ORIGINAL ARTICLE

A pilot study for detecting release instant using a single inertia measurement unit in shot put

TADAHIOKO KATO[1] ✉, KEI MAEDA[2], JUN MIZUSHIMA[3], KEIGO OHYAMA-BYUN[4], TAKAHIRO ADACHI[5], JUN FUKUDA[5]

[1]*Department of Materials and Human Environmental Sciences. Shonan Institute of Technology. Fujisawa, Japan.*

[2]*Department of Health and Sports Sciences. Kyoto University of Advanced Science. Kyoto, Japan.*

[3]*Department of Health and Sports Sciences. Toyo University. Tokyo, Japan.*

[4]*Institute of Health and Sport Sciences. University of Tsukuba. Tsukuba, Japan.*

[5]*Department of Sports and Health Sciences. Kyushu Snagyo University. Fukuoka, Japan.*

ABSTRACT

Evaluating and understanding the release parameters is crucial in the throwing events of athletics, however, calculating the release parameters is time-consuming for data collection and can be expensive. The present study aimed to investigate a method for detecting the release instant from data collected using a single inertia measurement unit (IMU) in shot put. Two male shot putters participated in the study. Each participant performed six competitive throws with a 9-axis IMU (100 Hz) attached to the back of the participant's throwing hand. Three different methods were examined from IMU data: threshold values of resultant acceleration, waveform of resultant acceleration, and waveform of the angular velocity around the radio-ulnar axis of the hand. The release instant as a true value was obtained from the video recorded in sync with the IMU, and the error of the release instant detected from the IMU was calculated. The final number of trials analysed was four for participant A and six for participant B. As results, there were various cases where the threshold value of acceleration did not exceed the value depending on the participant and trial, and the release instant could not be detected. The release instant detected from the moment the acceleration decreased based on the acceleration waveform had a large error (4.00 ± 2.26 frames). The release instant, which was detected from the moment when the angular velocity became negative based on the angular velocity waveform, was detected in all trials for both participants, and the error was low (1.20 ± 0.92 frame).It was found that utilizing the detection of dorsiflexion timing of the wrist joint, with the angular velocity around the rotational axis parallel to the radio-ulnar axis of the hand as a cue, proved to be a highly accurate approach for determining the release instant.

Keywords: Biomechanics, Dorsiflexion, Throwing, Event detection.

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✉ **Corresponding author.** *Department of Materials and Human Environmental Sciences. Shonan Institute of Technology. Fujisawa, Japan.*
E-mail: kato@mate.shonan-it.ac.jp
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INTRODUCTION

In the throwing events of athletics, throwers compete for distance by throwing objects. This throwing distance is determined by variables called release parameters, such as the velocity of the object (initial velocity), angle of release, and location of release (release height) at the instance of release (Hay, 1993). Aerodynamic factors influence the throwing distance in discus and javelin throws (Bartlett & Best, 1988; Hay & Yu, 1995; Hubbard & Cheng, 2007), whereas, in shot put and hammer throw, these factors have minimal effect due to the density of the objects being thrown (Hay, 1993). Therefore, evaluating and understanding these release parameters is crucial, particularly for shot put and hammer throw events. Release parameters have traditionally been calculated using 3-D motion analysis methods such as video-based DLT method or optical motion capture systems (Dinsdale, Thomas, Bissas, & Merlino, 2017; Kato, Kintaka, Urita, & Maeda, 2017; Kato, Maeda, Mizushima, & Maeda, 2022; Kumar, Murali, & MR, 2016; Landolsi et al., 2018; Liu & Yu, 2021; Thomas, Dinsdale, Bissas, & Merlino, 2019; Van Biesen, McCulloch, & Vanlandewijck, 2018). Although these methods provide accurate data on release parameters, the video-based DLT method is time-consuming for data collection, and optical motion capture systems can be expensive (Lee & Yoo, 2017). Consequently, these methods make it challenging to readily use data for training and coaching purposes.

