Journal of Human Kinetics volume 72/2020, 29-38 DOI: 10.2478/hukin-2019-0006
Section I – Kinesiology

Movement Variability During the Flight Phase in a Single Back Sideflip (Wildcat) in Snowboarding

by
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Understanding the structure and variability of motion is essential for sports technique development and an effective training design. Biomechanical analysis is particularly important in new disciplines with spatially complex motions, such as snowboarding. This study aimed to evaluate the level of variability of the kinematic variables in a single backside snowboard flip known as a "wildcat". Forty-six correct flips performed by 7 experienced athletes (age: 24.9 ± 4.34 year; body mass: 71.6 ± 12.87 kg; body height: 177.4 ± 6.99 cm) were recorded using an optoelectronic VICON system in the controlled setting of an indoor freestyle park. Athletes were equipped with special boards with wheels and the geometry of the ramps corresponded to the actual on-snow conditions. The analysis revealed two distinct single flip strategies, which differed in the way the tuck position was sustained. For all the measured variables, the coefficient of variation was computed, which allowed to identify the athlete with the highest (average 45.3%) and lowest (average 20.5%) variability of kinematic variables. Moreover, it was shown that the lowest values of the coefficient of variation occurred at the end of the grouping phase (average 14%) and that among all the different variables, those related to the duration of motion were most unstable (average 63%, SD = 48.5%).

Key words: *snowboarding, sports technique, movement variability, motion capture.*

Introduction

„Biomechanics is uniquely positioned to assist with regard to understanding of already existing techniques, new skill development, increasing safety and equipment design and/or modification" (Prassas and Sanders, 1999). Therefore, biomechanical insights are of particular assistance in new sports with high injury risk. One of such sports is snowboarding, which is developing very rapidly. The main hazards of snowboard are high speed, hard-packed snow and limited visibility (Hasler et al., 2010). The most common causes of injuries are human mistakes (Bladin et al., 2004), usually of technical nature (Zygmuntowicz and Czerwiński, 2007). In freestyle snowboarding aerial disciplines, technical errors usually have strong impact on landing. Consequently, the landing has been the most studied phase of motion, both in terms of kinematic and kinetic variables (Delorme et al., 2005; McAlpine and Kersting, 2006; McAlpine et al., 2012; Klous et al., 2014; Klous et al., 2014). However, there are no data about the flight phase of snowboarding with quantitative measurements. Landing conditions are determined by the way the flight phase is performed and the orientation of the snowboarder in relation to the movement direction. A distinctly tilted body position is adopted at the jumping ramp by the athletes of various board sports such as snowboarding, wakeboarding, surfing, skateboarding, etc. Snowboard jumps can be performed with or without rotation (straight jump, called *ollie*). The aerial manoeuvres with rotation can be divided into three categories: rotations about the vertical

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Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 72/2020 in April 2020.

body axis (*frontside* and *backside*), flips (*backflip, frontflip, sideflip* and *back loop*), and two-plane rotations (e.g. *inverted airs, corkscrew, f/s rodeo, b/s rodeo, butter shifty*). In this study we analysed a flip called a *wildcat*, with rotation about the sagittal axis (*sideflip*) in the direction opposite to the direction of motion (FIS, 2016).

The variability of movement structure, defined as the normal changes occurring in the structure of movement when repeating the same motor task (Knudson, 2007), is often believed to be related to the efficiency of motion (Stergiou et al., 2006). The three main frameworks which aim to describe the relationship between variability and efficiency include the Generalized Motor Program Theory (GMPT), Uncontrolled Manifold Hypothesis (UCM), and Dynamical Systems Theory (DST).

According to the GMPT (Summers and Anson, 2009), variability of the movement structure should be attributed to errors and noise in the control system (Yeadon, 2017). Hence, one of the objective of subjects learning a motor activity is to reduce movement variability (Jones, 2012).

Latash and his theory of the UCM (Latash et al., 2002) identifies movement variability with motor redundancy. Motor redundancy is a situation in which multiple ways to complete the task are available. According to the UCM, when a multi-component system changes the state of individual parts, the control system does not have to interfere as long as the expected effect remains unchanged. It implies that that the variation of individual components is acceptable.

