THE EFFECT OF A CHANGE IN THE DIFFICULTY LEVEL OF THE BIG AIR JUMP TAKE-OFF PHASE IN JOINT KINEMATICS OF SNOWBOARDING ATHLETES

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ABSTRACT

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The purpose of this study was to elucidate the kinematic differences in the take-off phase of backside 360°, backside 540°, and backside 720° jumps in freestyle snowboarding. The study was conducted with 3D motion analysis. Five athletes (1 woman, 4 men), aged 18-30 years, performed backside 360°, backside 540°, and backside 720° jumps from Ruka Park's biggest jumper. The jumps were filmed with two high-speed cameras, one on each side of the jumper. The performance area was calibrated with a 2 m x 4 m calibration frame. Videos were manually digitized with Vicon Motus 10.0.1. Segments were determined according to DeLeva's (1996) segment parameters. Twenty markers in each subject were digitized from each frame and both cameras.

Vicon Motus 10.0.1 was used to calculate centre of mass horizontal and vertical velocities, knee and hip joint angles, and knee and shoulder joint angular velocities for each jump. The results were interpreted descriptively and on a case. Results show that each subject had their own style of doing the jumps. Centre of mass vertical velocity increased as the difficulty level of the jump increased for all subjects. Instead, centre of mass horizontal velocity decreased as the difficulty level of the jump increased for some subjects, and for some subjects, centre of mass horizontal velocity increased as the difficulty level of the jump increased. The change in average knee joint angles in front leg as the difficulty level of the jump changed varied between subjects. Average knee joint angles in back leg increased as the difficulty level of the jump increased. Average hip joint angles increased both in front and back legs as the difficulty level of the jump increased for all but one subject. Knee and elbow joint angular velocities were higher when there were more rotations in the jump.

As a conclusion, the joint angles in knees and hips, and the angular velocities in knee and elbow joints varied between jumps. However, the changes were subject-dependent. Centre of mass vertical velocity increased as the difficulty level of the jump increased, and centre of mass horizontal velocity varied more. Further studies should include more subjects to have statistical information from the differences. Also adding more cameras would make digitizing and analysing easier. In the future, the effects of the weather must also be better considered when planning measurements. Accelerometers, pressure insoles, and muscle activity measurement could possibly be combined with further studies.

Key words: snowboarding, motion analysis, freestyle, big air, kinematics

ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
COM	centre of mass
COP	centre of pressure
GRF	ground reaction force

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APPENDICES

1 INTRODUCTION

Snowboarding is popular sport and there are a lot of competitive athletes (Flørenes et al. 2010). Snowboarding includes freestyle snowboarding, snowboard-cross, and alpine snowboarding. In freestyle snowboarding athletes perform tricks and jumps either on the slopes or using specially built rails and half pipes. (Vernillo et al. 2018.) This study focuses on freestyle snowboarding.

Snowboarding needs field experiments of biomechanical research because of the large distance over which the activities take place and the specific surface and slope (Klous et al. 2010). Kinematic data collection in alpine environment needs to be planned and conducted very conscientiously. The environment is very challenging.

Snowboard research is quite recent and the research for sport performance indicators in snowboarding is scarce. A search of snowboarding research reveals studies focussed on injury risk. Other studies have either focused on other snow sports such as skiing or ski jumping or other components of snowboarding such as forces on body or equipment (boots and bindings). The landing has been the most studied phase of motion in snowboarding both in kinematic and kinetic variables (Bacik et al. 2020).

There are only a few three-dimensional (3D) analyses of biomechanics of snowboarding. It is due to the complexity of the field data collection. Most of those studies are limited to a restricted capture volume. (Krüger et al. 2011.) The activities take place over a large distance (Muñoz et al. 2018). It is also difficult to conduct research in a standardised natural on-snow environment (Bacik et al. 2020). The specific topography of the slope brings its own addition to research (Muñoz et al. 2018). This study was performed in an outdoor environment which makes it more challenging to implement. There are only a few biomechanical studies about the flight phase and take-off phase of snowboarding. It can be due to the recent advent of the sport. This study will focus on kinematic variables in snowboarding jump take-off.

Technology used in skiing biomechanics research includes high speed cameras. Challenges such as variable temperature, light, surfaces and the tedious process of carrying and setting up the testing equipment influence to measuring methods. Difficult movements including all anatomical axes being attempted cause it even more challenging to precisely measure biomechanical parameters. (Kupiers 2010.) The purpose of this research is to analyse snowboarding in order to better understand its kinematics. This study will investigate the kinematics of the take-off phase.

2 FREESTYLE SNOWBOARDING

Snowboarding is a very popular snow sport in which jumping is an essential part of the sport (McAlpine 2010; Vernillo et al. 2018). It got its current form in the United States in the 1960s (Vernillo et al. 2018). Snowboarding received Olympic sport status in 1998 (McAlpine 2010). Snowboarding is influenced by surfing and skateboarding (McAlpine 2010). Slalom was the first discipline, but today snowboarding includes also snowboard-cross, Big Air, Half Pipe and Slope Style (Atkinson & Reilly 1995, 323). It involves performing jumps and ‘aerobatics’ on obstacles which can be found in snow parks. Freestyle snowboarding is the most popular snowboard style. (Zygmuntowicz & Crezwiński 2007.) Freestyle snowboarding is skill-based discipline where athletes perform tricks and jumps either on the slopes or using specially built rails and half pipes (Vernille et al. 2018).

In snowboarding both feet are placed on the same board (Delecluse et al. 2001). Athletes stand perpendicular to the long axis of the board and change direction and speed by altering their body position with respect to the board. Most of the snowboarders ride with the left leg forward and use their arms for balance. Heels rest on the backside of the board and the toes rest on the frontside of the board. (McAlpine 2010.) Boards used in freestyle snowboarding are large and flexible which allow the boarder to make spectacular jumps and figures in the air or on the slope (Delecluse et al. 2001).

Snowboarding is an athletic sport. Athletes need strength, aerobic fitness, coordination, technique, proper equipment, and mental strength to prevail in a contest. Those properties are required to prevail over an entire season. (Platzer et al. 2009.) It is important to know for example the muscular forces, biomechanics and energy systems involved in snowboarding. That kind of knowledge could be used for training prescription, performance enhancement, injury prevention and talent identification. (Vernillo et al. 2018.)

2.1 Big Air

One of the freestyle snowboarding disciplines is Big Air (Zygmuntowicz & Crezwiński 2007). It is one of the most recently developed snowboarding disciplines (Atkinson & Reilly 1995, 323). Big Air was a new event in the 2018 Winter Olympics (Parmar & Morris 2019). It is performed on artificial slopes, and it is very spectacular and popular discipline. In the Big Air the athletes perform one jump. The time needed to reach the top-level is approximately ten years. (Atkinson & Reilly 1995, 323.) There are different age limits for different events in freestyle skiing and snowboarding. To compete in international Big Air competitions, a competitor must have reached the 13th birthday before the end of the previous calendar year. To compete in major competitions, a competitor must have reached the 15th birthday before the end of the previous calendar year. (FIS 2020.)

In Big Air competitions judging criteria include execution, difficulty, amplitude, variety, and progression (FIS 2020). Execution encompasses take-off, grabs, air control, flow, style, and landing. Control should be maintained throughout the whole run. In a well-executed take-off, the competitor should have proper timing on the take-off to get a clean “pop” off the lip of the jump. In a clean landing, the competitor will land on the feet or lightly on edge with no other part of the body or equipment contacting the snow. Grab should be made on the board and not anywhere else. Style and flow are subjective. Amount of rotation, direction of rotation, axis, blind landings, grabs, use of course, trick location, amplitude, risk taking, combinations, straight airs and small rotation tricks, jumps, and rails are factors affecting the difficulty level. New or uncommon tricks, creativity, and grabs are the factors affecting the progression criteria. (FIS 2019.) The difficulty is related to the number of vertical and horizontal spins (Parmar & Morris 2019). The scoring system is similar to the system used in gymnastics (Atkinson & Reilly 1995). There is detailed technical data of the Big Air ramp, kicker, and landing dimensions in The International Snowboard / Freestyle Ski / Freeski competition rules book (FIS 2020).

Most of the injuries during Big Air competitions result from falls. Athletes suffer from injuries because of technical errors such as loss of control, catching the edge, carelessness, and for taking risks. To lessen the number of injuries a proper preparation for the snowboarding season is necessary. (Zygmuntowicz & Crezwiński 2007.) Big Air has the highest incidence of injuries of snowboarding disciplines (Platzer et al. 2009).

3 FACTORS AFFECTING SNOWBOARDER’S PERFORMANCE

Factors affecting snowboarder’s performance are strength, aerobic fitness, coordination, technique, equipment, environment, and psychological factors. Fitness testing is necessary to evaluate physiological factors. (Platzer et al. 2009.) Board’s design, the snowboarder’s stance and riding technique determines part of a snowboarder’s performance. Posture controlling is the hardest element when learning to snowboard. Snowboarder needs an asymmetrical lateral positioning of the body. The size of the base of support, the position of the centre of pressure (COP), the snowboarder’s body mass, and the direction of the gravitational force affects the stability. (Staniszewski et al. 2016.)

Orientation of the body is an important factor when making turns (Meyer 2012). Turns need the direction impulse. It starts when the snowboarder puts his/her weight on one edge of the board to make it change direction. Snowboarder leans in the sagittal plane while his/her head must face the slide’s direction. (Staniszewski et al. 2016.) It helps to initiate turns with considering pre-rotation as the most important factor in the initiation phase. Pre-rotation helps to transfer an angular momentum from torso to the legs. (Meyer 2012.)

Balance control is necessary also in turns. Stability is maintained during the turn with an inertial force which is in opposite direction to the centripetal force but the same velocity and magnitude. The value of the inertial force cancels out the forces which might overturn the snowboarder. It is directly proportional to the square of the rider’s velocity and inversely proportional to the curve’s radius. (Staniszewski et al. 2016.) Control of a correct position is done with m. rectus femoris activation. Knee and ankle extensions release the board from pressure and make the turns possible. The m. vastus medialis has an active role in turns. (Delecluse et al. 2001.) The snowboarder’s lean angle into the turn must increase when velocity is greater or turn radius is smaller (Spörri et al. 2012).

Factors that affect jump performance in freestyle skiing include starting position of the skier on the hill, approach speed prior to the jump, jump height, wind velocity and direction, rotation rate of the skier, the position and time of the manoeuvre, and the landing surface characteristics. These factors influence not only to take-off phase but also to the landing. (Mecham et al. 1999.) The same factors affect the performance of jumps in freestyle snowboarding as well.

Also, changing conditions on the ski course affect athletes' performance. Unfortunately, changing conditions cannot be avoided completely in outdoor circumstances. (Supej et al. 2005.) Supej et al. (2005) investigated 3D kinematics on a slalom ski course and the effect of changing conditions on several kinematic parameters. Investigated parameters were the centre of gravity and arithmetic mean of the skis' velocity, the length of the centre of gravity's and arithmetic mean of the skis' trajectory, the horizontal and vertical point of the start and the end of the turn and the time needed to complete a turn. They found out that almost all the observed parameters result in differences. It is impossible to assure same conditions to all competitors under weather and snow conditions. (Supej et al. 2005.)

3.1 Jumping Performance

Snowboarding jumps involves flips and twists while being in the air. There are several different flips which include twisting and tucking motions. Jumps can be several meters high and air flight is several meters long, too. The landing zone is lower in the slope than jump kicker when a total drop of the jump will be over 10 meters. (Mecham et al. 1999.) International Ski Federation describes jumping in snowboarding in Judges Handbook – Snowboard & Freeski Edition 2019/2020 as follows. In a well-executed take-off, the snowboarder has proper timing on the take-off to get a clean "pop" off the lip of the jump. The width of take-off can affect the difficulty of jump. Snowboarder reaches high arching trajectory. Airtime or amplitude of a jump needs to be considered. Rushed take-off, low pop, or starting the rotation prematurely on the lip of the jump can negatively affect the execution. The tricks should be completed in preparation for landing. Landing should be made on the feet with no other part of the body or equipment contacting the snow. Grabs should be made on the board/ski and not anywhere else. (FIS 2019.)

Snowboarding jump can be performed with or without rotation (Bacik et al. 2020). Trick can also be on or off axes, inverted, and on frontside or backside during take-off or landing (Turnbull et al. 2011). The aerial manoeuvres with rotation can be divided into three categories. Those categories are rotations about the vertical body axis, two-plane rotations, and flips. (Bacik et al. 2020.) Average airtime and average degree of rotation are the strongest key performance indicators associated with success in snowboarding. The differences between athletes in those two indicators are the things that separate top three rankings from the others in the competitions. If the athlete is focusing only on airtime and not on the number of rotations, he/she does not achieve high scores in competitions. (Harding & James 2010.) The amount of rotation can affect the difficulty but not always. Sometimes larger amount of rotation does not necessarily increase the difficulty. By spinning in all directions, snowboarder can increase the difficulty. Also, the axis of a rotation can increases the trick difficulty. (FIS 2019.)

While making turns and preparing for the jumps, snowboarder must lean with his/her bodyweight towards the centre of the turn to maintain balance. In frontside position the centre of gravity will be at the toe side and in backside position it will be at the heel position. (Delecluse et al. 2001.) Any body movement that causes the athlete's somersaulting axis to move away from the direction of the total angular momentum vector will produce twisting around longitudinal axis (Marinšek & Čuk 2013). To perform multiple rotations with control, snowboarder's centre of mass (COM) must gain as much height above the lip as possible. Airtime can also be gained by travelling horizontally. Jump height is determined by the vertical velocity of the COM at the take-off. It is dependent on the horizontal velocity before take-off. Snowboarder can increase propulsive forces by "pumping" the snow. It involves lower limb extension when ground reaction force (GRF) increases, thus applying pressure into the snow, allowing the force normal to snow to cause more horizontal velocity. (Turnbull et al. 2011.)
Also edge control and board trajectory are important factors in gaining required speed to perform multiple rotations in the air. Snowboarder can increase speed with forceful ankle pronation and large valgus knee angles for pressure. (Turnbull et al. 2011.) Knee angular movements tend to be slower in the high speed (Berg & Eiken 1999). To initiate rotations, the snowboarder will forcefully rotate the arms from the wide position toward the CoM and the direction of desired rotation (Turnbull et al. 2011).

In this study subjects performed backside jumps with different degrees of rotation. In backside jumps athlete is heading towards the jump slightly off-centre where weight is on the heel edge. In the transition phase athlete is moving from the heels to a flat base with weight slightly over toes. This makes a S-curve. During take-off, athlete must stay low and leading shoulder moves towards back foot as athlete approaches the lip. Athlete must try to dig toe edge, so he/she is spinning off a solid footing and extend legs at the final moment. During flight-phase athlete keeps turning head and shoulder in the direction of rotation and pulls knees up. If the jump is done right, athlete can keep spinning until the board touches the snow in a straight line. (Whitelines 2013.)

3.2 The level of difficulty of the jump and its effect in performance

The level of difficulty of the jump and its effect in performance has not been studied much in snowboarding in the past. Snowboarders rotate their hips and knees forward towards the front of the board to assist vertical velocity of the COM at take-off. From this position, anterior-lateral hip boost and simultaneous lateral-vertical arm thrust assist horizontal velocity. At the take-off, hip and arm movements are quickly ceased to combine the momentum of these segments. This “boost” also allows the rider to align their COM over the centre of the board which maximises the vertical component of his/her velocity. It also provides an axis to assist rotation and helps to prepare the rider for landing. (Turnbull et al. 2011.)

Bacik et al. (2020) evaluated the level of flight variable variation of the snowboard single backside flip in their study. It is important to adopt and maintain a stable position during rotation. Adopting and maintaining a stable body position leads to lower variation of the variables during a jump. It also leads to improved stability and effective performance. However, it must be remembered that the values of coefficients of variation of kinematic variables are highly dependent on the type of movement. (Bacik et al. 2020.) Snowboarder’s trajectory in the air is predetermined as their angular momentum is conserved considering the only external force on the system act at the COM. It results in no external torques. The snowboarders, therefore, must alter the distribution of their body mass around the COM to initiate specific rotational tricks. Rotational inertia may be reduced with several elements. It can be reduced by retracting arms toward the COM for spinning, by tucking the legs up, or crunching head and shoulders down for backward and forward flips. (Turnbull et al. 2011.)

In general, the higher the jump, the more twists can be performed. Gymnasts must be physically capable to produce enough power at take-off before adding twists to the somersaults. If there is not enough height and angular momentum in twisting somersaults, it can lead to landing asymmetries. Landing asymmetries can lead to injuries. (Marinšek & Čuk 2013.) The same applies to snowboarders.

Jumping in figure skating

In contrast to snowboarding, there is previous research on jumping in figure skating. King et al. (1994.) have studied kinematic differences between three different level of jumps in figure skating. They performed 3D analysis where they analysed hip flexion, take-off angle, vertical and horizontal velocity, rotational velocity, time to attain the rotating position, tilt, and jump height. Hip flexion was defined as the maximum anatomical hip flexion angle of the free leg during take-off in this study. Take-off angle is the ratio of vertical to horizontal velocity of the centre of mass. Rotational velocity was defined as the maximum rotational velocity of the skater’s shoulders about the longitudinal axis. Tilt formed the angle between the skater’s longitudinal and the vertical axes. Jump height equalled to the maximum distance from the ice to the skater’s inferior foot measured at the toe. Final rotating position was analysed from the video. Jump distance, take-off length and skid length and width were obtained. (King et al. 1994.)

In figure skating, when athletes are about to increase their number of revolutions, they increase their rotational velocity and time in the air. (King 2005; King et al. 1994.) The time in the air depend on the vertical velocity at the take-off. In figure skating, vertical velocity is developed during the propulsive phase of the jump. Skater extends the hip, knee, and to some extent the ankle and creates downward forces against the surface. Joint range of motions varies from jump to jump and from athlete to athlete. Upward motion of the free limbs and motion of the trunk affect the forces applied to the surface during take-off. It has the potential to increase the impulse generated during the take-off. The propulsive phase of the jumps is preceded by eccentric muscle contractions. The stretch shortening cycle is an important component to generating vertical velocity. (King 2005.)

The time in the air can also be affected by the landing position. When landing with more flexed joints, skater gains a few hundredths of a second of flight time. This amount of time can result in an extra 10 to 20 degrees of rotation. (King 2005.) When performing more rotations in the air, skaters took off in more closed positions, and attained greater rotational velocities in jumps with more rotations (King et al. 1994). Angular velocity depends on skater’s angular momentum during flight and skater’s moment of inertia (King 2005). Increase in rotational velocity results from an increase in angular momentum and/or a decrease in moment of inertia. Tighter body positions decrease moment of inertia in the air and increases the rotational velocity. (King et al. 1994.) Angular momentum is a measure of the angular motion about the axis of rotation, and it is the product of moment of inertia and angular velocity and is continuous during the flight phase. Angular velocity during the flight phase can be altered only by changes to moment of inertia which can be manipulated with arms and legs by positioning them closer of farther from the axis of rotation. Angular velocity increases when moment of inertia decreases and vice versa, and it is the primary determinant of angular velocity during the flight phase. (King 2005.)

The hypothetically best technique would allow the skater to maintain more translational energy and jump higher and farther. Comparing double Axels to single Axels (Axel is a figure skating jump), the skaters exhibit greater pre-flight rotation. Skaters must have sufficient adductor strength to resist the large centrifugal forces acting against the skater as pulling into rotation position. Skater who has greater vertical velocity during Axel take-off, has greater angular momentum and is more vertical at take-off when performing more rotations during the jump. (King et al. 1994.)

King et al. (1994) found out in their study that there were differences between jumps. Take-off lengths for triple Axels were shorter than for single and double Axels. Instead, skid lengths and widths for triple Axels were longer than for single Axels. Increased skidding at the take-off may increase angular momentum by allowing skaters to initiate greater rotation on the ice. Jump lengths were shortest for triple Axels. Hip flexion angles were smallest during triple Axels. Vertical velocities at take-off were almost the same for all three jumps. Horizontal velocity at take-off was a bit less for triple Axels than for single or double Axels. Take-off angles were steepest for triple Axels. Jump heights were similar across Axels. Rotational velocities increased with increased rotations. Time required to the rotating position was on average shorter for triple Axels than for single or double Axels. (King et al. 1994.)

Mazurkiewicz et al. (2018) have also explored the technical differences between three figure skating jumps with different levels of difficulty. They performed a 3D kinematic analysis to determine which parameters are the most important for performing the triple Axel successfully. Results show that the jumps were higher when more rotations were performed in the jump. The flight phase as well was longer when more rotations were performed Skater changes his/her pre-take-off technique to perform more rotations in the air. At the take-off, the vertical velocity was the highest in the most difficult jump. Horizontal velocity was the highest in the easiest jump. Reducing the horizontal velocity enabled the skater to achieve greater vertical velocity. Moment of take-off was determined based on the velocity of the centre of gravity. Joint flexion angles are different during different jumps. Ankle joint flexion angles were higher during the entering phase in one and a half rotation jump than in multiple rotation jumps. In the knee joint flexion angles and hip joint flexion angles there were no significant differences between jumps during the pre-take-off phase. (Mazurkiewicz et al. 2018.)

There are three main mechanical components to achieve a correct balance of time in the air and rotational energy in figure skating. First one is appropriate level of downward force during propulsion. Second one is appropriate level of torque during approach, preparation, and propulsion. The forces generated from the movement of the body and limb segments create a torque about the axis of rotation. This torque creates angular momentum by providing angular impulse about the axis of rotation. Third one is control of moment of inertia during the flight phase of the jump. Vertical velocity at take-off is similar in higher revolution jumps as compared to lower revolution jumps, but those who have better technique and thus have ability, can generate greater vertical velocity at take-off. To add more revolutions in jumps, athletes must develop technique to generate greater vertical velocity at take-off, to generate greater angular momentum at take-off, and to decrease moment of inertia at take-off and during flight phase. (King 2005.)

4 SNOWBOARDING BIOMECHANICS

In snowboarding, the activities take place over a large distance. Because of that biomechanical research requires field experiments. The research set-up must be developed to cover a large test area to enable kinematic data collection in specific circumstances. Due to large area and specific circumstances several fixed cameras are required. Another option is to use cameras with panning, tilting, and zooming features. (Klous et al. 2010.)

To prescribe more specific training for snowboarding athletes, one need to have a good understanding of factors such as body posture, joint angles and velocities, muscle activation patterns, etc. A great deal of what is currently known regarding the biomechanics of alpine skiing can be applied to snowboarding. Alpine skiing and snowboarding are both gravity-assisted and share similar snow surface and carving/turning mechanics. (Turnbull et al. 2011.)

4.1 Kinematic Analysis

Kinematics is a study of body movements without considering the causes of the motion such as forces (Robertson et al. 2004, 9 & Meyer 2012). Kinematic analysis provides information on positions of an athlete’s body and skis/board in space. Kinematic analysis expresses movement using trajectory, angle, velocity, angular velocity, acceleration, and angular acceleration. (Vaverka et al. 2012.) In kinematics, the linear and angular positions of bodies and their time derivatives are quantified. (Robertson et al. 2004, 9). Kinematic methods include two-dimensional (2D) and 3D motion analyses (Robertson et al. 2004, 9 & Meyer 2012), Global Positioning System (GPS), goniometer, accelerometer, and Inertial Measurement Units (IMU). (Meyer 2012.) Imaging or motion capture systems are the most common methods for collecting kinematic data (Robertson et al. 2004, 12).

Video-based systems for kinematic analyses in snowboarding are common applications (Krüger & Edelmann-Nusser 2009). Systems record the motion of markers placed on the moving subject (Robertson et al. 2004, 12). Videos are analysed by converting the location points of the images to digits. That is known as digitization. Then data from horizontal and vertical coordinates at known time intervals or frames per second are used to calculate motion paths and kinematic information such as linear and angular position, velocity, and acceleration. (Pueo 2016.)

