MISSIE - A NEW METHOD TO ANALYSE PERFORMANCE PARAMETERS OF FIGURE SKATING JUMPS

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Competitive figure skaters have to perform triple and quadruple jumps with a high grade of execution. Monitoring flight time and rotational velocity, as the most critical parameters in successful figure skating jumps, objectifies and enhances feedback quality and quantity in the technique training process. 11 figure skaters performed 412 jumps on ice. All jumps were sampled with an inertial measurement system (MISSIE) and filmed with high speed video. With respect to time values of figure skating jump events toe pick, release of glide leg, take off and landing inertial data were manually and software algorithm analysed, and video data were manually analysed. Bland-Altman-Plots document very good performance of MISSIE concerning raw data and analysis by software algorithm. MISSIE can be used for figure skating jump analysis and feedback, being superior to traditional video analysis.

KEY WORDS: figure skating, jump, motion analysis, inertial sensors, performance analysis

INTRODUCTION: In the men's single skating the ability to perform triple axel and quadruple rotated jumps became basic requirements for competitive skaters. At ISU World Figure Skating Championships 2016 the best six skaters in the short program and free skating performed 33 triple axel or quad jumps in total, representing the most difficult jumping elements with the highest base values, as a single jump or in a combo. This number raised continuously from 21 in 2010 to 28, 30, 31, 33 in the following years with 31 in 2015. The total score in the short program and free skating in single figure skating is highly dependent on performance, and accordingly element scores, of the jumping elements in both men and women.

Performance analysis is the foundation of an ideal regulation of the training process. Figure skating jumps are traditionally analysed by video based motion capturing methods (Albert & Miller, 1996; Johnson & King, 2001; King, Arnold, & Smith, 1994; King, Smith, Higginson, Muncasy, & Scheirman, 2004; King, 2002; Lockwood, Gervais, & Mccreary, 2006). Flight time and rotational velocity are the most critical parameters for successful figure skating jumps (Albert & Miller, 1996; King, 2005). Video based motion capture methods are inappropriate for routine performance analysis by demanding time, effort, costs and are high in complexity. Within motor learning, performance parameters can be used as knowledge of result to enhance feedback and thereby increasing learning speed of the athlete (Schmidt, 1988). For beneficial effects of feedback in motor learning or technique training, time between execution of the motor task and given feedback should be limited to 5-10s (Daugs, 2000; Rockmann-Rüger, 1985). Video based motion capturing methods are unable to provide performance data within seconds. Common inertial sensor based motion capturing systems do not cover rotational velocity of elite figure skates of >2000°/s.

Therefore, an inertial sensor based system (MISSIE) was developed in our workgroup. The system determines biomechanical relevant events of the jump: toe pick (E_1), release of glide leg (E_2), take off (E_3) and landing (E_4) as the key events of figure skating jumps. By the time values of the events E_1 - E_4 flight and contact times can by calculated. It further measures rotational velocity during flight and provides the performance data within small time interval by automatic data analysis with specific software algorithms. The aim of this work is to validate the developed inertial sensor system MISSIE with an available criterion measure – video based motion capturing and frame to frame analysis.

METHODS: A total of 412 single, double and triple jumps performed by 11 elite and sub-elite skaters with a balanced distribution to the six jump elements of figure skating (Toeloop (T): 95, Salchow (S): 65, Loop (Lo): 57, Flip (F): 63, Lutz (Lz): 44, Axel (A): 88) were successfully sampled by MISSIE. S, Lo and A are edge jumps (N=210) and hold E_3 and E_4, T, F, Lz (N=202) are toe pick jumps and hold E_1-E_4. MISSIE contains one 1D-accelerometer (ACC) per skate (861Hz, ±70g) with the sensitive axis aligned with the leg axis, a 3D-gyroskop

(GYR) (109Hz, ±4000°/s) fixed to a neoprene belt at the posterior side of the pelvis near to L4 and L5 and a 3D-gyroskop (109Hz, ±4000°/s) adhered to the skin above Th1 between scapulae. Total weight of MISSIE including neoprene belt and wires was 500-540gr depending on the size of the belt. Simultaneously all jumps were sampled with a high speed video camera (Casio EXILIM EX-F1, 300Hz, 512x384px).

