

# A Case Study in Upper Body Kinematics of an Elite Axe Thrower Using Sensor Technology

Case Study

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## Abstract

**Introduction:** This field-based case study assessed linear accelerations of the scapula and elbow in an elite axe thrower in three different axe throwing techniques using two wearable sensors.

**Methods:** One elite axe thrower (35 years; height 181 cm; weight 92 kg) participated in this case study. One wearable sensor (an accelerometer) was located on the dorsal surface of the upper thorax between the medial borders of the scapula. An additional sensor was located on the medial epicondyle of the right elbow to capture linear acceleration magnitudes. The participant performed three different throwing techniques, namely a one hand underarm throw, a two-handed overhead throw, and a one hand overarm throw for a total of four repetitions.

**Results:** Significant differences in scapula acceleration magnitudes were detected in the three throwing techniques analyzed along with significant differences in all acceleration channels ( $p < 0.001$ ). In contrast, no significant differences in triaxial acceleration magnitude were observed in the elbow in all throwing techniques ( $p > 0.50$ ).

**Conclusions:** Magnitudes of scapular acceleration varied significantly depending on the type of throw. In contrast, acceleration magnitudes at the elbow displayed high variability despite a non-significant outcome. A wearable sensor could be a valuable tool to enhance throwing performance.

**Key Words:** Throwing. Axe Throwing. Sensors.

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## Introduction

The sport of axe throwing has gained popularity. This popularity can largely be linked to the simultaneous growth in axe throwing facilities. A report published by IBIS World shows that over the five years to 2022, operators in the axe throwing centers industry have benefited from increased consumer spending levels and time spent on leisure and sports<sup>1</sup>. Axe throwing's association with broadcaster ESPN in the United States of America has also arguably boosted the sport's popularity. Consequently, what was once considered a recreational activity is becoming a professional sport with a hierarchy of athletes from elite to amateur. Anecdotally,

the sport is said to have evolved from a lumberjack pastime activity, however, in contemporary axe throwing, players compete for points and for the opportunity to compete in worldwide events. Despite the increase in participation and distinctions between elite and amateur athletes, sparse research in axe throwing kinematics exists.

Axe throwing is defined as a striking sport in which competitors must throw an axe with accuracy and appropriate velocity to hit a circular target located on a wooden board. Akin to other throwing sports, axe throwing is a complex motor skill. In particular, the throwing motion is multifaceted as it requires flexibility, muscular strength, coordination,



synchronicity of muscular firing, and neuromuscular efficiency<sup>2</sup> which requires coordination of the whole body<sup>3</sup>. Because of the precision required for success in axe throwing combined with the high number of repetitions to achieve expertise and consistency, axe throwers could be at risk for repetitive stress injuries if incorrect or poor technique is applied. Recent studies have found that athletes who specialize in throwing typically have lower humeral torsion (retroversion) and a greater range of external shoulder rotation than non-athletes<sup>4</sup>. This can be expanded to the elbow given the repeated functional movements involved<sup>5</sup>. Notably, the thrower's shoulder must be flexible enough to allow the excessive external rotation required<sup>2</sup>. The complex interplay of the scapula combined with the articulation of the humerus and the ulna requires both strength and endurance given the repetitive nature of throwing. Therefore, understanding the biomechanics, specifically the kinematics, of different throwing techniques and styles and the diverse motion involved is critical for developing evidence-based intervention strategies.

The accuracy and the velocity of throwing techniques are often used to investigate the differences in quantitative characteristics of throwing movements<sup>2</sup>. Due to their portability, wearable technology (specifically an accelerometer) is emerging as a digital, low-cost, and accurate device that enables field-based measurements. Nevertheless, whereas accelerometers are commonly used in sport science research, they are not widely used in strength and performance<sup>6</sup>. Despite this, a sensor can be considered a valid assessment tool for shoulder and elbow kinematics<sup>7</sup>. Notwithstanding the increasing popularity of axe throwing, upper body kinematics in different throwing techniques are not well understood. This is due in part to the novelty in axe throwing. Therefore, the purpose of this field-based case study was to assess linear accelerations of the scapula and elbow in different axe throwing techniques using wearable technology. In this regard, reliability of the sensor to differentiate between throwing techniques was analyzed.

