How to spin to win

- A study about the biomechanical and physiological determinants in a snowboard jump

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Abstract

Aim and objectives

The aim of this study was to examine how different biomechanical, physiological and anthropometry variables relate to snowboard jump performance. The first objective was to investigate the differences in velocity at take-off, jumping height, jumping length and air-time (AT) in straight jumps and tricks with different degrees of rotations in a jump. The second objective was to identify which biomechanical and physiological parameters correlate with snowboard jump performance, which was defined as the ranking of the athletes' best 720° jump subjectively determined by an experienced snowboard judge.

Method

Eleven students at Malung-Sälens Snowboard High-school performed straight jumps and backside rotations on a snowboard jump, while data on snow variables such as velocity at take-off, jumping height, jumping length and AT were collected. An experienced judge evaluated all 720° jumps. Participants also performed strength and flexibility tests to assess their physiological performance. The physiological tests included: 1RM squat, squat jump with weight equal to 40% of their 1RM squat weight, unweighted squat jump, countermovement jumps, countermovement jumps with arm swing, chin-ups, brutal bench and a modified sit and reach test.

Results

While performing the 720° rotations the riders had significantly higher jumping height and AT than during the 360° jumps. No significant correlations were found between the best subjectively judged 720° and jumping height, jumping length or AT. None of the physiological tests results produced significant correlations with subjectively judged snowboard performance.

Conclusions

When the participants performed a higher degree of rotation, jumping height and AT increased significantly. No relationships were observed between jumping height, jumping length, or AT with subjectively judged snowboard jump performance. It is believed that the rank of the best 720° was primarily based on the athletes' personal riding style. The

physiological tests showed no relationship to the subjectively judged snowboard jump performance. Other factors such as psychology, technique and coordination might be more important for performance.

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1 Introduction

Snowboarding is an Olympic sport divided into two alpine disciplines: Parallel slalom and Boarder-cross, and two freestyle disciplines: Half-pipe and Slopestyle. Slopestyle is the latest addition to the Olympic program and Sweden has recently created a national freestyle team. This has increased the demands placed on athletes and coaches to develop improved ways of training, monitoring and assessment of performance. There is not much research published in this area and there is a gap the sport science knowledge about the physiological and biomechanical demands on an athlete performing a snowboarding jump, which is a part of what athletes do in a Slopestyle competition. Researching which biomechanical and physiological aspects are important and correlate with snowboarding performance will help coaches and athletes to structure their training for optimal performance.

1.1 Background

This paper focuses on jumping in snowboarding. A competition that only includes a single jump is called Big Air. Jumps are usually included in a Slopestyle competition, but riders also perform tricks on boxes, handrails and other man made features (International Ski Federation, 2010, p. 49). The jumping is a big part of the final score. A snowboard jump is used to perform aerial tricks often including rotations around one or more axis of rotations.

1.1.1 Snowboard Terminology

The snowboarding community practice has its own terminology that explains different movements and aerial tricks. This terminology was used in this report and this sections aims to explain these expressions. See also Appendix C for a complete dictionary of the snowboard terminology used in this paper.

In snowboarding, riders can have either their left foot forward or their right foot forward. A rider that normally ride with his/her left foot forward is described as having a regular stance. Whereas a rider that normally rides with his/her right foot forward is described as having a goofy stance. Should a rider with regular stance ride with his/her right foot forward it is called riding switch. The same is applied to a goofy rider that rides with his/her left foot forward. (International Ski Federation, 2010, p. 14)

When completing aerial rotations the different directions have their own names. If a regular rider rotates clockwise or a goofy rider rotates counter clockwise the rotation is described as a backside rotation. The rider starts the rotation by turning his/her back towards the landing. Backside rotations can also be performed switch, which result in a counter clockwise rotation for a regular rider and a clockwise rotation for a goofy rider. It is then called a switch backside rotation. (International Ski Federation, 2010, p. 16)

Frontside rotations occur when a regular rider rotates counter clockwise or when a goofy rider rotates clockwise. Switch frontside rotations occur when a regular rider rides switch and rotates clockwise or if a goofy rider rides switch and rotates counter clockwise.(International Ski Federation, 2010, p. 20)

In a jump, rotations are made in 180° intervals so that the snowboarder lands with the nose (front end of snowboard) or tail (back end of snowboard) down the landing. Examples of rotations are 180°, 360°, 540°, 720° etc. The most common rotations occur during the longitudinal axis. Sometimes these rotations can be performed inverted, this is called a cork. If the rider is inverted more than once it is called a double or triple cork depending on the number of times the rider is inverted.

When performing aerial rotations in snowboarding, judges reward riders that also to perform a grab (International Ski Federation, 2010, p. 45). A grab is when one or both hands grab either edge of the board (International Ski Federation, 2010, p. 20). The grab should be distinct and be held as long as possible during the spin (International Ski Federation, 2010, p. 45). Examples of different grabs are Indy, Mute, Nose, Tail and Stalefish.

A snowboard jump consists of a take-off, plateau and landing. The part of the jump where the take-off is located is called the kicker. After the kicker there is usually a flat section that the riders fly over, that is called the plateau. The landing is where the snowboarders land. The edge where the plateau ends and the landing begin is called the knoll. The landing is usually quite steep to ease the impact of touchdown. The landing has a “sweet spot” where the incline is most favorable. Landing too short or long will result in a higher impact.

In half-pipe snowboarding riders perform tricks in a man made feature that can be described as a pipe cut in half with two walls. The riders ride from side to side and jump over the edges of the half-pipe walls and perform aerial tricks including rotations and flips.

1.1.2 Judging in Snowboard Competitions

The results in a freestyle snowboard competition are based on subjective measurements by judges often called the Overall Impression (OI) (Swatch TTR World Snowboarding Tour, 2010-12-27; International Ski Federation, 2010).

Swatch Ticket To Ride World Snowboarding Tour (TTR) is the largest collaboration of independent freestyle snowboard events with over 180 events all over the world. The events have all different formats and the vast majority of them employ the Overall Impression (OI) judging system. The TTR definition of OI judging system is as follows:

"The judges will score the run by evaluating the run's "Overall Impression" which includes the execution of the run and the routine (variety of tricks) attempted. In OI judging the judges evaluates the specific tricks individually and as a sequence and looks at line, inherent style and overall flow of the rider on the course. What is desired is the highest level of progression…a run that is done with maximum technicality and one that has a new move or sequences that pushes snowboard progression forward."

In summary, the focus is on the whole run appraised (flow, amplitude, tricks) and on the progression. Secondary is the emphasis on tricks and trick sequences and third is the emphasis on style and risk. (Swatch TTR World Snowboarding Tour, 2010-12-27)

The International Ski Federation (FIS) judges also use an OI system. The judges look at control of trick, execution, difficulty, control, amplitude and landing. A rider that shows control of the trick has good balance and executes the trick smoothly. Arms should be in control and not waving around. A spin should be done in one fluid movement with the same rhythm from beginning to end. Amplitude is the combination between height and length of the jump. Since it is more difficult to master a trick with long airtime, a rider with longer airtime (AT) but with the same trick will be rewarded more points than a rider with less airtime. Nevertheless a trick must be carried out in a safe manner; flying too far is not recommended or rewarded as it increases the risk of injuries. The landing is the last component of the trick and is what separates a completed trick with a non-completed trick. Judges deduct points according to a scale depending on the size of the fault. It ranges from minor hand drags to when the board is not the first thing to touch the snow. (International Ski Federation, 2010, p. 45f)

