Classification of Aerial Acrobatics in Elite Half-Pipe Snowboarding Using Body Mounted Inertial Sensors (P237)

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CLASSIFICATION OF AERIAL ACROBATICS IN ELITE HALF-PIPE SNOWBOARDING USING BODY MOUNTED INERTIAL SENSORS

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TOPICS: Half-Pipe, Aerial Acrobatics, Technology, Rate Gyroscopes, Performance, Competition Judging

Abstract: We have previously presented data indicating that the two most important objective performance variables in elite half-pipe snowboarding competition are air-time and degree of rotation. Furthermore, we have documented that air-time can be accurately quantified by signal processing of tri-axial accelerometer data obtained from body mounted inertial sensors. This paper adds to our initial findings by describing how body mounted inertial sensors (specifically tri-axial rate gyroscopes) and basic signal processing can be used to automatically classify aerial acrobatic manoeuvres into four rotational groups (180, 360, 540 or 720 degree rotations). Classification of aerial acrobatics is achieved using integration by summation. Angular velocity ($\omega_{i, j, k}$) quantified by tri-axial rate gyroscopes was integrated over time (t = 0.01s) to provide discrete angular displacements ($\theta_{i, j, k}$). Absolute angular displacements for each orthogonal axes (i, j, k) were then accumulated over the duration of an aerial acrobatic manoeuvre to provide the total angular displacement achieved in each axis over that time period. The total angular displacements associated with each orthogonal axes were then summed to calculate a composite rotational parameter called Air Angle (AA). We observed a statistically significant difference between AA across four half-pipe snowboarding acrobatic groups which involved increasing levels of rotational complexity ($P < 0.001$, $n = 216$). The signal processing technique documented in this paper provides sensitive automatic classification of aerial acrobatics into terminology used by the snowboarding community and subsequently has the potential to allow coaches and judges to focus on the more subjective and stylistic aspects of half-pipe snowboarding during either training or elite-level competition.

Key words: Automated Scoring, Technology, Gyroscopes, Acrobatics

1- Introduction

A current and relatively recent shift in performance assessment and athlete monitoring ideology is to move data collection and analysis from the sport science laboratory into the field. This shift can introduce objectivity into sporting environments normally reliant upon subjective perceptions to evaluate technique and performance. There are a number of examples of this shifting ideology becoming more prevalent in elite-level winter sport. Researchers for example have documented the use of an electromagnetic tracking system to quantify angular displacement and joint moment torques related to snowboard turns [DY1]. The same system has been used to calculate the degree of dorsiflexion, eversion and external rotation of the ankle joint complex during on-snow trials of snowboard boots [DT1] and a dynamometric platform focussed on field based load data acquisition has been developed and used to measure load components transmitted between boots and snowboard bindings [BP1]. Additionally, combinations of accelerometers and rate gyroscopes have been recently utilised to objectively describe the motion characteristics of ski jumping [OS1] and additionally, to collect measurements under skier's feet to gain objective insight into ground reaction force and an athlete's weight balance in the field [MS1]. At present elite-level half-pipe snowboarding seems well positioned to integrate technology and allow for some of the important technical aspects of the sport to be quantified. Interestingly, half-pipe snowboarding is a sporting discipline long exuding an anarchistic, non-conformist ideology with a focus on the aesthetic. Thus, successful integration of field-based monitoring afforded by micro-technology must be focussed upon relevant, practical information related strongly to training and competition performance.