Wearable devices are now being used for immediate data collection and feedback. In particular, the inertial measurement unit (IMU) is becoming smaller and less expensive. Recent research has explored the use of IMUs to evaluate athletes' posture (Brice, Hurley, & Phillips, 2018; Wada et al., 2020), behaviour of sports equipment (Gao et al., 2009; Wada, B. Shepherd, D. Rowlands, & A. James, 2016), joint power (Jiang, Gholami, Khoshnam, Eng, & Menon, 2019; Nagahara & Murata, 2020), and ground reaction force (Karatsidis et al., 2017; Shahabpoor & Pavic, 2018) across various sports. In the context of throwing events, IMUs have been employed to estimate the throwing velocity in team handball by attaching them to the wrist or arm segments and using machine learning (Gençoğlu & Gümüş, 2020; van den Tillaar, Bhandurge, & Stewart, 2021). Furthermore, the throwing velocity in team handball can be estimated from the acceleration measured by a wrist-mounted accelerometer without the need for machine learning, yielding unbiased results with minimal errors (Skejø, Bencke, Møller, & Sørensen, 2020). Based on previous research, it is feasible to estimate release parameters in throwing events using a single IMU attached to the hand or wrist.

Determining the release instant is essential for obtaining accurate release parameters, which have been traditionally determined visually using video images (Dinsdale et al., 2017; Kato et al., 2017; Kato et al., 2022; Thomas et al., 2019). For example, in shot put, the acceleration of the shot had calculated using an accelerometer embedded inside the shot without relying on video images (Gao et al., 2009). Another study has also evaluated the kinematics of throwing motion using multiple IMUs (Saračević, Atiković, Štuhec, & Čuk, 2018). However, these research efforts have not specifically investigated the release parameters and the detection of release instant moment from the sensors. Therefore, in order to estimate release parameters using the IMU, it is necessary to first establish a method for detecting the release moment solely based on the IMU data.

The aim of this research was to investigate methods for detecting the release instant from data collected through the use of the IMU.

MATERIAL AND METHODS

Participants

Two well-trained male shot putters (personal best of shot put, 18.29 m and 17.35 m) volunteered to participate in the study after providing informed consent. Both participants were right-handed throwers and competed at the national level in Japan. The study protocol was approved by the research ethics committee.

Measures and procedures

Following a self-selected warm-up, which included warm-up throws, each participant performed six competitive throws. A 9-axis wireless IMU with an accelerometers range of 200 G and gyro sensors range of 6000 deg/s was used at a sampling rate of 100 Hz (SS-MS-HMA5G3, SPORTS SENSING Co., Japan). After static calibration, the IMU was attached to the dorsum of the participant's right hand, and the shot put motion was recorded by two high-speed cameras (Ex-F1, Casio, Japan) at a frame rate of 300 fps with a shutter speed of 1/2000 s. The IMU was attached such that its X, Y, and Z-axes of the IMU were parallel to the long axis of the right hand, the left-right axis (parallel to the dorsiflexion axis of the wrist joint), and the axis perpendicular to the long axis and the left-right axis, respectively. The angular velocity was positive in the direction of palm flexion and negative in the direction of dorsiflexion.

The IMU was controlled using a dedicated application (SPORTS SENSING Co., Japan) on a wirelessly connected computer. LED lights (SS-WSYLT1, SPORTS SENSING Co., Japan) were synchronized with the IMU measurement using a synchronization unit (SS-WSY12, SPORTS SENSING Co., Japan) and placed within the cameras' field of view to synchronize the time axis of the video images and IMU data.

The captured video was converted to 100 fps using video editing software (Adobe Premier Pro 14.2, Adobe, Inc.) based on the frame when the LED light began to emit light. The converted video was then played back frame by frame at 100 Hz using video playback software (Quicks time 7.79, Apple, Inc.), and the number of frames was obtained as the true value of the release time, representing the instance when the shot was completely released from the fingertips in both videos. The study protocol was approved by the research ethics committee at the Shonan Institute of Technology.