1.2 Previous Research

1.2.1 Research on Snowboard Judging

Half-pipe snowboarding has been an Olympic sport for over a decade and research has been done on the factors used to differentiate between riders. Harding and James (2010, p. 66) analysed performance indicators at the half-pipe competition Australian Burton Open over three years. Panning video footage was used to collect data about AT and degrees of rotation. Average AT and average degree of rotation were the strongest predictors of performance. Harding and James (2010) defined AT as “Air-time begins the first moment there is no longer contact between the snowboard and the snow and ends the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre” (2010, p. 69). During a run in a half-pipe, the rider jumps up over the edge of one wall and then continues to the next wall resulting in several jumps during the run. The average AT can be explained as the total AT during the run divided in number of times the rider left the snow (jumps). Degree of rotation was defined as “[…] measured in degrees and reflects the amount of rotations (calculated using the rules associated with the sport specific approximations) an athlete completes during individual aerial acrobatic manoeuvres performed during a half-pipe snowboarding routine” (Harding & James, 2010, p. 70). The average degree of rotation can be explained as the sum of all rotations made divided on the number of times the rider jumps off the wall and leaves the snow. In the competition scores, the two predictors of performance explained 71-94% of the shared variance. Moderate to large effects sizes were discovered that differentiated the athletes placing in the top three positions and the ones that did not with consideration to average AT and average degree of rotation. (Harding & James, 2010, p. 66).

Objectively measuring AT and degrees of rotation has been integrated into a snowboard competition. Harding, Mackintosh, Martin, Hahn, & James (2008c) hosted an invitational half-pipe competition, where the athletes wore inertial sensors. Average degree of rotation and average AT explained 76% and 23% respectively of the shared variance in the scores set by a judge with experience of the Olympics and World Cup. Average AT and average degree of rotation had a large effect on competition scores, but riders had to achieve highly on both accounts to receive high competition scores. Long AT alone, without a high number of rotations did not achieve high scores. The fact that objective measures could not explain the whole variance should not be considered a weakness. Style and execution probably explains the remainder and are considered important aspects by the practice community. These are qualities that can only be perceived subjective by the human eye. (Harding J. W., Mackintosh, Martin, Hahn, & James, 2008c, p. 285)

The snowboard community's opinion about the idea of objectively measuring AT and degrees of rotation in half-pipe competitions to distinguish skill between riders has been discussed (Harding & James, 2008d, p. 242 ff). This could help judges differentiate between riders who perform at a very similar level. It is easy to make mistakes when the judges have to watch from 200 m away and write a score for each hit. Introducing technology into the judging of the sport can be an issue, because it might change the sport itself and it is questionable if that is desirable. Competitors might change the way they ride as a result of this. Another consequence might be the introduction of the spin to win concept, where the number of rotations is the most important factor and the style component is removed. Many people in the industry are very negative towards this trend. Nevertheless the authors claim the objective technology could be introduced and integrated with the subjective judging in the sport if it is done with the support of key practice community members. This is to ensure the integrity of the sport and the room for individuality and freedom of expression (Harding & James, 2008d, p. 245 ff;Harding, Toohey, Martin, Mackintosh, Lindh, & James, 2007b, p. 845ff; Harding, Toohey, Martin, Hahn, & James, 2008b, p. 467; Harding et. al., 2008c, p. 288f). No reseach has been found concerning judging in Big Air or Slopestyle competitions, however it is belived that the judging is very similar.

1.2.2 Technology used in snowboard research and competition

In the research where AT, degrees of rotation and other variables has been examined several different methods have been used with different kinds of technology. Harding, Small and James (2007a) used data from a tri-axial accelerometer and a tri-axial rate gyroscope to calculate AT in a half-pipe. Data was compared to high-speed video footage. A high correlation was found between the two methods and 100% of the aerial acrobatic manoeuvres were detected.

Harding, Mackintosh, Hahn and James (2008a) used a tri-axial accelerometer and tri-axial rate gyroscope data integration by summation to automatically classify aerial acrobatic manoeuvres in a half-pipe. The equipment successfully identified aerial rotations up to 540° around the longitudinal axis. In rotations over 540°, snowboarders tend to utilize inversion and hence a different axis of rotation to complete the rotation. The method underestimated measures and was therefore classified incorrectly. The authors acknowledged that objective measures of degree of rotation are not necessary as coaches and judges are trained and used to recognize this (Harding et al., 2008, p. 456).

The analysis method used in Harding and James (2010) to calculate AT and degrees of rotation is quite time consuming, however there are several automated objectivity systems available on the market. They have been tested, validated and integrated into the half-pipe sport. However many of them have not published methodologies and validation information and are considered commercial projects. EIM-solutions and Swatch/Swiss Timing are two very similar systems, which are image based systems that utilise manual post processing of light emitting diode (LED) photographic images (1000Hz) over a calibrated, software generated grid to extract objective jump height during snowboarding. Shadowbox Live™ and Hangtimer™ use inertial sensors and signal processing to generate snowboard specific objective data. Shadowbox Live™ use a Kalman filtered analysis of 100Hz tri-axial accelerometers, tri-axial rate gyroscopes, tri-axial magnetometer and GPS data to establish a three dimensional trajectory form which the objective information is derived. The Hangtimer™ system consists of 100 Hz tri-axial accelerometers and an unpublished signal processing technique that provides information about airtime. All systems are at the forefront of development of technology to provide automated objective data and have close ties to elite sport. EIM solutions and Swatch/Swiss Timing are the objective data providers for the TTR and O'Neill Evolution Snowboard events. The advantages of these two systems are the fact that the riders do not have to wear any equipment, the processing times are fast, they are accurate and reliable (±10cm and ±5cm for Swatch/Swiss timing and EIM solutions respectively) and they measure jump height instead of AT. AT can in some instances be defective, for example, if a rider lands in the flat section of the pipe. The disadvantages with the systems are that the set up time is very long, it takes two people to run, jump height is the only data provided, and they are not commercially available which removes the opportunity for coaches and athletes to utilize the technology in training. (Harding & James, 2010, p. 77 ff)

1.2.3 Kinetics and Kinematics in Snowboarding

Some research has been done on the kinetics and kinematics in snowboarding. Krüger and Edelmann-Nusser (2009, p. 19f) examined the kinetics and kinematics of a snowboarder in a jump. One participant was equipped with a full body inertial measure suit (Moven, Xsens Technologies, the Netherlands) while performing a single test run over a jump. The trick performed was a 360° rotation with an incorporated Indy grab. At the initiation of the jump on the kicker the rider actively pushed off and was therefore exposed to a higher normal force and loads up to 1.2 body weights (BW) on the front leg and 1.35 BW on the back leg were recorded. In the landing the rider experienced up to 3.8 BW and 1.2 BW on the back and front leg respectively. McAlpine and Kersting (2006, p. 2 ff) also measured forces in a snowboard jump and found peak vertical ground reaction forces of 4.79 BW (SD=0.66) and 3.74 BW (SD=0.3) in the lead foot for two participants during snowboard landings. Overcoming these forces requires muscle strength and suggests the importance of physical fitness as an important factor for successful landings.

When performing the 360° rotation in the jump, the rider winded up the body to initiate the rotation and gain angular momentum. In the in run phase when the rider approached the jump Krüger and Edelmann-Nusser (2009, p. 19f) found internal rotations of 2–11° for the front leg and up to 15° external rotation for the back leg are measured. At takeoff an increase in plantar flexion of 12° of both legs, an internal rotation of 41° (front leg) and an external rotation of 32° (back leg) were measured, which was caused by the rotation of the upper body around the longitudinal axis. Throughout the landing phase, an increase of inversion 25° was measured in the front leg. On the other hand 15° of eversion was present in the back leg. When comparing these movements and loads to loads produced in cadaver studies a potential risk of injury is discovered (Funk, Srinivasan, & Crandall, 2003; Boon, Smith, Zobitz, & Amrami, 2001; Krüger & Edelmann-Nusser, 2009, p. 21 ff).