Finally, the theory of DST (Clark and Phillips, 1993) assumes that biological systems self-organise according to environmental, biomechanical and morphological constraints in order to find the most stable solution for the performance of a given movement. Increased variability of the pattern indicates loss of movement stability, while reduced variability reflects very stable behaviour of the system. Based on the DST theory, movement variability can also be considered an adaptive or compensatory potential that can be used to respond to changing conditions (Bradshaw et al., 2007).

Nevertheless, all three theories (GMPT, UCM and DST) agree that reduced variability is conducive to more efficient movement patterns (Stergiou and Decker, 2011). Therefore, the aim of the study was to evaluate the level of flight variable variation of the snowboard single back side flip (wildcat).

Methods

Participants

The study group consisted of 7 male snowboarders, participating in a snowboard instructor course (age: 24.9 ± 4.34 year; body mass: 71.6 ± 12.87 kg; body height: 177.4 ± 6.99 cm; training experience: 4 ± 2.5 year). The evaluations were carried out twice, in May and November. The selection for the study participants was purposeful. The main inclusion criterion was the ability to perform at least a single *wildcat* flip in a standardised laboratory environment. The exclusion criterion was pain declared during warm-up jumps and injuries within six months of the evaluations. All participants were provided with a detailed explanation of the potential risks and benefits of the study and signed an informed consent form before the research commenced. The study followed ethical guidelines consistent with the Declaration of Helsinki and was approved by the ethics committee of the institution of the authors.

Research methods

The body position was captured by the motion capture system (Vicon, USA), composed of 10 cameras (MX-T40 Bonita NIR) with 100 Hz sampling. The capture volume was 3 m high, 6.5 m long and 4.2 m wide. Static and dynamic calibrations were performed and showed acceptable accuracy.

The additional 4 RGB cameras synchronised with the Vicon system were used to observe the space before the beginning of the flight phase. The origin of the global (lab) coordinate system was located on the left-hand side (as viewed by the incoming forward-facing skateboarder) of the ramp’s edge. The X-axis aligned with the ramp’s edge, the Z- axis aligned with the direction of gravity, and the Y-axis was orthogonal to both of them. Thirty-nine markers were placed at the anatomical locations according to the Plug-in-Gait protocol (Clark et al., 2016) and two additional markers were fixed to the snowboard and next two to the edge of the ramp. The location of the joints was reconstructed with Nexus software (Nexus 2.0, Vicon, Oxford, UK).

Based on that, a simplified model (14 segments connected by joints) of the snowboarder's body was constructed. Relative masses of the 14 segments were assigned based on Zatsiorski's indices (Zatsiorsky, 1998) and the relative mass of the board itself was taken as 10% of the snowboarder's body mass. At every moment, the centre of mass and the tensor of inertia I of the model were computed. The trace of I (cumulative moment of inertia) was used as a descriptor of the snowboarder's posture. Indeed, although for rigid bodies the cumulative moment of inertia is constant, it may vary when the body position changes in time.

Measurement protocol

Controlled lab-like conditions were provided by a jump located in the "Freestyle Park" facility in Chorzów, Poland (Figure 1). The jump consisted of in-run ramps and a foam pit which ensured safe landings. The ramps' design corresponded to the geometry of natural on-snow structures. They were located indoors and had a fixed (wooden) surface, thus standardising the weather conditions (air movement, temperature, precipitation) and mechanical conditions (coefficient of friction, ramp geometry). Participants moved on the surface of the ramp on dedicated boards with wheels. Each participant wore a black uniform (required by the motion analysis system) and a protective helmet. Boards were chosen individually. In-run specification is as follows: starting platform's height: 5.6 m; in-run length: 16.6 m; height of the ramp lip: 2.3 m; angle of the ramp lip: 30^{o}. The platform's height was measured to the lowest point of the in-run to the starting point. The in-run length was measured from the starting platform to the ramp lip. The ramp limp height was measured from the ramp lip to the lowest point of the in-run. NIR cameras were placed on a special 12 x 6 m truss, located about 2 m above the ramp lip.