Three different methods for detecting release instant using the IMU were examined, based on accelerometer and gyro sensor data. In sprint acceleration, the touchdown and take-off of the foot were detected using an accelerometer attached to the calf or heel, employing either acceleration threshold or waveform analysis (Purcell, Channells, James, & Barrett, 2006; Schmidt et al., 2016). In the shot put, the shot's acceleration was measured using an accelerometer integrated into the shot itself, and its acceleration exhibited a peak followed by a decrease during the release, with a maximum value exceeding 15 G (Gao et al., 2009). Considering that the IMU was affixed to the hand in this study, it is expected that the acceleration values would be different from those of the shot. Following a kinetic chain perspective (Blazevich, 2017), it can be inferred that hand acceleration reaches its peak before the release and gradually decreases toward release, albeit to a lower level than the shot's acceleration.

The first method for detecting the release instant involved setting four threshold values (10.0 G, 7.5 G, 5.0 G, and 2.5 G), and the release instant was determined as the point when the resultant acceleration fell below each threshold (BT 10.0 G, BT 7.5 G, BT 5.0 G, and BT 2.5 G).

The second method utilized the waveform of the resultant acceleration. For all trials of both participants, waveforms were observed in which the resultant acceleration increased before release and then started to decrease just before release. Therefore, the instant when the resultant acceleration began to decrease was extracted as DRA (Decrease of Resultant Acceleration).

Regarding the gyro sensors, the focus was on the angular degrees of freedom of the hand joints, which influence hand motion. The wrist joint encompasses two types of motion—palmar and dorsal flexion, as well as radial and ulnar flexion. However, evaluating flexion and ulnar flexion requires a relative positional relationship with the forearm. On the other hand, the release is characterized by a snap of the wrist (palm flexion) in shot put motion (Fok & Bain, 2022). Hence, the behaviour of the hand enables the observation of palm flexion and dorsiflexion of the wrist joint, particularly before and after the release. Consequently, the angular velocity waveforms around the left-right axis of the IMU attached to the hand were employed as the third method for detecting the release instant. Across all participants and trials, the angular velocity around the radio-ulnar axis of the hand exhibited a negative increase immediately before and after the release instant, followed by a positive increase.

Therefore, the instant at which the angular velocity became negative was detected as NAV (Negative Angular Velocity).

Statistical analysis

The mean value, standard deviation, and error range were calculated for the release moments obtained from the acceleration and angular velocity of the IMU, in comparison to the release instants determined from the video images. The error range, presented as absolute values, was analysed using a student t-test with a significant level set at 5% for comparison.

RESULTS

Trials in which the IMU lost contact from the hand before the release of the shot were excluded from the analysis. The final number of trials analysed was four for participant A and six for participant B. Figure 1 and 2 shows the resultant acceleration and Figure 3 and 4 shows the waveforms of the angular velocity around the radio-ulnar axis of the hand before and after the release instant, identified as 0 s, as detected from the video for each participant and trial. In participant A's first trial, the waveform was interrupted due to the removal of the IMU from the hand after release.