1.2.4 Kinetics and Kinematics of other aerial sports

To understand the techniques used in snowboarding, research on other aerial sports can help explain the mechanisms behind performance. Gymnastics has similarities to snowboarding in the aerial disciplines. A successful landing is highly dependent on the push off and flight phase (Marinsek & Cuk, 2010, p. 123 ff). For a gymnast to be able to control ground reaction forces (GRF) in the landing, muscular coordination and neuromuscular control is important. The ability to predict magnitude of loading and the ability to overcome the load created at the point of contact with the landing surface are also essential skills (Marinsek & Cuk, 2010, p. 123 ff). A tactic to overcome the load in the landing is to increasing the joint stiffness in particularly the knee, which results in more impact being absorbed by the heels. Passive tissue properties such as visco-elasticity of the muscles and tendons also help to dissipate some energy. Increasing muscle power in the legs is another strategy to increase the time to peak force in the landing and the time to actively decrease the impulse of the GRF with the muscles, thus reducing its impact (Liebermann, 2008, p. 122 ff; Marinsek & Cuk, 2010, p. 123 ff; Minetti, Ardigo, Susta, & Cotelli, 1998, p. 1780). Minetti et al (1998, p. 1788) found that elite skiers where better than sedentary persons at powerdissipation in drop landings suggesting the importance of of physical conditioning to succesfullt land jumps. To increase the capability of absorbing landings, muscular strength must be increased through eccentric training (Minetti et al., 1998, p. 1790). When examining landings in snowboarding it is important to remember that they are always performed so that the rider stands sideways to the direction of travel whereas in gymnastics most landings are performed so that the athlete faces forward or backward. This may change some of the techniques used in the different sports.

Ski jumpers have similarities with snowboarders in the way that they are exposed to similar forces in a jump. The loads and techniques used in ski jumping has been the topic in several scientific studies. In ski jumping athletes have to overcome increased centrifugal forces in the curved path of the in run before take-off (Müller, 2009, p. 89; Janura, Cabell, Elfmark, & Vaverka, 2010, p. 196). Virmavirta & Komi (1991, p 177) found that ski jumpers EMG in knee extensors were relatively low on the straight in run, which is the first downhill part of the jump where the skier gathers speed. However the EMG became relatively higher in the curved path as vastus lateralis and medialis began to compensate for increased centrifugal forces due to the curvature of the in run before take off. Snowboarders likely experiences the same forces in the in run and at take-off.

Timing is extremely important for a successful take off in ski jumping. If the athlete takes off too early the flight length will be greatly reduced, if the timing of the take off is too late the extension of the lower extremities is not completed before the athlete leaves the ramp, which also results in shorter jump length (Müller, 2009, p. 89). Timing is extremely important in snowboarding especially when performing rotations, but is difficult to measure quantitatively.

1.2.5 Physiological characteristics important to snowboard performance

There is sparse with published research about the physiology of snowboarders. Platzer, Raschner, Patterson & Lembert (2009) examined the physiology of the Austrian national snowboard team (n=37) who competed in the disciplines parallel slalom, snowboard cross, big air and half-pipe. The results were compared with FIS points in the different disciplines and overall World Cup points. The physiological tests performed included bicycle ergometry test (relative power at last stage of incremental test), countermovement jumps (CMJ) and isokinetic leg power and core test on a Con-Trex. In the isokinetic leg power test the relative (Watts/kg body weight) concentric power values during knee flexion and extension for the left and right legs were added together. The relative (Watts/kg body weight) concentric power values for hip flexion and extension were added together. To test upper body strength, an isometric bench press peak maximal force and isometric bench pull peak maximal force exerted were executed. GRFs were measured and relative (N/kg) strength of bench pull and bench press were summed together and used for analysis. This test was not performed on the freestyle athletes. To assess balance, a one-legged static balance test on a Biodex balance system was carried out. The mean of the stability indices during 30 seconds on the left and right leg was the variable used in analysis. Finally a boarder cross-start was simulated to test for maximum push off speed. The freestyle athletes did not participate in this test (Platzer et al, 2009, p. 1428 ff)

The test battery explained 61% of the variance in FIS points in women's parallel events, 78% of variance in FIS points in men's half-pipe and 98% of variance in FIS points in women's snowboard cross. World cup points could explain 61 and 73% of the variance in men and women respectively. (Platzer et al., 2009, p. 1430)

A significant correlation (r=0.88 $P > 0.05$) was found between CMJ and men's half-pipe FIS points. The authors point out that only nine athletes were included in the analysis so the results should be interpreted with caution. Half-pipe coaches argue that riders should not jump at take off but agree that explosive strength is beneficial. No significant regressions were discovered for men's big air. Among the women significant correlations were established although no women were freestyle competitors. This suggests that maybe men's fitness was more homogenous than women's in elite snowboarding (Platzer et al., 2009, p. 1431 ff). If the group investigated is homogenous physiologically rather than heterogenous it is difficult to establish strong relationships between physiological test with performance (Impellizzeri, Marcora, Rampinini, Mognoni, & Sassi, 2005a; Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005b).

When designing tests to monitor and predict performance, it is important that the tests are relevant to the sport. Cronin and Sleivert (2005, p. 213) advocate that isokinetic and isometric assessment bear little or no resemblance to the accelerative/deccelerative motion demonstrated in muscles during resistance training and sporting performance. It is not clear which characteristic predicts performance the best and it is important to remember that just because a strength or power attribute predicts performance well, training the attribute will not automatically improve performance. The challenge for sport scientists is to develop test batteries that provide insight information of the key mechanisms that make up the performance (Cronin & Sleivert, 2005, p. 232).

1.3 Aim and objectives

The aim of this study was to examine how different biomechanical, physiological and anthropometry variables relate to snowboard jump performance. The first objective was to investigate the differences in velocity at take-off, jumping height, jumping length and air-time (AT) in straight jumps and tricks with different degrees of rotations in a jump. The second objective was to identify which biomechanical and physiological parameters correlate with snowboard jump performance, which was defined as the ranking of the athletes' best 720° jump subjectively determined by an experienced snowboard judge.

2 Method

2.1 Participants

Eleven male elite snowboarders who were students at the Snowboard National Sports Secondary School in Malung-Sälen, volunteered to participate in this study by giving written consent. The participants competed in national and international competitions and championships. Seven participants were regular riders and four were goofy riders. Means, standard deviations (SD) and range for age, body height, body mass and years of experience in the sport are presented Table 1.

Table 1 – Participant characteristics

	Mean ± SD	Range
Age (yr)	17.5 ± 1.4	16-20
Height (cm)	179.9 ± 5.5	172-188
Body mass (kg)	68.9 ± 9.0	58-86
Years of experience (yr)	10.0 ± 3.4	6-15

2.2 Data collection method

The data collection method used in this study was quantitative and empirical. The first part of the study entailed collecting data about the participants' snowboarding capacity while performing tricks on a jump. Degrees of rotation, velocity at take-off, height and length of the jumps as well as air-time (AT) were measured. A judge with experience from World Cup and Olympic events subjectively evaluated the tricks. The second part included laboratory testing of the participants' upper- and lower- body strength and flexibility.

