3 zone				
	Mean	SD	Mean	SD	Mean	SD	F	p-value	η^2
GRFx back leg [N]	**2.09**	5.23	**1.44**	4.64	**2.19**	5.30	0.325	0.728	0.044
GRFy back leg [N]	**-0.72**	2.61	**-1.54**	2.40	**0.67**	3.13	3.560	0.056	0.337
GRFz back leg [N]	**19.12**	15.79	**20.26**	13.74	**20.19**	19.32	0.075	0.928	0.011
GRFx front leg [N]	**-7.65**	5.40	**-7.93**	3.62	**-7.54**	5.58	0.044	0.957	0.006
GRFy front leg [N]	**-2.29**	3.43	**-1.43**	3.21	**22.50**	75.25	0.819	0.461	0.105
GRFz front leg [N]	**863.02**	217.18	**861.67**	217.92	**829.50**	257.55	1.509	0.267	0.232

Table 2: The amplitude (the maximum value - the minimum value) of GRF (anterior-posterior component GRFx, medial-lateral component GRFy and superior-inferior component GRFz) during the throwing phase.

	The 20 zone		The bullseye		The 3 zone				
	Mean	SD	Mean	SD	Mean	SD	F	p-value	η2
GRFx back leg [N]	**3.43**	3.92	**3.45**	2.74	**3.61**	4.48	0.019	0.981	0.003
GRFy back leg [N]	**2.26**	1.67	**2.10**	0.90	**2.44**	2.17	0.123	0.885	0.017
GRFz back leg [N]	**18.32**	17.74	**17.01**	13.56	**13.43**	11.08	0.986	0.398	0.123
GRFx front leg [N]	**7.20**	3.59	**6.56**	3.96	**5.63**	3.32	5.084	0.022*	0.421
GRFy front leg [N]	**4.05**	3.69	**4.47**	3.60	**5.13**	4.62	0.342	0.716	0.047
GRFz fron tleg [N]	**46.96**	20.26	**41.06**	15.31	**35.04**	16.59	2.316	0.135	0.249

Discussion: The purpose of this study is to explore whether the ground reaction force of the lower limbs is involved in the regulation of throwing at different heights. The results showed that range of anterior-posterior GRF of the front leg varied significantly when darts were thrown at the 20 zone, bullseye and 3 zone respectively. We observed from figure 3 that GRFx from the front leg gradually generated braking forces during the throw. All participants had significantly greater range of anterior-posterior GRF, when darts were thrown at the 20 zone on the dartboard. This means that more front leg braking force was generated when darts were thrown at the 20 zone. In addition, our study found that vertical GRF shifted slightly from the back leg to the front leg during throwing. Previous darts sport study has observed that foot pressure transfers from the back foot to the front foot during throwing (Vasiljev et al., 2017). From the theory of ballistics, throwing a dart at a high position requires greater throwing speed than when throwing at a low position.

To provide faster dart throwing speed, the joints on the upper limb may need to generate quicker rotation. This may cause that the body's center of gravity to shift forward. Past research has shown that amateurs have an excessive center of gravity forward shift compared to professionals when throwing darts (Endo & Miyanishi, 2014). Based on the above, our study suggested that the greater amplitude of braking force generation served to avoid the forward shift of the body's center of gravity.

CONCLUSION: The present study has clarified differences in dart throwing GRFs between different target heights. It was concluded that players achieved throws at the higher target by adding braking force from front leg during the throwing phase.

REFERENCES

Endo, S., & Miyanishi, T. (2014, October). A biomechanical analysis of competitive and recreational players in relation to the darts throwing technique. In *ISBS-Conference Proceedings Archive*.

Nakagawa, J., An, Q., Ishikawa, Y., Oka, H., Takakusaki, K., Yamakawa, H., ... & Asama, H. (2015). Analysis of human motor skill in dart throwing motion at different distance. *SICE Journal of Control, Measurement, and System Integration*, *8*(1), 79-85.

Vasiljev, R., Rubin, P., Milosavljevic, S., & Vasiljev, I. (2017). Transfer of under-foot load and mechanisms of control in dart sports. *children*, *19*(3), 235-242.