We have recently documented the importance of air-time (AT) and degree of rotation (DR) on elite-level half-pipe snowboarding competition performance [HT1, HS1] and the capacity of signal processing using data obtained from accelerometers to automatically calculate aerial acrobatic AT [HS1]. Air-time, however, comprises only one objective aspect of an athlete's training and competition performance and capacity to automatically calculate this variable in the field can only ever provide part of the objective performance puzzle. It is therefore imperative to investigate the potential to objectively assess the DR component (Figure 1A) of aerial acrobatics. Although previously documented work [HT1, HS1] has highlighted the importance of DR on competition performance occurring during two World Cup competition finals, it is theorised the most likely benefit of automatic classification of aerial acrobatics will be in monitoring acute training load and long term training performance with elite-level athletes. The capacity to classify rotations automatically and to regularly log how often each manoeuvre is performed throughout routine training is theorised to provide a form of objective performance monitoring not currently used within half-pipe snowboarding. Theoretically tri-axial rate gyroscopes should allow objective assessment of DR and potentially contain information necessary to report on exact degree of rotation, direction of travel, direction of rotation, presence of inversion and ultimately provide unparalleled instantaneous acrobatic identification.

Rotation terminology used by half-pipe snowboarding practice communities is not based upon assessment of exact degree of rotation achieved. It is based upon a sport specific approximation. The take-off (Figure 1B) and more specifically the landing angles (similar but opposite to the take-off angle) associated with half-pipe snowboarding aerial acrobatics generate a situation where exact degree of rotation achieved will always be less than the terminology used to describe it. Theoretically, the degree of rotation achieved during rotations performed predominantly around a single axis is at least, 90 degrees less than the rotation the athlete is credited with based on conventional terminology. Rotational terminology can be based upon the following rules; an athlete will land aerial acrobatics travelling in the same direction they were initiated with in 180, 540, 900 and 1260 degree rotations. In contrast an athlete will land travelling in the opposite direction of the initiation during 360, 720 and 1080 degree rotations. These rules apply only in half-pipe and quarter-pipe snowboarding (resultant of the take-off and landing occurring on the same lip). Although snowboarders can ride forwards or backwards, these rules apply regardless of the direction of travel when aerials are initiated. Although the experienced snowboard community are trained to recognise aerial acrobatics, there is potential for automated classification to provide continual performance assessment (albeit a purely objective assessment) without constant human attention. Coaches, judges and support staff may thereby focus their attention on the more subjective aspects of performance whilst relying on automated inertial sensor feedback for continual recording of objective information.

(A) **(B)**

Figure 1. (A) Australian snowboard athlete mid-rotation during front-side 720 degree rotation and **(B)** displaying take-off angle typical of acrobatics performed in half-pipe snowboarding. Perisher Blue Australia 2007. Images: Heidi Barbay.

This paper focuses on the capacity of tri-axial rate gyroscopes to automatically classify aerial acrobatics into four rotational groups of increasing complexity (180, 360, 540 and 720 degrees of rotation). These aerial acrobatics are regularly utilised by the competitive half-pipe snowboard community in training and competition environments. Basic signal processing techniques and the associated classification results will be presented promoting the use of body mounted inertial sensor data to provide objective information with relevance to a specific sporting practice community.