Anthropometric measurements were taken and an individual warm-up was administered prior to the jumping session. Each participant chose the warm-up time and exercises according to their own experience. All athletes had already practised at the freestyle park so they were familiar with the conditions of performing under these specific conditions. Each athlete attempted to perform a wildcat flip 10 times. A performance was described as successful when the snowboard made contact with the ground (the surface of the foam pit) first, i.e. before the body. The rest intervals between trials were selected individually and lasted from 3 to 6 minutes. A total of 46 successful wildcat flips were recorded and analysed.

Results

Based on the position of the body markers, several kinematic variables were computed:

(1) positions: vertical (COMz) and horizontal (COMy) position of the centre of mass (based on Zaciorski's indices (Zatsiorsky, 1998),

(2) speeds: vertical ($Vcom_z$) and horizontal ($Vcom_y$) components of the instantaneous velocity of the COM,

(3) geometric: the angle between the axis passing through the body COM and head COM and the vertical plane ,

(4) inertial: cumulative moment of inertia of the body (trace I), defined as the trace of the normalised inertia tensor.

Subsequently vertical displacement of the COM and the cumulative moment of inertia were used to divide the flight into the following phases: raising (A-C) and falling (C-E), grouping (A-B), maintaining a stable position (B-D), and ungrouping (D-E) (Figure 2). The cumulative moment of inertia analysis revealed that two distinct techniques were used by participants: one with a prolonged period spent in the grouped position (Figure 2) (participant 2, dashed lines) and another one with immediate ungrouping after reaching the grouped position (participant 3, solid lines).

The values of quantities (1)-(4) attained at the phase boundaries (A, B, C, D - Fig. 2) were used for 4 different types of motion variables: linear, speed, angular, and inertial. Apart from the variables at the phase boundaries, we also calculated their increments during individual phases (during flight). The duration of individual phases itself provided yet another class of time variables. The coefficient of variation (CV) for each variable was calculated by grouping them according to the participant, instant of the movement, and the type of the variable. The values of CV were also used to evaluate across-subject variability where due to the lack of normality, the Kruskal-Wallis test was deployed.

The analysis of tCV revealed further differences between individuals (Figure 3). Three participants (1, 4 and 5) differed significantly with regard to the variability presented by the entire group; they were characterized by greater repeatability of basic flight variables. The only significant difference between snowboarders was observed between participants 1 and 5. Snowboarder 1 had the most stable flight variables among all the participants. With regard to the phase structure, the most variable were parameters related to increments within phases (phase times, changes in body position or location). The average CV reached 53% (SD-41.0%), while the mean for the instantaneous quantities at phase boundaries was 25% (SD-37.2%). Comparison of the variability at the phase boundaries showed that the most stable was the end of the body grouping phase (B) where the average variation of kinematic variables of flight was 14% (SD- 13.5%), i.e., more than three times less than the flight variables. As far as the variable type is concerned (Figure 5), most variation was observed in time variables with the average CV of 63% (SD-48.5%). The most stable variables were those describing the inertial variables based on the tensor inertia (the average CV was 15% (SD-9.2%)).

Figure 1

The ramp on which the tests were performed.