Video data were analysed by frame to frame analysis. Therefore relevant frames corresponding to E_3 und E_4 in all jumps and additionally E_1 and E_2 in toe pick jumps (T, F, Lz) were manually identified. Definitions of the relevant pictures for video analysis are described in Table 1. Real camera sampling rate was determined at 299.7Hz in previous work (unpublished data). Event time values $E_{V.1}$-$E_{V.4}$ were calculated from frame number and video sampling rate.

Table 1
Definitions of relevant pictures (frames) for video analysis

event	description of relevant picture
E_1	first picture with ice contact of the blade at toe pick
E_2	first picture without ice contact of the blade of the glide leg after toe pick by take off leg
E_3	first picture without ice contact of the blade at take off
E_4	first picture with ice contact of the blade at landing

ACC data were in first step analysed manually by an experienced observer. The observer used information about the frequency characteristics of ACC data (blade with ice contact: high amount of high frequent signal content, blade without ice contact: low amount of high frequent signal content), ACC gradient due to foot, leg and body whole movement at E_1-E_4 and the location of the maximum in GYR data to set markers for event time values $E_{M.1}$-$E_{M.4}$ in ACC and GYR data. In a second step software algorithms to determine event time values $E_{K.1}$-$E_{K.4}$ were developed in MATLAB®. Software algorithm used sliding windows to verify ACC gradient characteristics as used for manual analysis.

ACC data and video data were synchronized by E_4, respectively $E_{V.4}$, $E_{M.4}$ and $E_{K.4}$ because determination of E_4 was most clear. Data were tested for agreement using Bland-Altman-Plots (BA-Plot) comparing $E_{V.1\text{-}4}$ - $E_{M.1\text{-}4}$. Performance of final software algorithm was quantified by BA-Plots comparing $E_{M.1\text{-}4}$ – $E_{K.1\text{-}4.}$ BA-Plot (Bland & Altman, 1999) quantify the agreement of two measurement methods using the differences between observations made using the two methods on the same subjects. The 95% limits of agreement (uLoA, lLoA), estimated by mean difference ±1.96 standard deviation of the differences, provide an interval within which 95% of differences between measurements by the two methods are expected to lie. The mean difference represents the bias of the two methods.

RESULTS: All data combinations analysed in BA-Plots showed normal distribution. Table 2 shows the results of BA-Plot for the analysed data of time values $E_{V.1\text{-}4}$, $E_{M.1\text{-}4}$ and $E_{K.1\text{-}4}$. All results for E_2 include just the data of the jumps F and Lz, analysis of T jumps is still in progress. Number of successfully analysed data N_A specifies the quantity of analysable data with respect to data quality. BA-Plot $E_{V.1\text{-}4}$ - $E_{M.1\text{-}4}$ quantifies the agreement of time values measured by video and by ACC data. BA-Plot $E_{M.1\text{-}4}$ – $E_{K.1\text{-}4}$ (Figure 1 to Figure 4), quantifies the agreement of the software algorithm with manual set markers. This can also be considered as the algorithms performance.

Mean calculation time of the software algorithm was 0.15s per jump. Number of successfully analysed data (N_A) in $E_{V.1\text{-}4}$ - $E_{M.1\text{-}4}$ is reasonable in video data, since N_A in $E_{M.1\text{-}4}$ – $E_{K.1\text{-}4}$ is 100%. Problems in video quality and frame content were: masking of the examined skate behind the other skate, examined skate partly or completely out of the capturing window or poor sharpness by auto focus problems.