2- Methods

2.1 – Subjects, Equipment, Experimental Procedure And Data Collection

Ten athletes were recruited to participate in this study. Data collection was performed during southern hemisphere winter seasons (2005 – 2007) at Perisher Blue Ski Resort (altitude 1720 m) on the resort's custom snowboard half-pipe (length 80 m, width 18 m, transition height 5 m, gradient ≈ 15 degrees). Data collection was performed during routine training sessions and competitions between 2005 and 2006. Experimental procedures were approved by the Ethics Committee of the Australian Institute of Sport on 18th August 2005 (ref: 20050808) and in accordance with Griffith University requirements, cleared under special review in January 2008 (ref : PES/01/08/HREC). Implementation of previously developed sensors [CI1, JD1] comprising of one tri-axial accelerometer (100Hz, ± 6g) and one tri-axial rate gyroscope (100Hz ± 1200d.s^{-1}) were used throughout data collection process. This paper focused on tri-axial rate gyroscope data as DR associated with aerial acrobatics relies on angular velocity for calculation. Data were processed in combination with a previously documented method of air-time calculation [HS1] in order to assess degree of rotation achieved during aerial acrobatics. Raw data was stored on board the sensor unit (256MB Trans Flash) for the duration of data collection process and sampled post collection by a computer software suite developed in house [M1]. Accelerometer components underwent 2-point static calibration in three orthogonal axes (up/down, forward/back and left/right) aligning each axes of sensitivity with and against the direction of gravity. Rate gyroscope components underwent a 2-point calibration integrating angular velocity over time throughout 0 and 90 degrees in three orthogonal axes (yaw, pitch, roll) prior to each data collection session [M1, GK1]. Panning video footage of each half-pipe run was collected using a Sony 3CCD 50Hz digital video camera from the bottom and centre of the half-pipe. Video footage was analysed by video analysis software (DARTFISH 2.5 Basic). A sensor was attached to the lower back of each athlete, situated ≈ 5cm to the left of the spine. Data were collected from one athlete at a time during routine national team training sessions and from all athletes concurrently during a half-pipe snowboard competition (AIS Micro-Tech Pipe Challenge 2007). Data collection allowed athletes to train and compete in routine fashion and eliminated constriction or alteration of performance. Panning digital video camera filmed complete half-pipe runs and tri-axial accelerometer / rate gyroscope data was collected for the duration of each data collection session. Data on 216 aerial acrobatic manoeuvres was collected.

2.2 – Signal Processing

This study focused upon aerial acrobatics performed predominantly around a single axis (yaw) resulting in what are termed by the snowboard community as 'flat spins or rotations'. These rotations are essentially void of inversion (rotation in the pitch axis) and as such simplify classification. Classification of aerial acrobatics is achieved using integration by summation. Angular velocity ($\omega_{i,\,j,\,k}$) quantified by tri-axial rate gyroscopes was integrated over time (t = 0.01s) to provide discrete angular displacements ($\theta_{i,\,j,\,k}$). Absolute angular displacements for each orthogonal axes ($i,\ j,\ k$) were then accumulated over aerial acrobatic duration to provide total angular displacement achieved in each axis. The total angular displacements associated with each orthogonal axes were then summed to calculate a composite rotational parameter called Air Angle (AA).

2.3 – Mathematical Representation of Signal Processing Technique

1. Rate gyroscope data (providing angular velocity) was sampled at 100Hz such that t= 0.01s and additionally in 3 orthogonal axes ***(i, k, j)***; of which one single axis of rotation is denoted by *j* in the following mathematical integration.
2. **N** = number of sample points associated with the air-time of one aerial acrobatic manoeuvre.
3. **AT** = air-time measured in seconds (calculated using a previously documented signal processing technique using acceleration [HS1].
4. **AA** = Air Angle; a measure of cumulative displacement achieved in all three orthogonal axes for the duration of aerial acrobatics.

$$\theta_{jn} = \int_{o}^{t} \omega_j \, dt \tag{1}$$

At $t = t_n = n\Delta t$,

$$\approx \sum_{i=1}^{n} \omega_{ji} \Delta t$$

$$= \Delta t \sum_{i=1}^{n} \omega_{ji},$$

And

$$\omega_i = \frac{\partial \theta_i}{\partial t} \tag{2}$$

$$N = \frac{AT}{\Delta t} \tag{3}$$

$$\text{Let } \Theta_{Nj} = \sum_{i=1}^{N} \left| \theta_{ji} \right| \tag{4}$$

$$AA = \sum_{j=1}^{3} \Theta_{Nj} \tag{5}$$

$$= \Delta t. \sum_{j=1}^{3} \sum_{i=1}^{N} \left| \omega_{ij} \right|$$

3- Results

3.1 – Graphical Representation of Inertial Sensor Data and Air Angle Measurement

Figure 2 shows the distinct raw accelerometer data pattern exhibited throughout a half-pipe snowboard run. Previously described aspects of this rhythmical pattern is utilised to calculate air-time associated with aerial acrobatics [HS1]. Figure 2 additionally displays the mathematically derived Air Angle measurement (derived using raw rate gyroscope data) associated with each aerial acrobatic manoeuvre. The Air Angle measurement subsequently allows for reliable classification of these aerial acrobatics into discrete rotational groups (180, 360, 540, 720 or 900 degrees of rotation).