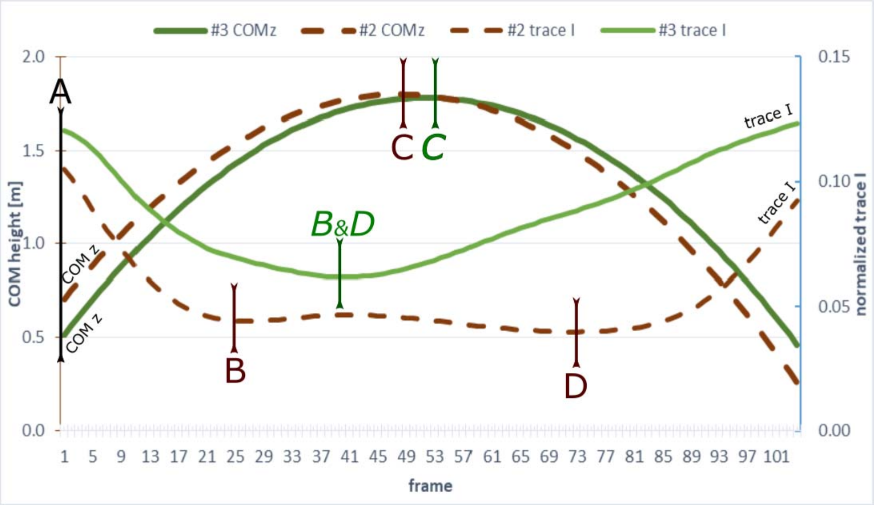

Figure 2

Example of the vertical displacement of the COM (hCOM) and change of cumulative moment of inertia (trace I) in the wildcats of two snowboarders (No. 2 and No. 3). The beginning of flight and extrema of trace I and COMz were used to determine the boundaries of the movement phases. Phase boundaries were denoted with letters: A - beginning of flight, B - end of grouping, C - maximum height of COM, D - beginning of ungrouping.

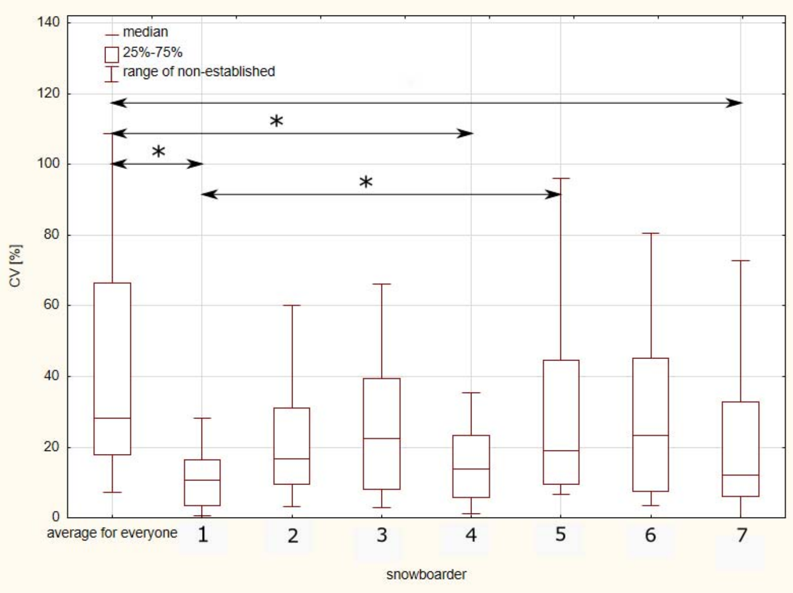

Figure 3

*Differences in the coefficient of variation (CV) for all variables between the study participants and variability for the whole group (average for everyone). * - $p < 0.05$*

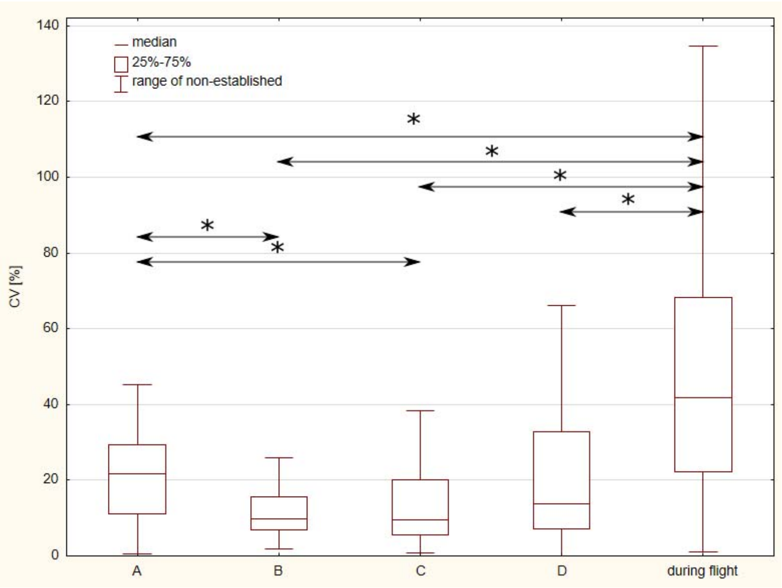

Figure 4

*Coefficients of variation for kinematic variables of flight at phase boundaries (A, B, C, D) and in individual phases. * - p <0.05*

