APPLICABILITY OF A FULL BODY INERTIAL MEASUREMENT SYSTEM FOR KINEMATIC ANALYSIS OF THE DISCUS THROW

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The aim of the study was the application of a full body inertial measurement system (IMS) for a kinematic analysis of the discus throw and the evaluation of its applicability. For this purpose, one male sports student performed three discus throws equipped with the IMS. All trials were additionally filmed by high-speed video. The results indicate that performance-relevant information can be obtained regarding the temporal coordination of the body segments and body joint angles. Limitations exist for the accurate detection of the last foot contact related instant and the discus release instant by solely using the IMS data.

KEY WORDS: motion analysis, inertial sensors, discus throw.

INTRODUCTION: The discus throw can be divided into two stages, the launch and the flight (Hubbard, 1989). The launch phase consists of the thrower's movements in the circle, aiming at optimizing the release of the discus in order to maximize the throwing distance. The most relevant discus release parameters are the release speed, the release height and the release angle (Bartlett, 1992). To achieve maximum release speed through complex rotational movements, optimizing technique is vital in discus throwing (Leigh & Yu, 2007). Therefore, biomechanical movement analyses are performed to evaluate techniques of elite athletes on the basis of video information (Dickwach & Knoll, 2003; Hildebrand & Perlt, 2007; Leigh & Yu, 2007). Problems arising from the extraction of three-dimensional (3D) kinematic information on the basis of two-dimensional (2D) video data can be associated with accuracy of position data (in particular for rotational movements), temporal resolution (in general 50 or 60 Hz) and the time needed for subsequent analysis. Therefore, alternative methods overcoming these problems should be taken into consideration.

Advances and miniaturization in sensor technology enabled ambulatory motion analysis with the use of inertial sensors (e.g. Bonato, 2003). By combining inertial sensors (accelerometers and gyroscopes) and magnetometers, fixed to body segments, drift free orientation of the segment can be estimated. With the integrated use of a biomechanical model and sensor fusion algorithms, full 3D kinematics of the body segments can be obtained (Roetenberg et al., 2009). A full body inertial measurement system (IMS), therefore, implies potential for the analysis of complex movements in a real sports environment. Recent applications included motion analysis in alpine skiing (Brodie et al., 2008) and freestyle snowboarding (Krüger & Edelmann-Nusser, 2009). Krüger & Edelmann-Nusser (2010) also reported good agreement between IMS and a video based system for analyzed knee angles in alpine skiing.

The purpose of this pilot study was the application of an IMS for a kinematic analysis of the discus throw (characterized as a complex rotational movement) and the evaluation of its applicability in terms of: 1. What kinematic data relevant to performance can be obtained? 2. How reliable is the detection of the critical instants of the discus throw (to subdivide the movement into phases) by solely using the IMS data?

METHOD: One male sports student (22 yrs, 1.88 m, 84 kg, former decathlete, 15 years athletics training experience, personal best discus performance: 48 m) performed three discus throws (indoors; 1 kg discus). The throws were simultaneously recorded using an IMS and high-speed video (HS). The IMS (MVN; Xsens Technologies, Netherlands) consists of a suit equipped with 17 inertial sensor units (MTx) and two transmission units. Each unit integrates 3D linear accelerometers, 3D rate gyroscopes and 3D magnetometers. The full scale range of all inertial sensors is 1200 deg/s (gyroscopes) and 50 m/s^2 (accelerometers), except for two sensors located at the lower arm and hand segment of the throwing arm with a measurement range of 100 m/s^2. IMS data acquisition was performed with the MVN Studio software (v2.6). As the input for the biomechanical model (23 segments, 22 joints) subjects' anthropometric data (9 parameters) were used. Prior to the discus throws the subject needed to perform four standard poses for the calibration of the IMS. All IMS data of the discus throws were then sampled at a rate of 120 Hz. The HS videos were recorded at a frame rate of 300 Hz (Exilim EX-F1, Casio; 512 x 384 pixels) from lateral perspective. Systems were time synchronized by detecting the instant of landing after a vertical jump in both the sensor and video data. 3D Segment orientations, angular velocities and accelerations as well as joint positions, velocities and accelerations were calculated in MVN Studio and exported for further processing using MATLAB (The Mathworks). Additional kinematic parameters that have been identified to be performance-relevant (Dickwach & Knoll, 2003; Leigh & Yu, 2007) were then computed and are presented in Table 1.