2.2.1 Snowboard testing

The tests on snow were carried out over two days at Kläppen Snow Park in Sälen. The jump that was used for testing was a Tombstone Tabletop jump (Canadian Association of Snowboard Instructors, 2006) and was categorized as a black feature, which is the category used for the most difficult features. The position from which participants started was far enough up the hill to gain the velocity they desired coming in to the kicker. Figure 1 shows the distance and pitch characteristics of the jump used. The flat area before the incline of the kicker was approximately 20m and the width of the plateau and landing was 25m. The incline of the kicker and landing was measured with a Silva ClinoMaster clinometer (Silva Sweden AB, Sollentuna, Sweden).

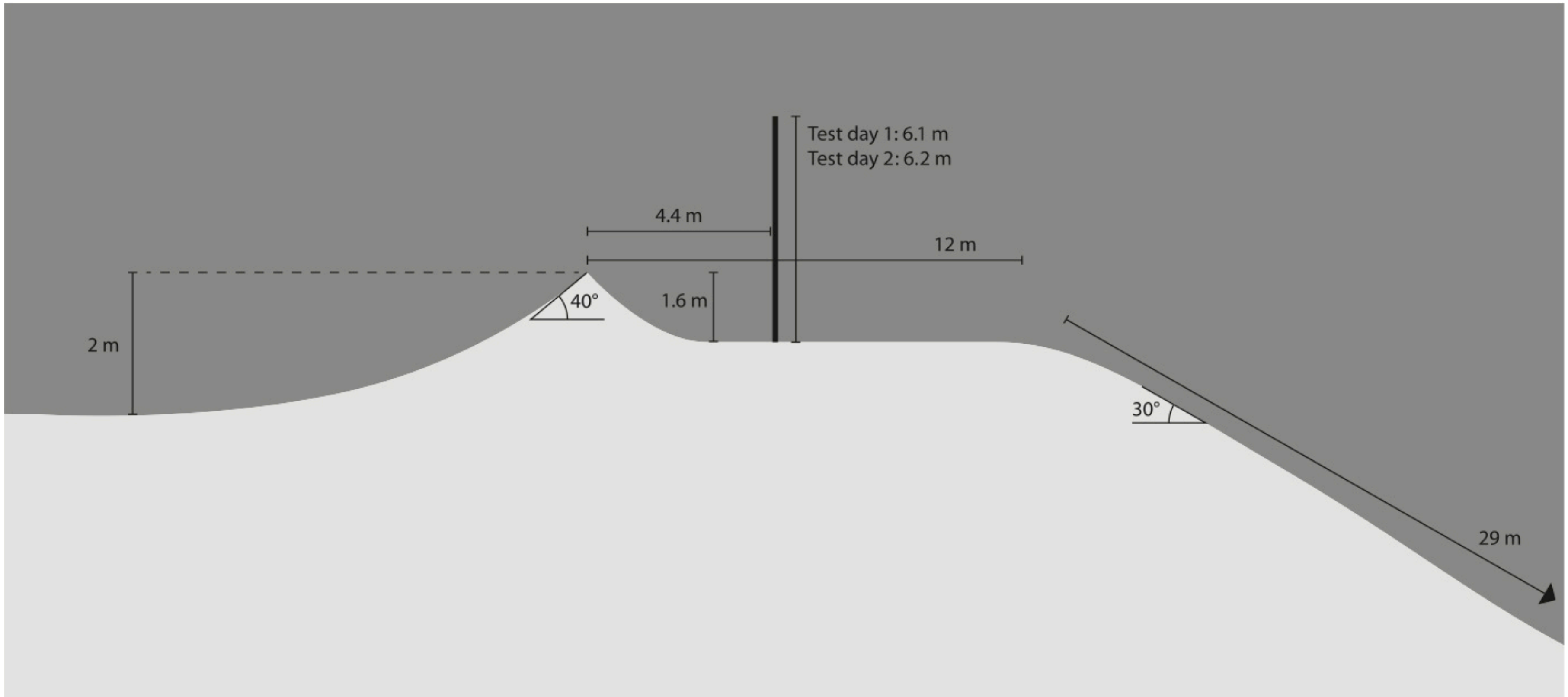

Figure 1 – Jump characteristics

Before testing, the participants warmed up for approximately 30min with sub maximal riding in the piste and the park. When testing started, first performed two straight jumps with no rotation. After this the participants were instructed to perform aerial backside or switch backside rotations on a jump, starting with a rotation that they were confident they could land and then increasing the rotation by 180 degrees. The test continued until they could not complete a greater rotation. Participants were instructed to grab Indy during their rotations to standardise the tricks. An Indy grab is when the rear hand grabs the board on the toe edge between bindings (International Ski Federation, 2010, p. 21).All the riders used their own equipment. The participants all had similar equipment with freestyle boards, boots and bindings.

Regnly Skitester photocells (Regnly Timing AB, Kolsva, Sverige) were placed on the kicker to measure take-off velocity. The first set of photocells was placed 2.5m before take-off and the second set was placed at the take-off point. The photocell pairs were 5m from each other and 20cm above the snow. A Canon XH A1 camera was placed to film the entire jump in a chairlift tower, perpendicular to the mid part of the plateau of the jump and at a height of approximately 4-6m over the plateau. The chairlift pole was approximately 39m from the side of the kicker. The camera was handheld, due to limited opportunities to attaching the camera to a tripod or to the post.

To measure jumping height over the plateau, a vertical wooden measuring stick was placed 4.4m from the take-off point. This was used as a reference tool during the video analysis in Dartfish Pro Suite 5.5 (DartFish Ltd., Freiburg, Schweiz). Its placement was based on a test film of a rider in the jump and was estimated to be where most participants would reach their peak height. The wooden stick was 6.1m the first day and 6.2m the second day, due to difficulty in drilling in the snow. A horizontal line was placed across the camera footage crossing the point where the reference stick was stuck in the snow. In the frame where the rider was perceived to have his highest position the distance between the horizontal line and the estimated centred position of the sacrum was measured. The sacrum was chosen because it was the part of the body least prone to change position or distance from the centre off mass.

To measure length of the jump, lines were placed in the landing area at every 1 m (International Ski Federation, 2008, p. 51). The first line was placed at the end of the plateau and the beginning of the landing area of the jump and was labelled as the start of the measurements with the value of 0m. Every meter after that had a value of 1, 2, 3 etc. The first day, lines were drawn up to 14 m. The second day, lines were drawn up to 10m as no one had jumped further than 10m the first day. A person standing by the landing area subjectively determined the length of the jump by sight. The person recording the take-off velocity also recorded the length of the jump. The line that the snowboarder landed with their front foot in front of was recorded. The total jumping length was calculated using the cosine function: 12 + (length down the landing * cos 30), see also Figure 2.