Coordinates will be processed to obtain the kinematic variables which will describe the movements of segments or joints. (Robertson et al. 2004, 12.)

A 2D motion analysis is a much simpler approach that assumes that movement is confined to a predefined plane or plane of motion. For example, walking can be measured from a side in 2D view in most situations. Although there are complex activities which involve movements in more than one plane. In these occasions a 2D analysis is not accurate enough. (Pueo 2016.) Multicamera setup is necessary to calculate 3D joint angles when there occur motion in two or more planes. 3D coordinate data can be obtained if the motion is recorded by two or more cameras simultaneously. (Pueo 2016.) The 2D views of each camera are then converted to a 3D view of the movement (Robertson et al. 2004, 52). Direct Linear Transformation (DLT) is used to reconstruct synchronized points in space into 3D coordinates (Robertson et al. 2004, 37 & Pueo 2016). Global Coordinate System (GCS) must be defined when the 3D view of the movement is established. (Robertson et al. 2004, 38.)

High speed video cameras are one of the most important pieces of equipment used to analyse athletic motion in training and competition. Those cameras are one of the most versatile tools for frame-by-frame analysis of movement. (Pueo 2016.) High speed camera is a video camera capable to record a high number of frames per second. A normal commercial camera records at 25 or 30 Hz. High speed cameras record at 100 to 1000 Hz. (Buscà et al. 2016.) Minimum frame rate can be calculated by dividing object velocity with maximum distance moved. Selected frame rate should be higher than the resulting value to possess enough frames covering the entire movement. Minimum shutter speed can be calculated by dividing object velocity with maximum motion blur. The maximum motion blur should be selected to perform an accurate analysis. Slightly blurred images are useful for frame-to-frame analysis in most cases. (Pueo 2016.)

Video analysis can be performed not only in controlled laboratories, but also outdoors and in competitions (Pueo 2016). Outdoor tracking systems differ from those developed for indoor sports. They have larger capture areas and variable lighting conditions. (Barris & Button 2008.) Klous et al. (2010) found out that the reliability and the validity of a field experiment was similar or just slightly lower than that observed in laboratory settings. They concluded that kinematic data collection and analysis can be performed in large area field experiments for skiing and snowboarding. However, one should remember that bigger errors are more common in field studies than in laboratory studies. (Klous et al. 2010.)

Kinematics of human joints are commonly described by measuring the motion of rigid bodies attached to bones (Maletsky et al. 2007). Angular position is a part of the angular kinematics. There are two classes of angular position. They are angular orientation or position of single bodies and the angle between two segments of the body. Angular position of single bodies is called segment or absolute angles. The angle between two segments of a body is called relative, joint, or cardinal angles which measure the angular position of one segment relative to another. (Robertson et al. 2004, 26-27.) To describe the relative motion, a sequence of transformation matrices is used. For example, goniometers, video cameras, electromagnetic sensors, optical devices, and fluoroscopy are used to measure the relative motion of two bones. (Maletsky et al. 2007.) Segment angles follow the right-hand rule (positive rotations are counterclockwise and negative rotations are clockwise). Joint angles are useful because the human body is a series of segments linked by joints. Joint angle can be defined with three coordinates or two absolute angles. (Robertson et al. 2004, 26-27.)

4.2 3D Motion Analysis

Most of the skiing disciplines involve complex movements in all directions (Meyer 2012). Also snowboarding includes multi axis movements. Those movements require a 3D video system to obtain accurate data. Three-dimensional motion analysis is quantitative analysis. It means that video recordings are used to undertake a detailed analysis of movement patterns. (Pueo 2016.) Three-dimensional motion capture system is considered as a standard for kinematic analysis (Sorenson et al. 2015). To understand the function of human joints, knowledge of accurate kinematics of joints, including a 3D rigid body and surface kinematics is essential (Lu & Chang 2012). Three-dimensional body segment position and orientation are calculated with their relative motion, joint displacements, and rotations (Leardini et al 2017). Differences in joint profiles can be expected depending on whether expressed in the global coordinate system or in proximal, distal, or joint coordinate systems (Camomilla et al. 2017).

To locate 3D coordinates requires more than one camera (Robertson et al. 2004, 13). A 3D motion analysis can be done with only two cameras but only one side of the skier can be reconstructed reliably (Meyer 2012). To capture both sides of the body, more cameras are needed. The overall visibility enhances, and the negative effect of markers occlusion decreases. (Meyer 2012 & Robertson et al. 2004, 13.) Each of the cameras capture some of the markers placed on the bony landmarks. Every marker should appear at least in two cameras. (Robertson et al. 2004, 37-38.) According to Meyer (2012), only in few prior studies had used markers placed on the skier's suit to help the digitization (Meyer 2012).

Every camera provides a set of 2D coordinates. Direct Linear Transformation (DLT) method is often used to calculate the 3D coordinates from a set of 2D coordinates. (Robertson et al. 2004, 37-38.) The DLT filming technique is based upon calibrating the space. The object is filmed with a set of control points of which spatial coordinates are known. The control object must have a minimum of six control points and a greater number of control points offers a better accuracy in the data collection. The control object is usually a metal cube frame which is placed in the object space. It is proven that the combination of high-speed cinematography with the 3D DLT technique is successful in collecting data of a dynamic movement in harsh alpine conditions (Arndt 1992). Nonlinear transformations are also used to determine 3D coordinates from a set of 2D coordinates (Robertson et al. 2004, 37-38). The 3D motion analysis is more complex than a 2D analysis (Meyer 2012). Even though, the 3D motion capture is considered the golden standard, it is still time consuming and requires a lot of training to master it. It requires considerably more time compared to the 2D motion capture and is also an expensive method. (Maykut et al. 2015 & Sorenson et al. 2015.)

In most of the studies presented in Meyer's paper 50 Hz frame rate video cameras were used in 3D motion analyses. The frame rate is insufficient to record for example impacts such as jump landings or body vibration. Higher acquisition frequencies were used in several studies. (Meyer 2012.)

When using a multiple camera system, a potential source of error is incorrect positioning of the cameras. The angle between the optical axes of two cameras looking at the same point should be no more than 120 ° or less than 60 °. (Meyer 2012.) The optimal camera positioning is about 90 °. To gain the most accurate data, cameras should be positioned as close as possible to the field of data collection. Panning should be minimized. (Kupiers 2010.) There are more methodological problems in motion analysis. Instrumental errors are inaccuracies caused by the motion measurement process while assuming body segments are rigid. (Klous et al. 2010.) For example, the ski or snowboard, binding, boot and ankle are considered as a rigid body (Arndt 1992). Inaccuracies can occur for example in calibration or in digitizing. There can also be misplacement of anatomical landmarks and soft tissue artifacts. (Klous et al. 2010.) Skin based markers are considered the most reliable. Skin markers are impossible to use in the ski field due to safety issues. Markers attached to clothing are necessary. Resulting limitations due to marker movement must be tolerated. All markers should be readjusted and attached following a warm-up to improve precision. (Kupiers 2010.)

Motion capture system has complex adjustments and is sensitive to cold and light (Kupiers 2010) such as daylight or highly reflective surroundings. That is the reason why for example Luthi et al. (2006) performed a kinematic analysis of the aerials take-off using an automatic motion capture system at night. (Jones 2012.) The fact that video analysis is time consuming is another limiting factor. Video analysis is considered the criterion method for calculating objective data. There is unfortunately a large delay in information feedback. However, image-based systems are accurate and reliable. One disadvantage of image-based systems among others is a long set up duration. (Harding & James 2010.)

4.3 Segmental Analysis

The bodies are thought to have a computational centre, called the centre of mass (COM), in relation to which the forces acting on the body are estimated. The COM describes the equilibrium point around which the mass is distributed evenly. The COM can be determined by dividing the body into parts whose masses and COM are known. This is called segmental analysis. Segmental analysis is used to determine COM location during movement. COM of the body mass moves during movement. (Enoka 2008, 47.)

To estimate various anthropometric segmental dimensions such as segmental weights and COM locations, investigators have derived regression equations (Enoka 2008, 47-48). De Leva’s segment parameters are described in table 1.

Table 1. Body segment parameters. Segment COM-positions are referenced to proximal endpoints relative to segment lengths and segment masses are relative to total body mass (de Leva 1996). Endpoints are presented in appendix 1.

Segment	Endpoints		Mass (%)		COM (%)	
			Female	Male	Female	Male
Head	VERT	MIDG	6.68	6.94	58.94	59.76
Trunk	MIDS	MIDH	42.57	43.46	37.82	43.10
Upper arm	SJC	EJC	2.55	2.71	57.54	57.72
Forearm	EJC	WJC	1.38	1.62	45.59	45.74
Hand	WJC	MET3	0.56	0.61	74.74	79.00
Thigh	HJC	KJC	14.78	14.16	36.12	40.95
Shank	KJC	LMAL	4.81	4.33	44.16	44.59
Foot	HEEL	TTIP	1.29	1.37	40.14	44.15
			100.00%	100.00%		

VERT (vertex), MIDG, MIDS, MIDH (mid-gonion, mid-shoulder, mid-hip – the points midway between the gonions and joint centres), SJC, EJC, WJC, HJC, KJC, (the joint centres of shoulder, elbow, wrist, hip, knee), MET3 (3rd metacarpale), LMAL (lateral malleolus), TTIP (the tip of the longest toe).

5 KINEMATIC RESEARCH OF SNOWBOARDING

Snowboard jump landing has been investigated more than the take-off. McAlpine and Kersting (2006) investigated snowboard jump landing. The purpose was to develop a protocol for the collection of meaningful data in a real snowboarding environment. They collected kinematic and kinetic data with a four high speed camera motion system at 120 Hz and a snowboard mounted force platform. Cameras were running through SIMI motion software. They used a calibration cube and wand to calibrate the system. On-snow data were collected from experienced snowboarders performing a series of jumps. Ankle joint kinematic data were calculated based on shank and boot markers. Ankle joint range of motion was calculated. Results show that these methods are appropriate for on-snow data collection. Joint loads examined in this study were potential for ankle injury. (McAlpine & Kresting 2006.)

Take-offs in snow sport have been investigated earlier in aerials event in freestyle skiing. Jones (2012) used two high speed cameras to capture the take-off phase of the jump. The cameras recorded at 250 Hz with an exposure time of 0.8 ms. The light gate, that a participant passed through, activated cameras. Cameras were placed in front of the kicker on each side of the inrun. Cameras made an angle of 62° to aid with the reconstruction of 3D coordinates. The intention was a 90° angle but due to geographical limitations it was smaller. This enabled the calculation of the angular velocity on the kicker and at the take-off and the entry speed into the kicker. (Jones 2012.)

Delorme et al. (2005) examined kinematics of ankle joint complex in snowboarding. They found out that the front and back ankle joint complexes rotated asymmetrically. The front ankle joint complex was everted, and the back ankle joint complex was inverted during both heel-side and toe-side turns. Front leg supported weight and back leg was used to achieve better control of the snowboard. Also, dorsiflexion was bigger on the back ankle complex. (Delorme et al. 2005.)

In the initiation phase of the jump, the snowboarder pushes off actively and joint angles change. Krüger and Edelmann-Nusser (2009) studied joint angles in freestyle snowboarding jump. In their study they discovered an increased plantar flexion of 12° of both legs. There was an internal rotation of 41° of front leg and an external rotation of 32° of back leg. The rotations of legs were caused by the rotation of the upper body around the longitudinal axis. (Krüger & Edelmaan-Nusser 2009.)

Klous et al. (2010) collected data of three skiers and two snowboarders to determine accuracy and reliability of kinematic data collection in a ski and snowboard field experiment to validate the kinematic set-up. They collected data on two different turning techniques with five panning, tilting, and zooming cameras. Area of motion was large (35 x 15 m). The requirements for defining the optimal camera positions for panning, tilting, and zooming cameras were obtained from the literature. They used markers for 3D tracking of the lower extremity segments. Approximately 100 markers were attached at anatomical landmarks and at non-anatomical landmarks. Skiers and snowboarders used a tight-fitting stretch-suit during experiments to reduce errors caused by skin movement artifacts. The suit was black-and-white to increase marker visibility. The results show that the accuracy of data was similar to that observed in laboratory settings. Kinematic data collection can be performed in large area. Set-ups in field experiments are, however, strongly dependent on the prevailing circumstances. (Klous et al. 2010.)

6 RESEARCH PROBLEMS

The take-off phase in snowboarding Big Air jumps has not been studied so far. There are some kinematic studies of the take-off phase in freestyle skiing aerials. Differences in joint kinematics as the difficulty level of the jump changes have been studied earlier for example in figure skating. This study included five subjects, of which four were able to perform all the jumps studied. Due to the number of subjects the results are reviewed for individual subjects as a case study.

6.1 Research Questions

The aim of the study is to elucidate the kinematic differences of backside 360°, backside 540°, and backside 720° jumps in freestyle snowboarding. The goal of the motion analysis is to determine changes in joint angles and segment shifts as well as velocities during a single jump take-off phase. The aim is to find out how the above variables change when the difficulty level of the jump changes.

Research questions are as follow:

1. How do changes in jump difficulty level affect joint angles in knees and hips and angular velocities in knees and elbows in a snowboarding Big Air jump take-off?
2. How do changes in jump difficulty level affect CoM horizontal and vertical velocity in a snowboarding Big Air jump take-off?

6.2 Hypotheses

The hypotheses of the study are as follow:

1. Hip joint angles and knee joint angles extend during take-off. Extension is greater when there are more rotations in a jump.
2. Horizontal and vertical velocity is greater when there are more rotations in a jump.
3. Angular velocity is greater when there are more rotations in a jump.

7 METHODS

This study included a total of five subjects (1 woman, 4 men) aged 18-30 years (Table 2). The subjects were elite and academy level athletes in snowboarding. Subjects were presented with a written informed consent to be signed before participating in the study (Appendix 2) and gave information about their injury background (Appendix 3). All the subjects were healthy, non-injured and at an adequate level to perform jumps studied in this study. The inclusion and exclusion criteria are presented in more detail below. This study received ethical statement from the ethical committee of the University of Jyväskylä and all the tests were conducted according to the Helsinki declaration. Subjects were volunteers and were allowed to discontinue the study if they wanted.

Inclusion criteria:

a. The subject was able to perform the movements and performances tested in the study safely and with sufficient quality.
b. The subject was healthy.

Exclusion criteria:

a. The subject had an injury that interfered with or prevented them from performing the movements.
b. The subject was not able to complete the required number of successful performances within the maximum number of attempts.
c. The subject was ill (respiratory infections, fever, etc.).

TABLE 2. Subject information.

Subject	Sex	Front leg
1	Female	Left
2	Male	Right
3	Male	Right
4	Male	Left
5	Male	Left

7.1 Experimental Protocol

The data collection took place at Ruka Ski Centre, Finland. Measurements were made in April 2021. The measurements were made once and all data for use in this study were collected in a single day. The measuring location was Ruka Park's largest jumper which just meets the size requirement of a jumper used in the World Cup Games.

The measurements started by assembling the calibration cube (Figure 1) and placing the cameras on the slope. Cameras were placed on 90-degree angle to each other to point at the jumper. The distance of the cameras from the jumper was approximately 30 m. Filming area was 2 m wide and 4 m long. The calibration cube was a metal cube frame, and it was placed in the object space. A 2 m x 4 m cube was constructed with 8 control points. The calibration cube was removed after filming the object space and filming of the motion of interest could be started.

FIGURE 1. Calibration cube was set on the peak of the jumper with the help of load straps.

Prior to the start of data collection, the snowboarders read and signed a consent form and a preliminary and health survey (Appendix 3). The form explained the study, how the data would be collected and what it would be used for. Preliminary and health survey included questions about the health status of the subjects. After that, markers were placed on the subjects to the anatomical landmarks. External markers were used to make a 3D analysis of the segments. Markers were used to define X, Y and Z planes.

The task to be performed by each subject was three jumps, each one with different level of difficulty. The first jump was backside 360°, the second jump was backside 540°, and the third jump was backside 720°. The jumps performed for this study were within the capability of the subjects even though one subject did not achieve successful performances in 540° and 720° jumps within the maximum number of attempts.

7.2 Marker Positioning

The markers used in this study were reflective motion capture markers and kinesio tape. The positions of the markers were a total of 20 anatomical landmarks according to DeLeva's (1996) segment parameters (Figure 2 and 3). Some of the markers were positioned to the equipment such as boots and helmet since it was not possible to place them directly on the skin or clothes. In some joints such as elbow joint and knee joint kinesio tape was used around the joint centre to enable to see the marker position in a rotating movement. The kinesio tape also stays in place better in case the subject fall over in a jump. Clothes were tight pants and tight sweater.

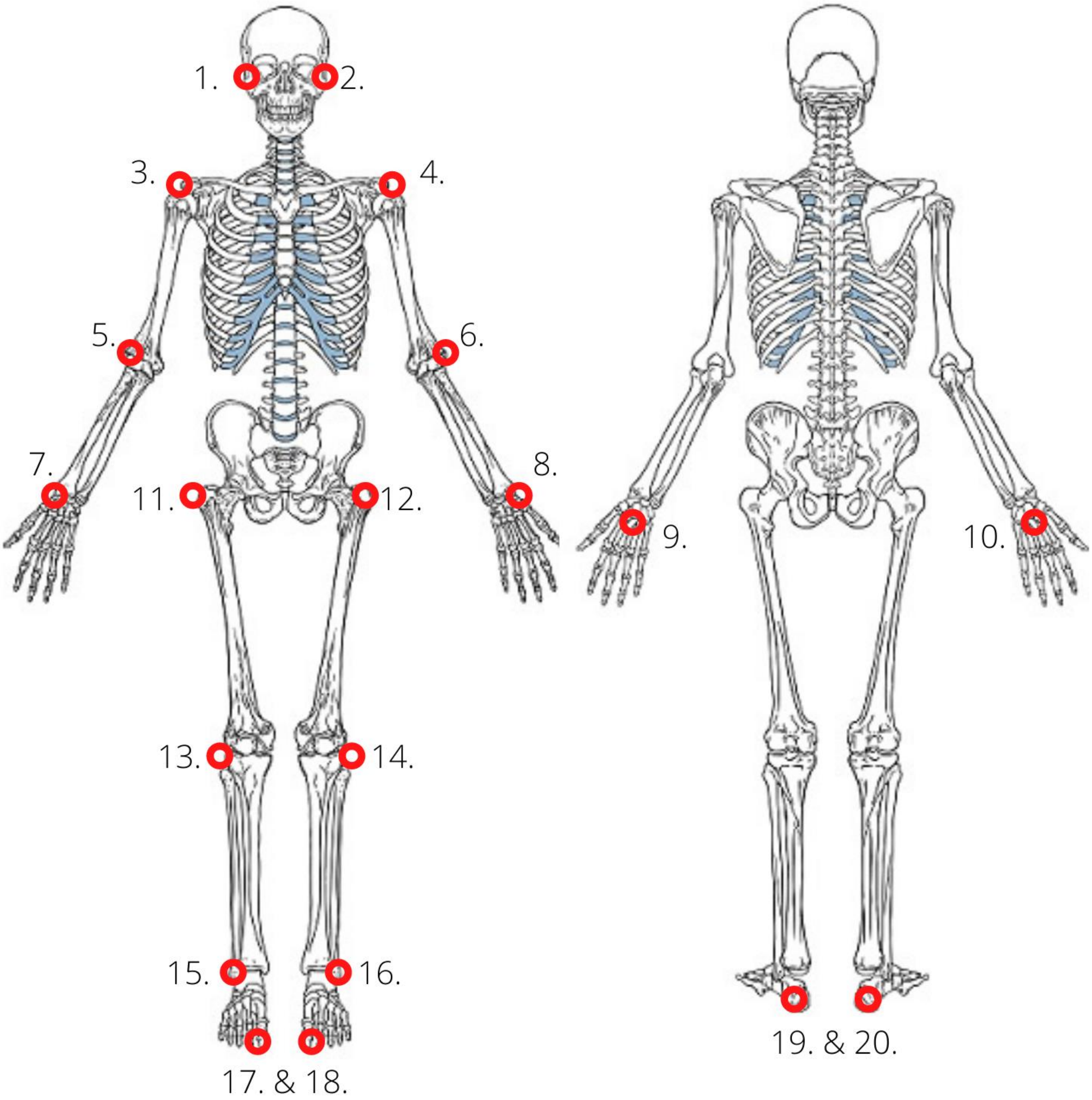


FIGURE 2. Marker placement. 1. & 2. vertex; 3. & 4. the joint centres of shoulder; 5. & 6. the joint centres of elbow; 7. & 8. the joint centres of wrist; 9. & 10. 3rd metacarpal; 11. & 12. the joint centres of hip; 13. & 14. the joint centres of knee; 15. & 16. lateral malleolus (boot); 17. & 18. the tip of the longest toe (boot); 19. & 20. heels (boot).

FIGURE 3. Marker and kinesio tape positioning in a subject.

Markers should move as little as possible in relation to the anatomical landmarks of the segments. Therefore they are placed over prominent bone landmarks where possible and away from any large muscle mass which was likely to change the marker's position when contracted or relaxed. (Arndt 1992.)

7.3 Filming Procedures

Motion analysis was captured with two high speed cameras (Sony RX10 II and III, Sony Corporation, Tokyo, Japan). The cameras were positioned on tripods inserted in the snow. Tripods legs were resting upon the solid ground surface or on plywood to prevent any movement of the tripods. Due to the cold weather, the cameras were plugged in throughout the filming to prevent any malfunction.

Frame rate was 250 frames per second (fps) and the recording time was 4 s in both cameras. Exposure time was set to maximum since the snow reflected the sunlight strongly. Cameras were placed on 90-degree angle to each other to point at the jumper in order to assist with the reconstruction of three-dimensional coordinates. The distance of the cameras from the jumper was approximately 30 m. Filming area was 2 m wide and 4 m long. (Figure 4.) The cameras were zoomed as close as possible to enable the entire shooting area to be visible in the image. Figure 6 shows a view from behind camera 1. Calibration videos were shot with a frame rate of 100 fps and their duration was approximately 1 s.

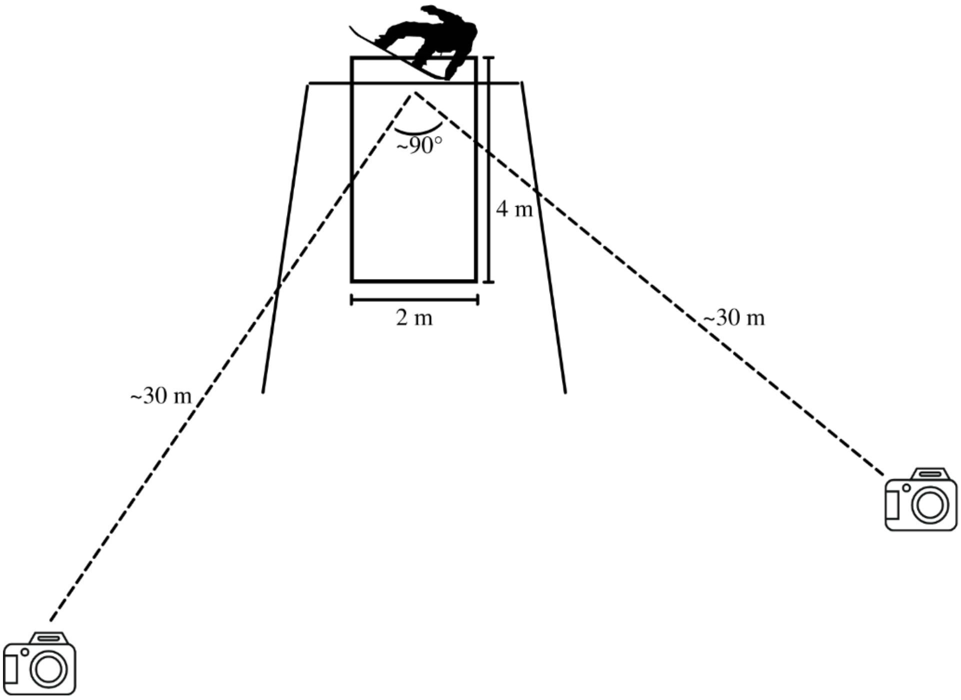


FIGURE 4. Shooting setup and estimation of camera distances.