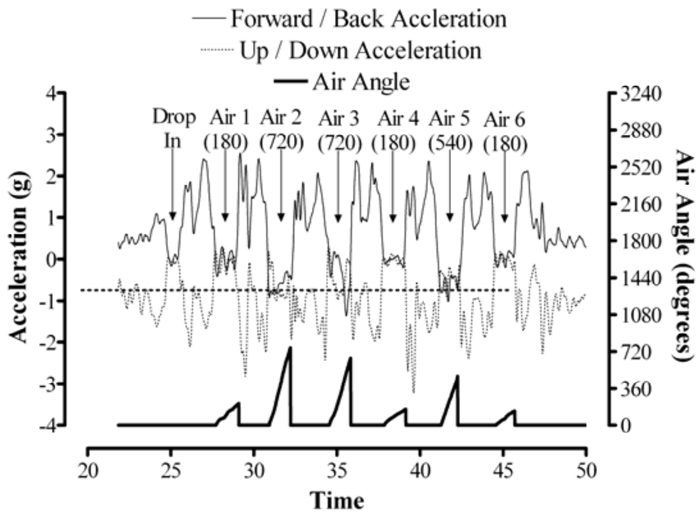

Figure 2: Raw acceleration data used to calculate air-time, Air Angle measurement and subsequent classification of aerial acrobatics. Australian snowboarder routine during AIS Micro-Tech Pipe Challenge 2007. Perisher Blue Australia.

3.2 – Statistical Assessment

Difference between average Air Angles measured for each rotational group (180, 360, 540, 720) was evaluated using a One-way ANOVA. All groups were normally distributed (Shapiro-Wilk statistic for 180, 360, 540 and 720 = .0987, 878, 942, 966, P = 0.141, 0.301, 0.086, 0.664 respectively) however, equal variances were not assumed (Levene statistic = 3.619, P = 0.013) and as such, a Dunnett T3 post-hoc test was used to determine significant differences between groups. Precision of estimation was described using 95% confidence limits. Significance was accepted at the level $p<0.05$. All statistical analysis was performed using SPSS 13.0 for Windows, SPSS Inc, Chicago Illinois USA, www.spss.com

3.3 – Graphical and Tabular Representation of Air Angle Range

Figure 3 presents Air Angle (mean ± range) for aerial acrobatics and their relationship to one of four rotational groups routinely used by the practice community (based upon an approximation of angular displacement). Average Air Angle for each of the rotational groups became significantly greater for each of the rotational groups (F = 2075.80, P < 0.001). The clinical significance however is of the utmost importance. Absence of overlapping Air Angle measurements between four rotational groups ensures the measurement provides reliable classification of aerial acrobatics performed predominantly around a single axis during half-pipe snowboarding. Table 1 provides numerical information on Air Angle measurements and recommended ranges for reliable acrobatic classification. Mean differences relate to AA measurement of rotational group immediately below.

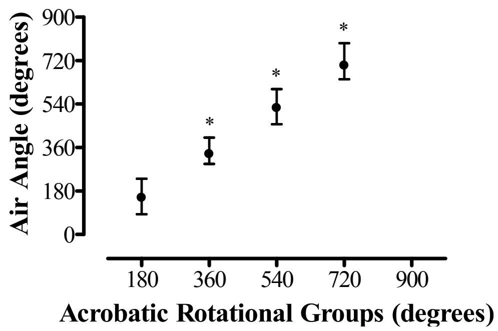

Figure 3. Air Angle measurement (mean ± range) and relationship to four specific rotational groups (n = 216 acrobatic manoeuvres. * = statistical significance from the preceding rotational group (a group with a lower degree of rotation).