## Scientific Methods

### *Participant*

One male participant (age, 35 years; height, 181 cm; weight, 92 kg) volunteered for this study and was a registered player with the International Axe Throwing Federation (IATF). The player had been competing for two years and had recently competed internationally at an IATF sanctioned event. The participant trained twice per week for approximately three hours in total. Before data collection, the university research ethics subcommittee approved all procedures proposed in the study (H21114).

### *Protocol*

A total of three different throwing techniques were analyzed using sensor technology (Figure 1). The first throw was defined as a single hand underhand throw whereby the participant was required to throw the axe using his dominant and preferred hand (right-hand) towards the centre of the score board. The second throw was defined as a straight delivery (two hands, overhead) that required the participant to draw the axe from the mid scapulothoracic region using two hands towards the centre of the score board. The third throw was defined as a single hand (overhand) throw that required the participant to throw the axe using his dominant and preferred hand towards the centre of the score board (Table 1, Figure 1). A period of 10 seconds was permitted between throws to enable the participant to retrieve the axe from the board, walk to the throwing line and then resume throwing.

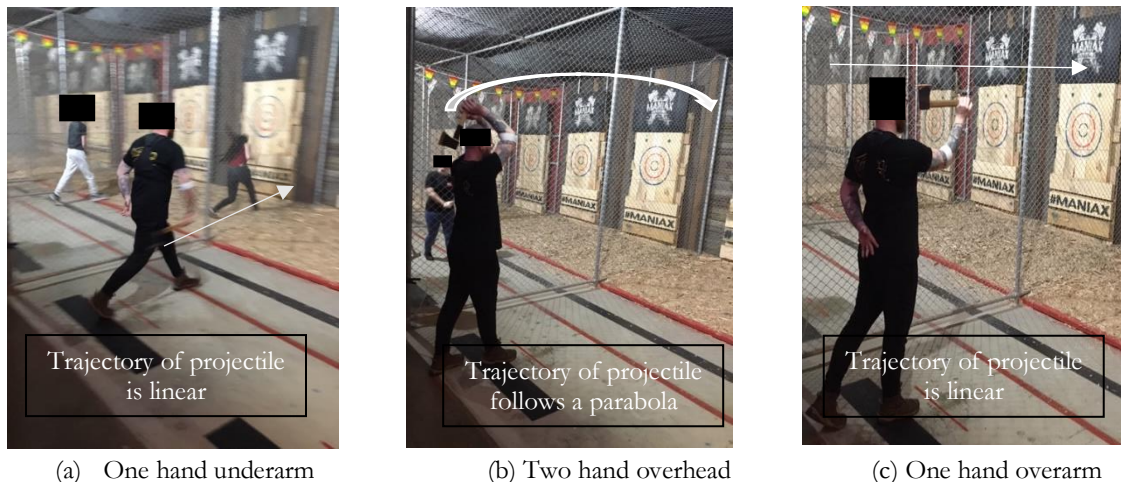
**Table 1.** Definition of axe throwing protocol used.

Throw type	Description
<b>1. Single hand underhand</b>	The thrower faces the target. The axe is drawn from a position of slight elbow extension before flexion of the upper limb.
<b>2. Two hands, overhead</b>	The thrower faces the target. The axe is drawn from the scapulothoracic region and thrown straight, with a slight forward lean of the torso.
<b>3. One hand overarm</b>	The thrower faces the target. The axe is drawn from a position of elbow flexion before extension of the upper limb.

The case-study was conducted in an axe throwing venue that was frequented by the participant. The participant completed a pre-exercise screening questionnaire and signed an informed consent declaration. Prior to the start of the study, the participant completed approximately five warmup throws that consisted of throwing the axe at the wooden