FIGURE 5. The view from behind of camera 1.

The videos were shot manually. Both cameras had a cameraperson who pressed the camera button when the subject disengaged from the jumper into the air. The cameras the recorded a 4-second video backwards from the buffer memory from the moment the button was pressed. Per trial, the subject was in the field of view for approximately 0.2 seconds.

7.4 Film Analysis

Film analysis was made with Vicon Motus 10.0.1 program. In the analysis, the coordinate system was calibrated as follows: the X direction was the length direction, the Y direction was the width direction, and the Z direction was the height direction. DLT-11 parameters were utilized in the digitization of the analysis material.

Digitization was performed manually by digitizing every frame from the video. This amounted to between 46 and 52 frames digitized per trial. From the calibration video only three images were digitized. Frames were synchronized.

Raw coordinates were scaled with process wizard. There were no gaps, and therefore no gaps were interpolated over, and no endpoint gaps were extrapolated over. Scaled coordinates were filtered. Quintinc spline processing was not used. The global transformation frame was used to automatically define translations and rotations, hence the origin and axes match the Z-axis vertical and XY plane to be even with the surface on which the calibration frame rests.

7.5 The Three-Dimensional Kinematic Analysis

In the analysis phase, a three-dimensional model of the snowboarders was formed from which the centres of mass of the whole body and individual segments were determined using the material of DeLeva et al. (1996). The mass of the board and boots was not considered in the analysis phase. 3D models composed of 14 segments (Figure 6).

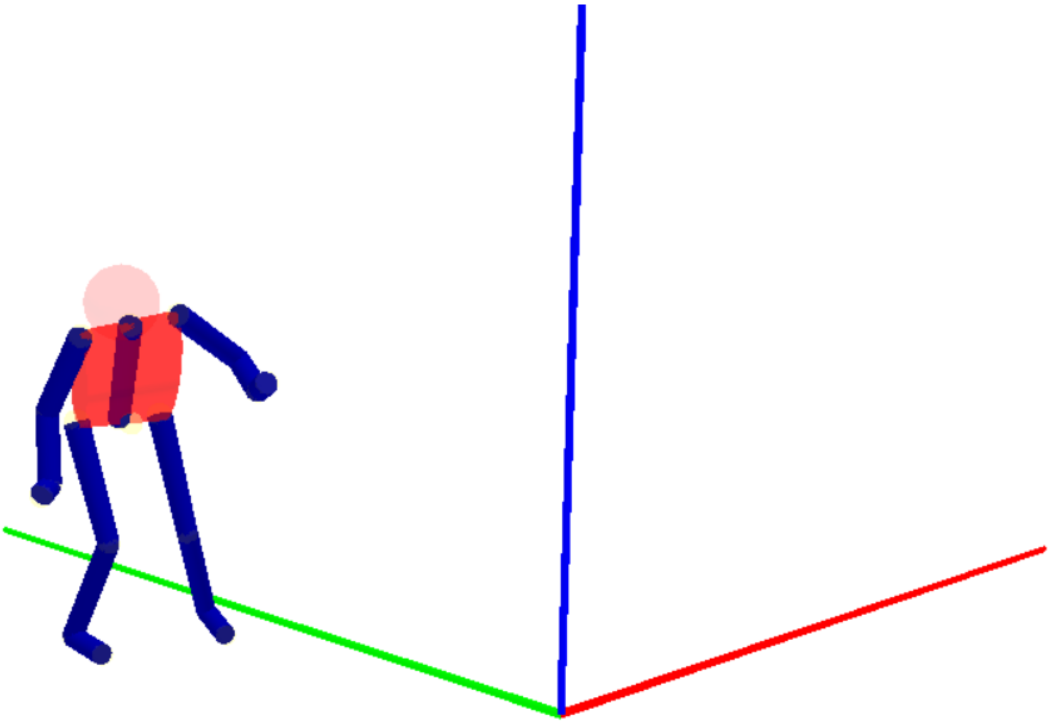


FIGURE 6. A 3D model formed of a snowboarder.

A vertical line passing through the snowboarder's centre of mass was used to determine the inertia. Based on the position coordinates of the points used in the analysis, all 14 segments were calculated with their own mass centres according to De Leva (1996). Trunk was a complex segment. Centre of mass, hip, and shoulder were virtual points. Virtual point is a point a halfway of two points, in this case between left and right shoulder joint centres and left and right hip joint centres.

7.6 Calculation of the Kinematics

The kinematics were calculated with the process tool in Vicon Motus 10.0.1. The angles selected for examination were hip angles and knee angles, the angular velocity was examined from the knees and elbows, and centre of mass horizontal and vertical velocity was examined. At the request of the national team coach, the movement of the arms was also desired to be included in the review. Therefore, angular velocity was analysed from the elbow joint and not from the hip joint.

For example, knee angle was determined by calculating vector angle between lateral malleolus, knee joint centre and hip joint centre. Vector angle is from the P1-V segment to the V-P2 segment (Figure 7.) Since the knee was the joint of interest, the hip was considered as the first segment and the ankle as the second.

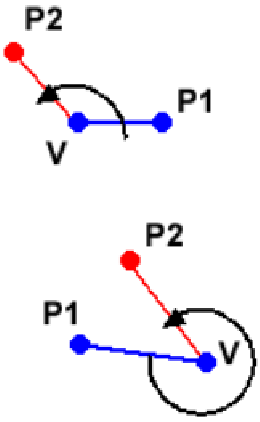


FIGURE 7. Vector angle.

7.7 Statistical Analysis

Average knee and hip joint angles and centre of mass average vertical and horizontal velocities and standard deviations were calculated from the entire execution filmed. Due to the small number of subjects statistical analyses were not made.

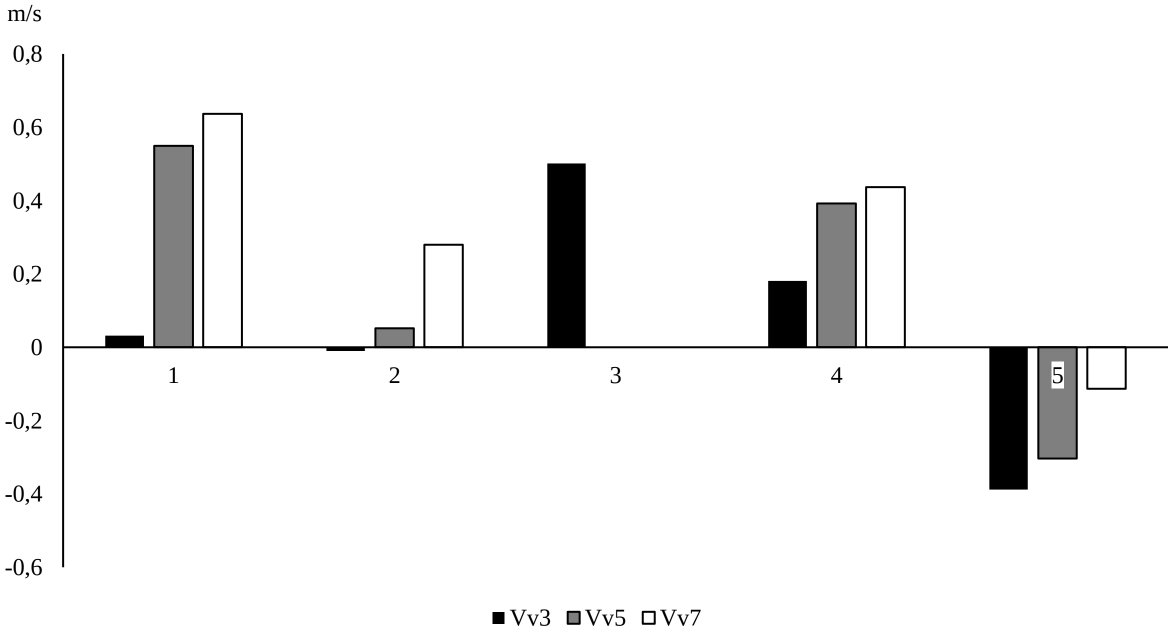
8 RESULTS

8.1 Centre of Mass Velocities

8.1.1 Centre of Mass Vertical Velocity

Upward motion has a positive velocity and downward motion has a negative velocity. The results in this situation do not consider the vertical movement of the snowboarder up the jumper. The gradients of the slope were not considered in the motion analysis.

Figure 8 presents that centre of mass vertical velocity is the slowest in backside 360° jumps and the fastest in backside 720° jumps for all subjects. In tables 3, 4, and 5 can be seen centre of mass vertical maximum, minimum, and average velocities. At its lowest the velocity was negative or close to zero. Highest centre of mass vertical velocity was 1.167 m/s for subject 3 in backside 360° jump. From the figures 9, 10, and 11 can be seen that the centre of mass vertical velocity increases towards detachment from the jumper.



*Vv3 = vertical velocity in backside 360° jump, Vv5 = vertical velocity in backside 540° jump, Vv7 = vertical velocity in backside 720° jump.
FIGURE 8. Centre of mass average vertical velocities of the five subjects.

TABLE 3. Centre of mass vertical velocity in backside 360° jumps.

ID	1	2	3	4	5
Minimum (m/s)	-0.304	-0.479	-0.373	-0.137	-0.713
Maximum (m/s)	0.270	0.260	1.167	0.388	-0.147
Average (m/s)	0.032	-0.010	0.501	0.181	-0.388
Standard deviation	0.212	0.270	0.577	0.200	0.212

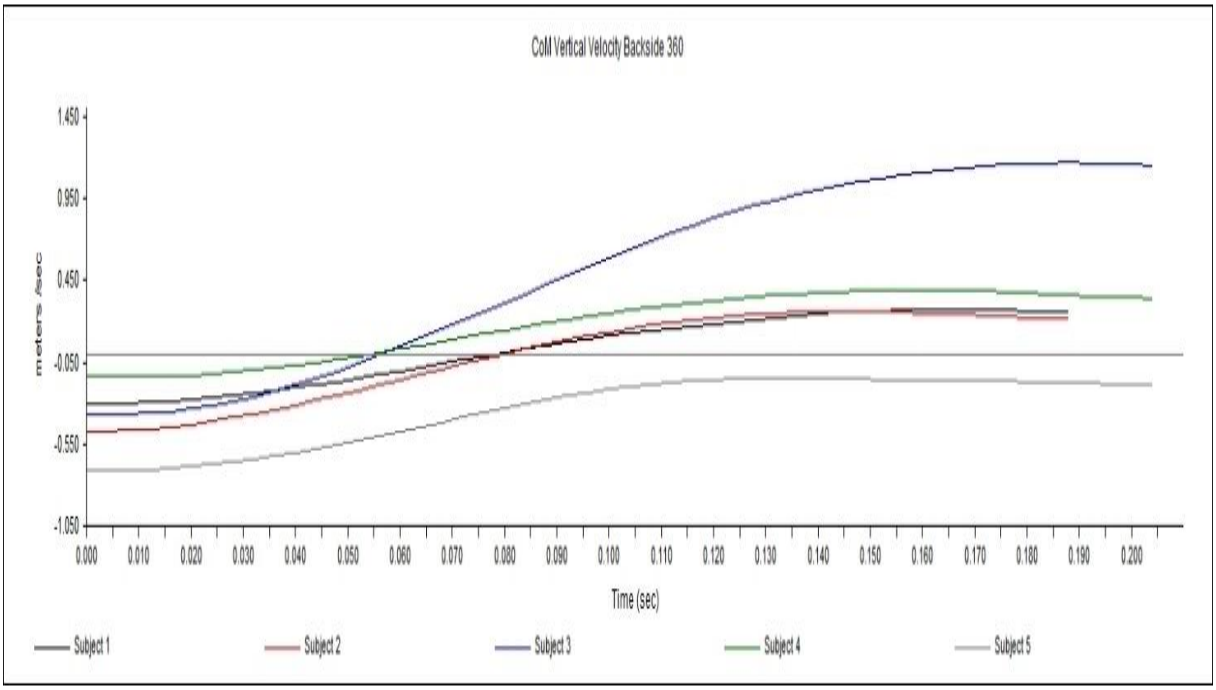


FIGURE 9. Centre of mass vertical velocity in backside 360° jumps.

TABLE 4. Centre of mass vertical velocity in backside 540° jumps.

ID	1	2	4	5
Minimum (m/s)	-0.105	-0.677	-0.268	-0.611
Maximum (m/s)	1.024	0.539	0.733	-0.064
Average (m/s)	0.549	0.052	0.392	-0.303
Standard deviation	0.408	0.454	0.369	0.160

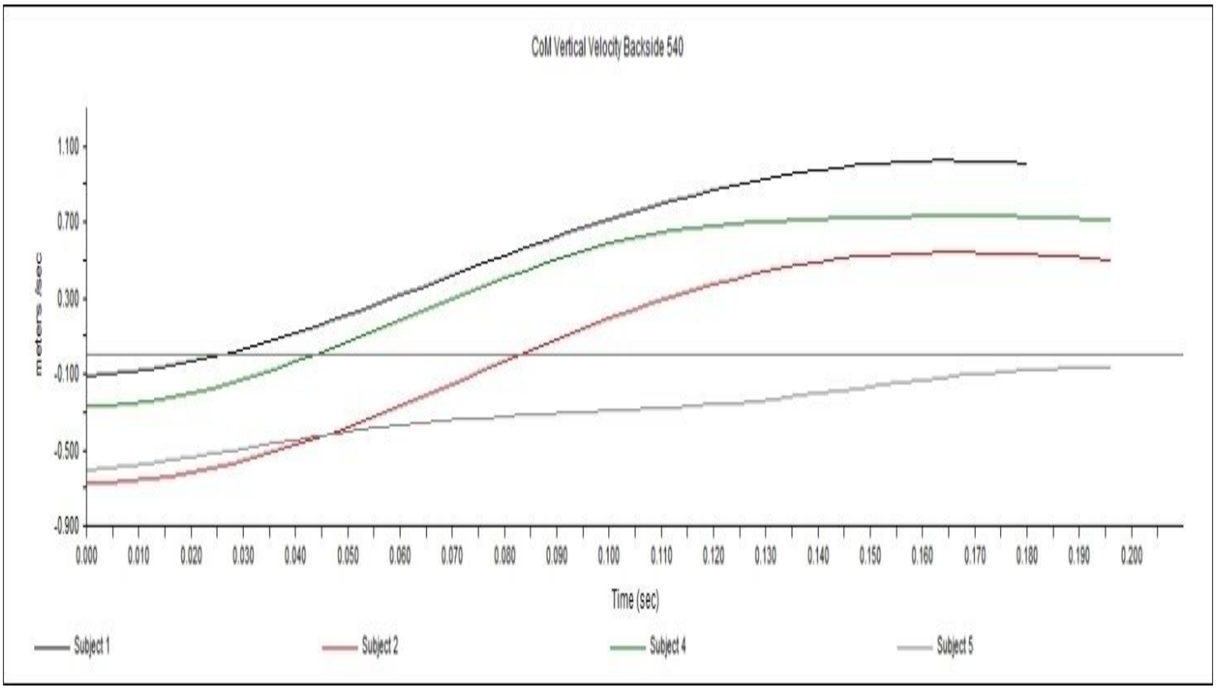


FIGURE 10. Centre of mass vertical velocity in backside 540° jumps.

TABLE 5. Centre of mass vertical velocity in backside 720° jumps.

ID	1	2	4	5
Minimum (m/s)	-0.255	-0.390	0.023	-0.479
Maximum (m/s)	1.230	0.669	0.684	0.089
Average (m/s)	0.637	0.280	0.437	-0.113
Standard deviation	0.530	0.393	0.245	0.195

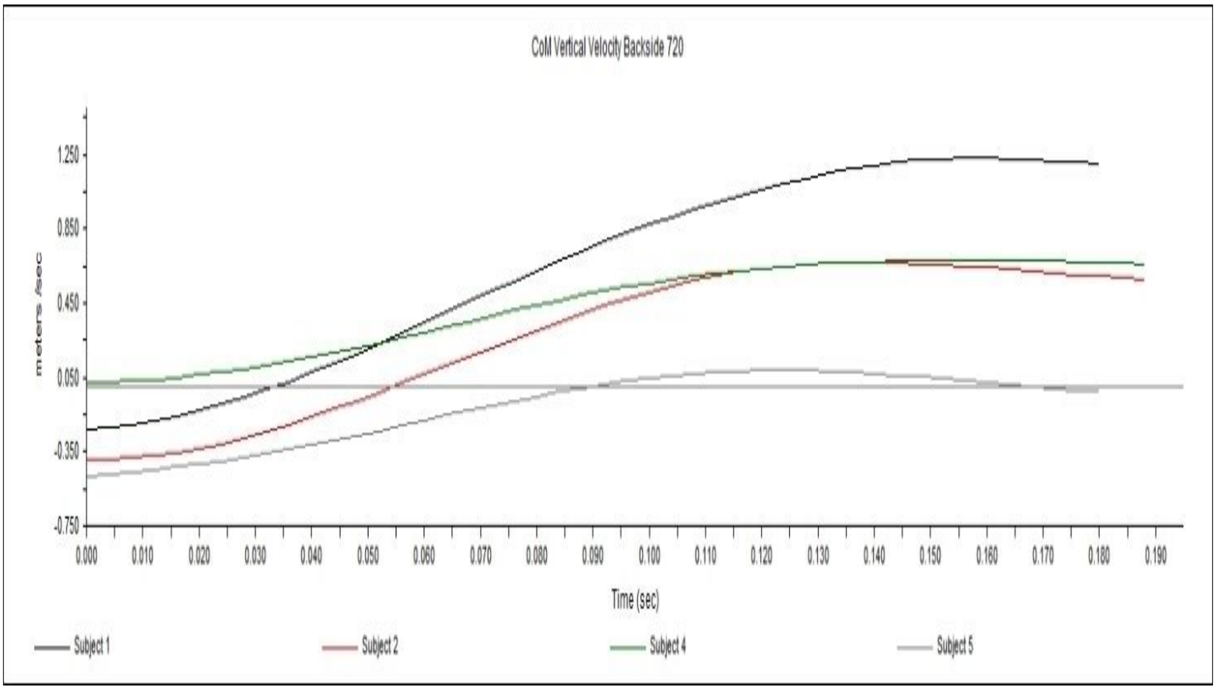
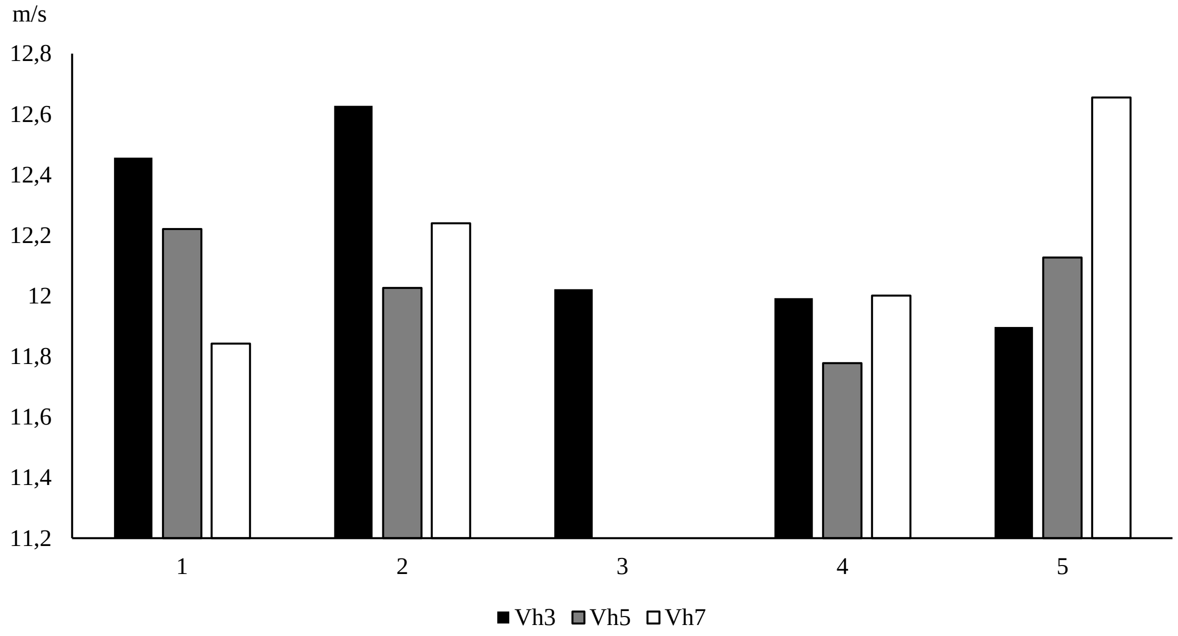


FIGURE 11. Centre of mass vertical velocity in backside 720° jumps.

8.1.2 Centre of Mass Horizontal Velocity

Centre of mass average horizontal velocities are presented in figure 12. From the figure can be seen that centre of mass horizontal velocity varied between subjects and jumps. For some subjects it was the slowest in backside 360° jumps and for some subjects it was the slowest in 720° jumps. No connection can be detected between the difficulty level of the jump and the centre of mass horizontal velocity.

In tables 6, 7, and 8 can be seen centre of mass horizontal maximum, minimum, and average velocities. Velocities were approximately between 10 m/s and 13 m/s. From the figures 13, 14, and 15 can be seen, however, that the centre of mass horizontal velocity decreased for all subjects toward detachment of the jumper.



*Vh3 = horizontal velocity in backside 360° jump, Vh5 = horizontal velocity in backside 540° jump, Vh7 = horizontal velocity in backside 720° jump.
FIGURE 12. Centre of mass horizontal average velocities of the five subjects.

TABLE 6. Centre of mass horizontal velocity in backside 360° jumps.

ID	1	2	3	4	5
Minimum (m/s)	11.503	11.929	11.090	11.126	11.110
Maximum (m/s)	13.037	13.099	12.649	12.566	12.397
Average (m/s)	12.456	12.628	12.022	11.993	11.897
Standard deviation	0.510	0.385	0.527	0.493	0.426

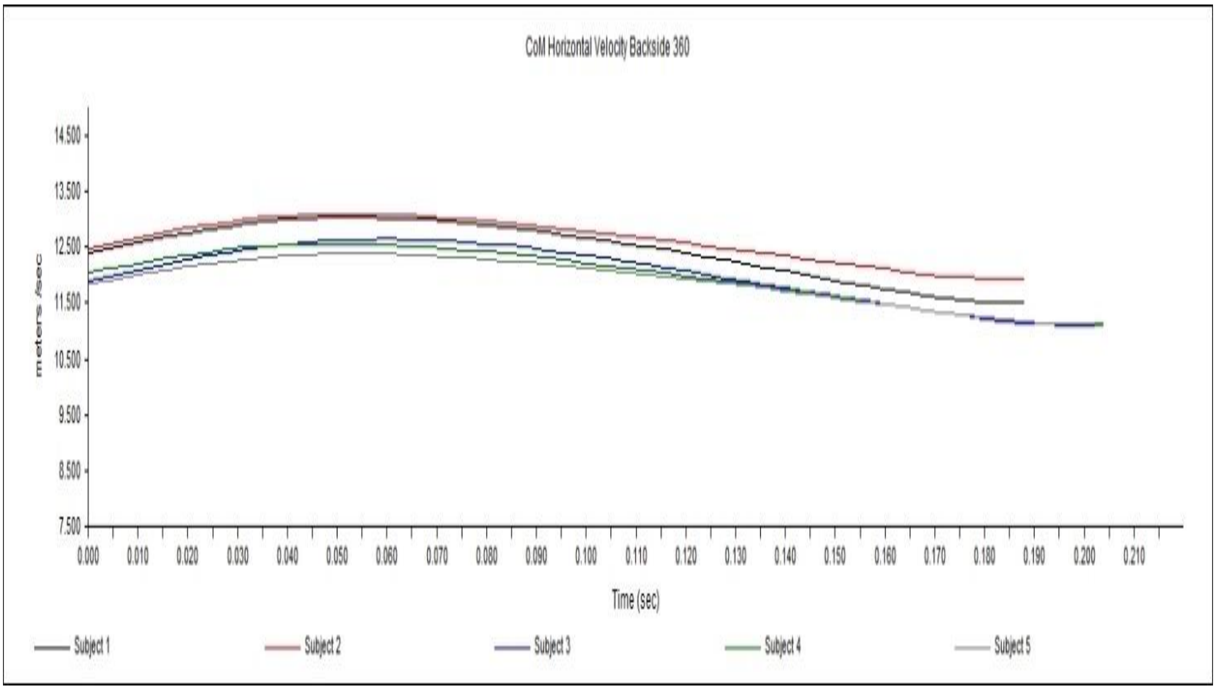


FIGURE 13. Centre of mass horizontal velocity in backside 360° jumps.