Table 1. AA measurement information. Mean differences between rotational group and the preceding lower rotational group. Recommended AA ranges for successful classification of acrobatics using the method documented in this paper.

Rotational Group Degrees	n	Mean Degrees	SD Degrees	95% CL Degrees	Mean difference ± SEM Degrees	P value	Recommended Range Degrees
180	159	152.13	33.00	146.96 - 157.30	NA	NA	80 – 240
360	5	332.80	47.41	273.93 – 391.67	180.67 ± 21.36	P = 0.004	285 – 410
540	32	522.66	44.52	506.61 – 538.71	189.86 ± 22.62	P = 0.002	450 – 610
720	20	699.40	40.04	681.44 – 717.36	176.74 ± 11.64	P < 0.001	640 – 810

4- Discussion

This paper investigated the effectiveness of processing rate gyroscope data using integration by summation to classify half-pipe snowboarding aerial acrobatics into sport specific rotational groups. The signal processing of gyroscope data was used in combination with a previously documented method of quantifying acrobatic air-time using acceleration [HS1]. The calculation of air-time associated with aerial acrobatics provided the duration over which to assess angular velocity. The terminology used by the practice community to describe acrobatic rotation is based upon an approximation of angular displacement and the relationship between direction of travel at take-off and landing. Provided rotations are performed predominantly around a single axis, the signal processing method presented in this paper provides reliable classification of aerial acrobatics.

Mean differences in AA measurement between preceding rotational groups (for example between 360 and 180, 540 and 360, 720 and 540) were statistically significant (mean difference ± SEM = 180.67 ± 21.36, 189.86 ± 22.62, 176.74 ± 11.64; P = 0.004, 0.002, < 0.001 respectively). Of the utmost importance however, was the absence overlapping AA measurement limits between the different rotational groups (Figure 3, Table 1). Whilst 95% confidence limits provide tight upper and lower ranges of AA measurement for each rotational group, such statistically derived limits generate incorrect acrobatic classification as a number of AA measurements fall outside those ranges. The absence of overlapping AA measurement limits between groups therefore affords some flexibility outside statistically derived likelihoods whilst still ensuring reliable classification of aerial acrobatics. The recommended ranges the authors suggest for successful aerial acrobatic classification are provided in Table 1.

Developing the capacity to automatically classify aerial acrobatics was initiated based on the practical relevance of this information [HT1, HS1] and a focus on integrating objectivity into a sport that has relied on subjective performance assessment since inception. Alongside the previously documented ability to calculate air-time [HS1] the automation of aerial acrobatic classification is theorised to provide enhanced performance assessment during training and competition; freeing coaching and judging staff to focus intently on the subjective execution and overall composition of acrobatics incorporated into half-pipe snowboarding routines. The signal processing method documented however can not assess exact degree of rotation, direction of travel, direction of rotation or the presence of inversion and is focused upon acrobatics that are performed predominantly around a single axis. Subsequently, the impact on current performance assessment protocols is theorised to be limited. Coaches and judges are trained to recognise aerial acrobatics and whilst the classification system documented can automate that process, it does not provide any additional information to what can already be determined with the naked eye.

One of the problems with this method was an inability to reliably classify acrobatics performed in more than one axis, such as those that incorporate inversion. This was revealed in acrobatics above 540 degrees of rotation. Acrobatics up to 540 degrees (apart from a few specific inverted manoeuvres) are predominantly performed in one axis (yaw) as they are undemanding of most elite athletes. As the degree of rotation increases however, athletes begin to employ inversion (and hence another axis of rotation) in order to successfully complete required rotation. It is upon processing these inverted manoeuvres that the method documented in this paper fails to reliably classify aerial acrobatics. Signal processing of inverted aerial acrobatic manoeuvres (all of which were 720 degree rotations) generated AA measurements that often fell below recommended ranges and were subsequently classified incorrectly (into a lower rotational group). This is the primary reason (in addition to limited samples of inverted 720 degree rotations) this paper focussed upon acrobatics performed predominantly in one axis. All acrobatics comprise a small component of rotation in all axes (unproblematic for classification via AA measurement) however aerial acrobatics incorporating inversion as a major component will require different signal processing.