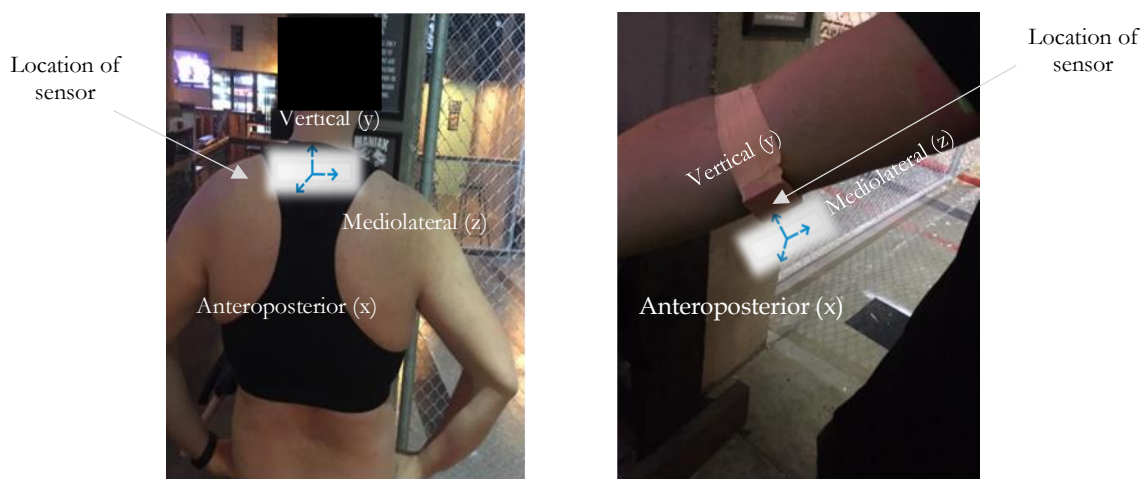
board in a self-selected throwing technique. Once the warmup was completed, two wearable sensors (referred to as a sensor from herein) was manually fitted to the participant.

**Figure 1.** Three different throwing techniques used by one participant.



To assess the impact of the scapular in the three different throwing techniques, one sensor was secured into a protective garment (vest) that was worn by the participant. The sensor sat in the dorsal surface between the right and left sides of the medial border of the mid scapula at the back of the trunk to reside over the posterior surface of the thoracic vertebrae with the y axis in alignment with the cervical vertebra. To assess the impact of the elbow, the second sensor was manually secured to the participant's medial epicondyle with the y axis in alignment with the lateral epicondyle of the humerus. The sensor was attached using double-sided adhesive tape to ensure fixation and to reduce unwanted movements.

**Figure 2.** Location of sensor on participant.



Measurements were made on the elbow joint as it allows good validity and intertester reproducibility<sup>6</sup>. Linear scapular and elbow accelerations along three orthogonal axes was measured in the vertical (y, upward-downward), anteroposterior (x, forward-backward) and mediolateral (z, side to side) and were collected during arm elevation and lowering in all throwing techniques. The sensors were manually fitted to the participant prior to testing with the participant asked to perform shoulder retraction and protraction along with elevation and depression and flexion and

extension of the elbow to assess for comfort and maneuverability. Once the protocol was explained, the participant was asked to perform four repetitions for each throwing technique (see Table 1) All throws were performed from a static and standing stance whereby lunging or similar movements were not permitted. Specifically, the throwing stance and the blade of the axe was positioned away from the body. The player's feet were located on the black throwing line (Figure 1). The participant was instructed to throw the axe after an acoustic countdown by the principal author (i.e., "3, 2, 1, go").

Advances in accelerometers offer real-time detection of motion<sup>8</sup>. Therefore, activity was measured using the ActiGraph GT9X + accelerometer (ActiGraph, LLC, Pensacola, FL, USA). This device (3.5 x 3.5 x 1 cm, 14 grams) measures linear acceleration during movement. Prior to testing, the sensors were initialized to record accelerations at a sampling frequency of 100 Hz. The raw accelerometry signals were converted from gt3x files to CSV format and saved and exported to Microsoft Excel (Microsoft Corporation Redmond, Washington DC, USA version 4.90.4, build 6470.27615). Raw data was analyzed using the ActiLife software program (Version 6.13.4, ActiGraph, LLC). The ActiGraph sensor provides data in the form of 'counts'—an aggregate measure of the intensity and magnitude of accelerations over a given time period. In this instance, counts were a result of summing post-filtered accelerometer values (raw data at 100 Hz) into epoch "chunks." In this regard the value of counts will vary based on the frequency and intensity of the raw acceleration. The filtering process by which counts are produced is proprietary to ActiGraph.