TABLE 7. Centre of mass horizontal velocity in backside 540° jumps.

ID	1	2	4	5
Minimum (m/s)	11.366	10.909	10.946	11.270
Maximum (m/s)	12.648	12.468	12.182	12.516
Average (m/s)	12.221	12.026	11.778	12.127
Standard deviation	0.414	0.525	0.421	0.401

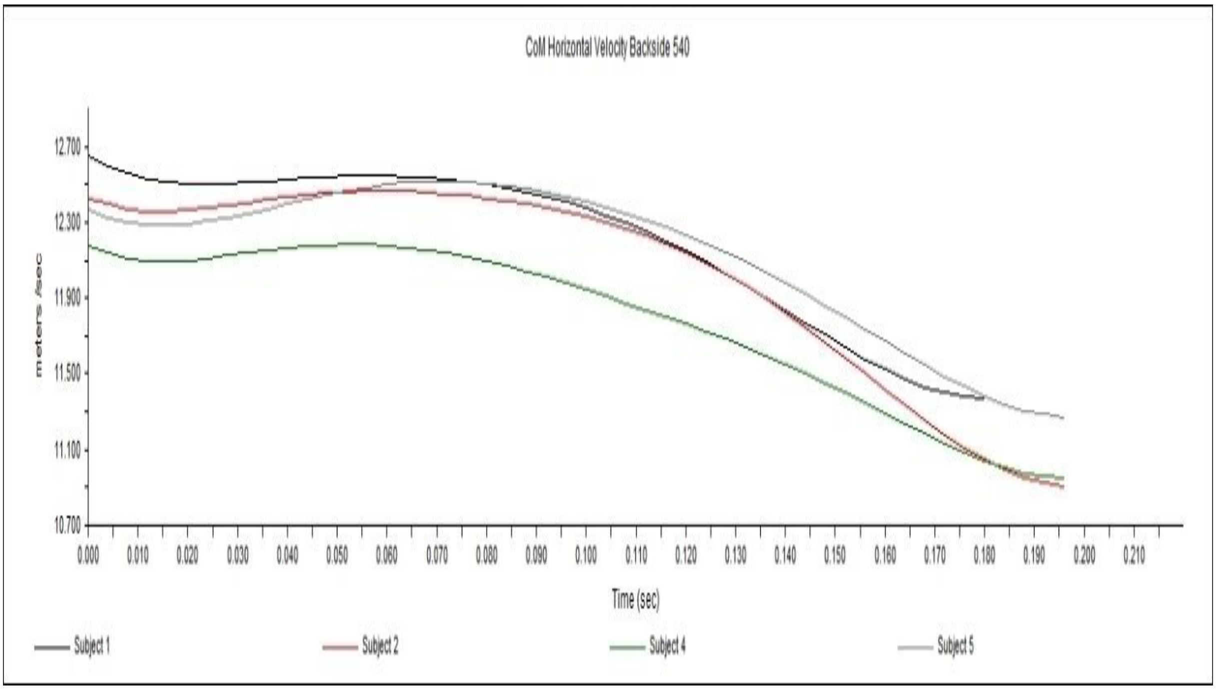


FIGURE 14. Centre of mass horizontal velocity in backside 540° jumps.

TABLE 8. Centre of mass horizontal velocity in backside 720° jumps.

ID	1	2	4	5
Minimum (m/s)	10.918	11.582	11.301	11.977
Maximum (m/s)	12.362	12.714	12.420	12.956
Average (m/s)	11.843	12.240	12.001	12.655
Standard deviation	0.469	0.381	0.355	0.321

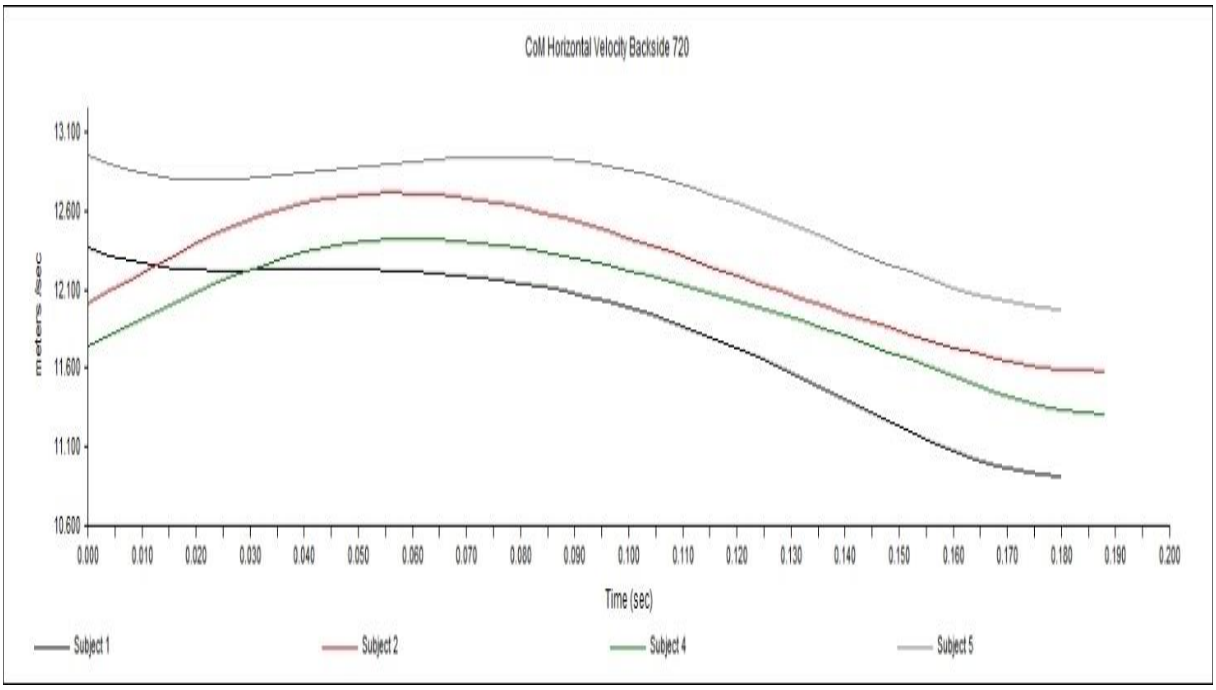


FIGURE 15. Centre of mass horizontal velocity in backside 720° jumps.

8.2 Joint Angles

8.2.1 Knee Joint Angles

Average knee joint angles in front leg are presented in figure 16 and in back leg in figure 17. On the back leg, the knee angles were on average larger/remained the same as the difficulty level of the jump increased. On the front leg there was more variation between subjects. Knee joint maximum, minimum, and average angles in backside 360° jump are shown in table 9, in backside 540° jump in table 10, and in backside 720° jump in table 11. From the figures 18-23 can be seen that each subject has a different way of using their knees in the take-off. Some subjects extend their knees when some subjects flex their knees. Variation is especially in the front legs. For the back leg, it was discovered that it extends towards the take-off.

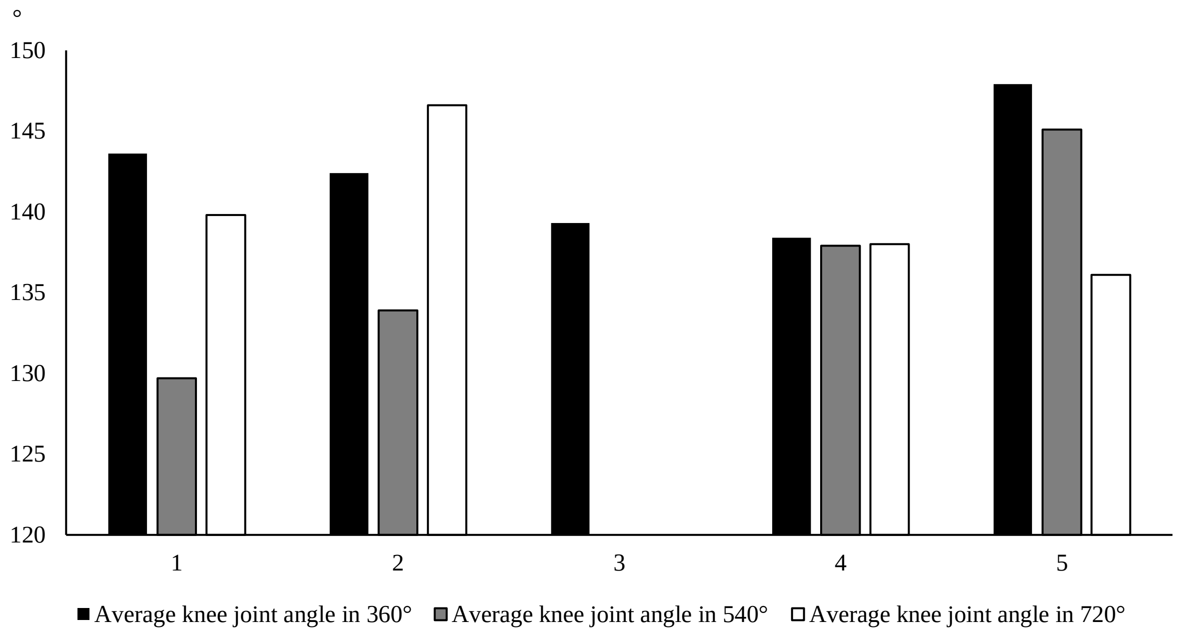


FIGURE 16. Average knee joint angles in front leg.

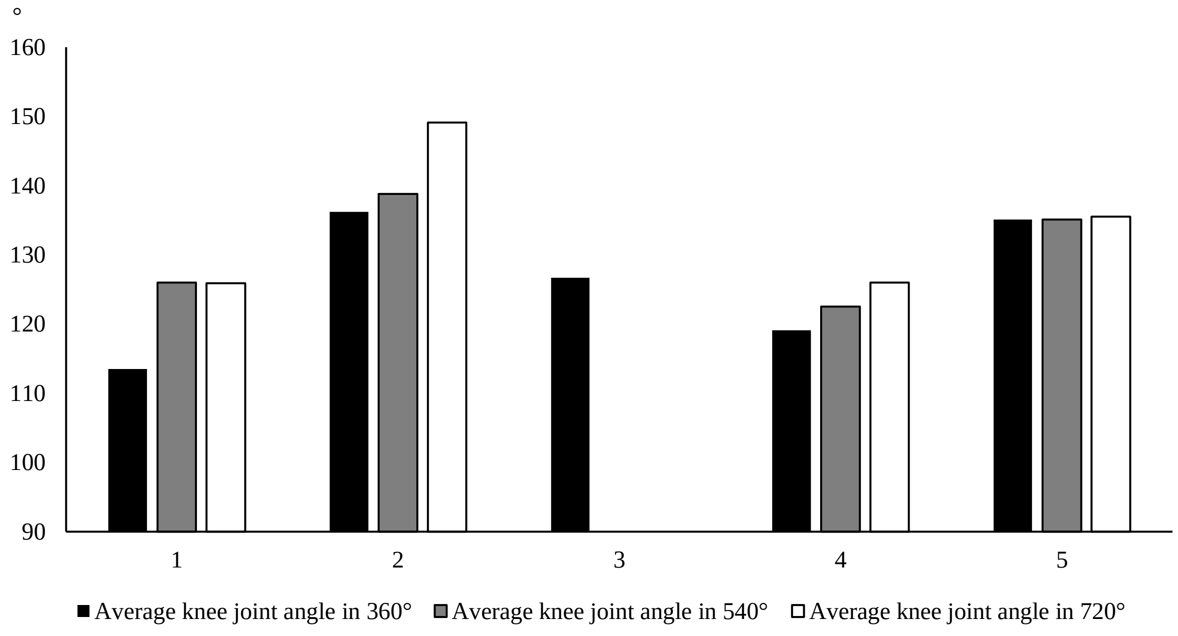


FIGURE 17. Average knee joint angles in back leg.

TABLE 9. Knee joint angles in backside 360° jump.

Subject	1		2		3		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	141.6	109.1	135.6	127.7	125.5	109.7	133.1	108.6	145.4	133.6
Max. (°)	145.8	117.8	146.5	152.8	148.9	142.0	141.4	131.0	151.2	136.5
Avg. (°)	143.6	113.5	142.4	136.2	139.3	126.7	138.4	119.1	147.9	135.1
St. deviation	1.599	3.268	3.662	8.172	8.868	9.075	2.132	7.940	2.069	0.965

*FL=front leg, BL=back leg.

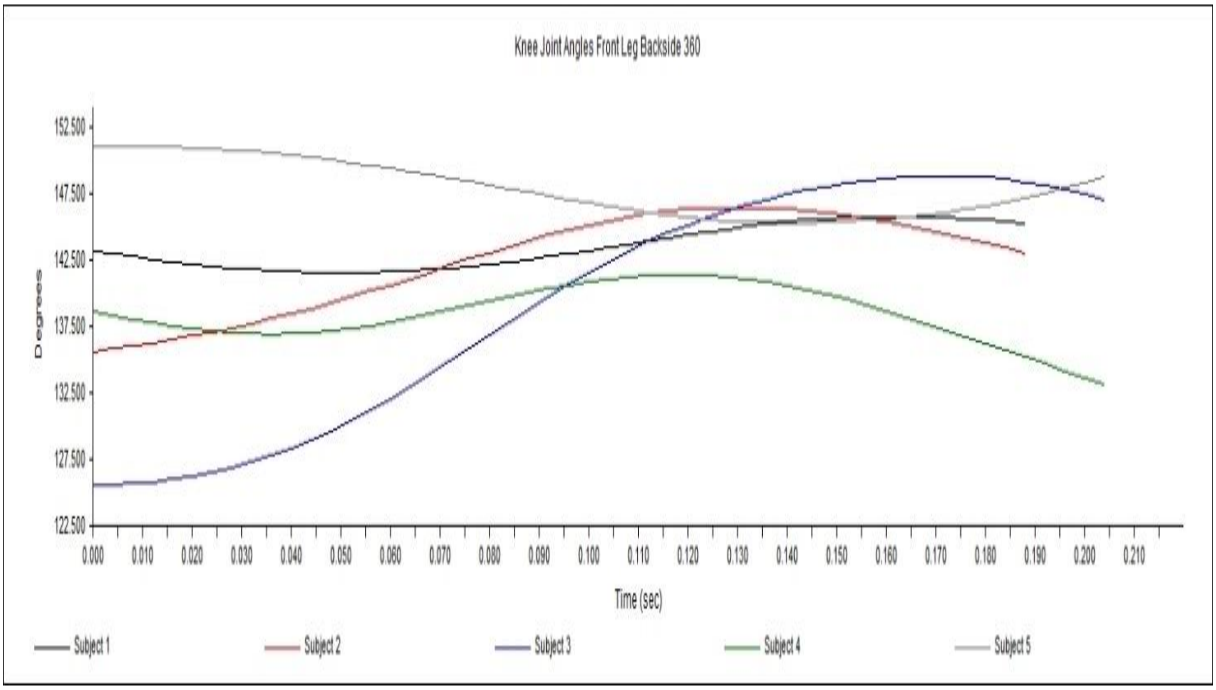


FIGURE 18. Knee joint angles in front leg in backside 360° jumps.

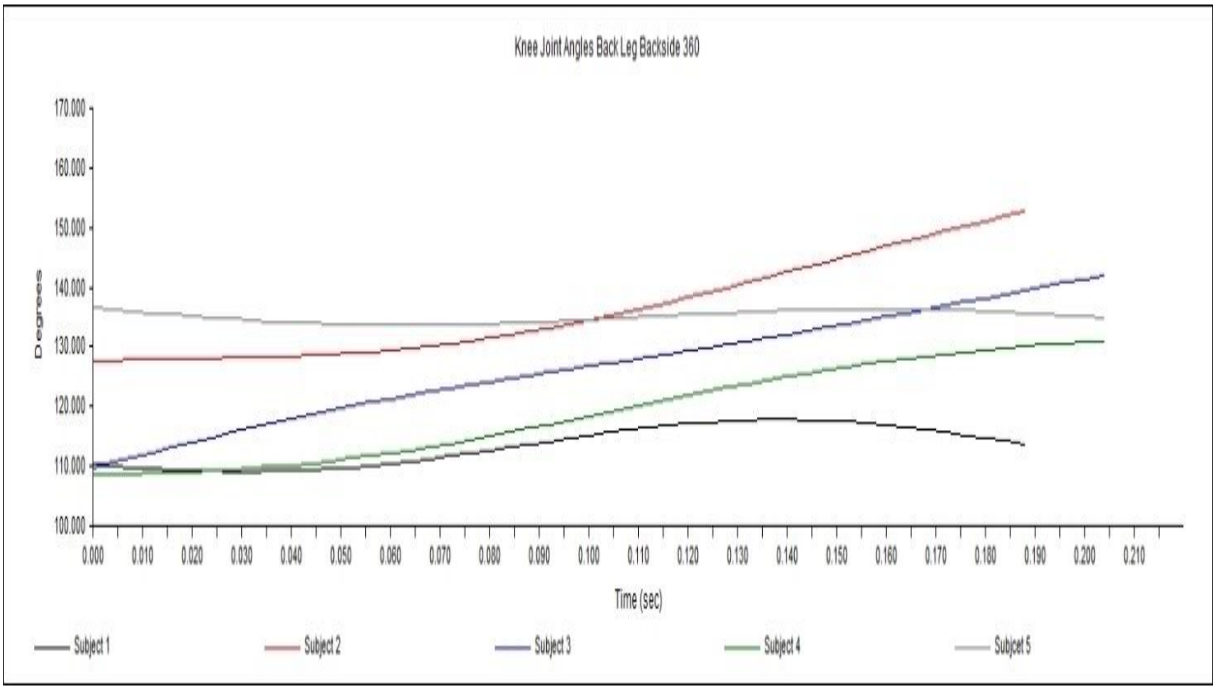


FIGURE 19. Knee joint angles in back leg in backside 360° jumps.

TABLE 10. Knee joint angles in backside 540° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	126.5	107.7	131.6	122.5	135.6	102.0	137.0	125.1
Max. (°)	141.5	163.1	137.8	154.4	140.1	140.2	150.4	143.0
Avg. (°)	129.7	126.0	133.9	138.8	137.9	122.5	145.1	135.1
St. deviation	4.216	17.889	2.112	9.645	1.598	12.733	3.370	5.242

*FL=front leg, BL=back leg.

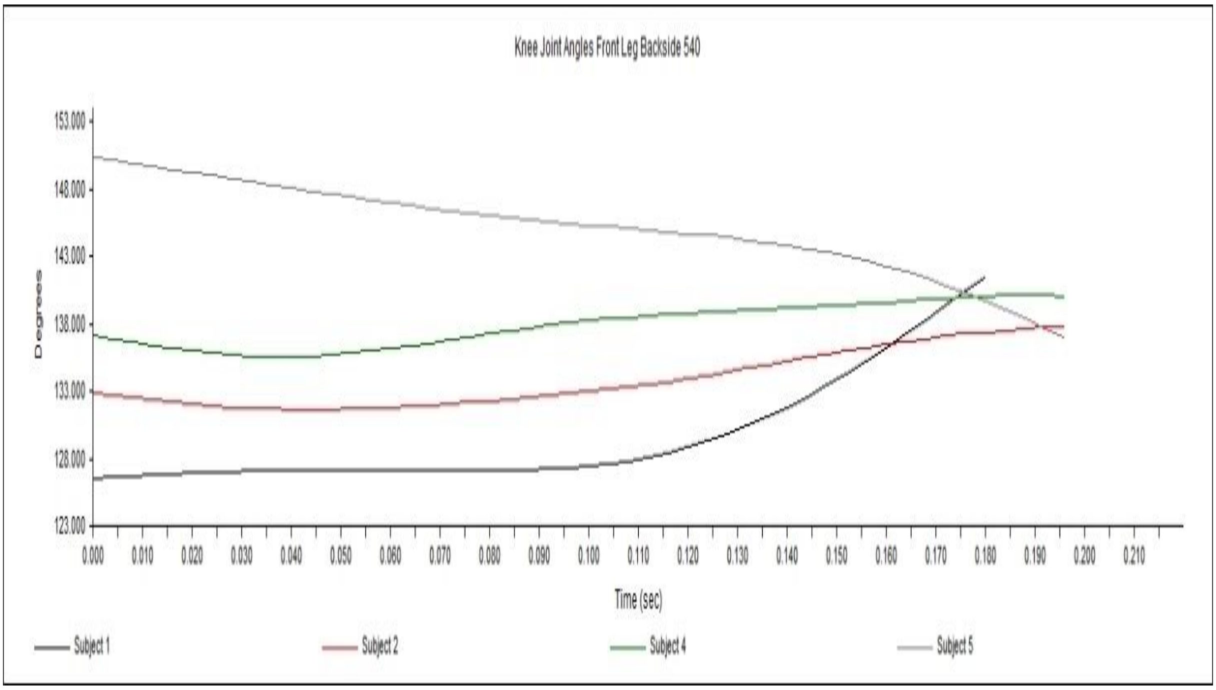


FIGURE 20. Knee joint angles in front leg in backside 540° jumps.

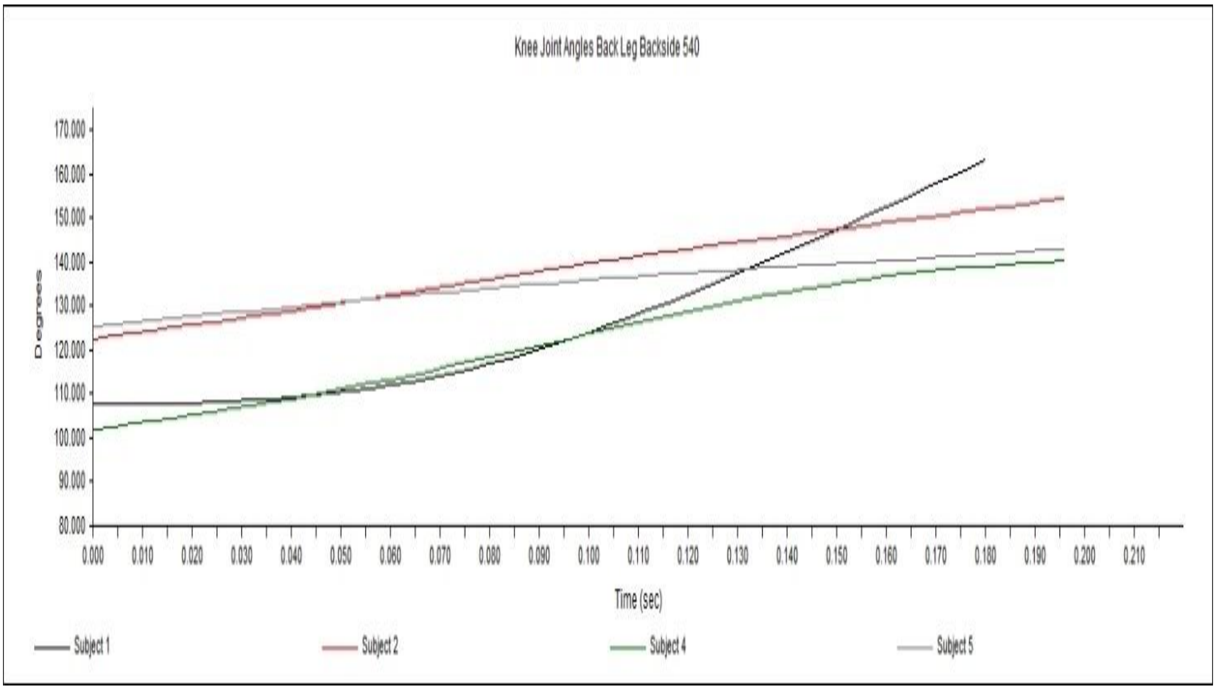


FIGURE 21. Knee joint angles in back leg in backside 540° jumps.