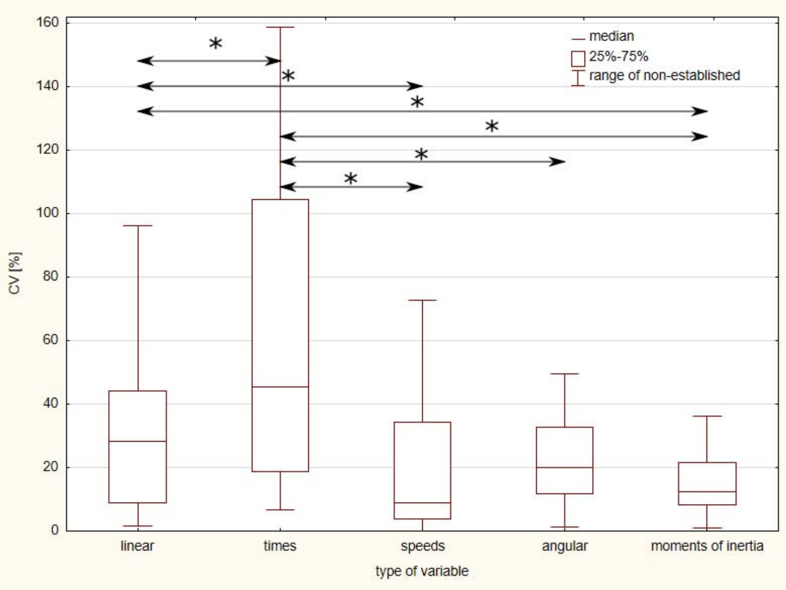

Figure 5

*Coefficients of variation for flight variables by type. Linear - variability of position and displacement variables in translational motion, times - variability of time of individual phases, speeds - variability of speed in translational motion, angular - variability of angular variables - position and displacement, moments of inertia - variables of moment of inertia - normalized values, speed (change gradient) and degree of grouping. *- p < 0.05*

Discussion

This study aimed to evaluate the level of variation of flight variables for a single snowboarding back sideflip (*wildcat*). To our knowledge this is the first study of this type. The analysis of flight variables in the back sideflip (*wildcat*) using the coefficient of variation (CV) allowed to indicate the most stable, i.e. least variable parameters which included the moment of inertia among the flight variables (CV = 15%, SD = 9.2%) and the most stable instants of motion which turned out to be the completion of grouping. The correlation of these variables indicates how important it is to adopt and maintain a stable position (grouping) during rotation. By the law of conservation of angular momentum, the moment of inertia determines the angular velocity which can be exercised using the angular momentum gained in the in-run (take-off) phase. Grouping itself also plays the role a countermovement. Adopting and maintaining a stable, grouped body position leads to lower variation of the variables during the flip, and, consequently, improved stability and effective performance. This is confirmed by the results of snowboarder 1, who had the lowest coefficient of variation, and his movements were the most effective and reproducible. He was one of the two participants who were able to perform a double rotation under the test conditions. This confirms the theory that reduced variability leads to a more effective performance of a given movement pattern (Stergiou and Decker, 2011). Snowboarders who were able to maintain a grouped position showed a much lower CV. This was also confirmed by the average variation of kinematic variables of flight amounting to 14% only (SD- 13.5%) at the end of the grouping phase. However, it should be emphasized that the flight parameters were relatively variable, with the average for all of them of 30% (SD 39.1%). There are no studies in the literature on rotation in the sagittal axis (sideflips) characteristic of boardsports such as snowboarding. This may be explained by the fact that the history of the development of these sports is rather short, yet dynamic and that it is difficult to conduct research in a standardised natural on-snow environment (Żebrowska et al., 2012). However, similar values of the coefficient of variation have been found in other snow sports. Nedergaard et al. (2015) obtained an average CV of 25.7% in a study of kinematic variables of the ski cross start phase. Kurpiers et al. (2009) carried out a biomechanical analysis of mogul skiing and received CV value of 47%. Furthermore, in a study of snowboard landing CV for kinematic variables was on average 26% (McAlpine et al., 2012).