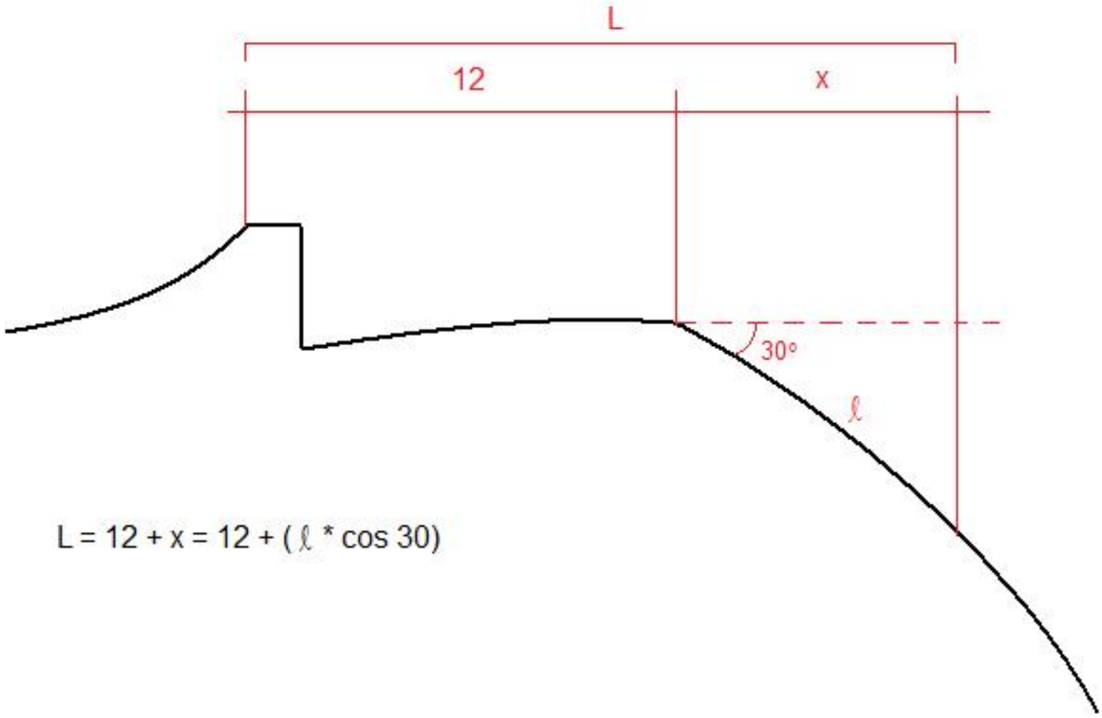

Figure 2 – Calculation of jump length

AT was calculated using the timing tool in the Dartfish Pro Suite 5.5 software (DartFish Ltd., Freiburg, Switzerland). The definition of AT used by Harding and James (2010) was used for this analysis. It was described as: “Air-time begins the first moment there is no longer contact between the snowboard and the snow and ends the moment any part of the snowboard comes in contact with the snow following an attempted aerial acrobatic manoeuvre” (2010, p. 69).

All the jumps were analysed for AT and jumping height by one person on two occasions with a one-week interval. The average of the two measures was used in the result analysis. The frame at which the max height was calculated was recorded. To determine the reliability of the person doing the analysis a paired sample *t*-test was performed with the data from the two occasions. There was a significant difference between AT and frame at the first and second analysis (*P*-value < 0.05), whereas jumping height showed no significant difference. Intra class correlation coefficients were calculated to examine if the error was constant (Table 3). This examines the correlation between the two measurement occasions.

Table 2 – Correlation coefficients between the air-time (AT), jumping height and frame data from the first and second analysis occasions

Variable	*r*	*P*
AT Single measures	0.982	*
AT Average measures	0.991	*
Jumping height Single measures	0.961	*
Jumping height Average measures	0.980	*
Frame Single measures	0.997	*
Frame Average measures	0.998	*

**P*-value <0.001

The estimator is the same when calculating the single measures, whether the interaction effect is present or not. The average measure estimate is computed assuming that the interaction effect is absent.

The degree of rotation was decided through the normal rules of snowboarding. In snowboarding rotations are always performed at intervals of 180°; 360°, 540°, 720° etc, so that the rider lands with the nose or tail facing in the direction of travel.

The weather during the tests was favorable with sun and mixed clouds. The temperature ranged between -1.7° C and -8.2° C, with a mean temperature of -3.3° C on the first day and -7.0° C on the second day. The mean humidity was 54.2% on the first day and 85.4% on the second day. Mostly it was calm but some tailwinds of up to 4m/s were registered.

2.2.2 Physiological Tests

Physiological tests were performed over two days when the snowboard season was over, 6-8 weeks after the snow tests. To warm up before the physiological tests, the participants performed a series of complex resistance exercises with a light 20 kg barbell.

To test for lower body strength and power the participants performed 1 repetition max (RM) squat, jump squat with 40% of their 1RM squat result, jump squat without weights, countermovement jump (CMJ) and CMJ with arm swing (CMJ_A). The 1RM squat was performed with a barbell. The protocol that was used was a slightly modified version of the protocol developed by Dayne, McBride, Nuzzo, Triplett, Skinner, & Burr (2011). The warm-up loads were based on previous 1RM squat testing. The participants warmed up by performing 10 repetitions at 50% of their previous 1RM, followed by 2-4 repetitions at 70% of their previous 1RM. Finally, one repetition at 90% of their previous 1RM was carried out. Three minutes of rest was allowed between each set of squats. Squats were performed down to the point where the femur was at a horizontal position. After the warm-up, the participants attempted their 1RM.

The protocol for jump squats using a barbell with 40% of their 1RM was a slightly modified version of Dayne et al. (2011). Before testing, the participants were familiarized with the exercise and performed jump squats with only the barbell (20kg) on their shoulders. Participants were instructed to lower the bar until the femur was in a horizontal position. At this point they were instructed to jump up as fast as possible while holding tightly onto the bar and the feet leaving the floor. After a resting period, each participant performed three trials of the exercise with a 1-minute rest between trials and the best result was used for analysis. To measure average power output a linear transducer (MuscleLab, Ergotest Innovation A.S., Norway) was attached to the left side of the barbell. The transducer was calibrated by manually measuring a 1m distance on the transducer string with a measuring tape before testing.

The equipment used for the three jumps without weights: squat jump, CMJ, CMJ_A was the Ivar Jump and Speed analyser, (LN Sport Konsult HB, Mora, Sweden). The participants performed three jumps of each jump and the best result was used for analysis. In the squat jumps the participants were instructed to flex their knees and hips to a self-chosen position were they believed they could perform their highest jump. After holding this position for two seconds they were instructed to push off the floor and jump as high as possible. Hands were placed on the hips during the entire jump. To avoid overestimating flight times, the participants were instructed to land with straight legs. In the CMJ the participant squatted down and immediately jumped upward while holding their hands on their hips. For the jump to be counted as a correct jump the participant had to land with straight legs. CMJ_A was performed just as the standard CMJ, except that the participants could utilise an arm swing to increase jumping height.

Chin-ups and brutal bench were used to test for upper body strength. In the chin-up test the participant started by hanging from a bar with both hands with straight elbows, thereafter pulling up so that the chin was above the bar, then lowering the body again until the elbows were straight. The test result was how many properly completed chin-ups the participant could perform. In the brutal bench test, sit-ups were performed where the participant hanged in a position so that the knees were in a 90-degree angle with the trunk hanging vertically down. The thumbs were held against the jaw and the participant then moved upward until the elbows touched the knees. This movement continued until the participant could not continue; the recorded result was the number of completed sit-ups.

The modified sit-and-reach test developed by Hoeger (1987) as cited in Maud and Foster (2006, p. 235) was used as a test for flexibility. This test was selected due to its similarities with reaching to grab the board on the toe edge. In the protocol used, the participants sat with their backs against a wall with their head, back and buttocks touching the wall. A 32.5 cm high box was placed at their feet. The participants held out their hands and placed one upon the other, without placing one in front of the other. A measuring stick was placed on top of the box with the zero point at the fingertips. The participant then reached forward as far as they could and held the position for 2 s. The distance moved from the starting point to the position where the participant held the position for 2 s was recorded. The procedure was repeated and the average of the two results was used for analysis. (Maud & Foster, 2006, p. 235)

2.3 Statistics

All data was tested for normal distribution using Shapiro-Wilks test. Means and SD were calculated for all variables and tests. A one-way ANOVA for repeated measurements was performed to detect differences in jumping height, jumping length and AT between the different rotations. To find significant differences between two specific degrees of rotations the Fischer LSD test was used. Pearson's correlation coefficient was used to examine correlations between normal distributed scale data. Spearman's rank correlation was used to calculate correlations between ordinal and scale data and data not normally distributed. A paired sample *t*-test was performed on the video analysis data from the two occasions to determine the reliability of the method and analyser. Intra class correlation coefficients were also calculated to determine if the errors were constant. The level of significance was set at P-value of <0.05. For intra class correlations, significance levels were set at P-value of <0.01. IBM SPSS Statistics 19 Software for Windows (SPSS Inc., Chicago, IL, USA) was used for the statistical analyses.