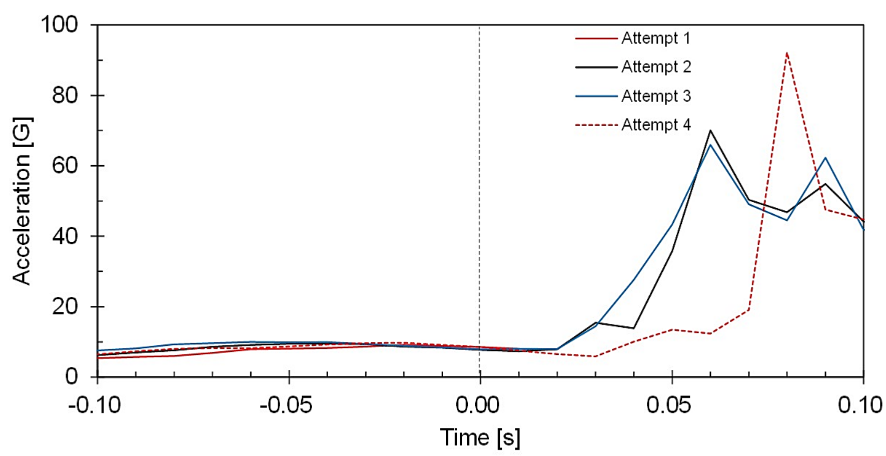

Figure 1. The resultant acceleration of the hand around the release instant for participant A. 0 s shows the release instant detected from the video image.

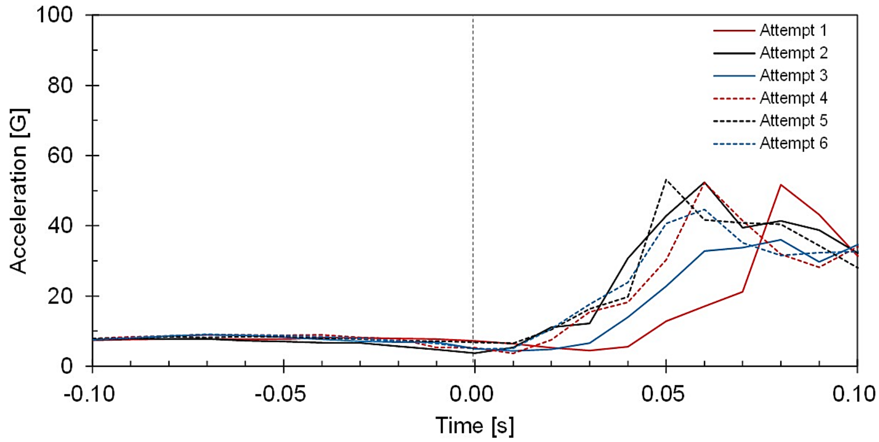

Figure 2. The resultant acceleration of the hand around the release instant for participant B. 0 s shows the release instant detected from the video image.

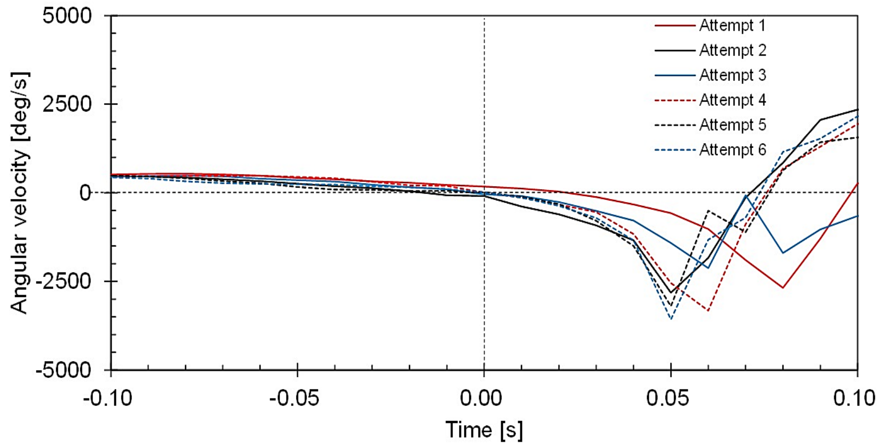

Figure 3. Angular velocity around the radio-ulnar axis of the hand of participant A around the release instant. 0 s shows the release instant detected from the video image.