It should be noted that the values of coefficients of variation of kinematic variables are highly dependent on the type of movement. In simple natural jumps (SJ), the variation is about 10%. In the study published by Bobbert et al. (1996), the height of the CMJ jump in 6 female volleyball players was characterized by a variation of 7.5%, but in three types of jumps, this value increased to 10.3%. The variation of CoM height at the beginning of the take-off phase in the CMJ was 9.7%, but in the SJ jump performed with the lowest possible position of the take-off, it reached 16.4%. On the contrary, for the same type of the jump (SJ) performed from the preferred position, variability was only 5.6%. In this study, vertical velocity was characterized by variation of about 6%. However, the hip angle variation at the moment of the beginning of the take-off reached 20.5% in the CMJ and 15.7% in the SJ. The research of more complex jumps provided interesting insights. Recorded during the Olympic Games in Seoul (Hwang et al., 1990), 21 gymnastic somersaults (seven layout double backward somersaults - L, seven twisting double backward somersaults TW, and seven tucked double backward somersaults - TDB) showed very little variation of the take-off angle: 7% (L), 6.5% (TW), and 5.6% (TDB). These values were even smaller for the landing angle (ca. 3% each) in all somersaults. Similarly, the variation in horizontal velocity at the beginning of landing accounted to several percent (9% for L, 7% for TW, and 12% for TDB). These small values of variation in such complex techniques demonstrate high repeatability and effectiveness of performance resulting from perfect technique and full control during the flight (which is a prerequisite for obtaining and maintaining a stable position), while counteracting destabilising forces that are connected with the movement of bodies in space, e.g. centrifugal force. This is confirmed by the analysis of parameters of variability in individual phases of rotation performed in this study, where the smallest variation occurred between the end of grouping and the beginning of ungrouping. The comparison of variation of the cumulative moment of inertia in the phases of performance of two isolated wildcat techniques also confirms that faster adoption of a compact position (board grip) and its longer holding until opening (board release) are characterized by very little variation in the moment of inertia. Compared to a technique in which the board grip occurred much later and was very short, the moment of inertia showed great variation throughout the rotation. Therefore, it can be concluded that adoption (and maintaining) a grouped position in rotations represents one of the conditions for their effective performance in all sports where competitors rotate around different axes of the body. As the grouping mechanism appears to be essential to body stabilisation during flight and the effective performance of the rotation, it would be interesting to identify what mechanisms ensure effective aerial manoeuvres for motions without the grouping phase, e.g. simple flips and rotation about the long axis.

This study represents a pioneering attempt to analyse *wildcat* side flips in snowboarding using the environment very similar to natural on-snow conditions provided by a safe, standardised and repeatable ramp located in a freestyle park. The results obtained using this method motivates further research in other groups of athletes and the analysis of aerials with a higher level of difficulty, in various sports practised on jumps and in-run ramps, especially freestyle sports. It also seems reasonable to extend the research equipment with further systems providing data from other areas. This will undoubtedly help develop technical models of performing individual elements and identify variables that have the greatest effect on their proper performance, translating into effective training of athletes in various sports.

Limitations of the study

Due to the characteristics of the ramps which require athletes to have a high level of snowboarding skills, a limitation of this study is a small sample size. This represents a certain limitation to the present study. Furthermore, it represents a specific criterion for the selection of snowboarders at an adequately high performance level.

Practical implications

The above results may be used as a methodological guide for coaches in freestyle and gymnastic sports, in which body control in the air is one of the basic criteria for achieving an elite sports level. The study indicates the factors and technique that have a direct impact on the efficiency and repeatability of performing rotation during flips. In this specific case, they concern a rotation in the sagittal axis and snowboarding technique, but the conclusions may also be applicable to many related sports.

Conclusions

The correct performance of a *wildcat* flip is characterized by about 30% variation of kinematic variables of flight. Global CV (concerning all movement variables) offers opportunities to evaluate movement stability. Adoption and maintaining a stable body position during the flight phase seems to be critical for effective performance of a snowboard flip, which can be achieved, among other things, by grouping.

The novel application of the research apparatus in the freestyle park facility opens up new opportunities for research in various sports, especially freestyle sports such as snowboarding, skiing, rollerblading, and bmx, which are increasingly added to the official Olympic program.

Acknowledgements

This work was supported by a Polish Ministry of Science and Higher Education grant (No. 0014/RS4/2016/54). The motion data used in this project were measured in cooperation with the Centre for Research and Development of Polish-Japanese Academy of Information Technology www.bytom.pja.edu.pl.

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