Table 1. Computed kinematic parameters

Parameter	Description	Unit
v_hip/ v_shoulder/ v_elbow/ v_hand	Resulting velocities/ accelerations for the hip/ shoulder/ elbow and wrist joint of the throwing arm	m/s
a_hip/ a_shoulder/ a_elbow/ a_hand		m/s^2
s_hand	Path of the wrist joint of the throwing arm	m
hip-shoulder	Separation angle of the hip and shoulder line	°
trunk tilt	Tilt angle of the trunk expressed as forward and backward tilt	°
knee left/ knee right	Angles of the knee joint with respect to the mediolateral axis	°

From the HS video data, the six critical instants (T1-T6) of the discus throwing movement were detected (see Figure 1), which lead to five phases: preparation, entry, airborne, transition, and delivery (Bartlett, 1992). The detection of the same instants by solely using the IMS data was done using the time course of the resulting velocity of the joint origin of the segment right hand for T1 (local minimum) and T6 (global maximum) and the ground contacts of the respective foot identified in the MVN Studio software (T2-T5).

Figure 1. Subject performing a discus throw wearing the IMS. Phases of the throw were subdivided according to six critical instants (from left to right): T1: maximum backswing; T2: right foot off; T3: left foot off; T4: right foot down; T5: left foot down; T6: release (Bartlett, 1992)

RESULTS: The velocity profiles of the throwing arm joints are presented in Figure 2. The results illustrate the temporal deviation of the velocity peaks within the last phase of the movement in order to accelerate the discus. Figure 3 shows the time course of relevant body angles, from which the particular values at critical instants can be extracted (e.g. hip-shoulder separation at release).

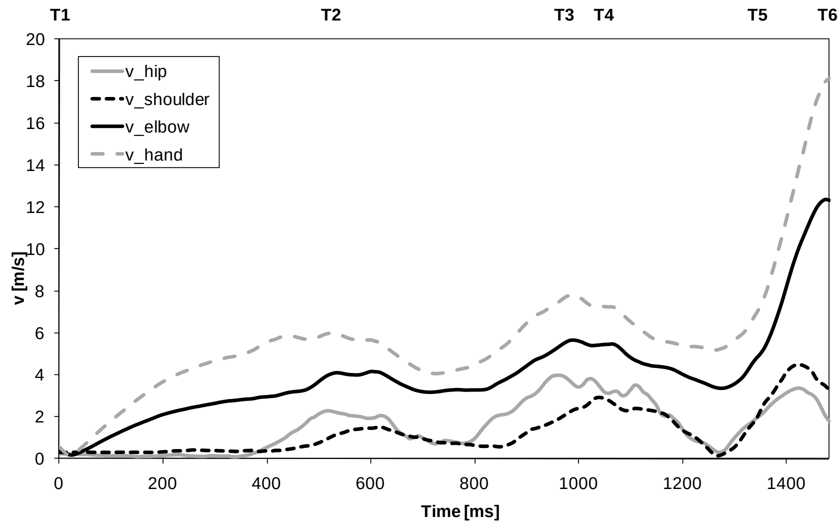

Figure 2. Resulting velocity of the respective joints of the throwing arm for one discus throw. T1 – T6 indicate instants of the movement phases.

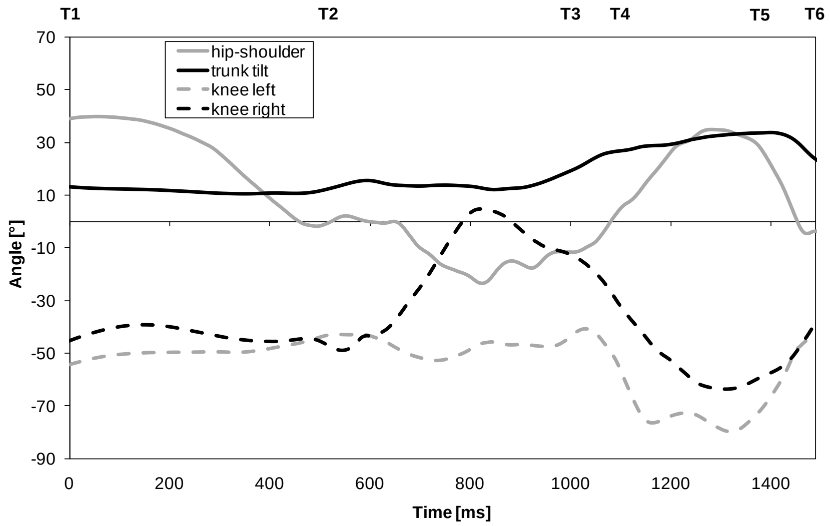

Figure 3. Angles of the left and right knee joint (<0°: flexion), hip-shoulder separation (>0°: line of the hips leading the line of the shoulders) and trunk tilt (>0°: forward tilt) for one discus throw. T1 – T6 indicate instants of the movement phases.