TABLE 11. Knee joint angles in backside 720° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	120.2	98.4	139.9	129.1	132.9	105.8	134.4	124.9
Max. (°)	147.8	155.0	151.3	164.3	144.5	143.8	138.2	143.9
Avg. (°)	139.8	125.9	146.6	149.1	138.0	126.0	136.1	135.5
St. deviation	8.097	17.493	4.272	12.522	3.878	12.629	0.848	7.159

*FL=front leg, BL=back leg.

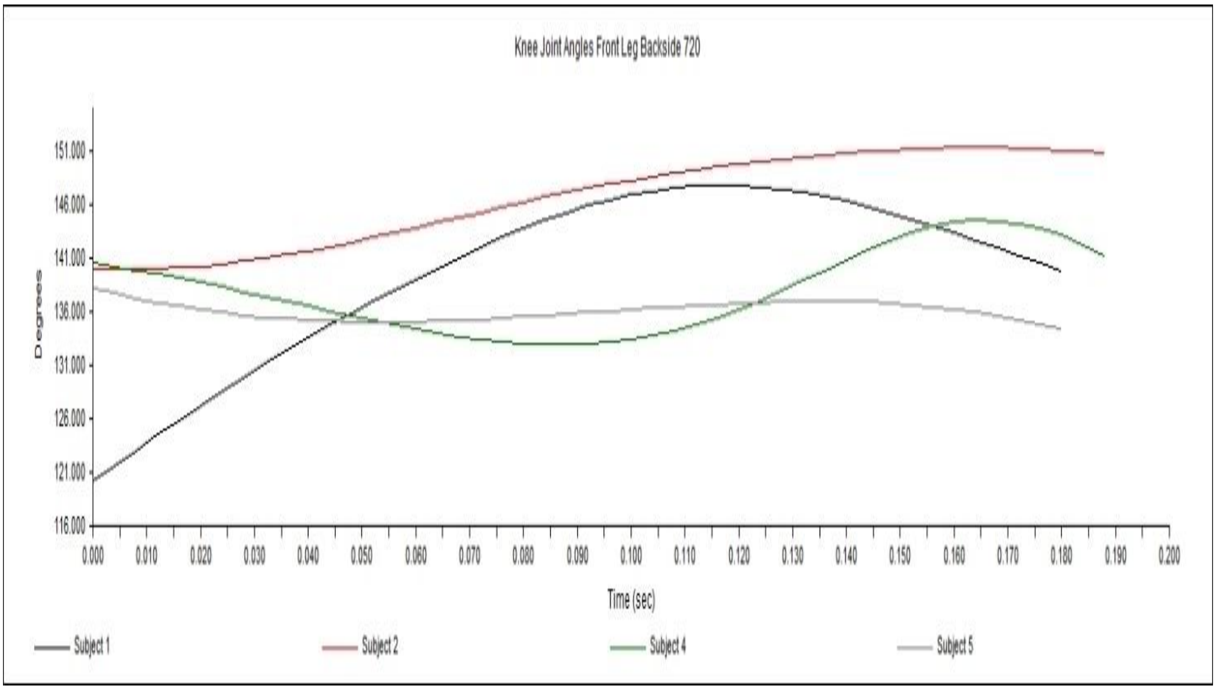


FIGURE 22. Knee joint angles in front leg in backside 720° jumps.

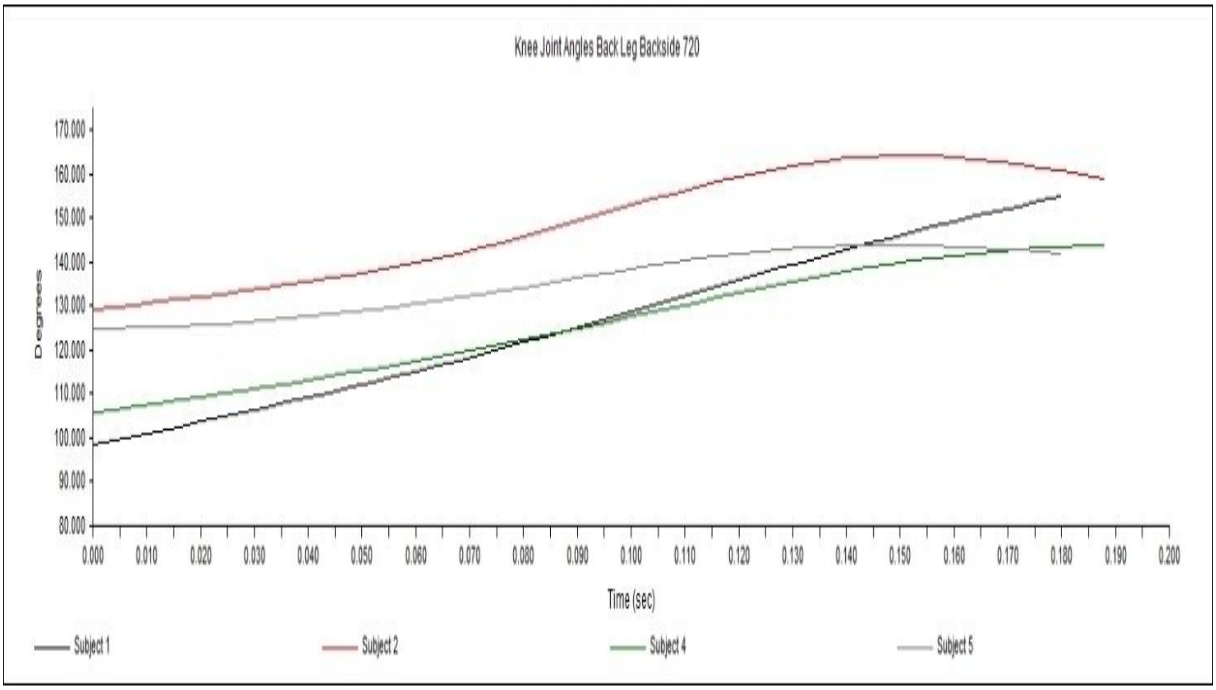


FIGURE 23. Knee joint angles in back leg in backside 720° jumps.

8.2.2 Hip Joint Angles

Average hip joint angles in front leg are presented in figure 24 and in back leg in figure 25. The angles of the hip joint are more similar between subjects than those in the knee joint. Most subjects have larger angles in hip joints in both the front and back legs as the difficulty level of the jump increases. Hip joint maximum, minimum, and average angles in backside 360° jump are shown in table 12, in backside 540° jump in table 13, and in backside 720° jump in table 14. From the figures 26-31 can be seen that there is a slight extension of the hip joint toward detachment of the jumper, but the angle remains quite same during the whole take-off phase.

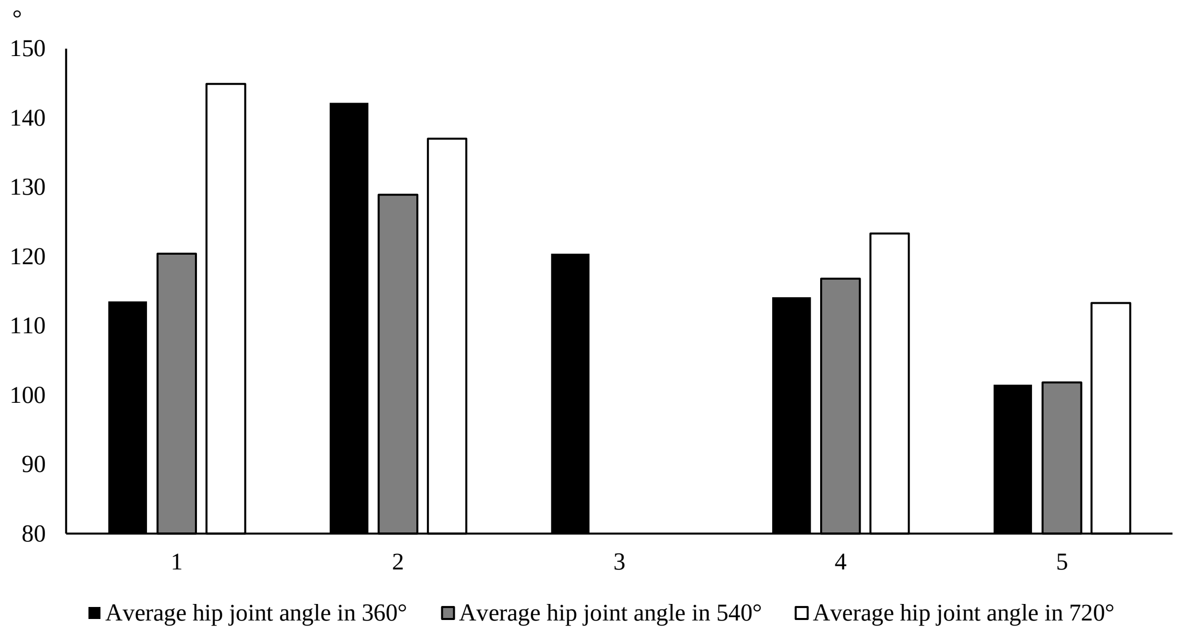


FIGURE 24. Average hip joint angles in front leg.

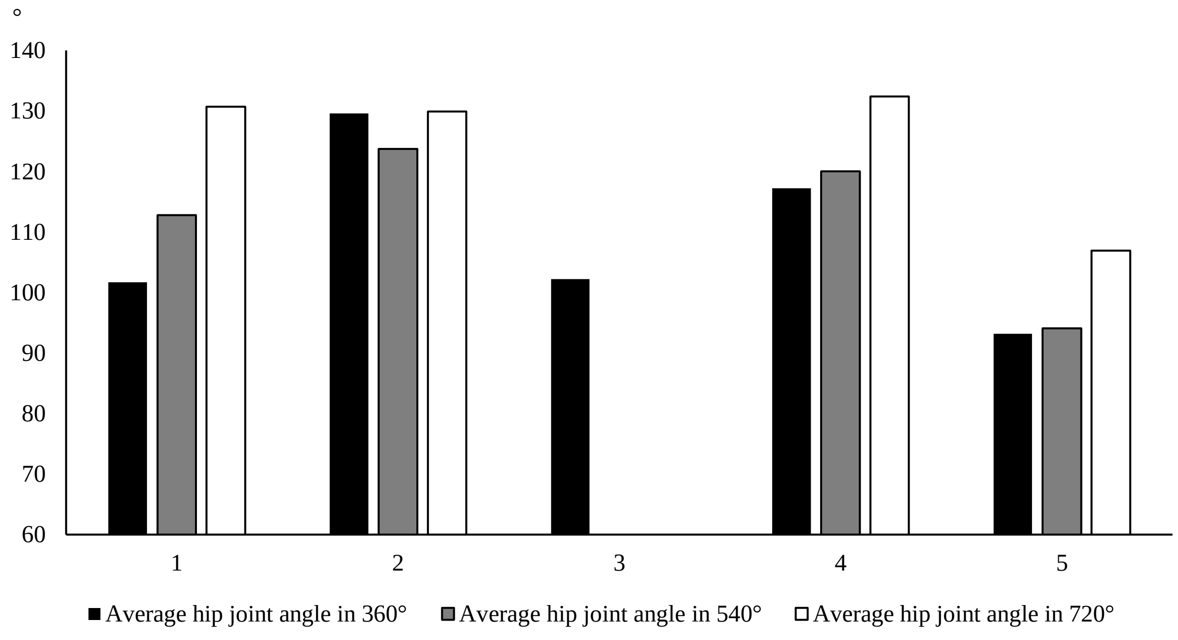


FIGURE 25. Average hip joint angles in back leg.

TABLE 12. Hip joint angles in backside 360° jump.

Subject	1		2		3		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	111.8	98.1	128.5	121.1	100.7	89.1	108.8	101.8	91.6	77.1
Max. (°)	117.3	104.1	149.9	143.0	144.3	114.8	118.8	124.1	111.2	100.9
Avg. (°)	113.5	101.7	142.2	129.6	120.4	102.2	114.1	117.2	101.5	93.2
St. deviation	1.356	1.877	7.424	7.631	15.783	7.901	3.966	7.155	6.884	6.979

*FL=front leg, BL=back leg.

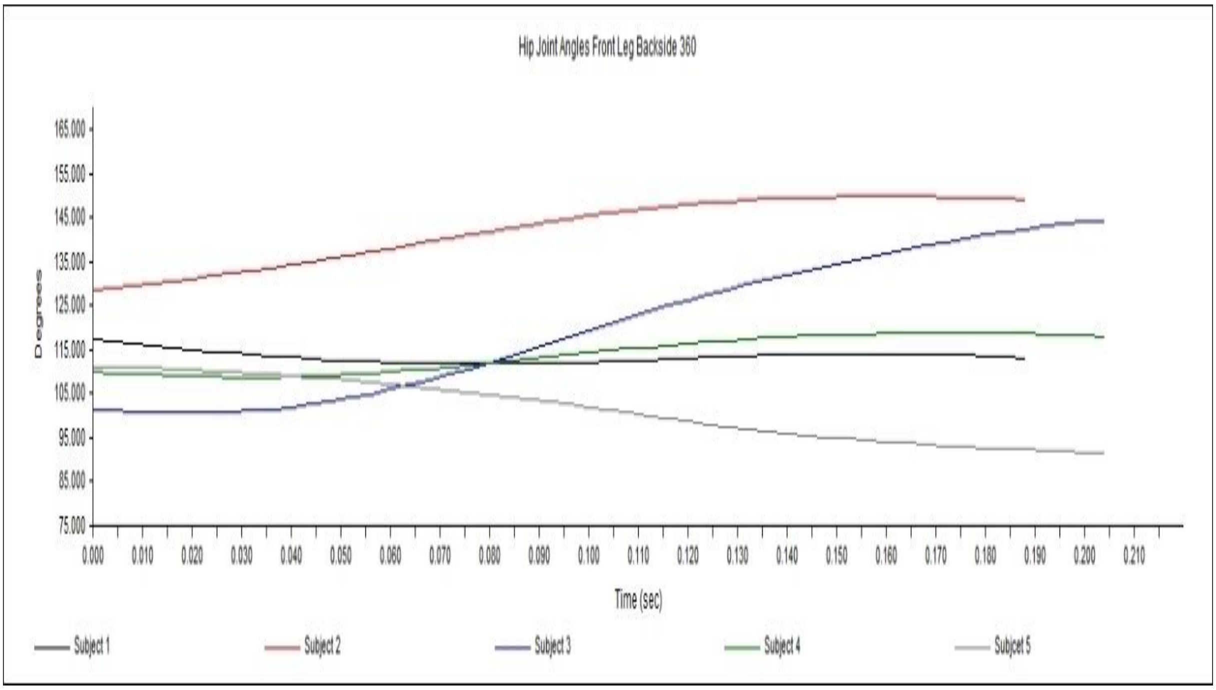


FIGURE 26. Hip joint angles in front leg in backside 360° jumps.

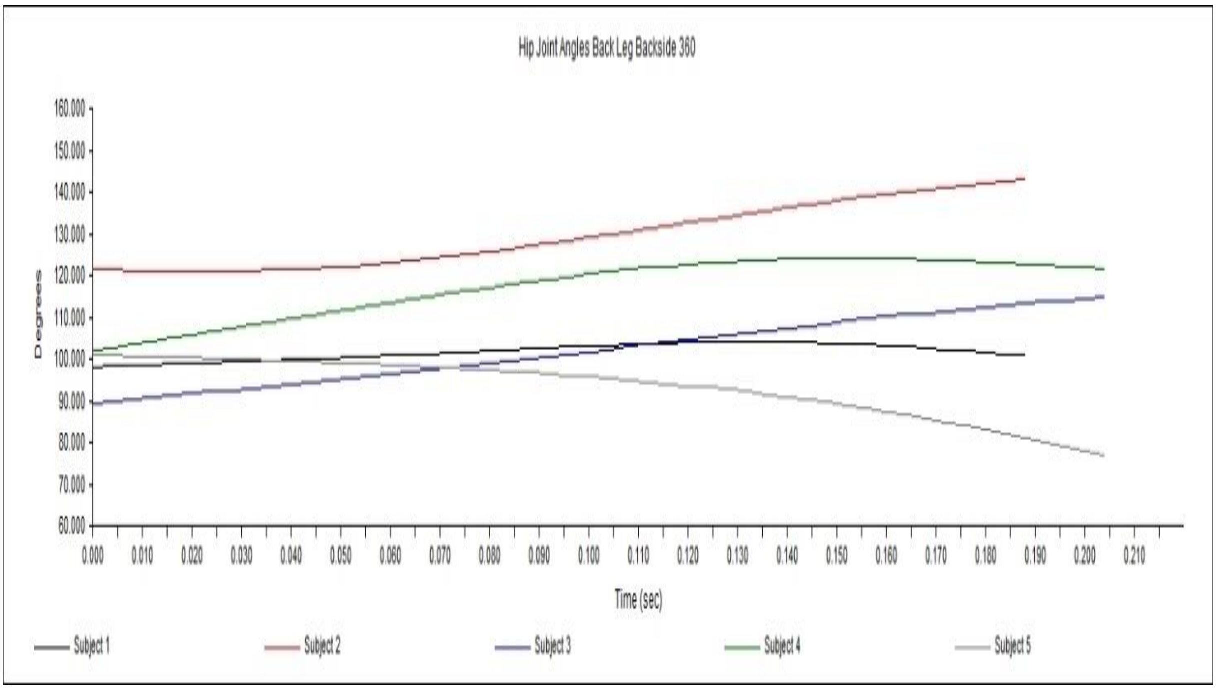


FIGURE 27. Hip joint angles in back leg in backside 360° jumps.

TABLE 13. Hip joint angles in backside 540° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	113.1	104.7	122.7	114.3	111.1	110.4	90.3	90.3
Max. (°)	136.1	129.3	138.4	137.0	121.3	125.1	112.0	97.1
Avg. (°)	120.4	112.8	128.9	123.7	116.8	120.0	101.8	94.1
St. deviation	6.952	8.118	5.648	6.580	4.020	4.405	5.755	2.203

*FL=front leg, BL=back leg.

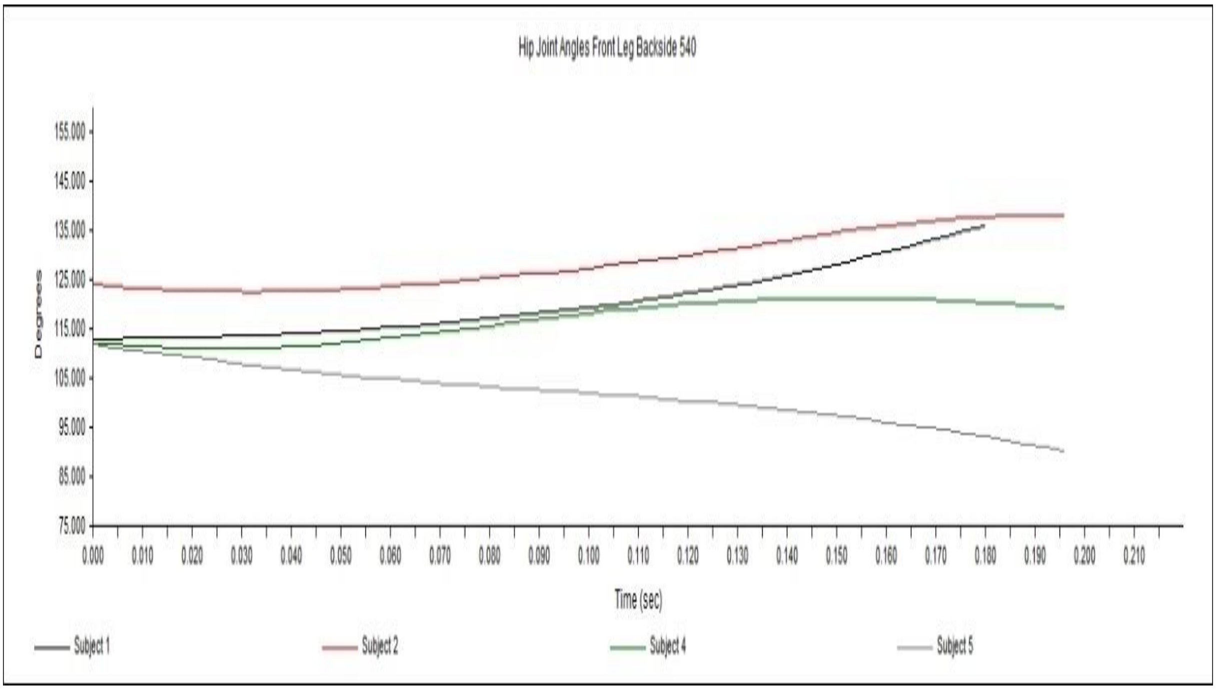


FIGURE 28. Hip joint angles in front leg in backside 540° jumps.

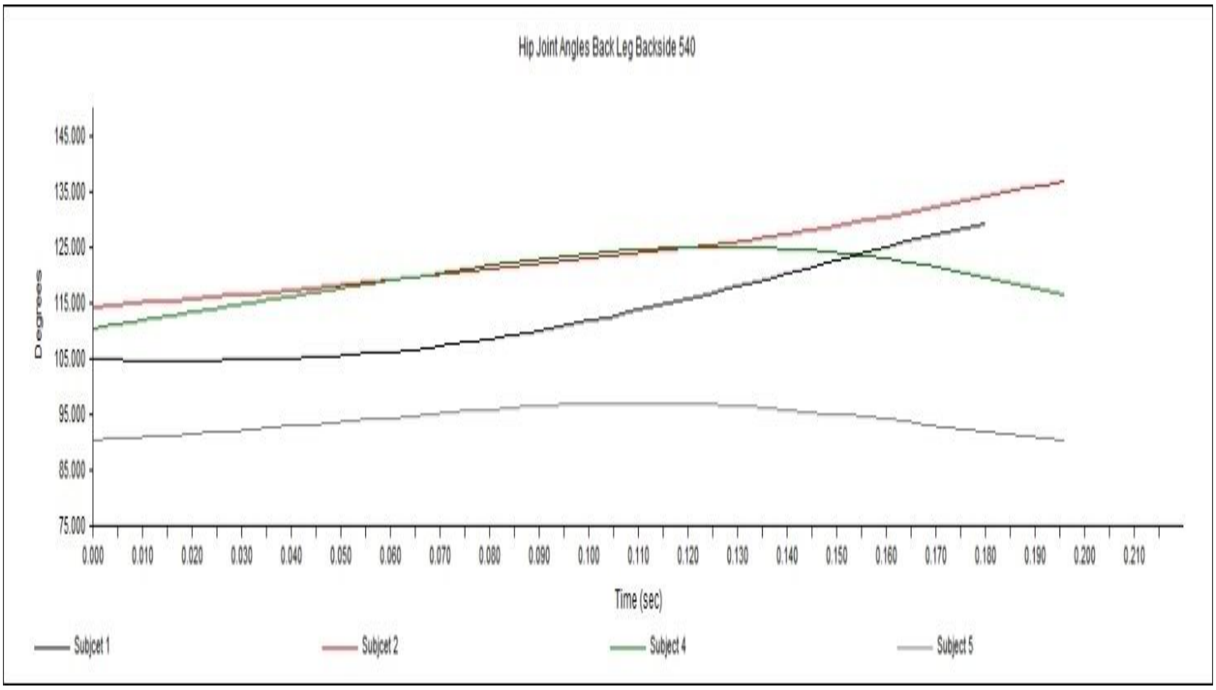


FIGURE 29. Hip joint angles in back leg in backside 540° jumps.