Table 2
Results of Bland-Altman-Plots with mean difference (mean), lower Limit of Agreement (lLoA), upper Limit of Agreement (uLoA), sample size(N) and Number of successfully analysed data (N_A)

Bland-Altman-Plot	mean [ms]	lLoA [ms]	uLoA [ms]	N	N_A	[%]
$E_{V.1} - E_{M.1}$	0.0	-4.3	4.3	202	174	86
$E_{V.2} - E_{M.2}$	-3.7	-9.1	1.8	107	53	50
$E_{V.3} - E_{M.3}$	1.4	-5.5	8.3	412	206	50
$E_{V.4} - E_{M.4}$	0.0	0.0	0.0	412	402	98
$E_{M.1} - E_{K.1}$	0.0	-0.5	0.5	202	202	100
$E_{M.2} - E_{K.2}$	0.1	-1.0	1.3	107	107	100
$E_{M.3} - E_{K.3}$	0.1	-1.7	1.9	412	412	100
$E_{M.4} - E_{K.4}$	0.0	-0.4	0.4	412	412	100

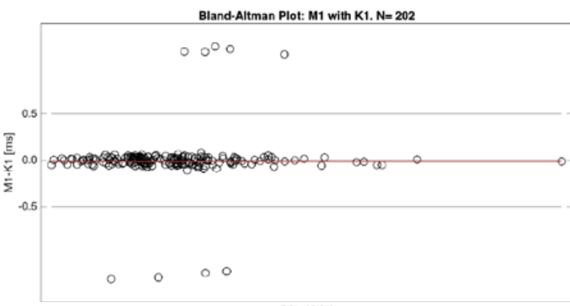

Figure 1: Bland-Altman-Plot $E_{M.1} - E_{K.1}$, E_1: toe pick

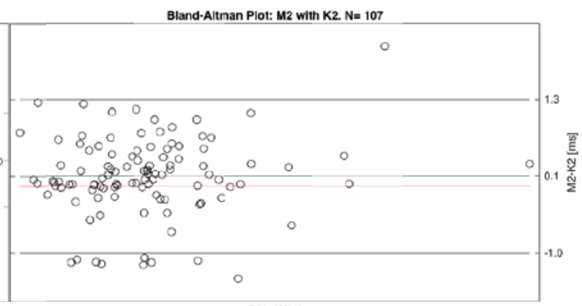

Figure 2: Bland-Altman-Plot $E_{M.2} - E_{K.2}$, E_2: release glide leg

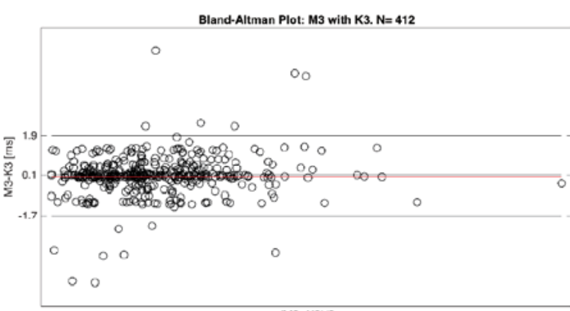

Figure 3: Bland-Altman-Plot $E_{M.3} - E_{K.3}$, E_3: take off

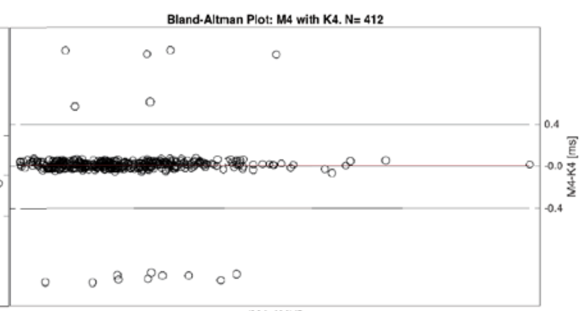

Figure 4: Bland-Altman-Plot $E_{M.4} - E_{K.4}$, E_4: landing

DISCUSSION: E_4 was used for synchronizing video data and ACC data, therefore $E_{V.4}$ - $E_{M.4}$ (Table 2) shows perfect agreement. $E_{V.1}$ - $E_{M.1}$ shows very good agreement, with mean = 0.0ms additionally confirms synchronous capturing of video and ACC data, lLoA = -4.3ms and uLoA = 4.3ms appears logical if taking the frame distance in a 299.7Hz video d_F = 3.3ms into account. The intrinsic error of time measuring by video ER_V = ±1.7ms (half frame distance) and the fact of very little visual frame to frame differences in high speed video and therefore potential of misidentification of the relevant frame are a limitation of the video capturing method. Identification of relevant frames for E_2 and E_3 was even more difficult, since it was hard to see when the blade exactly left the ice, particularly for E_2. This explains poor agreement for $E_{V.2}$ - $E_{M.2}$ and good agreement for $E_{V.3}$ - $E_{M.3}$.