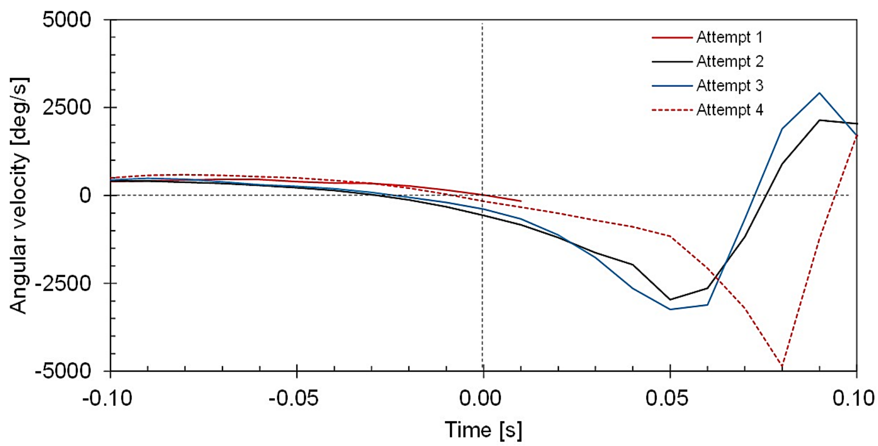

Figure 4. Angular velocity around the radio-ulnar axis of the hand of participant B around the release instant. 0 s shows the release instant detected from the video image.

Table 1. Means and absolute means of errors in detecting release instant for each method. Negative values mean that estimated release instant preceded true (by video) instant.

Participant		Acceleration [frame]					Angular velocity [frame]
		BT 10.0 G	BT 7.5 G	BT 5.0 G	BT 2.5 G	DRA	NAV
A	Attempt 1	-	-	-	-	-1	1
	Attempt 2	-	1	-	-	-3	-2
	Attempt 3	-	-	-	-	-5	-2
	Attempt 4	-	1	-	-	-1	0
B	Attempt 1	-	0	3	-	-3	3
	Attempt 2	-	-6	-1	-	-8	-1
	Attempt 3	-	-3	0	-	-6	0
	Attempt 4	-	-1	1	-	-3	1
	Attempt 5	-	-2	-	-	-4	1
	Attempt 6	-	-2	0	-	-6	1
Mean ± SD			-1.50 ± 2.33	0.60 ± 1.52		-4.00 ± 2.26	0.20 ± 1.55
Absolute mean ± SD			2.00 ± 1.85	1.00 ± 1.22		4.00 ± 2.26	1.20 ± 0.92

Table 1 shows the mean value, standard deviation, and error range of the error and absolute error in the release instant detected from the acceleration and angular velocity, in comparison to the release instant determined from the video. No trials were observed with accelerations above 10.0 G or below 2.5 G for both participants. BT 7.5 G was detected in two out of four trials for participant A and in all trials for participant B. BT 5.0 G was not detected in any of participants A's trials; in contrast, it was detected in all trials for participant B. DRA and NAV were detected in all trials for both participants. The results of student t-tests, as shown in Figure 5, indicate that DRA (4.00 ± 2.26 frames) had a significantly larger absolute error than BT 7.5 G (2.00 ± 1.85 frame), BT 5.0 G (1.00 ± 1.22 frame) and NAV (1.20 ± 0.92 frame). There was no significant difference between BT 7.5 G, BT 5.0 G, and NAV.

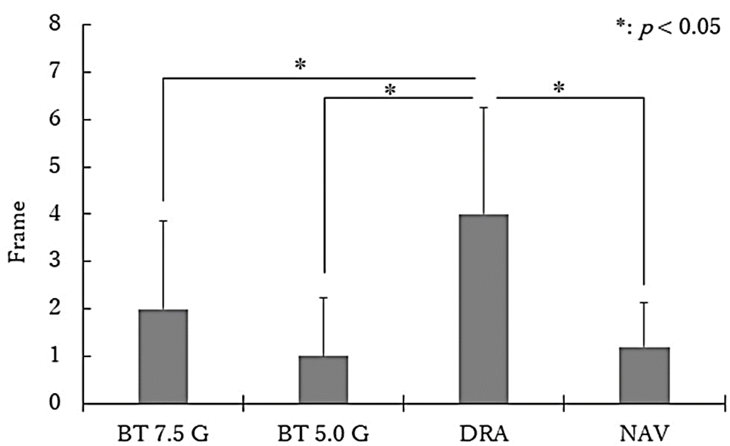

Figure 5. Comparison in absolute errors in detecting release instant for each method. BT 10.0 G and BT 2.5 G were removed from the comparison, as no trial was observed for both participants.