TABLE 14. Hip joint angles in backside 720° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	129.8	107.7	129.7	116.9	108.0	111.4	105.6	99.9
Max. (°)	150.9	154.4	145.8	141.1	138.2	142.3	115.2	111.2
Avg. (°)	144.9	130.7	137.0	129.9	123.3	132.4	113.3	106.9
St. deviation	5.867	14.869	5.979	9.207	10.524	10.157	2.636	3.595

*FL=front leg, BL=back leg.

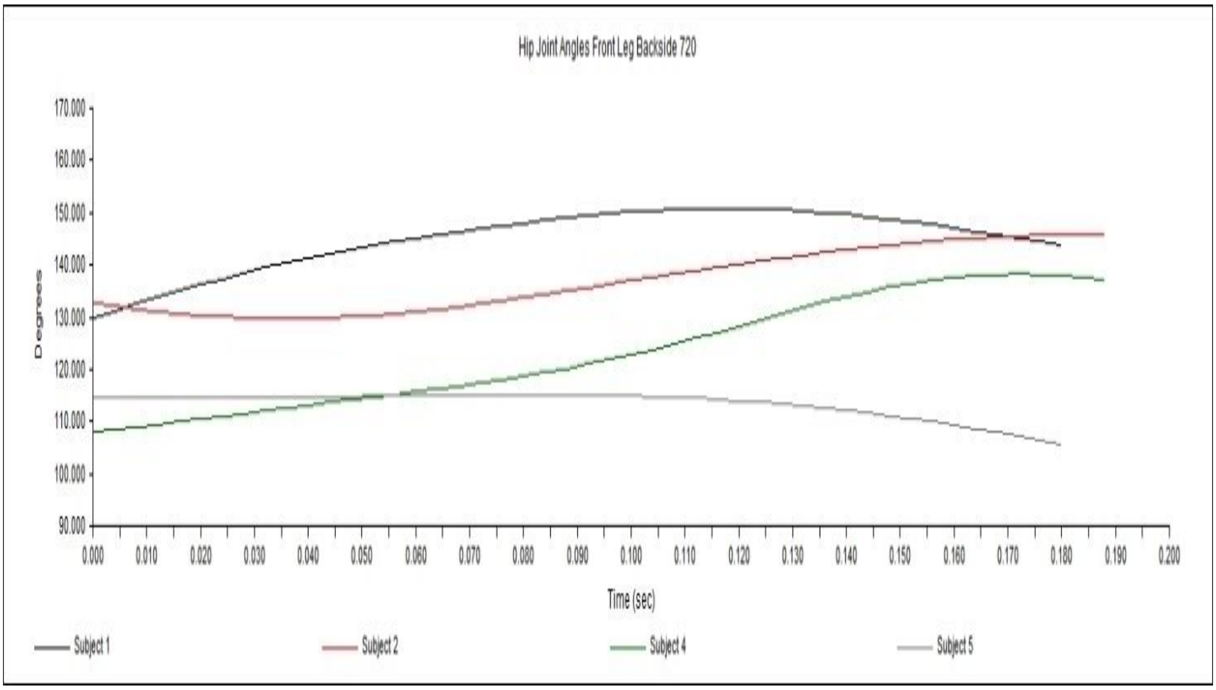


FIGURE 30. Hip joint angles in front leg in backside 720° jumps.

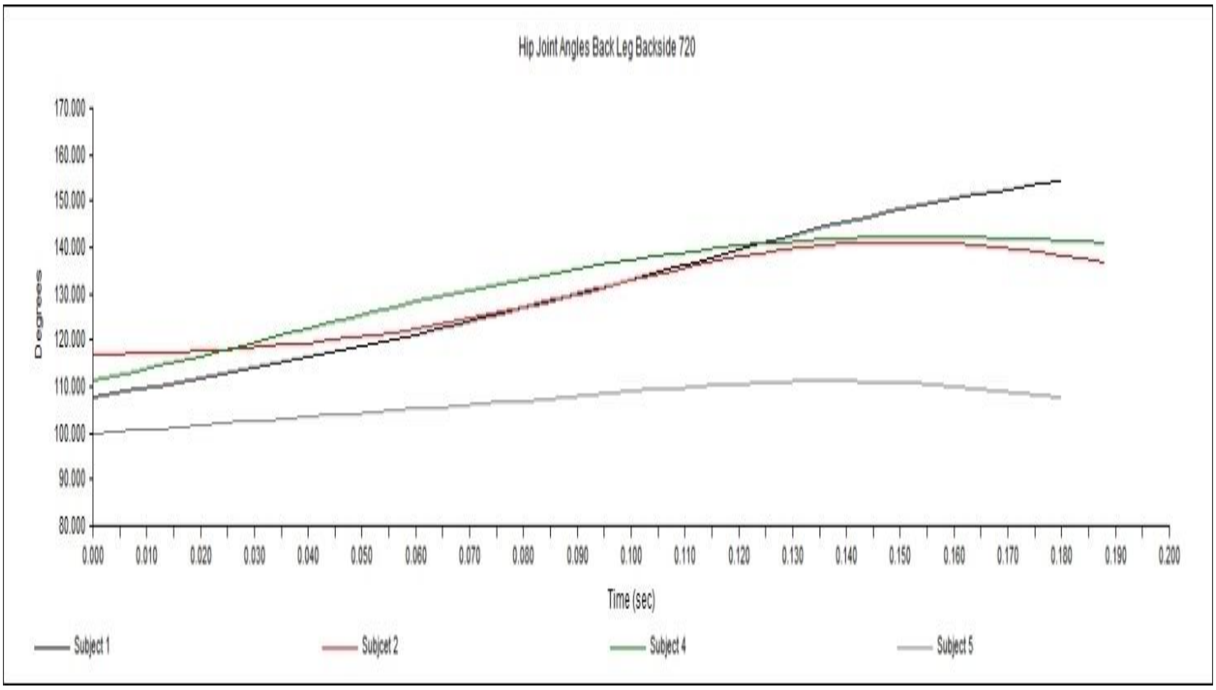


FIGURE 31. Hip joint angles in back leg in backside 720° jumps.

8.3 Angular Velocities

Positive angular velocity indicates counterclockwise rotation, and the angular displacement increase, while negative angular velocity indicates clockwise rotation, and the angular displacement decrease.

8.3.1 Knee Joint Angular Velocities

Positive angular velocity values indicate knee extension and negative angular velocity values indicate knee flexion. Knee joint angular velocity is the highest in backside 720° jumps and the slowest in backside 360° jumps. In figures 32 and 33, and in table 15, knee joint angular velocities in backside 360° jumps are represented. There was first front leg extension and before the detachment of the jumper front leg flexion for all subjects. Back leg extension can be seen at some point of the take-off phase. In figures 34 and 35, and in table 16, knee joint angular velocities in backside 540° jumps are represented. Just before the detachment of the jumper occurred a fast knee extension in front leg for all subjects. In back leg there was extension. In figures 36 and 37, and in table 17, knee joint angular velocities in backside 720° jumps are presented. Variation in front legs are visible: some subjects had knee extension while some subjects had knee flexion. All subjects had knee extension in back leg.

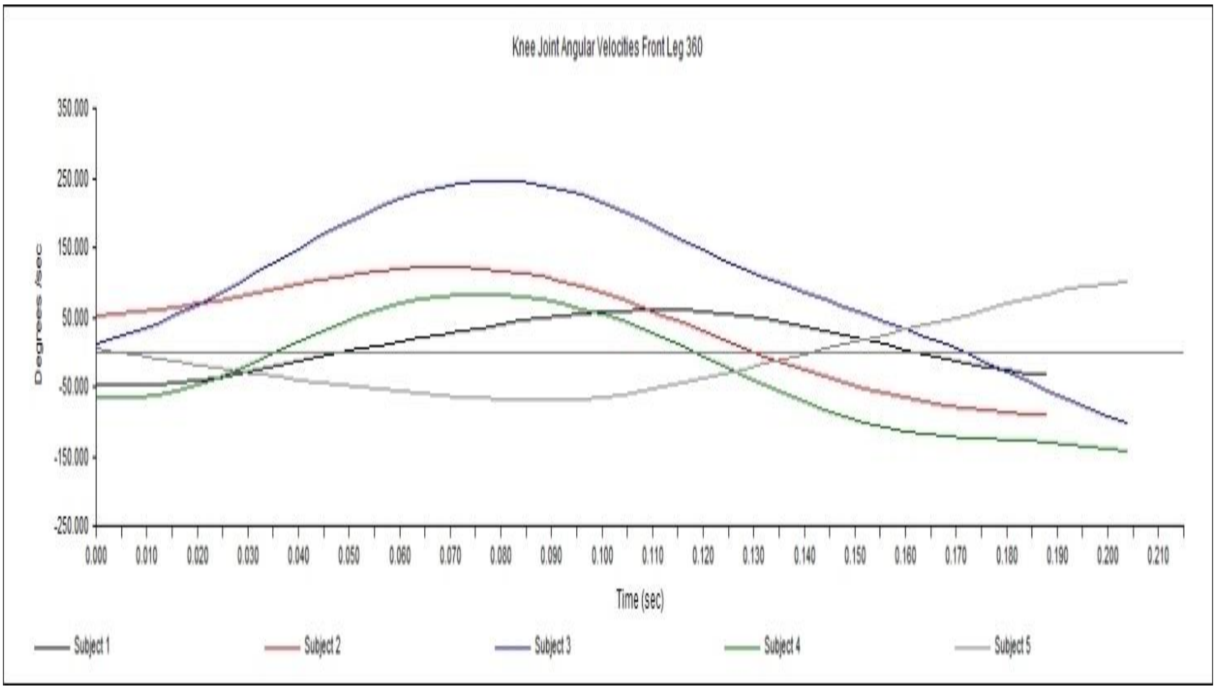


FIGURE 32. Knee joint angular velocities in front leg in backside 360° jump.

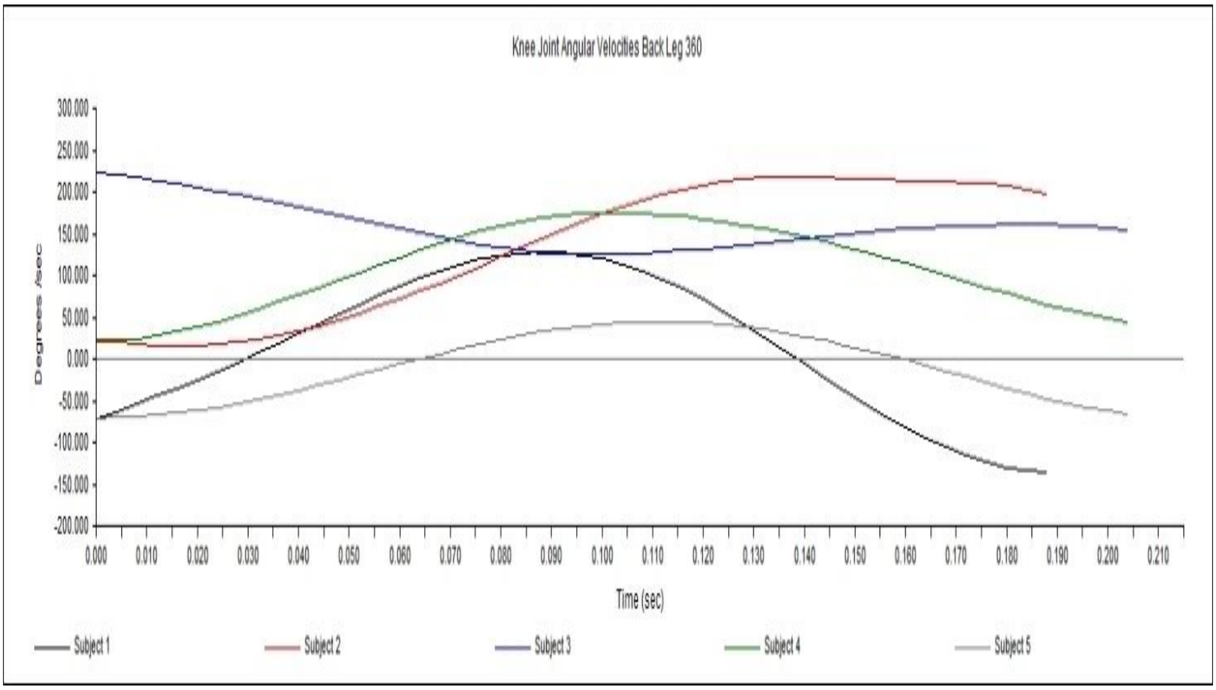


FIGURE 33. Knee joint angular velocities in back leg in backside 360° jump.

TABLE 15. Knee joint angular velocities in backside 360° jump.

Subject	1		2		3		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	-47.7	-137.1	-89.6	15.4	-102.7	124.5	-142.4	21.0	-69.0	-70.7
Max. (°)	60.7	127.9	122.1	217.8	246.6	222.3	82.8	175.0	101.6	44.8
Avg. (°)	10.4	15.4	38.4	132.8	103.0	158.9	-28.4	108.4	-10.3	-9.6
St. deviation	36.963	84.992	73.505	80.920	103.1	27.8	76.938	50.8	52.066	40.155

*FL=front leg, BL=back leg.

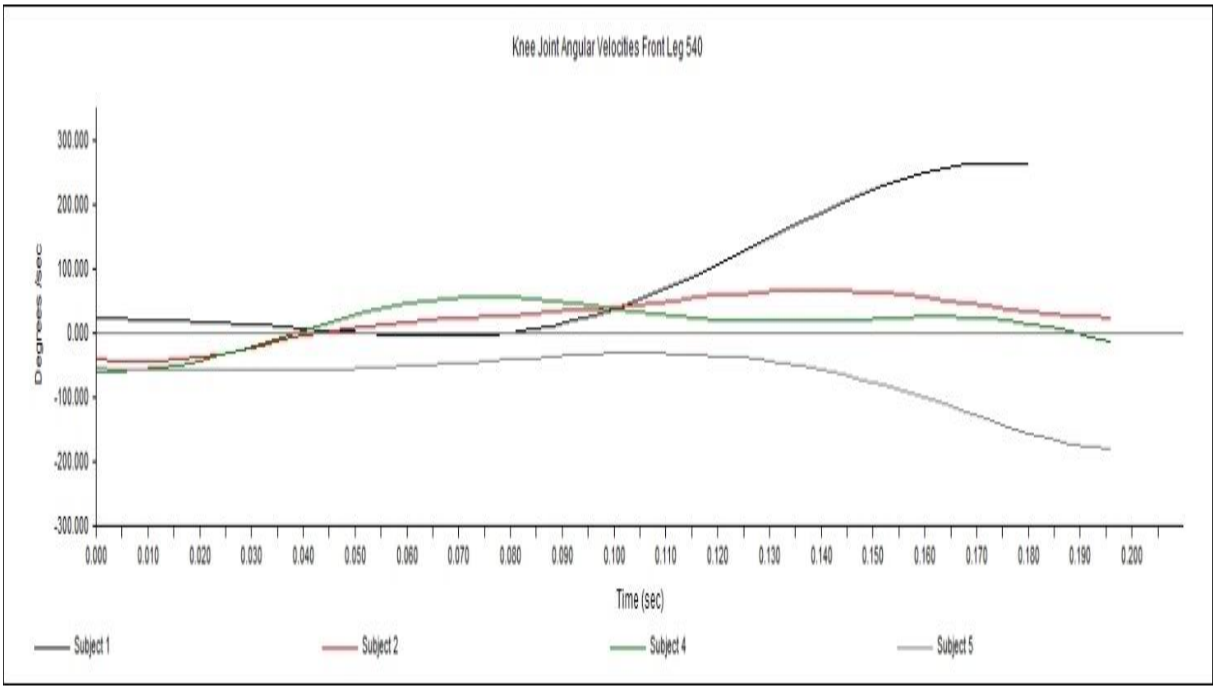


FIGURE 34. Knee joint angular velocities in front leg in backside 540° jump.

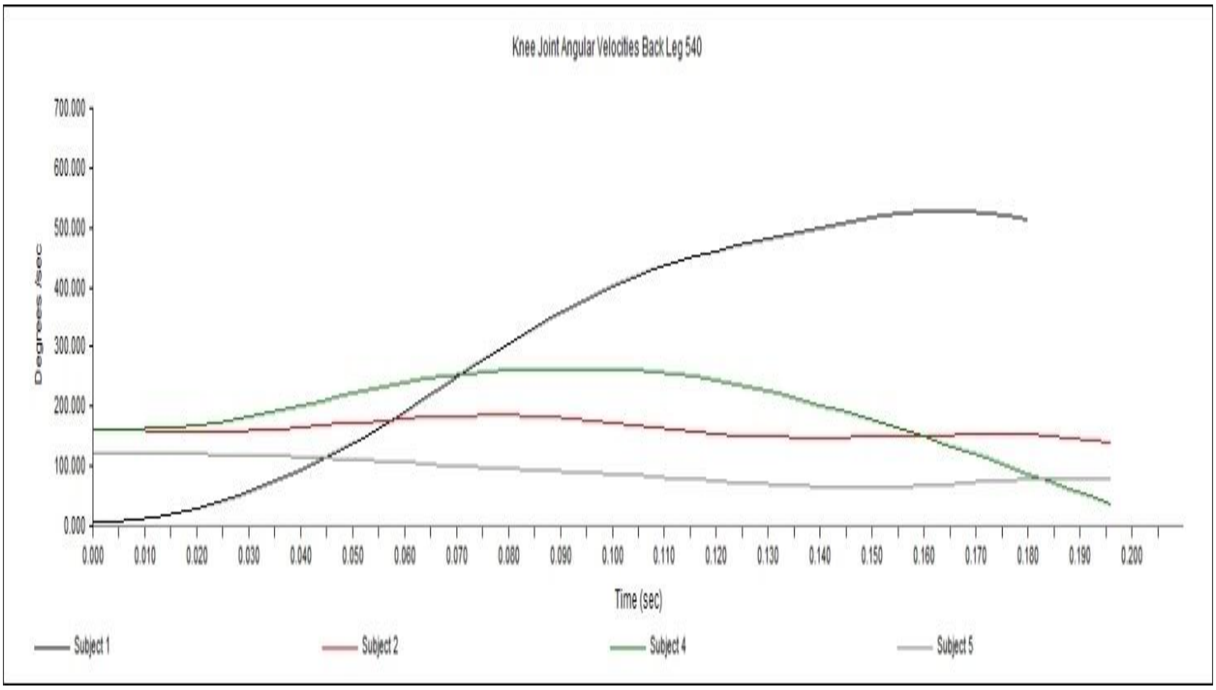


FIGURE 35. Knee joint angular velocities in back leg in backside 540° jump.

TABLE 16. Knee joint angular velocities in backside 540° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	-4.8	6.1	-44.8	140.5	-60.3	35.8	-180.5	64.8
Max. (°)	264.1	529.0	66.7	185.3	57.2	263.5	-30.8	121.5
Avg. (°)	84.6	306.7	24.3	162.3	14.2	192.9	-69.3	91.7
St. deviation	98.863	193.214	34.687	12.704	32.853	62.559	42.408	20.054

*FL=front leg, BL=back leg.

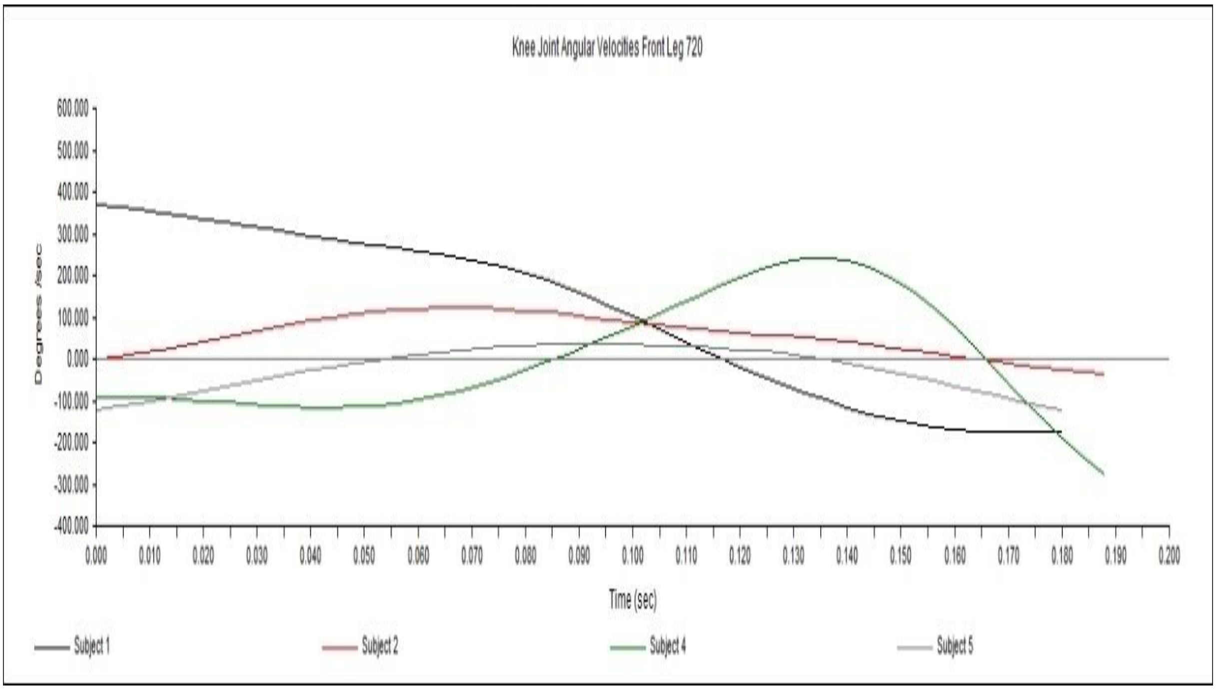


FIGURE 36. Knee joint angular velocities in front leg in backside 720° jump.