Although the method is intuitively appealing (providing a measurement with the same units as rotational group terminology), it is unnecessary for acrobatic classification. Proportionality of angular velocity to angular displacement should theoretically allow classification of acrobatics in the same manner, albeit with a different unit of measurement, by accumulating and summating discrete, absolute angular velocity measurements over air-time. Furthermore, summation of angular displacements over three axes is void of physical reference, is essentially an arbitrary measurement and is the reason for the method's failure to classify acrobatics incorporating inversion. It does however provide an indication of acrobatic complexity and is a platform for future refinement of the concept. Considering the community perceive some inverted manoeuvres an easier method of achieving higher degree of rotation, AA measurements could potentially gauge acrobatic complexity. Future work however will focus on the calculation of exact degree of rotation, direction of travel, direction of rotation and presence of inversion. This work may enhance current training and competition performance assessment in snowboarding, skateboarding and surfing.

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6- References

[BP1] Bianchi L., Petrone N., Marchiori M. A dynamometric platform for load data acquisition in snowboarding: design and field analysis. In The Engineering of Sport 5, Hubbard, M., Mehta, R. D., Pallis, J.M. ISEA, 2, 187 –193, 2004.

[CI1] Catapult Innovations. Mini Max. http://www.catapultinnovations.com, Catapult Innovations Melbourne Australia, 2007.

[DT1] Delorme S., Tavoularis S. Kinematics of the Ankle Joint Complex in Snowboarding. In Journal of Applied Biomechanics, 21, 394 – 403, 2005.

[DY1] Doki H., Yamada T., Nagai C. Horaki, M. Development of a measurement system for snowboarding turn analysis. In The Impact of Technology in Sport, Subic, A., and Ujihashi, S. Taylor & Francis London., ASTA, 324 – 325, 2005.

[GK1] Green J., Krakauer, D. New iMEMS® Angular-Rate-Sensing Gyroscope. In Analog Dialogue 37(03), 2003.

[HS1] Harding J. W., Small J. W., James D. A. Feature Extraction of Performance Variables in Elite Half-Pipe Snowboarding Using Body Mounted Inertial Sensors, In *BioMEMS and Nanotechnology III,* edited by Dan V. Nicolau, Derek Abbott, Kourosh Kalantar-Zadeh, Tiziana Di Matteo, Sergey M. Bezrukov, Proceedings of SPIE Vol. 6799 (SPIE, Bellingham, WA, 2007) 679917, 2007.

[HT1] Harding J. W., Toohey K., Martin D. T., Mackintosh C., Lindh A. M., James D. A. Automated Inertial Feedback For Half-Pipe Snowboard Competition And The Community Perception. In The Impact of Technology on Sport II, Fuss F. K., Subic A., Ujihashi S. Taylor & Francis London., 20, 845 – 850, 2007.

[JD1] James D. A., Davey N., Rice T. An Accelerometer Based Sensor Platform for Insitu Elite Athlete Performance Analysis. In IEEE Sensors, Vienna., 2004.

[M1] Mackintosh C., G. LOGAN V21.0 Copyright ©. Australian Institute of Sport, CRC for Micro-Technology, 2004 – 2008.

[MS1] Michahelles F., Schiele B. Sensing and Monitoring Professional Skiers. IEEE Pervasive Computing, 4, 40 – 46, 2005.

[OS1] Ohgi Y., Seo K., Hirai N., Murakam M. Measurement of Jumper's Body Motion in Ski Jumping. In The Engineering of Sport 6, Moritz, E. F., Haake, S. Springer Science + Business Media, LLC., 1, 275 – 280, 2006.