DISCUSSION

This study aimed to investigate methods for detecting the release instant in shot put using the IMU. Two participants threw the shot with the IMU attached to their hand. The primary focus of the study was to assess the errors in detecting the release instant detected from acceleration and angular velocity compared to the true value detected from video images. The results of the study confirmed that using a threshold for resultant acceleration and analysing the waveform of angular velocity around the axis paralleled to parm flexion and dorsiflexion of the wrist joint can effectively detect the release instant with minimal errors.

Regarding the threshold of resultant acceleration, BT 7.5 G showed small errors in detecting the release instant for participant A, but exhibited errors of up to six frames (0.06 s) for participant B. BT 5.0 G had small errors in participant B, which was not detected in any trials in participant A. Furthermore, BT 10.0 G and BT 2.5 G were never detected in any of the trials. Additionally, the method of DRA showed significantly higher errors compared to other methods. In the throwing motion, the kinetic chain perspective suggests that the body moves from the centre to the extremities in sequence and with acceleration (Blazevich, 2017). In addition, the initial velocity of the shot is a critical factor affecting on the throwing distance (Hay, 1993). Therefore, it is assumed that the hand velocity around the release instant also varies between the trials, depending on the participant's skill level and the differences in throwing distance among trials. Consequently, the resultant acceleration of the hand may differ not only between participants but also between trials. Based on the results of this study, it can be stated that BT 7.5 G and BT 5.0 G can be used to detect the release instant with relatively high accuracy for participant A and participant B, respectively. However, given that both methods failed to detect the release instant in some trials for each participant, further verification is required to determine whether hand acceleration depends on the characteristics of the participants and the throwing distance to detect the release instant using the threshold of resultant acceleration.

NAV was detected within 3 frames (0.03 s) of the true value in all trials for both participants. This indicates that the hand's behaviour near the release instant resembled dorsiflexion of the wrist joint. In terms of hand behaviour, in baseball pitching, the angular velocity of flexion-extension in the proximal and the middle finger joints increases in the extension direction just before the release instant, followed by a rapid increase in the flexion direction, which has been suggested to be due to high joint stiffness of the fingers (Matsuo et al., 2018). Therefore, in shot put, it is plausible that the interphalangeal joints rapidly extend and then flex near the release instant, and the hand joints are dorsiflexed by the reaction. The IMU attached to the hand may measure the angular velocity of rotation in the direction of extension (dorsiflexion) around the hand's right and left axes. The rotation behaviour of the hand around the radio-ulnar axis near the release instant, as shown in the present results, is a distinctive characteristic of shot put. It is considered the most accurate method for detecting the release instant examined in the present study.

There are several limitations to the study's design. Since there were two participants, and their competition level was sub-elite, it cannot be assured that similar results would be obtained in athletes of different competition levels. As mentioned earlier, the optimal threshold values for hand acceleration may vary for different athletes. Therefore, it is necessary to verify the results with a large number of participants and a wider range of competition levels. In addition, the behaviour of the hand and wrist joints inferred from the angular velocity waveforms in this study needs to be verified through detailed analysis using an optical motion capture system.

CONCLUSIONS

The present study aimed to investigate three different methods for detecting the release instant in shot put using data obtained from a single IMU. The release instant determined from synchronized video images was considered as the reference value, and a comparison was made based on the absolute error in relation to this reference. Among the methods examined, it was found that utilizing the detection of dorsiflexion timing of the wrist joint, with the angular velocity around the rotational axis parallel to the radio-ulnar axis of the hand as a cue, proved to be a highly accurate approach for determining the release instant.