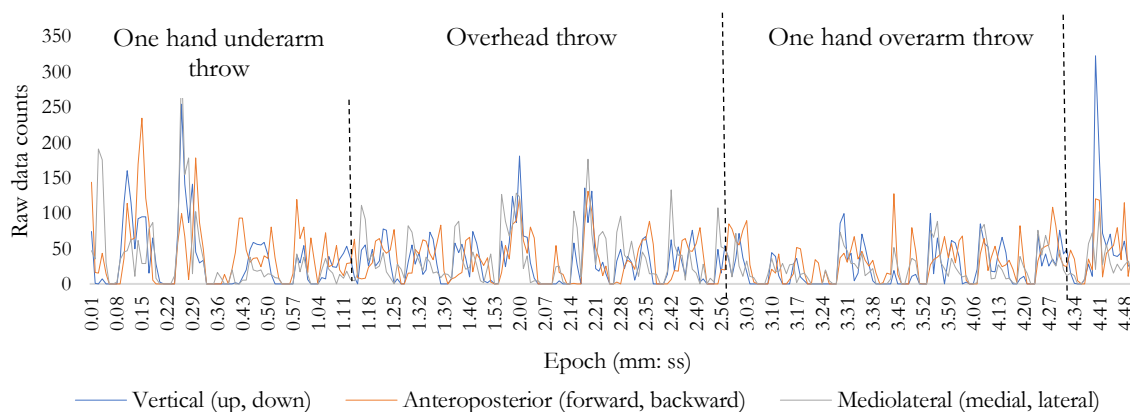
### Statistical Analysis

The normality of appropriate data sets was established by the Shapiro–Wilk test using the Analyse-it statistical software package (Leeds, United Kingdom, version 4.92). As the normality of data was not evenly distributed, non-parametric tests were used. The coefficient of variation (CV), that is – the ratio of the standard deviation to the mean acceleration magnitude in each throw and individual axis, was used to show the extent of variability at the scapula and elbow. The interquartile range (IQR) was used to assess the median spread of the acceleration data. Threshold values as an effect size ( $d$ ) were used and classified as 0.1–0.3 (small), >0.3–0.5 (moderate), >0.5–0.7 (large), >0.7–0.9 (very large) and >0.9 (extremely large)<sup>9</sup>.  $p \leq 0.05$  was considered statistically significant.

### Results

Table 2 presents the results from the magnitude of scapula acceleration expressed as counts. Significant differences were detected in all acceleration channels in all throwing techniques. However, higher dispersions of acceleration magnitude were seen in the anteroposterior channel.

**Figure 3.** Raw data based on triaxial acceleration magnitudes of the scapula in three throwing techniques.



Despite high variability between throwing techniques, non-significant results were seen in the magnitude of elbow acceleration (Table 3). While the two-handed overhead throw caused the largest accelerations, this also resulted in the highest variable distribution of acceleration. In contrast, the results from the one hand underarm throw were overall lower in magnitude compared to the two other techniques. In terms of the magnitude of acceleration in the elbow, the largest spike in acceleration magnitude was observed in the throws 1 and 2 in the overhead throw (Figure 4).

**Table 2.** Mean  $\pm$  SD of acceleration magnitudes of the scapula in three different throwing techniques. Where CV is the coefficient of variation and IQR is the interquartile range. Where  $p$  is significant at  $\leq 0.05^*$ .

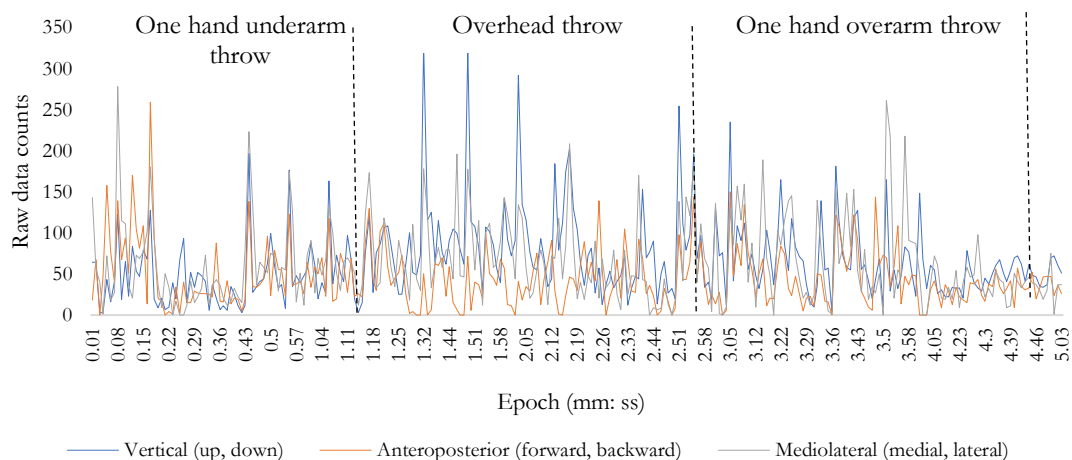
	Vertical (x)					Mediolateral (z)					Anteroposterior (y)				
	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$
1. One hand underarm	19.7 $\pm 12.1$	61.1	18.1			35.4 $\pm 12.7$	35.8	16.1			77.3 $\pm 39.4$	48.5	52.4		
2. Two hands, overhead	40.8 $\pm 7.0$	17.2	9.1			40.5 $\pm 10.7$	26.5	13.3			79.1 $\pm 10.5$	12.8	15.1		
3. One hand overarm	36.8 $\pm 11.3$	30.8	11.0			43.5 $\pm 13.0$	29.9	16.2			68.8 $\pm 18.3$	26.6	10.0		
				> 1 (extremely large)	<0.0001*				> 1 (extremely large)	0.0068*				> 1 (extremely large)	0.0097*