3 Results

3.1 Snowboard tests

In total 110 jumps were performed, 32 resulted in a crash and were discarded from the result analysis. Table 3 shows the take-off velocity, jumping height, jumping length and AT for the eight different rotations performed and the straight jumps without rotation. If a participant completed more than one jump of the same rotation the mean value of the participant's jumps was used in the statistic analysis when comparing different rotations. The 360°, 540° and 720° rotations had the highest number of participants performing them with 6 or 7 riders completing each rotation. The range in mean take-off velocity for the single axis rotation varied between 14.2m/s to 14.9m/s. In five out of the seven single axis rotations the mean take-off velocity was 14.7m/s. A one-way ANOVA showed a significant difference in jumping height and AT between the 360°, 540° and 720° rotations. Fischer LSD showed that there was a significant difference between the 360° and the 720° in terms of jumping height and AT (P-value<0.05). A tendency to difference in jumping height was discovered between the 360° and 540° rotation (P-value<0.1). The straight jumps had a longer mean jumping length than all rotations 900° and below.

Table 3 – Summary of difference in take-off velocity, jumping height and jumping length, air time (AT) between different rotations

Degree of rotation	Take-off velocity (m/s)	Jumping height (m)	Jumping length (m)	AT (sec)
0° (n=9)	14.6 ± 0.5 (n=9)[a]	5.7 ± 0.3	17.5 ± 1.6	2.06 ± 0.09
180° (n=2)	14.7 ± 0.0 (n=1)[a]	5.5 ± 0.2	16.8 ± 1.8	2.03 ± 0.04
360° (n=7)	14.2 ± 0.3 (n=7)[a]	5.5 ± 0.4	14.9 ± 1.8	1.86 ± 0.14
540° (n=6)	14.7 ± 0.9 (n=3)[a]	5.8 ± 0.4	15.9 ± 0.6	1.98 ± 0.07
720° (n=7)	14.9 ± 0.5 (n=5)[a]	6.1 ± 0.4*	16.3 ± 2.2	2.07 ± 0.16*
900° (n=3)	14.7 ± 0.0 (n=1)[a]	6.1 ± 0.4	16.2 ± 1.9	2.01 ± 0.14
1080° (n=2)	14.7 ± 0.0 (n=1)[a]	6.4 ± 0.4	17.6 ± 0.6	2.17 ± 0.07
Sdc[b] 1080° (n=1)	13.9 ± 0.0 (n=1)[a]	5.6 ± 0.0	14.7 ± 0.0	1.89 ± 0.00
1260° (n=1)	14.7 ± 0.0 (n=1)[a]	6.0 ± 0.0	17.0 ± 0.0	2.05 ± 0.00

[a] = Velocity data not available on all jumps. [b] = Switch double cork. The values shown are mean ± SD. * $P<0.05$ as compared to 360°.

The highest rotation completed by a majority of the participants was a 720°, which was performed by seven participants. Each participant's subjectively judged best 720° are presented in Table 4. The highest ranked jump has neither the highest jumping height, jumping length or AT, which is held by the second highest ranked jump.

Table 4 – Characteristics of participants' best 720° jumps with subjective ranking

Rank	Jumping height (m)	Jumping length (m)	Air time (sec)
1	6.5	18.9	2.22
2	6.6	20.7	2.37
3	6.5	15.5	2.12
4	6.0	14.6	2.00
5	6.4	16.3	2.05
6	5.7	14.6	1.99
7	6.2	18.1	2.19

3.2 Laboratory tests

The results of the strength and flexibility tests are presented in Table 5.

Table 5 – Physiological test results (n=9-11)

Test	Mean ± SD	Range
Squats 1RM (kg)	92.5 ± 20.7	60-130
Jump squat 40% 1RM (W)	421.0 ± 104.6	282.5-573.8
Squat jump (cm)	35.0 ± 3.8	31.6-40.7
Countermovement jumps (cm)	37.6 ± 3.4	33.5-42.1
Countermovement jumps with arm swing (cm)	43.8 ± 4.1	36.4-50.9
Brutal bench	19.7 ± 6.8	10-30
Chin-ups	9.0 ± 5.1	5-20
Sit-and-reach (cm)	36.3 ± 6.0	29.5-47.0

3.3 Correlations

The ranking with the best subjectively judged 720° jumps of each participant correlated with body height with $r = -0.91$ (P-value<0.05). No significant correlations were found between the subjective ranking for the 720° jumps and jumping height, jumping length or AT. None of the strength and flexibility tests produced significant correlations with the subjective ranking of the best 720° jumps.

4. Discussion

The main findings in this study were that jumping height and AT was higher in a 720° jump than a 360° jump. No correlations were found between jumping height, jumping length, AT or any physiological characteristics with the subjectively judged snowboard jump performance.

When comparing the different single axis rotations the range in mean take-off velocity was small, 14.2m/s to 14.9m/s. This was likely due to that these take-off velocities were appropriate to land in the sweet spot of the landing. The sweet spot is where the slope of the landing is most suited for touchdown. Looking at the straight jumps the jumping length and AT was higher than all rotations 900° and below. The jumping height was higher than the 180° and 360° rotations. A factor that explain this include that when the snowboarders perform rotations, the edge of the snowboard is in the snow just before take-off, resulting in a breaking effect. The push off on the kicker is likely not straight up, but more sideways resulting in lower jumping height, jumping length and AT. When performing 180° on a jump of this size the riders do not have to utilize edging as much at take-off, which might explain the fact that the jumping length, and AT was higher than for the 360° and 540° rotations. The jumping height for the 180° was the lowest among the rotations. This might be explained by the fact that a strong push off can result in over rotation.

In the rotations with most jumps: 360°, 540° and 720° the jumping height and AT increased with rotation, however the difference was only significant between the 360° and 720° rotation. The 1080° jumps had higher jumping height, jumping length and AT than the 360°, 540° and 720° jumps and the 1260° jump had longer jumping length and AT. The 900° jumps had higher jumping height and AT than the 360° and 540° jumps. It is reasonable that to achieve a higher degree of rotation a certain AT is needed. This has been shown in half-pipe snowboarding (Harding et al., 2008c, p. 285). The reasons for the lower jumping height, jumping length and AT for the lower rotation is unknown, is it lower because it does not need to be higher or because the participants can not perform the rotation higher and longer?

It is interesting to note that the sdc 1080° jump had among the lowest jumping heights, jumping lengths and AT. It is hypothesized that the trick is so complicated that rider focuses so much on initiation the rotation on the kicker that the push off is not prioritised. Psychology might have some interference with the short jumping length and AT, the complexity of the trick results in increased anxiety of flying too far and the rider reduces the velocity approaching the kicker. This combined with a weak push off at take off resulted in short jumping length and AT. The same factors might explain the fact that the 1260° had lower jumping height, jumping length and AT than the 1080°. The few jumps observed of this type make it hard to make generalizations.