AUTHOR CONTRIBUTIONS

TK conceived the study, participated in its design and coordination, performed the experiment and the statistical analyses, and drafted the original version of the manuscript. KM and KO participated in its design and coordination, performed the experiment, and heled in participants' recruitment. JM, TA and JF conceived the study and participated in its design and coordination. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Bartlett, R. M., & Best, R. J. (1988). The biomechanics of javelin throwing: a review. Journal of Sports Sciences, 6(1), 1-38. https://doi.org/10.1080/02640418808729791

Blazevich, A. J. (2017). Sports biomechanics: the basics optimising human performance. London: Bloomsbury Publishing.

Brice, S. M., Hurley, M., & Phillips, E. J. (2018). Use of inertial measurement units for measuring torso and pelvis orientation, and shoulder-pelvis separation angle in the discus throw. International Journal of Sports Science & Coaching, 13(6), 985-992. https://doi.org/10.1177/1747954118778664

Dinsdale, A., Thomas, A., Bissas, A., & Merlino, S. (2017). Biomechanical Report for the IAAF World Championships London 2017: Shot put men's. Retrieved from [Accessed 2024, July 11]: https://www.worldathletics.org/about-iaaf/documents/research-centre

Fok, M. W. M., & Bain, G. I. (2022). Wrist Injuries in Throwers. Management of Track and Field Injures, 105-110. https://doi.org/10.1007/978-3-030-60216-1_11

Gao, Z., Song, B., Liu, M., Song, G., Sun, W., & Ge, Y. (2009). Design and application of a multidimensional acceleration sensor for coaching of shot-put athletes. Sensors and Actuators A: Physical, 149(2), 213-220. https://doi.org/10.1016/j.sna.2008.11.029

Gençoğlu, C., & Gümüş, H. (2020). Standing handball throwing velocity estimation with a single wrist-mounted inertial sensor. Annals of Applied Sport Science, 8. https://doi.org/10.29252/aassjournal.893

Hay, J. G. (1993). The Biomechanics of Sports Techniques (4th ed.). Englewood Cliffs, NJ: Prentice-Hall.

Hay, J. G., & Yu, B. (1995). Critical characteristics of technique in throwing the discus. J Sports Sci, 13(2), 125-140. https://doi.org/10.1080/02640419508732220

Hubbard, M., & Cheng, K. B. (2007). Optimal discus trajectories. J Biomech, 40(16), 3650-3659. https://doi.org/10.1016/j.jbiomech.2007.06.010

Jiang, X., Gholami, M., Khoshnam, M., Eng, J. J., & Menon, C. (2019). Estimation of Ankle Joint Power during Walking Using Two Inertial Sensors. Sensors, 19(12), 2796. https://doi.org/10.3390/s19122796

Karatsidis, A., Bellusci, G., Schepers, H. M., De Zee, M., Andersen, M. S., & Veltink, P. H. (2017). Estimation of Ground Reaction Forces and Moments During Gait Using Only Inertial Motion Capture. Sensors, 17(1), 75. https://doi.org/10.3390/s17010075

Kato, T., Kintaka, H., Urita, Y., & Maeda, A. (2017). Kinematic and Technical factors for acceleration of whole body in rotational shot put technique. ISBS-Conference Proceedings Archive, 35(1). Retrieved from [Accessed 2024, July 11]: https://commons.nmu.edu/isbs/vol35/iss1/149

Kato, T., Maeda, K., Mizushima, J., & Maeda, A. (2022). Investigation of a theoretical model for the rotational shot put technique. ISBS Proceedings Archive, 40(1), 327.

Kumar, M., Murali, M., & MR, D. D. (2016). Kinematic analysis of shot release of intercollegiate athletes. International Journal of Physical Education, Sports and Health, 3(5), 131-134.