Reflecting on the lower vertical acceleration in the underarm throw, a corresponding higher acceleration magnitude was seen in the anteroposterior direction (Figure 3). In contrast, the two-handed overhead throw resulted in higher magnitudes of scapular acceleration in all channels.

**Table 3.** Mean  $\pm$  SD of acceleration magnitudes of the scapula in three different throwing techniques. Where CV is the coefficient of variation and IQR is the interquartile range. Where  $p$  is significant at  $\leq 0.05^*$ .

	Vertical (x)					Mediolateral (z)					Anteroposterior (y)				
	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$	Mean Count	CV (%)	IQR	$d$ (effect size)	$p$
1. One hand underarm	64.6 $\pm 35.4$	54.8	42.1			52.9 $\pm 42.4$	80.1	51.2			67.5 $\pm 43.2$	63.9	59.6		
2. Two hands, overhead	79.6 $\pm 65.1$	74.3	65.4			72.5 $\pm 65.4$	86.5	54.6			69.0 $\pm 62.2$	77.7	96.3		
3. One hand overarm	73.1 $\pm 46.7$	63.9	54.9			76.2 $\pm 45.0$	55.4	36.6			69.8 $\pm 38.5$	55.2	66.3		
				<1 (small)	0.767				<1 (small)	0.068				<1 (small)	0.971

**Figure 4.** Raw data based on triaxial acceleration magnitudes of the elbow in three throwing techniques.



### Discussion

The aim of this field-based case study was to assess the magnitude of linear accelerations in the scapula and elbow in a competitive axe thrower using sensor technology. Regarding scapular kinematics, the results show that the two handed, overhead throwing technique resulted in the highest accelerations in the anteroposterior axis (Table 2, Figure 3). This finding is consistent with increased scapular movement given the augmented acceleration and motion in all axes compared to the underarm and overarm throw. However, that vertical acceleration was higher in the overhead throw is not necessarily surprising as the gyration of the participant’s body segments along the kinetic chain when performing the throw would likely result in greater overall acceleration. Interestingly, the one-handed overarm throw caused larger mediolateral motion compared to the other techniques. This suggests a greater proportion of torso body sway, although a possible explanation for this result could be due to the velocity imparted to the axe by the participant. Velocity feedback can play a significant role in anticipating body position change because it carries information about the subsequent state of the body, i.e., a change in the centre of mass (CoM) acceleration<sup>10</sup>. Consequently, at the instantaneous time that the participant released the axe, the CoM was displaced to a greater magnitude, specifically to the right of the participant’s body. The consequence is asymmetry of the CoM, resulting in lateral sway. However, it is unknown how the CoM influences overall mediators of throwing performance and future studies to analyze segmental movement are needed.

As for elbow kinematics, no significant differences were observed in acceleration magnitude in all throwing techniques. This was despite larger magnitudes of acceleration and a greater scattering of vertical, mediolateral and anteroposterior observed in the overhead throw (Table 3, Figure 4). The disparities that were detected between the throwing techniques and overall variability in elbow acceleration is likely due to asymmetry and radial-ulnar deviation. Combined with initial velocity, the resultant acceleration magnitude would vary based on limb position and the weight of the axe. However, as this case study featured an elite axe thrower, movement may be driven by the centralized and major torso muscular to obtain consistent distal kinematics. How such motion would vary in an amateur thrower represents an area for future research. While prior studies have analyzed the inertial sensing systems of the elbow, such studies have been conducted under laboratory conditions<sup>11,12</sup>. This case-study, however, highlights the reliability and practicality of using sensor technology to monitor throwing kinematics in a typical competitive setting.