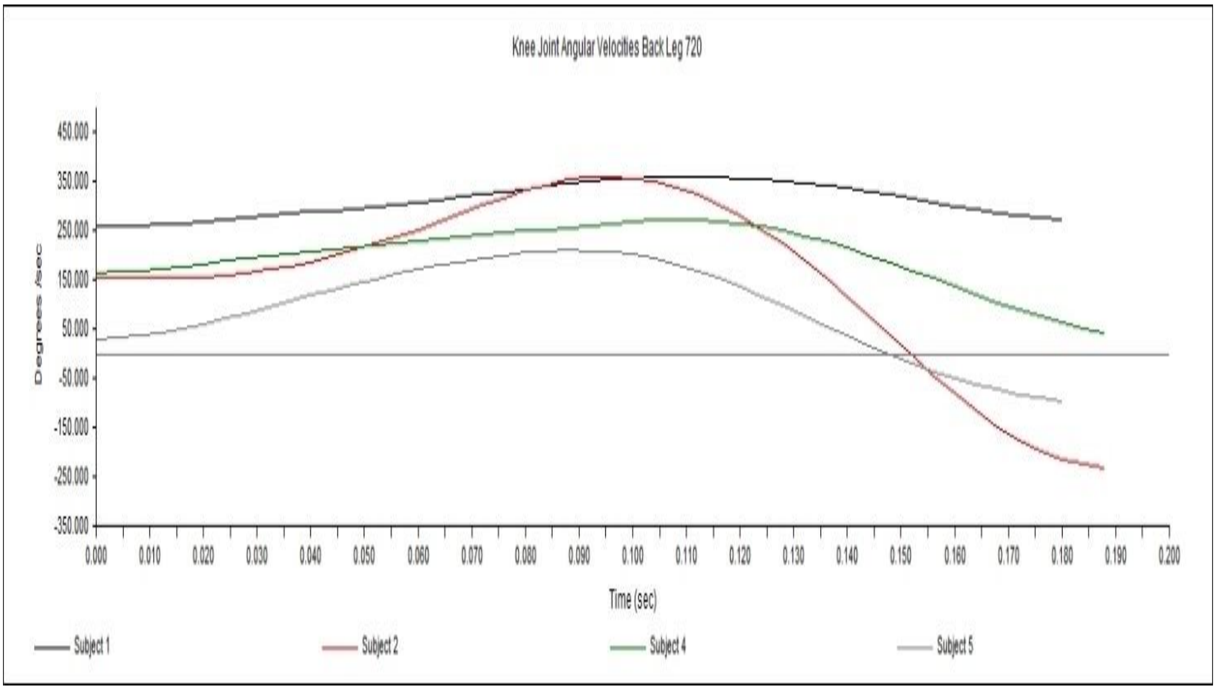


FIGURE 37. Knee joint angular velocities in back leg in backside 720° jump.

TABLE 17. Knee joint angular velocities in backside 720° jump.

Subject	1		2		4		5	
	FL	BL	FL	BL	FL	BL	FL	BL
Min. (°)	-176.7	259.6	-38.1	-234.1	-276.4	41.4	-122.0	-95.9
Max. (°)	369.1	361.1	122.2	361.1	241.6	273.2	35.4	210.7
Avg. (°)	109.2	313.0	56.4	154.5	-0.7	200.2	-23.6	92.1
St. deviation	197.224	34.009	47.763	176.558	140.241	62.776	52.041	94.782

*FL=front leg, BL=back leg.

8.3.2 Elbow Joint Angular Velocities

Elbow joint angular velocities were faster once the difficulty level of the jump increased. In figures 38 and 39, and in table 18, elbow joint angular velocities in backside 360° jumps are presented. Almost all subjects had front arm flexion and back arm extension. In figures 40 and 41, and in table 19, elbow joint angular velocities in backside 540° jumps are presented. Some of the subjects had front arm extension and some of the subjects had front arm flexion. Same can be seen in back arms but movement is slower toward detachment of the jumper. In figures 42 and 43, and in table 20, elbow joint angular velocities in backside 720° jumps are presented. Movements in elbows were similar as in backside 540° jumps. In back arm negative values refer to elbow extension and positive values refer to elbow flexion. In front arm negative values refer to elbow flexion and positive values mean elbow extension.

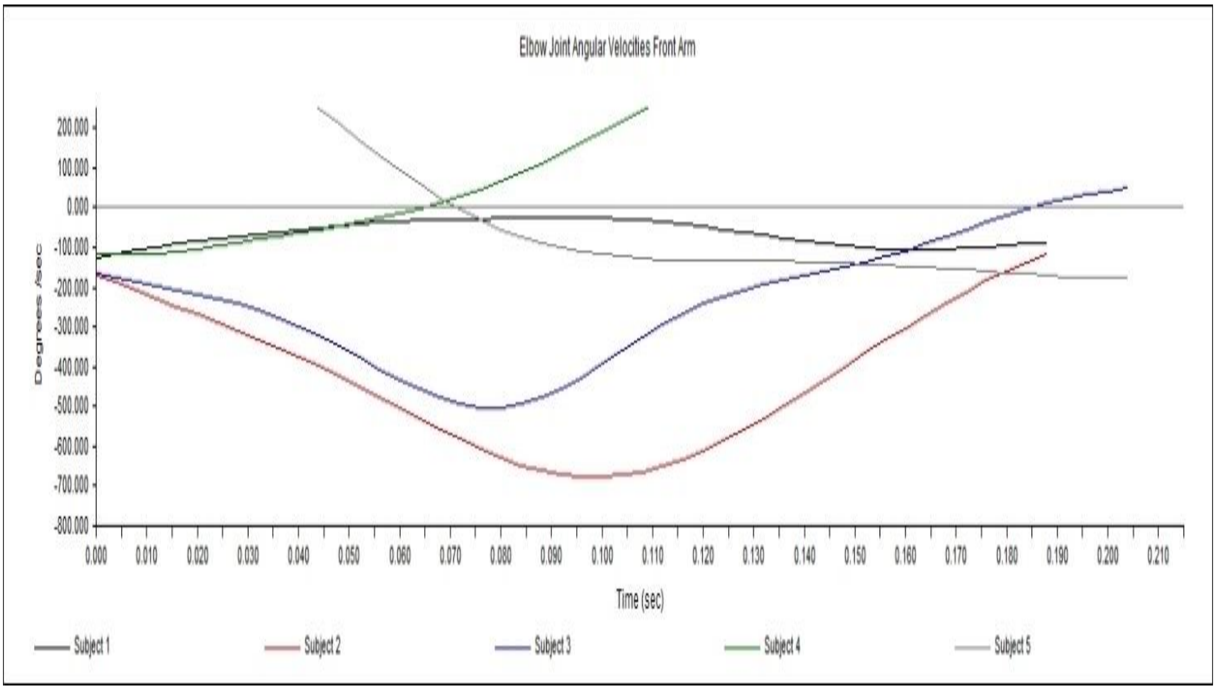


FIGURE 38. Elbow joint angular velocities in front arm in backside 360° jump.

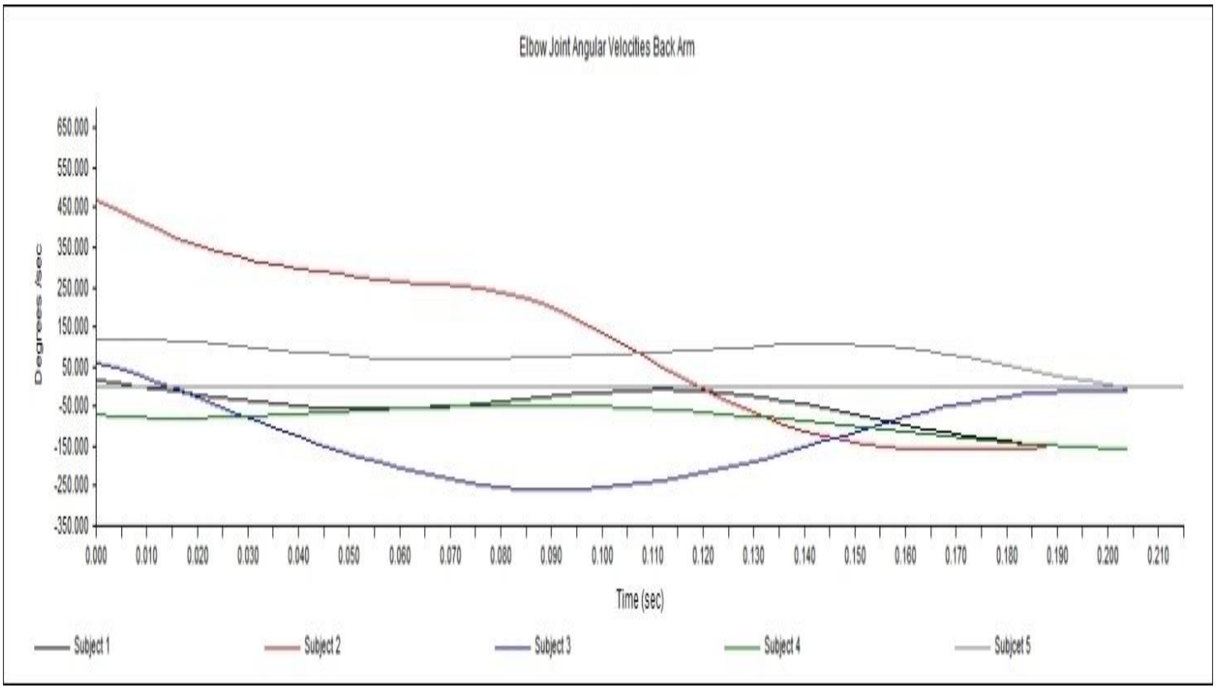


FIGURE 39. Elbow joint angular velocities in back arm in backside 360° jump.

TABLE 18. Elbow joint angular velocities in backside 360° jump.

Subject	1		2		3		4		5	
	FA	BA	FA	BA	FA	BA	FA	BA	FA	BA
Min. (°/s)	-127.1	-150.1	-676.2	-158.2	-503.2	-258.6	-117.9	-157.9	-177.3	-3.1
Max. (°/s)	-25.3	15.5	-114.6	471.1	48.6	60.5	469.2	-47.4	460.1	119.3
Avg. (°/s)	-65.7	-48.0	-426.2	118.3	-235.9	-125.7	193.1	-84.4	18.8	81.5
St. deviation	31.523	41.198	177.933	208.627	162.647	98.742	227.0	34.433	226.881	28.257

*FA=front arm, BA=back arm.

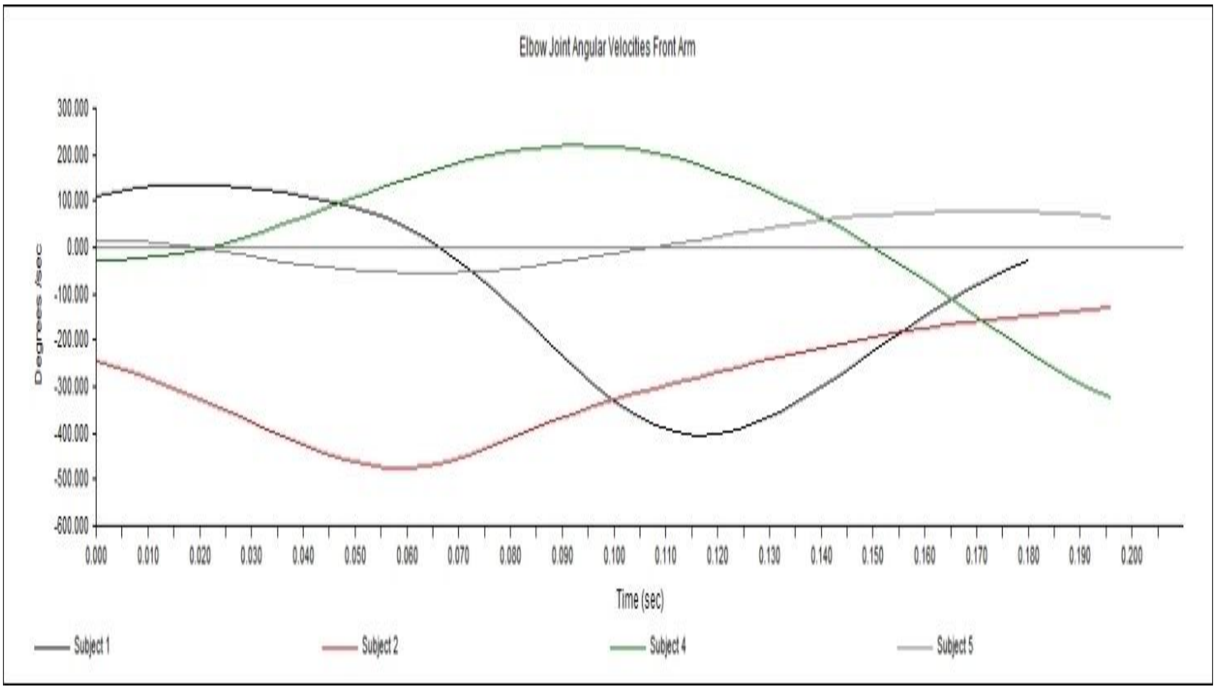


FIGURE 40. Elbow joint angular velocities in front arm in backside 540° jump.

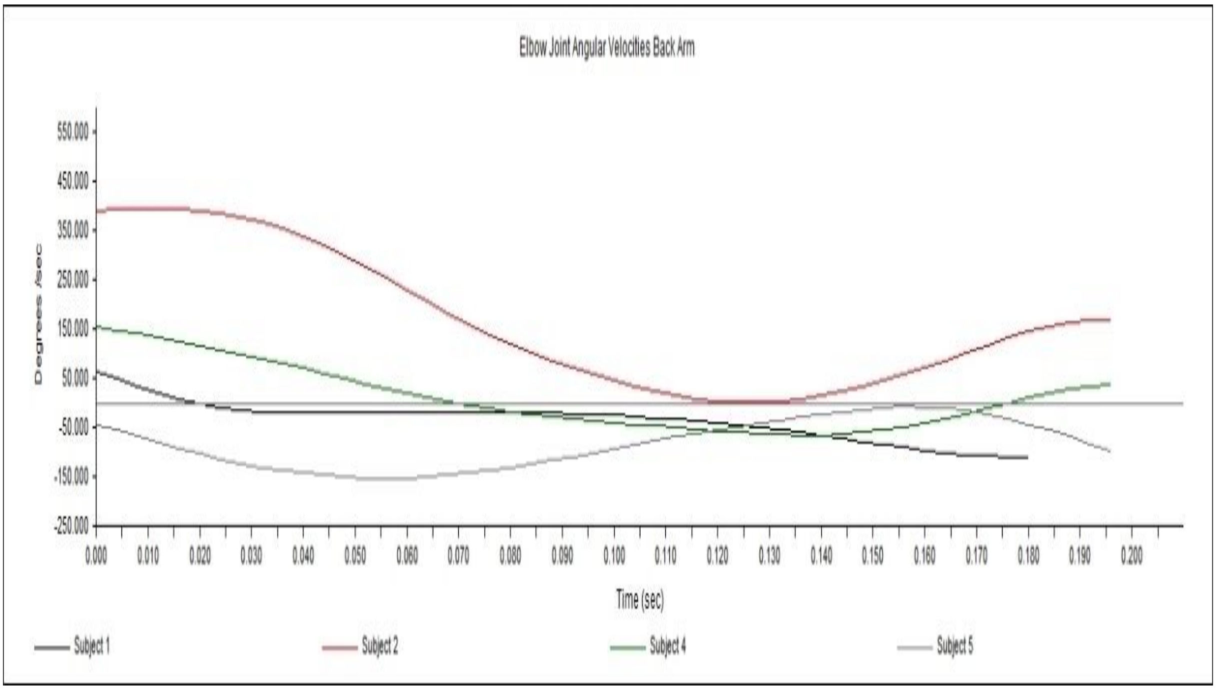


FIGURE 41. Elbow joint angular velocities in back arm in backside 540° jump.

TABLE 19. Elbow joint angular velocities in backside 540° jump.

Subject	1		2		4		5	
	FA	BA	FA	BA	FA	BA	FA	BA
Min. (°/s)	-404.0	-112.3	-474.3	1.5	-324.8	-65.5	-54.1	-153.2
Max. (°/s)	134.3	65.8	-130.2	396.0	219.3	155.1	78.5	-8.1
Avg. (°/s)	-105.4	-35.0	-297.5	166.7	41.5	10.4	12.1	-82.0
St. deviation	193.8	40.455	110.875	139.564	152.357	66.747	47.973	48.632

*FA=front arm, BA=back arm.

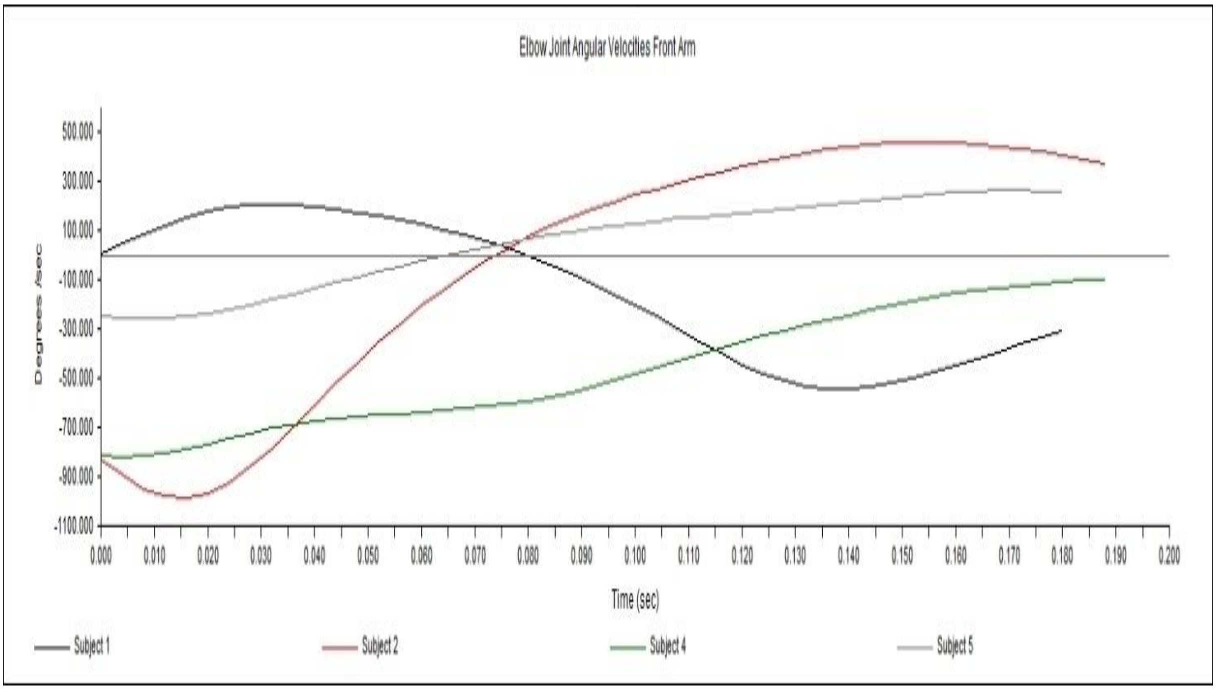


FIGURE 42. Elbow joint angular velocities in front arm in backside 720° jump.

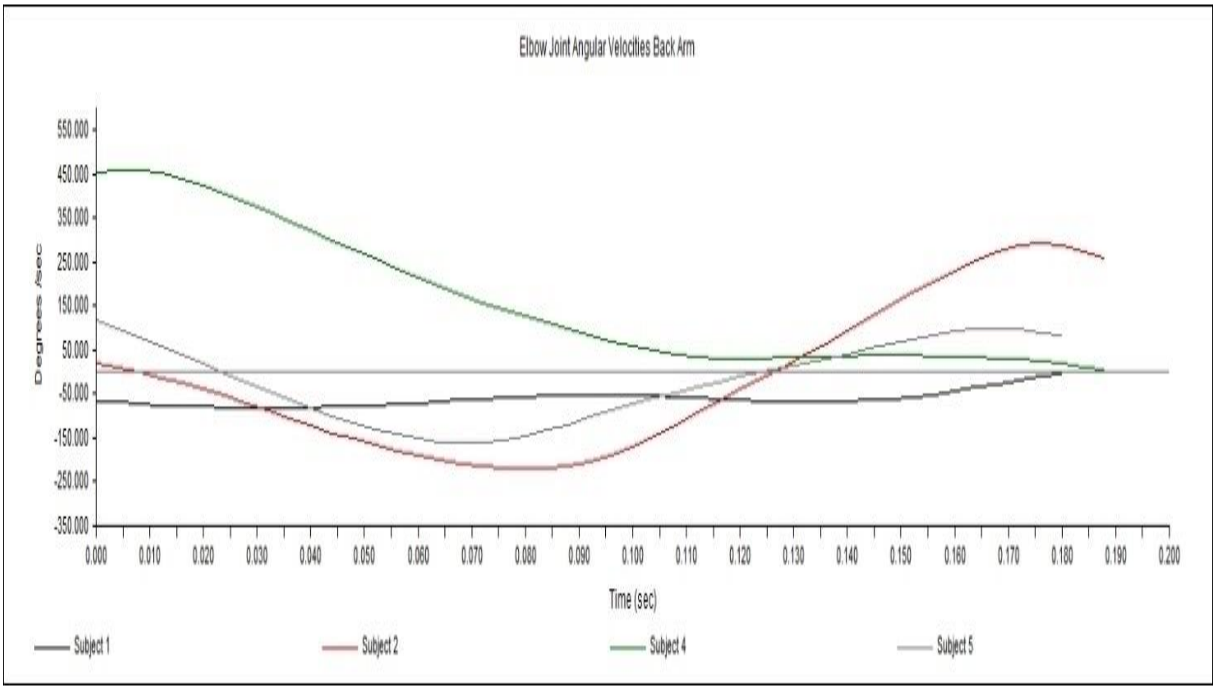


FIGURE 43. Elbow joint angular velocities in back arm in backside 720° jump.

TABLE 20. Elbow joint angular velocities in backside 720° jump.

Subject	1		2		4		5	
	FA	BA	FA	BA	FA	BA	FA	BA
Min. (°/s)	-541.5	-81.3	-989.3	-220.6	-817.6	3.5	-256.2	-160.1
Max. (°/s)	207.5	-3.6	461.2	291.9	-96.8	459.1	267.9	119.6
Avg. (°/s)	-141.3	-60.4	-32.9	-17.0	-468.4	160.4	50.3	-20.9
St. deviation	277.970	18.081	522.839	169.792	240.485	157.1	180.8	90.8

*FA=front arm, BA=back arm.

9 DISCUSSION

This study was a case study. The results are presented descriptively. The results are largely in line with the hypotheses. Centre of mass vertical velocity was higher once the difficulty level of the jump increased, and centre of mass horizontal velocity was also higher once the difficulty level of the jump increased for some subjects. Most of the subjects extend knees and hips more when there is more rotation in the jump. Knee and elbow joint angular velocities were higher once the difficulty level of the jump increased.

One subject was unable to successfully complete the jumps within the maximum number of attempts. His centre of mass horizontal velocity was lower than the velocity of two other subjects but quite the same as two other subjects. This could be due to the stress caused by the test situation. Muñoz et al. (2018) discussed in their study that increasing of the difficulty of the jump led snowboarders to fall and make mistakes more easily. According to Muñoz et al. (2018) and Turnbull et al. (2011), snowboarders need adequately high velocity to achieve sufficiently long airtime to perform the jump successfully. Also, snowboarder's COM must gain as much height above the lip as possible, thus, the vertical velocity is also an important factor since the jump height can be determined from the vertical velocity of the COM (Turnbull et al. 2011). The run-up velocity of the best athletes is significantly higher than the velocity of the rest (Muñoz et al. 2018).

Horizontal velocity of COM varied between subjects and between jumps. For subject 1, horizontal velocity was the highest in backside 360° jump and lowest in backside 720° jump (Figure 12). Her horizontal velocity thus slowed as the difficulty level of the jump increased. On the contrary, the subject 5 had the highest horizontal velocity in backside 720° jump and the lowest in backside 360° (Figure 12). He increased his velocity in more difficult jumps. For subjects 2 and 4, the lowest horizontal velocity was in backside 540° jumps and the velocity was somewhat higher in backside 360° and 720° jumps (Figure 12). Based on these results, it is not possible to observe an increase or a decrease in the horizontal velocity of a jump as the level of difficulty increased, since the results varied between subjects.