Landolsi, M., Labiadh, L., Zarrouk, F., Maaref, K., Ghannouchi, S., Tabka, Z., & Lacouture, P. (2018). Kinematic analysis of the shot-put: A method of assessing the mechanical work of the hand action force. Eur J Sport Sci, 18(9), 1208-1216. https://doi.org/10.1080/17461391.2018.1478449

Lee, Y., & Yoo, H. (2017). Low-cost 3D motion capture system using passive optical markers and monocular vision. Optik, 130, 1397-1407. https://doi.org/10.1016/j.ijleo.2016.11.174

Liu, H., & Yu, B. (2021). Rotation of the thrower-discus system and performance in discus throwing. Sports Biomech, 1-16. https://doi.org/10.1080/14763141.2021.1880619

Matsuo, T., Jinji, T., Hirayama, D., Nasu, D., Ozaki, H., & Kumagawa, D. (2018). Middle finger and ball movements around ball release during baseball fastball pitching. Sports Biomechanics, 17(2), 180-191. https://doi.org/10.1080/14763141.2016.1261932

Nagahara, R., & Murata, M. (2020). Inertial Measurement Unit Based Hip Flexion Strength-Power Test for Sprinters. Front Sports Act Living, 2, 571523. https://doi.org/10.3389/fspor.2020.571523

Purcell, B., Channells, J., James, D., & Barrett, R. (2006). Use of accelerometers for detecting foot-ground contact time during running. Microelectronics, MEMS, and Nanotechnology, 6036. https://doi.org/10.1117/12.638389

Saračević, Z., Atiković, A., Štuhec, S. S., & Čuk, I. (2018). How kinematics influences shot put results in track and field of international level athletes (a case study). Journal of Physical Education & Sport. https://doi.org/10.7752/jpes.2018.s173

Schmidt, M., Rheinländer, C., Nolte, K. F., Wille, S., Wehn, N., & Jaitner, T. (2016). IMU- based Determination of Stance Duration During Sprinting. Procedia Engineering, 147, 747-752. https://doi.org/10.1016/j.proeng.2016.06.330

Shahabpoor, E., & Pavic, A. (2018). Estimation of vertical walking ground reaction force in real-life environments using single IMU sensor. Journal of Biomechanics, 79, 181-190. https://doi.org/10.1016/j.jbiomech.2018.08.015

Skejø, S. D., Bencke, J., Møller, M., & Sørensen, H. (2020). Estimating Throwing Speed in Handball Using a Wearable Device. Sensors, 20(17), 4925. https://doi.org/10.3390/s20174925

Thomas, A., Dinsdale, A., Bissas, A., & Merlino, S. (2019). Biomechanical Report for the IAAF World Indoor Championships 2018: Shot Put Men.

Van Biesen, D., McCulloch, K., & Vanlandewijck, Y. C. (2018). Comparison of shot-put release parameters and consistency in performance between elite throwers with and without intellectual impairment. International Journal of Sports Science & Coaching, 13(1), 86-94. https://doi.org/10.1177/1747954117707483 van den Tillaar, R., Bhandurge, S., & Stewart, T. (2021). Can machine learning with IMUs be used to detect different throws and estimate ball velocity in team handball? Sensors, 21(7), 2288. https://doi.org/10.3390/s21072288

Wada, T., B. Shepherd, J., D. Rowlands, D., & A. James, D. (2016). A measurement of sport wheelchair propulsion based on AHRS. The Proceedings of the Symposium on sports and human dynamics, 2016(0). https://doi.org/10.1299/jsmeshd.2016.A-16

Wada, T., Nagahara, R., Gleadhill, S., Ishizuka, T., Ohnuma, H., & Ohgi, Y. (2020). Measurement of Pelvic Orientation Angles during Sprinting Using a Single Inertial Sensor. Paper presented at the The 13th Conference of the International Sports Engineering Association. https://doi.org/10.3390/proceedings2020049010