To the authors’ knowledge, the current study is the first study to investigate the effect of scapular and elbow acceleration magnitudes in an axe thrower, thus evaluating the reliability of sensor technology. Although prior shoulder kinematic description includes mobility, velocity, and acceleration<sup>10</sup>, the majority of prior research has studied shoulder joint angles<sup>7</sup>. Beyond studies assessing scapular mobility, there is no clear relationship between liner accelerations of the scapular and throwing actions in axe throwing. Consequently, the results of this study could provide a theoretical basis for the application of sensor usage in axe throwing performance monitoring.



Despite this, the results from this case study are limited by the single participant and practice situation in which the testing was performed. In this well-defined field-based environment, there were no typical game situations, such as action of opponents, tactical guidance, temporal and spatial pressure situations, or psychological pressure due to competition. Therefore, it is possible that the throwing techniques observed may be different in competitive situation. It remains to be shown, how far magnitudes of acceleration of the scapular and elbow can be transferred to competitive situation. Nevertheless, the outcomes of this study could be used to form part of an ongoing training intervention.

This case study used wearable sensors to infer linear acceleration magnitudes in an axe thrower in a characteristic training setting. While the sensors used are non-invasive and are accurate tools to analyze motion<sup>13</sup>, a limitation is that placing sensors over the skin can create soft tissue artefacts<sup>11</sup>. Though, the use of sensors represents opportunity to obtain field-based data for better practical application. This would improve continuous monitoring of throwing performance.

### Conclusions

The magnitude of scapular acceleration was observed to be significantly different amongst three different axe throwing techniques. Furthermore, such linear acceleration differences were seen in all acceleration channels. In contrast, acceleration magnitudes at the elbow displayed high variability despite a non-significant outcome. Collectively, this case study suggests that using a wearable sensor is a reliable method to detect linear accelerations in different axe throwing techniques which could be used to enhance performance. Future investigations are needed to determine the model acceleration magnitudes to allow for maximum effectiveness.

### Acknowledgements

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### References

1. IBIS World. Accessed 25 January 2023. <https://www.ibisworld.com/united-states/market-research-reports/axe-throwing-centers-industry>
2. Wilk K, Meister K, Fleisig G, James A. Biomechanics of the overhead throwing motion. *Sports Med Arth Rev* 2000;8(7):124-134.
3. Gromeier M, Koester D, Schack T. Gender differences in motor skills of the overarm throw. *Front Psychol* 2017;8:212. doi: 10.3389/fpsyg.2017.00212.
4. Roach NT, Lieberman DE, Gill TJ, Palmer WE, Gill TJ. The effect of humeral torsion on rotational range of motion in the shoulder and throwing performance. *J Anat.* 2012;220(3):293-301.
5. Costa V, Ramírez Ó, Otero A, Muñoz-García D, Uribarri S, Raya R. Validity and reliability of inertial sensors for elbow and wrist range of motion assessment. *Peer J* 2020;8:e9687.
6. Gogia PP, Braatz JH, Rose SJ, Norton BJ. Reliability and validity of goniometric measurements at the knee. *Phys Ther* 1987;67(2):192-195.
7. De Baets L, van der Straaten R, Matheve T, Timmermans A. Shoulder assessment according to the international classification of functioning by means of inertial sensor technologies: a systematic review. *Gait Posture* 2017; 57:278-294.
8. Evans S, James D, Rowlands D, Lee J. Using wearable technology to detect changes to trunk position and power in cycling. *Sports Biomech* 2020 38(1).
9. Hopkins W, Marshall S, Batterham A, Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41:3-13.
10. Masani K, Milos R, Popovic K, Nakazawa MK, Nozaki D. Importance of body sway velocity information in controlling ankle extensor activities during quiet stance. *J Neurophysiol* 2003;90(6):3774-82.
11. Shumway-Cook A, Woollacott M. Motor control: translating research into clinical practice; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2007.
12. Robert-Lachaine X, Mecheri H, Larue C, Plamondon A. Validation of inertial measurement units with an optoelectronic system for whole-body motion analysis. *Med Biol Eng Comput* 2017;55(4):609-619. doi: 10.1007/s11517-016-1537-2.
13. Cuesta-Vargas AI, Galán-Mercant A, Williams JM. The use of inertial sensors system for human motion analysis. *Phys Ther Rev* 2010;15:462-473.