In the ranking of the best 720° jumps there was a relatively large range in result in jumping height (5.7m-6.6m), jumping length (14.6m-20.7m) and AT (1.99s-2.37s). Despite this, no correlations were found between the rank of jumps with take-off velocity, jumping height, jumping length or AT. This can possibly be explained by the fact that there were only seven jumps in the analysis, correlations are more difficult to attain with few participants. This also proves the importance of personal style in the jump, which is described in the judging criteria's in both the FIS and TTR (International Ski Federation, 2010; Swatch TTR World Snowboarding Tour, 2010-12-27), and has been argued in many articles (Harding & James, 2010; Harding & James, 2008d; Harding et al., 2007b; Harding et al., 2008b). It is interesting that the highest ranked jump neither had the highest jump height, jumping length or AT. Also the lowest ranked jump had the third highest jumping length and AT.

A peculiar significant correlation was the one between the rank of the participants with the subjectively determined best 720° jumps and body height. In gymnastics, which has similarities to snowboarding in its rotational movements it has been found that increased body height has a negative impact on rotational performance (Ackland, Elliot, & Richards, 2003; Faria & Faria, 1989).

No significant correlations where found between the rank of the participants' subjectively judged best 720° jump with any of the strength or flexibility tests. This might be due to the small number of participants or because of the fact that none of the tests measure physiological variables that are important to performance. Other factors such as psychology, timing or co-ordination might be more influential in snowboarding performance. It is also plausible that the strength and flexibility in itself does not help performance, but that it is a prerequisite to avoid injuries (Hogg, 2003, p. 495)

The participants physiological test scores show a heterogeneous group. This is illustrated by the wide range in Squats, Jump squat at 40% of squat 1RM, Brutal bench and Chin-ups. The mean CMJ_A score was the highest jump score, and the highest CMJ_A score was a lot higher (50.9cm) than the Squat jump (40.7cm) and the CMJ (42.1cm). When comparing the participants' results in the CMJ all participants were in the range that the males in the Austrian national snowboard team achieved in the article by Platzer et al. (2009). The Austrian athletes (n=21) had a range in the results of 32.5-48.9cm (Platzer et al., 2009, p. 1428). The best Austrian athlete jumped 6.8cm higher than the best participant in this study, however the athletes in the Austrian national team were older than the participants in this study, with a mean age of 22 ± 3.9 years. Platzer et al. (2009, p. 1130) found a significant regression coefficient of 0.78 between FIS world cup points and countermovement jumps. However that statistical relationship was based on only nine participants so it should be interpreted with caution. Since only seven participants were include in the correlation analyses in this study it is not surprising that no such significant correlations were found.

In conclusion, jumping height and AT increased with degree of rotation. No relationships were observed between jumping height, jumping length, AT or with subjectively judged snowboard jump performance. The rank of the best 720° was primarily based on the athletes' personal riding style. The physiological tests showed no relationship to the subjectively judged snowboard jump performance. Other factors such as psychology, technique and coordination might be more important for performance. Therefore, more research is needed with a larger sample size to determine whether physiological variables are important for performance. In addition, research should focus on developing better methods for measuring snowboard jump performance in the field. Freestyle snowboarding is a sport but also an art form, therefore, athletes' personal style and freedom of expression is important and should be considered.

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Appendix A

Literature review

Aims and Objectives: *The aim of this study is to examine how different biomechanical and physiological variables relate to performance. The first objective is to examine how tricks with different rotations and no rotations in a jump differ in velocity at take-off, jumping height, jumping length and AT. The second objective is to identify which biomechanical and physiological parameters correlates with snowboard jump performance. Performance is defined as a ranking of the athletes best 720° jump and the points awarded to that jump subjectively determined by an experienced snowboard judge.*

Which search words did you use?

Snowboard, Snowboarding, Snowboard Jump, Performance, Determinants of performance, Skiing, Ski, Gymnastics, Body height, Power, Testing, Kinetics, Kinematics, Ski jump, Landings, Freestyle skiing, Harding

Where did you search?

Catalogue at GIH library, PubMed, Google Scholar and reference lists of relevant articles

Which searches gave relevant results?

Google Scholar: Snowboard Performance
Google Scholar: Snowboard Jump
Google Scholar: Snowboard Harding
PubMed: Gymnastics Body Height
PubMed: Ski jump

Comments

Most research concerning snowboarding is about injuries, not much about snowboard performance. Jason Harding has done research about half-pipe snowboard performance, however very little research was found about jumping. I found a lot of research in the reference lists of the good articles I found. I found good information on the FIS and TTR websites.

Appendix B Informed Consent Form

Försökspersonsinformation för studien:

Biomechanical and Physiological Determinants of Snowboard Jump Performance

(Biomekaniska och fysiologiska parametrar som förutsäger prestation i snowboard hopp)

Studien genomförs av Alette Vestly, Magisterkursstudent i Idrott vid GIH. Handledare för projektet är HC Holmberg, Professor vid Institutionen vid Hälsovetenskap vid Mittuniversitetet och Mikael Swarén, Laboratorieingenjör vid Institutionen för Hälsovetenskap vid Mittuniversitet. Båda är verksamma vid Nationellt Vintersportcentrum.

Bakgrund

Flera faktorer påverkar prestationen i snowboard/hopp; psykologiska, fysiologiska, biomekaniska, väder etc. Denna studie syftar till att undersöka och identifiera vilka fysiologiska och biomekaniska parametrar som är av betydelse för att prestera bra i snowboard/hopp.

Genomförande

Studien kommer genomföras vid två olika testtillfällen. Det första kommer genomföras vecka 10 och 11 under era vanliga träningstillfällen i Kläppen Snowpark. Efter uppvärmning kommer ni att få tre försök att genomföra en backside rotation med en standardiserad grab vid en fot i det andra svarta hoppet. Börja med det antal rotationer som ni känner er säkra på att kan klarar av att landa med. Klarar ni det försöker ni på en större rotation. Ett hopp räknas som godkänt om ni landar utan fall eller reverts.

Fotoceller kommer att vara placerade på kicken för att mäta utgångshastigheten från kicken. Längden på hoppet kommer mätas manuellt. Hela hoppet kommer att filmas från den bredvidliggande liftstolpen till stolsliften. Från videon kommer även tid i luften och hopphöjd att analyseras.

Det andra testtillfället kommer att äga rum i slutet av april eller i början av maj i samband med att ni har era ordinarie fystester. Ett flexibilitetstest kommer att adderas till testbatteriet. Flexibilitetstestet kallas ”sit and reach test” (sträcker dig fram sittandes på golvet med raka ben och försöker nudda tårna).

Vid knäböj kommer ett mätinstrument (en s.k. ”linear transducer”) att fästas vid skivstången och mäta hastighet/explosiviteten i rörelsen.

Alla testdeltagare kommer att få se på video efter hoppen och bedöma varje åkare, för att skapa en ranking (dessa resultat är helt anonyma och endast den sammanlagda rankingen kommer att presenteras). Eventuellt kommer en domare också titta på videomaterialet, bedöma åkningen och skapa en annan ranking. En tredje ranking kommer att skapas genom ranking av antal rotationer och tid som grab hålls. Dessa rankingar kommer sedan jämföras med testresultat från fystesterna.

Viktigt att tänka på

Dygnet (24 timmar) före testerna får du ej genomföra något tungt fysiskt arbete (>30min) eller använda alkohol.

Jag har muntligen informerats om studien och har tagit del av ovanstående skriftliga information. Jag är medveten om att mitt deltagande är helt frivilligt och att jag när som helst och utan närmare förklaring kan avbryta mitt deltagande.