The performance of the software algorithm was very good for all events as shown in Table 2, with the mean ≤ 0.1ms and LoA ≤ 2ms for $E_{M.1\text{-}4} - E_{K.1\text{-}4}$. For $E_{M.3} - E_{K.3}$ performance is lowest, but since ±2ms in flight time at expected maximum rotational velocity at 2200°/s in elite skates refers to a difference <4,4° in total rotational angle and therefore seems negligible.

Using video analysis, as a reference, is problematic even with expertise in video data collection, due to speed and three dimensionality of figure skating jumps.

CONCLUSION: Time values of events toe pick, release glide leg, take off and landing can precisely be determined by the inertial sensor system MISSIE. The use of software algorithms provided results far within requirements of optimal feedback delay in technique training in figure skating. MISSIE data are superior compared with video data due to the difficult video capturing environment in figure skating, speed of analysis and therefore practical relevance for technical feedback training.

CONFLICT OF INTEREST: The first author of this paper declares that he is the developer of the software algorithm of the MISSIE system.

REFERENCES:

Albert, W. J., & Miller, D. I. (1996). Takeoff characteristics of single and double axel figure skating jumps. *Journal Of Applied Biomechanics*, *12*(1), 72–87.

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, *8*, 135–160.

Daugs, R. (2000). *Evaluation of sport motor measuring station training in elite sport.* (*Evaluation sportmotorischen Messplatztrainings im Spitzensport*)(Bundesinst.). Köln: SPORT und BUCH Strauß.

Johnson, M., & King, D. L. (2001). A Kinematic Analysis Between Triple and Quadruple Revolution Figure Skating Jump.

King, D. L. (2002). A Biomechanical Analysis of Successful and Unsuccessful Quadruple Toe Loop Figure Skating Jumps. *Medicine & Science in Sports & Exercise*, *34*(5), 101. Retrieved from http://journals.lww.com/acsm-msse/Abstract/2002/05001/A_Biomechanical_Analysis_of_Successful_and.1799.aspx

King, D. L. (2005). Performing Triple and Quadruple Figure Skating Jumps: Implications for Training. *Canadian Journal of Applied Physiology = Revue Canadienne de Physiologie Appliquée*, *30*(6), 743–753.

King, D. L., Arnold, A. S., & Smith, S. L. (1994). A Kinematic Comparison of Single, Double, and Triple Axels. *Journal of Applied Biomechanics*, *10*, 51–51.

King, D. L., Smith, S., Higginson, B., Muncasy, B., & Scheirman, G. (2004). Characteristics of Triple and Quadruple Toe-Loops Performed during The Salt Lake City 2002 Winter Olympics. *Sports Biomechanics*, *3*(1), 109–123.

Lockwood, K. L., Gervais, P. J., & Mccreary, D. R. (2006). Landing for success: a biomechanical and perceptual analysis of on-ice jumps in figure skating. *Sports Biomechanics / International Society of Biomechanics in Sports*, *5*(2), 231–241. Retrieved from papers://6c494451-ee6e-4dd0-9f2c-10e1a6a49c65/Paper/p45

Rockmann-Rüger, U. (1985). *The influence of the time structure of the feedback enhancement on senomotoric optimising processes in sports.* (*Zum Einfluss der Zeitstruktur der Feedback-Vermehrung auf sensomotorische Optimierungsprozesse im Sport.*) Berlin.

Schmidt, R. A. (1988). *Motor control and learning*. Champaign: Human Kinetics.