In the figures 13, 14, and 15 can be seen that on the average, horizontal velocity COM slowed down just before take-off. This is probably due to pre-rotation before detaching from the jumper and to progressing upwards the jumper. Pre-rotation is the most important factor in the initiation phase, and it helps initiating turns by orientating the body (Meyer 2012). Skidding at the take-off increases angular momentum and allows greater rotation (King et al. 1994). In pre-rotation, snowboarder carves towards the lip, and in that phase horizontal velocity slightly decreases. In figure skating, horizontal velocity was highest with the easiest jump in Mazurkiewich's et al. (2018) study. In this study, the horizontal velocity in average, of all subjects in backside 360° was 12,20 m/s, in backside 540° 12,04 m/s and in backside 720° 12,18 m/s. The differences are not big but similar as in Mazurkiewich's et al. (2018) study.

The higher the number of rotations in the jump, the higher the vertical velocity of all subjects was. From the figures 9, 10, and 11 can be seen that vertical velocity increased towards the detachment of the jumper, and for some of the subjects it slightly decreased just before detachment. Increasing vertical velocity indicates extension of the knee and hip joint angles and decreasing vertical velocity indicates flexion of the knee and hip joint angles. Vertical velocity was highest with backside 720° jumps for all subjects. According to Mazurkiewicz et al. (2018), the vertical velocity is the highest with the most difficult jump (in this case, backside 720°) at the take-off. Horizontal velocity instead is the highest with the easiest jump. Reducing the horizontal velocity enabled the skater to achieve greater vertical velocity. (Mazurkiewicz et al. 2018.) In this study, vertical velocities of all subjects were higher in more difficult jumps (Figure 8), but only two subjects' horizontal velocity was the highest in easiest jumps (Figure 12). Vertical velocity at the take-off is an important factor in determining the height of the jump and time in the air (Turnbull et al. 2011; King 2005).

Subjects 1 and 2 had the same trend in average knee angles in front leg between different jumps. They had higher knee angles in front leg on average in backside 360° ja 720° jumps and smaller in backside 540 jump. In subject 4, the knee angles in front leg were very similar regardless of the jump. In subject 5, the more laps in the jump, the more knee angles in front leg decreased. In the back leg, on the other hand, the average knee angles increased or remained almost the same in all subjects as the difficulty level of the jump increased. (Figures 16 and 17.) From the figures 19, 21, and 23 can be seen that knee joint angles in back leg increased towards detachment from the jumper. This shows that snowboarders are extending their knees in the take-off. Figures 18, 20, and 23 present knee joint angles in front legs. The figures reveal greater differences between subjects in knee angles during performance. Some subjects extend the knee at the same time while others flex the knee and vice versa.

A snowboarder flexes his/her knees during airtime when grabs are possible, thus the legs are not straight in the air. Therefore, in the last few frames the front leg was already in the air and flexed. Back leg's knee flexion before detachment can be due to same reason. It is possible that the snowboarder starts to flex his/her back leg knees at the same time as front leg knees, and that is why there is flexion in knees before detachment. The snowboarder seems to be already preparing for the air flight position. And in case there is knee extension in back leg before detachment, knee extension slows toward the detachment.

The angles of the hip joint are more similar between the subjects than the angles of the knee joint. In figures 26, and 27 can be seen the hip joint angles in backside 360° jumps. There are variations in angles between subjects, but angles do not change greatly as the effort progresses. In figures 28-31 can be seen hip joint angles in backside 540° and 720° jumps. In figures it can be seen that there is a slight extension in the hip joint during take-off for all subjects. Just before detachment from the jumper some of the subjects flex their hips. This can be justified in the same way as the flexion of knee joint during the detachment phase.

Based on the average angles of the hip joint of all subjects, the smallest angles were in the backside 360° jumps (118.3° in front leg and 108.8° in back leg) and greatest in the backside 720° jumps (129.6° in front leg and 125.0° in back leg). This means that the subjects had more extended hips when there was more rotation in the jump and added jump height was needed. The knee angles were also the greatest, on average, in the backside 720° jumps (140.1° in front leg and 134.1° in back leg) and the smaller in the backside 360° jumps (142.3° in front leg and 126.1° in back leg) and 540° jumps (136.7° in front leg and 130.6° in back leg). The angles of the hip joint in both legs and the angles of the knee joint in the back leg are associated with an increase in vertical velocity. Forceful extension of the hips and knees raise the vertical velocity at the take-off.

Knee joint angular velocities were highest in backside 720° jump, and slowest in backside 360° jumps (Tables 15 & 17). According to Berg & Eigen (1999), knee angular movements tend to be slower in the high speed. As already mentioned, the average horizontal velocity was highest with backside 360° jumps (12,20 m/s), and slowest in backside 540° jumps (12,04 m/s). Berg & Eigen's (1999) argument is thus not valid in this study.

In summary, in backside 360° jumps almost all the subjects had first knee extension, and finally before detachment, knee flexion in front leg, but for one subject, the movement was the opposite (Figure 32). There was also extension in back leg knee joint for all the subjects at some point of the take-off (Figure 33). In backside 540° jumps all the subjects had steady knee joint position in front leg, no rapid knee extension/flexion, until the end of the take-off, when most of them had rapid extension in front leg (Figure 34). All subjects had knee extension in back leg. It was clearly faster for subject 1 before detachment, for others, the extension slowed before the detachment (Figure 35). In backside 720° there was variation in front leg movement between subjects. Some had first knee extension and then flexion, others vice versa (Figure 36). In back leg all the subjects also had knee extension, but two of them had knee flexion just before detachment (Figure 37). The knee angles and the angular velocities of the knee joint are in line with each other.

Elbow joint angular velocities are shown in figures 38-43. Positive angular velocity indicates counterclockwise rotation, and the angular displacement increases, while negative angular velocity indicates clockwise rotation, and the angular displacement decreases. In back arm negative values refer to elbow extension and positive values refer to elbow flexion. In front arm negative values refer to elbow flexion and positive values refer to elbow extension. The higher the positive number/the lower the negative number, the higher the angular velocity.

In tables 18, 19, and 20 can be seen that elbow joint angular velocities are higher on average, when there is more rotation in the jump. Highest angular velocity in elbow joint was for subject 2 in front arm in backside 720° jump (Table 20). The angular velocity was -989.3 °/s. This means rapid flexion of the elbow. In figure 42 can be seen that subject 2 in backside 720° jump first rapidly flexes his front arm elbow and then extends it just before take-off. However, the angular velocities of the elbows varied between subjects and between jumps and there was not only one specific way to use the arms to initiate rotations. According to Turnbull et al. (2011) the snowboarder will forcefully rotate the arms from the wide position toward the CoM and the direction of desired rotation to initiate rotations. The desired direction of rotation for front arm is flexion whereas for back arm it is extension. This was the case for some of the subjects but not for all.

In summary, in backside 360° jumps nearly all subjects had flexion in front arm, and extension in back arm (Figures 38 & 39). In backside 540° jumps there was variation even during movement in a single subject in front arm (Figure 40). Some of the subjects had extension and some flexion in elbow. The same applied to back arm, however, the movement of the elbow of the back arm slowed to close to 0 °/s just before the take-off (Figure 41). In backside 720° jumps (Figures 42 & 43), the movement of the elbow was similar to that of backside 540° jumps.

Limitations of the study

The clearest weakness of the study is probably the small number of subjects (n=5). Comparing kinematic differences between jumps would probably have been more meaningful if there were more subjects. In principle, all subjects were able to do all the jumps performed in this study even though one did not achieve successful performances in 540° and 720° jumps within the maximum number of attempts. The subject group was thus quite homogenous and differences in skill levels remained relatively small. In the future it would be interesting to investigate subjects with greater differences in skill levels and/or differences between successful and unsuccessful jumps.

The challenge of the study was the number of analyzable backside 540° and 720° jumps (n=5, of which four were analyzed). The challenge was possibly related to the difference in the research situation compared to training or competition. The small number of jumps examined and analyzed undermines the usefulness of statistical comparison. Therefore, no statistical analysis was performed.

The major inaccuracies in the study are related to the implementation of the 3D analysis. The measuring area was relatively long, so there might be slight optical distortion in the imaging at the edges of the camera's shooting range. To prevent this, the cameras were placed approximately 30 m from the shooting area and zoom in as close as possible to the shooting area. The shooting area itself was calibrated with a calibration cube and the calibration values were with good accuracy. Overall error for camera views with all digitized points was under 0,3 %.

The large size of the calibration frame could also have caused problems with the calibration. The calibration frame was large enough to cover the entire shooting area. Large calibration frame has practical implications such as construction and transport difficulties. They are also likely to be affected by stress deformation and they can bend. Bending distorts the calibration. The straightness of this calibration frame was checked with level and despite its large size, the frame did not bend. Second limitation was that all the markers were not consistently visible in both cameras.

The single biggest challenge and inaccuracy factor in the study was the appearance of markers during the motion. Although the jumps were filmed with two cameras, the big problem was that the markers did not appear on both cameras. Clear weather also caused its own difficulties in detecting markers. This made digitization difficult and in case of several frames it was necessary to rely heavily on visual assessment based on the position of different segments of the body. Since the location of the markers had to be estimated, that certainly has caused errors in digitization. The resulting inaccuracy was reduced by overlaying trajectories of individual points and by digitizing on point at the time. In future research use of three or more cameras would be a good solution. In most of the skiing disciplines, there are complex movements in all directions (Meyer 2012), and that applies to freestyle snowboarding, too. Adding cameras improves overall visibility and reduces the negative impact of markers occlusion (Meyer 2012). In this study, three camera -setup would have been difficult to arrange because the third camera would have been placed in run up line.

The weather also caused difficulties in conducting the study. The weather on the study day was sunny and the temperature in Ruka was approximately +10 C° at the time of the measurements. Due to the sunny weather, one of the three legs of one camera sank slightly into the snow between calibration and first trial. This changed the orientation of the camera by changing the shooting area slightly. Calibration correction was made with Magix Edit Pro 18 -program. Calibration video and trial video were set on two tracks, from which the transferred trial video was held in place. The original calibration video was set to transparent (transparency 50 %) and positioned in correct position. Thus, a correct calibration corresponding to the performance video was obtained.

Conclusions

In conclusion, as the difficulty level of a jump increased, centre of mass vertical velocity also increased. Centre of mass horizontal velocity increased for some subjects and decreased for some subjects. Knee joint angles varied between subjects and between jumps in front leg, but in back leg knee angles were, on average, larger/remained the same as the difficulty level of the jump increased. Hip joint angles had slight extension during the take-off phase. Knee and elbow joint angular velocities were higher when there were more rotations in the jump.

The information acquired in the study is available to be used in coaching. The use of the pelvis in take-off is minor than the use of the knees in take-off. More attention should be paid to the use of pelvic. Speed strength exercises and plyometric exercises are a good addition to training. Once this information is taken into account in the training, increasingly more difficult tricks can be performed.

Further studies should include more subjects to obtain statistical information from the differences. Also, adding more cameras would make digitizing and analysing easier. In the future, the effects of the weather conditions must also be better considered when planning measurements. Accelerometers, pressure insoles, and muscle activity measurement could possibly be combined with further studies.

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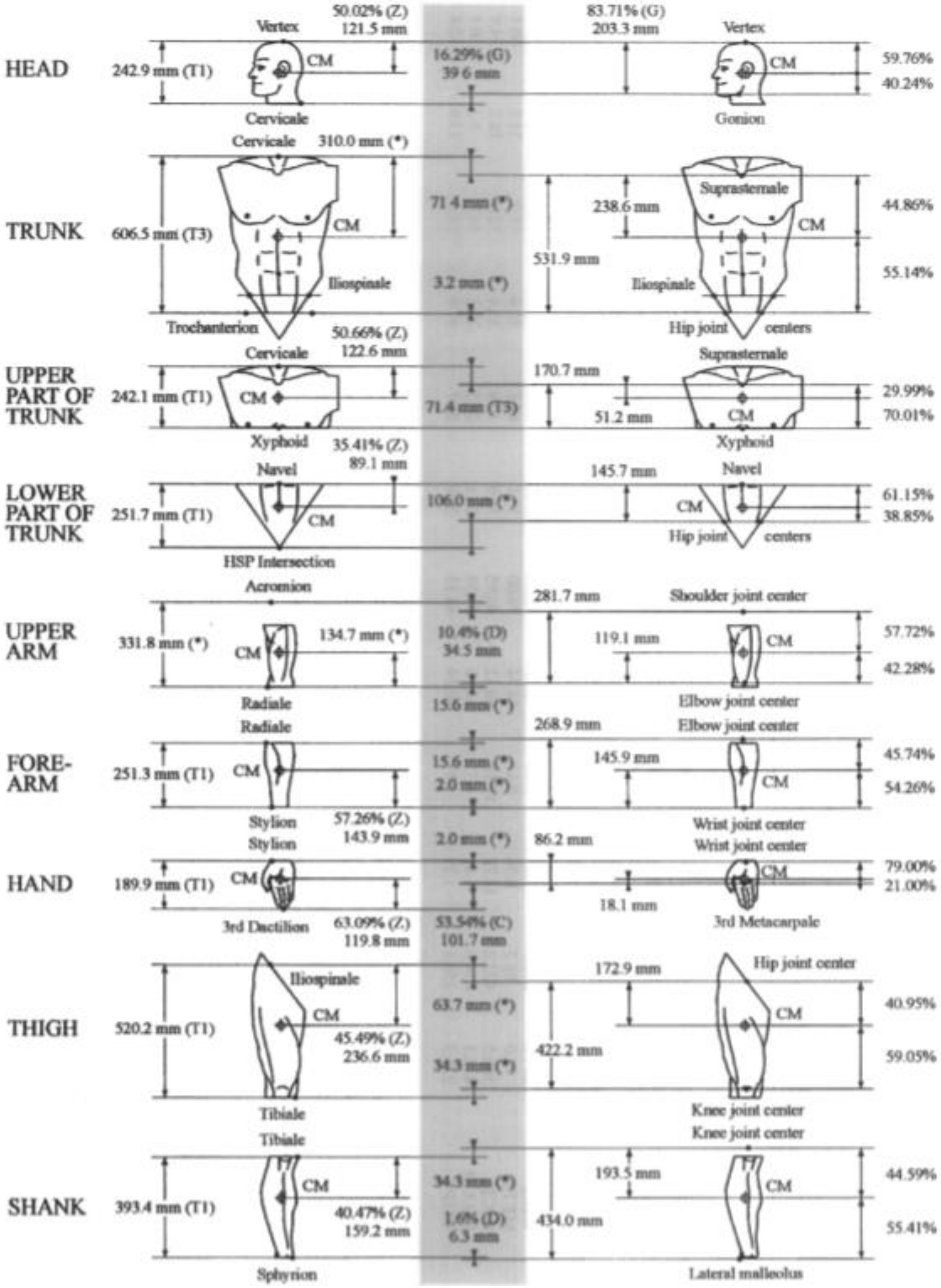
APPENDIX 1. The relative COM positions for males (de Leva 1996).



APPENDIX 2. Written consent of the study.

TIEDOTE TUTKIMUKSESTA

Tutkimus: Freestyle lajien biomekaaniset ja fysiologiset tekijät akatemia- ja maajoukkuetason laskijoilla.

Rekisterinpitäjä: Jyväskylän yliopisto

Pyyntö osallistua tutkimukseen:

Sinua pyydetään mukaan tutkimukseen, jossa tutkitaan freestylehypyn ominaisuuksia infrapunakameroilla, jalkapohjan painetta mittaavilla pohjallisilla ja kiihtyvyysantureilla. Lisäksi tutkimme slopestyle-harjoituksen kuormittavuutta sykettä ja erilaisia verimuuttujia seuraamalla. Tutkimuksella pyrimme kehittämään freestylevalmennusta ja tuottamaan laskijoille tietoa heidän suorituksistaan.

Sinua pyydetään tutkimukseen, koska olet jo kokenut laskija ja täytät tutkimuksen koehenkilöiltä vaadittavat ominaisuudet. Liitteessä on kerrottu henkilötietojen käsittelystä.

Mukaan pyydetään vähintään 20 akatemia- ja maajoukkuetason tutkittavaa.

Voit osallistua tutkimukseen, jos:

- olet maajoukkue- tai akatemiaurheilija
- pystyt suorittamaan tutkimuksessa testattavat liikkeet ja suoritukset turvallisesta ja riittävän laadukkaasti
- olet terve

Et voi osallistua tutkimukseen, jos:

- Sinulla on vamma, joka haittaa tai estää tutkittavien liikkeiden suorittamisen
- et saa suoritettua vaadittavaa määrää onnistuneita suorituksia maksimaalisten yritysten määrän puitteissa
- olet sairaana (hengitystieinfektiot, kuume yms.)

Vapaaehtoisuus:

- osallistuminen täysin vapaaehtoista
- voit keskeyttää tutkimuksen milloin tahansa
- **tutkimuksesta kieltäytyminen tai sen keskeyttäminen ei aiheuta ongelmia tai minkäänlaisia seuraamuksia omassa urheiluyhteisössäsi**

Tutkimuksen kulku:

- Esitietolomakkeen täyttäminen
- Tutkimukseen ja mittauksiin tutustuttaminen
- Harjoitusta edeltävät mittaukset osalla tutkittavista (laskimoveri- ja sylkinäyte, laktaattimittaus sekä kuormittuneisuus kysely)
- Suoritusten harjoittelu ja mittausten valmistelu (markkereiden kiinnitys & painepohjallisten asennus)
- 15 runin harjoitus ja osalla hypyt liikeanalyysiä varten. Harjoituksessa laskujen aikana mitataan sykemuuttujia ja otetaan sormenpääverinäytteitä laktaattimittausta varten.
- Harjoituksen jälkeiset mittaukset osalla tutkittavista (laskimoveri- ja sylkinäyte sekä kuormittuneisuus kysely)
- Harjoituspäivän jälkeiset mittaukset kahtena seuraavana päivänä (laskimoveri- ja sylkinäyte, laktaattimittaus sekä kuormittuneisuus kysely)

Tutkimuksesta mahdollisesti aiheutuvat haitat ja epämukavuudet:

Tutkimuksessa suoritetaan freestyle lajiharjoitus, joka sisältää hyppyjä ja muita lajille ominaisia suorituksia, joten pieni loukkaantumisriski on olemassa. Tämä riski ei kuitenkaan poikkea normaalista lajiharjoittelusta koituvista riskeistä tai epämukavuudesta. Kuitenkin mittaustilanteeseen, kuten normaaliin harjoitteluun, sisältyy urheiluvammojen, kuten lihasten revähdysten, riski. Tapaturmien ja sairastapausten välittömään ensiapuun mittauksissa on varauduttu, ja tutkijat ovat saaneet ensiapukoulutuksen. Mittauspaikalla on saatavilla ensiapuvälineet.

Mahdollisesti otettavista sormenpää- ja laskimoverinäytteistä saattaa aiheutua pientä kipua, mutta pitkäaikaista haittaa ei synny.

Tutkimuksen kustannukset:

Tutkimukseen osallistumisesta ei makseta palkkiota. Mittaukset eivät itsessään tuota kuluja tutkimukseen osallistuville.

Tutkittavien vakuutusturva:

Jyväskylän yliopiston henkilökunta ja toiminta on vakuutettu. Vakuutus sisältää potilasvakuutuksen, toiminnanvastuuvakuutuksen ja vapaaehtoisen tapaturmavakuutuksen.

Tutkimuksissa tutkittavat (koehenkilöt) on vakuutettu tutkimuksen ajan ulkoisen syyn aiheuttamien tapaturmien, vahinkojen ja vammojen varalta. Tapaturmavakuutus on voimassa mittauksissa ja niihin välittömästi liittyvillä matkoilla. Tapaturman lisäksi korvataan vakuutetun erityisen ja yksittäisen voimanponnistuksen ja liikkeen välittömästi aiheuttama lihaksen tai jänteen venähdysvamma, johon on annettu lääkärinhoitoa 14 vuorokauden kuluessa vammautumisesta. Korvausta maksetaan enintään kuuden viikon ajan venähdysvamman syntymisestä. Voimanponnistuksen ja liikkeen aiheuttaman venähdysvamman hoitokuluina ei korvata magneettitutkimusta eikä leikkaustoimenpiteitä.

Tapaturmien ja sairastapausten välittömään ensiapuun mittauksissa on varauduttu, ja tutkijat ovat saaneet ensiapukoulutuksen. Mittauspaikalla on saatavilla ensiapuvälineet. Tutkittavalla olisi hyvä olla oma henkilökohtainen tapaturma/sairaus- ja henkivakuutus, koska tutkimusprojekteja varten vakuutusyhtiöt eivät myönnä täysin kattavaa vakuutusturvaa esim. sairauskohtauksien varalta.

Tutkimustuloksista tiedottaminen ja tutkimustulokset:

Tutkimustuloksista tutkittava saa halutessaan itselleen datan analysoinnin valmistuttua. Tutkimuksesta valmistuu neljä pro gradu -tutkielmaa. Tulokset julkaistaan sellaisessa muodossa, että yksittäiset henkilöt eivät ole tunnistettavissa.

Lisätietojen antajan yhteystiedot:

Vastaava tutkija: Vesa Linnamo

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Otto Rantala, Jyväskylän yliopisto

Volter Pietarinen, Jyväskylän yliopisto

APPENDIX 3. Foreword and health survey.

ESITIETO- JA TERVEYSKYSELY

Nimi:_________________________ Synt.aika:___________ Paino:_______kg Pituus:________cm

Testauksen turvallisuuden kartoittamiseksi pyydämme sinua täyttämään oheisen terveyskyselyn. Tämä on vapaaehtoinen kysely, mutta ellemme tiedä testaamisen olevan turvallista, emme voi sitä tehdä.

Oireet viimeisen 6 kk aikana:	Kyllä	Ei	En osaa sanoa
1. Onko sinulla ollut rintakipuja?			
2. Onko sinulla ollut rasitukseen liittyvää hengenahdistusta?			
3. Onko sinulla ollut huimausoireita?			
4. Onko sinulla ollut rytmihäiriötuntemuksia?			
5. Onko sinulla ollut harjoittelua estäviä kipuja liikuntaelimissä?			
Missä?			
6. Oletko tuntenut ylikuormitus- tai stressioireita?			

Todetut sairaudet: Onko sinulla tai onko sinulla ollut jokin/joitakin seuraavista? (ympyröi)

01 sepelvaltimotauti	02 sydäninfarkti	03 kohonnut verenpaine	04 sydänläppävika
05 aivohalvaus	06 aivoverenkierron häiriö	07 sydämen rytmihäiriö	08 sydämentahdistin
09 sydänlihassairaus	10 syvä laskimotukos	11 muu verisuonisairaus	12 krooninen bronkiitti
13 keuhkolaajentuma	14 astma	15 muu keuhkosairaus	16 allergia
17 kilpirauhasen toimintahäiriö	18 diabetes	19 anemia	20 korkea veren kolesteroli
21 nivelreuma	22 nivelrikko, -kuluma	23 krooninen selkäsairaus	24 mahahaava
25 pallea-, nivus- tai napatyrä	26 ruokatorven tulehdus	27 kasvain tai syöpä	28 leikkaus äskettäin
29 mielenterveyden ongelma	30 tapaturma äskettäin	31 matala veren K tai Mg	32 kohonnut silmänpaine
33 näön tai kuulon heikkous	34 urheiluvamma äskettäin		

muita sairauksia tai oireita, mitä:____

Lääkitys: Käytätkö jotain lääkitystä tai lääkeainetta säännöllisesti tai usein? 1 En 2 Kyllä, mitä:____
____

Tupakoitko 1 En 2 Kyllä

Onko Sinulla todettu synnynnäinen sydänvika? 1 Ei 2 Kyllä,
mikä:____
____

Onko lähisuvussasi todettu perinnöllisiä sydänsairauksia tai sydänperäisiä äkkikuolemia?
1 Ei 2 Kyllä

Kuumetta, flunssaista oloa tai muuten poikkeavaa väsymystä viimeisen viikon aikana:
1 Ei 2 Kyllä

Olen vastannut kysymyksiin rehellisesti parhaan tietämykseni mukaan,

Päivä__________________ Allekirjoitus______________________________________