………………………… …………………………

Namnteckning Datum

………………………………

Målsmans underskrift (om du är under 18år)

Kontakt

Har du frågor eller funderingar tveka inte att kontakta mig på ***avestly@yahoo.se****, 072-3374925 eller någon av mina handledare:*

H-C Holmberg, hc.holmberg@miun.se

Mikael Swaren, mikael.swaren@miun.se

Appendix C Snowboard Terminology

Backside rotation	= A regular rider rotates clockwise and a goofy rider rotates counter clockwise
Banks	= Banked turns
Big Air	= Competition discipline where competitors are judged on tricks performed on a jump
Boarder-cross	= Competition discipline where four riders race head to head down a track with rollers, banks and jumps
Box	= A box made of wood with metal edges and a plastic sheet on top that is used to perform sliding tricks on
Cork	= Inverted spin around the XX axis
FIS	= International Ski Federation
Frontside rotation	= A goofy rider rotates clockwise and a regular rider rotates counter clockwise
Goofy stance	= Stance where the right foot is facing the direction of travel
Grab	= Grabbing the board with one or both hands
Half-pipe	= Competition discipline where competitors perform tricks on the walls of a half-pipe which is a man made structure in the shape of the bottom half of a pipe with added vertical walls
Heel side	= The edge of the snowboard where the heels are facing
Indy Grab	= Back hand grabs toe side between the bindings
Handrail	= A metal rail similar to handrail in stairs used to perform sliding tricks on
Kicker	= Part of jump where take-off takes place
Knoll	= The edge between the plateau and landing
Mute grab	= Front hand grabs toe side between the bindings
Nose	= Front end of snowboard
Nose grab	= Grabbing the nose with the front hand
Parallel slalom	= Competition discipline where two competitors race head to head down a course of gates
Plateau	= Part of jump between kicker and landing
Regular stance	= Stance where the left foot is facing the direction of travel
Rollers	= “waves” made out of snow

Slopestyle	= Competition discipline where competitors perform tricks on jumps, boxes, rails and other man made features
Stalefish grab	= Back hand grabs heel edge between the bindings
Switch	= Riding with the right foot forward for a regular rider and riding with the left foot forward for a goofy rider
Tail	= Back end of snowboard
Tail grab	= Grabbing the tail with the back hand
Toe side	= The edge of the snowboard where the toes are facing
TTR	= Swatch Ticket To Ride Tour World Snowboarding Tour

Appendix D Methodological Considerations

Since this study is the first of its kind and much of the methodology has never been trialled or tested before there were some complications and difficulties. This section aims to explain these and critically reflect about the reliability and validity of the study to help future researchers.

The validity in the method of measuring velocity at take-off can be argued as imprecise. The velocity during the last 2.5m before take-off could differ from the actual velocity at take-off as some of the riders perform carved turns just before take-off to aid the rotation. However measuring the precise velocity at take-off presents several difficulties in methodology and doubtlessly requires advanced expensive equipment, which the budget for this study did not cover. The resolution of 0.01s in the equipment determining velocity on the kicker was limited. When measuring velocity over such a short distance as 2.5m a difference of 0.01s is a large velocity difference. Only three different velocities were observed. The times observed for covering the last 2.5m of the kicker was 0.16s, 0.17s and 0.18s. This converts into m/s to 15.63m/s, 14.71m/s and 13.90m/s. Early in the research process other equipment was trialled however there were large difficulties in lining up the photocells on the kicker so that they connected. The steep, wide kicker made of snow makes is difficult to place and adjust the position of the photocells. Another problem in this study is the lack of velocity data from the first test day due to malfunctioning of the equipment.

When analysing jumping height, several sources of error where present. Baggy clothes worn by participants, filming from a distance and different body positions in the air at peak height made locating the sacrum difficult. Some participants also wore dark clothes, which resulted in difficulties to differentiate between the snowboarder and the dark forest in the background. Vibrations from the chairlift and from the person holding the camera resulted in the camera not keeping its horizontal position at all times. When the picture is not horizontal the horizontal lines from which jumping height was measured from were positioned wrong.

There is a risk of perspective errors when the referencing tool and the participant are not at the exact same distance from the camera. Despite this the errors are thought to be minimal due to the extensive distance between the participant, referencing tool and camera (39m). Sometimes the length reference had to be done in a different frame than in the frame where the participant reached peak height due to blocking of the referencing tool. Also in the AT analysis there were some limitations. The view from the camera was not completely side-on from the kicker, which made it hard to determine exactly which frame the rider left the snow at take-off and touched it in the landing. This resulted in the difference in AT between the two analysis occasions.

The only reliability factor examined in this study was the reliability of the video analyst in the analysis of jumping height and AT. There was a significant difference between the first and second analysis for AT and frame where jumping height was measured, however the unreliability is constant so the impacts for the total reliability is deemed minor. Sources of unreliability in this study that have not been examined are the subjective judging of the 720° jumps and the subjective determination of jumping length. The judge that ranked the 720° jumps where a very qualified judge with experience in judging in the World cup and Olympics. To increase reliability more than one judge could have been used and the judges could have analysed and scored the jumps twice. The method of measuring length was limited since two different individuals performed it due to limited availability. No comment can be made about the people determining jumping length except that they were experienced coaches with much experience in analysing snowboarding including jumping length. Having more than one person determining jumping length would increase reliability. The resolution of this method is also limited since the length could only be determined in whole meters. The reliability of the strength and flexibility tests is unknown since no test-retest was made. However other studies have shown reliability with the test protocols (Dayne et al., 2011; Maud & Foster, 2006).

Familiarization of the test protocol is important when doing any kind of strength testing (Maud & Foster, 2006, p. 124). Some of the younger participants in this study had less experience with the free weight exercises, such as the squats and were stopped from testing a higher weight due to the presence of poor lifting technique. This might have resulted in sub maximal results for some participants. When testing power output during the squat jump with 40% of 1RM squat weight, only one linear transducer and no force plate were used. This was used in Dayne et al. (2011). Since the jump squats is a free weight exercise and the familiarisation process of the exercise was very short it is possible the barbell was not horizontal at all times resulting in errors in both displacement and velocity of the barbell.

The standardisation of tricks was faulty in some aspects. One participant mixed backside- and switch backside rotations during the test days. Other grabs than indie grabs where observed and not all jumps had a grab in them. Also tricks with more than one axis of rotation were observed. It is plausible that all participants did not perform at their highest ability during the two testing days. They may not have reached the highest rotation they can achieve or they may not have performed their 720° jumps at their best capacity.

The snow tests where performed over two days to enable more participants. Some participants attended both days and some only one. This might give some riders and advantage cause the got more tries. The jump had the same measurements both days but snow conditions may have differed. The weather was pretty similar tho some gust winds on of the days may have resulted in longer flights.

All strength tests used in this study except the jump squat with 40% of 1RM squat, where tests that the participants normally performed twice a year. They where chosen because the participants had done them before and they where possible to do in the field. Instead of the jump squat with 40% of 1RM squat test some jump squat protocol with % bodyweight is suggested, as it would be more relevant to the sport. However no such protocol where found by the author. Some kind of balance test would be interesting to examine, as it is relevant for the sport.

One of the main weaknesses of this study is the low number of participants. Eleven riders participated in the study but only seven riders completed the 720° jump. The subjective ranking of the 720° jumps was chosen as the factor to measure snowboard performance because it was the trick with the highest degree of rotation that a main part of the participants completed. With such a low number of participants in the analysis it is difficult to get strong relationships between factors.

Much can be learned from this study in terms of what works methodology wise. With more time, more advanced equipment and a bigger budget many things can be improved. Further research should focus on improving methodology to better understand the mechanisms in freestyle snowboarding.