With respect to the subdivision of the movement phases of the discus throws Table 2 shows the phase durations observed and the differences when detecting the critical instants by solely using the IMS data.

Table 2. Phase durations determined from the HS videos (T1-T2: preparation; T2-T3: entry; T3-T4: airborne; T4-T5: transition; T5-T6: delivery) and time differences for each instant as detected by solely using the IMS data (n = 3 discus throws)

Instant	T1	T2	T3	T4	T5	T6
Phase duration (HS) [ms]	0	520-560	450-490	70-100	250-300	120-180
Diff. (IMS - HS) [ms]	42-75	0-8	0-2	8-50	167-308	17-25

DISCUSSION: Quantitative comparison of the obtained velocity profiles is limited, since no high-level athlete was investigated in this study and published values focus on discus release velocities (e.g. 23-25 m/s; Bartlett, 1992; Dickwach & Knoll, 2003). Moreover, they cannot be directly compared to the velocities at the wrist joint in this study (16-18 m/s). The profiles of specific performance-relevant body angles provide additional information on individual throwing technique. Leigh & Yu (2007) associated hip-shoulder separation angles at left foot off (25 to 50°), at left foot down (45 to 60°) and at the release (-10 to 0°) as well as the trunk tilt at right foot off (10 to 20°) and at the release (-10 to 0°) with throwing performance of female and male elite athletes. Dickwach & Knoll (2003) emphasized the relevance of the time courses of the knee angles that showed motion ranges of 25° (right knee) and 50° (left knee) for two elite athletes. Besides the reported parameters in the literature, a number of additional kinematic parameters can be easily extracted from the IMS data and should be analyzed for their particular performance-relevance. For the detection of the critical instants of the movement, sufficient accuracy can be achieved for the first three foot contact related instants, but not for the last one and also not for the instant of the discus release. Therefore, and since the relevant release parameters of the discus cannot be directly assessed by the IMS, additional video information would be necessary. Opposite to the advantages of the IMS for motion analysis in terms of an unrestricted capture volume and short-time data acquisition and analysis, possible drawbacks of the system, like an interference with the normal movement when wearing the IMS was not judged critical by the investigated subject.

CONCLUSION: This pilot study used a full body inertial measurement system for the kinematic analysis of the discus throw and emphasizes the potential of this approach for analysis of complex movements in sports. Like the discus throw, valuable application of the system is also expected for the rotational movements performed in shot put or hammer throw. Future studies need to evaluate the accuracy of the system for the assessment of kinematic data in particular in high-level athletes and should evaluate a possible interference with the movement.

REFERENCES:

Bartlett, R. M. (1992). The biomechanics of the discus throw: A review. *Journal of Sports Science*, 10(5), 467-510.

Bonato, P. (2003). Wearable sensors/systems and their impact on biomedical engineering. *IEEE Engineering in Medicine and Biology Magazine*, 22(3), 18-20.

Brodie, M., Walmsley, A. & Page, W. (2008). Fusion motion capture: a prototype system using inertial measurement units and GPS for the biomechanical analysis of ski racing. *Sports Technology*, 1(1), 17-28.

Dickwach, H. & Knoll, K. (2003). Zur Technik des Diskuswerfens auf der Grundlage von 3-D-Videobild- und –Bodenreaktionskraftmessungen. *Z. Angew. Trainingswissenschaft*, 10(2), 95-103.

Hildebrand, F. & Perlt, B. (2007). Moderne Techniken des Diskuswerfens. *Z. Angew. Trainingswissenschaft*, 14(2), 39-65.

Hubbard, M. (1989). The throwing events in track and field. In C.L. Vaughan (Ed.), *Biomechanics of Sport* (pp. 213–238). Boca Raton, FL: CRC Press.

Krüger, A. & Edelmann-Nusser, J. (2009). Biomechanical analysis in freestyle snowboarding: application of a full-body inertial measurement system and a bilateral insole measurement system. *Sports Technology*, 2(1-2), 17-23.

Krüger, A. & Edelmann-Nusser, J. (2010). Application of a Full Body Inertial Measurement System in Alpine Skiing - A Comparison to an Optical Camera Based System. Accepted for publication in the Journal of Applied Biomechanics.

Leigh, S. & Yu, B. (2007). The association of selected technical parameters with discus throwing performance: A cross-sectional study. *Sports Biomechanics*, 6(3), 296-284.

Roetenberg, D., Luinge, H. & Slycke, P. (2009). Xsens MVN: Full 6DOF human motion tracking using miniature inertial sensors. *Whitepaper*. Enschede: Xsens Technologies B.V.

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