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THE KINETIC CHARACTERISTICS IN COMPETITIVE SLALOM SKIING

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Abstract

The purpose of the present study was to quantify and describe ground reaction forces in competitive slalom skiing. Background: Recent alpine skiing research has measured forces in skiing using instrumentation which interferes to some extent with skiing technique. Instead, the rationale of this study was to estimate kinetic characteristics in competitive slalom skiing using plantar pressure measurement which minimizes technical interference and then to compare force characteristics in two courses typical of competitive slalom skiing. The specific research question was: What are the kinetic characteristics, force distribution and chatter in a slalom turn? Methods: 11 highly skilled, Norwegian male skiers were assessed through 5 left and 5 right slalom turns in the mid-portion of two race training courses with linear distances between gates of 10 and 13 meters. They were equipped with Pedar Insoles (Novel GmbH, Munich, Germany) from which ground reaction forces were determined and analyzed for kinetic characteristics. Descriptive statistics, t-tests, two-way repeated measures ANOVA and Pearson's and partial correlation were used to compare the two courses and turn directions and to check for relationships. Kinetic characteristics of slalom turns were subject-specific. No significant differences were found in the magnitude of ground reaction forces between courses or turn directions. Timing of gate passing and the apex were significantly later on the 13 meter course, and the timing of apex was later in turns to the right-regardless of the course. Significantly greater chatter of the inside ski was found on the 10 meter course. Significance: The Pedar insole system provides useful knowledge enabling coaches to give precise technique suggestions to their athletes.

Keywords: Kinetics, slalom skiing, inside/outside ski impulse ratio, chatter, Pedar

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Note

Due to time limitation, I was forced to submit an unfinished work to grading in May 2009. This second edition was worked on after the submission during the first two weeks of June 2009, and the work contained mostly of rephrasing and reproduction of the tables and figures. The content of the first version and the second versions are identical.

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1 Introduction

As ski racers, coaches and national teams battle for the world cup, world championships and the Nation's Cup titles, several research groups are gathering information on the turning technique during competitive slalom skiing using methods ranging from three dimensional video analyses, to force plates and electromyography. The slalom turning technique has evolved rapidly along with ski equipment. Recent alpine skiing research has focused on the racing technique assessed by kinematic analysis of centre of mass energy dissipation, or ski equipment characteristics such as ski stiffness, and/or vibrations in equipment level, muscle control during skiing etc. It is widely accepted that the skiing technique is in constant development, and that there are opposing philosophies for the optimal technique.

It is generally acknowledged that alpine skiing is characterized by large loading of the skis with forces typically around two times body weight. Due to uneven and hard terrain, there are vibrations and large fluctuations of force which the skier's body must absorb. The details of loading demanded in racing are not well understood. The kinetic characteristics which several research groups have assessed have not been related to slalom technique. A detailed description of the kinetic characteristics in slalom where a number of athletes are tested repeatedly in contrasting situations is lacking.

In slalom, the loading and unloading phases during turning follow each other in a cyclical manner. During the loading phase, turns around the gates are executed, while in the unloading phase, skis are unloaded in order to change skier's path to the opposite direction. In the skiing literature, descriptions of how the skier distributes the force between the outside and inside skis are not in agreement. One philosophy states that the force is distributed predominantly on the outside ski while another viewpoint promotes even loading of the inside and outside skis. Most of the research available today is based on the assumption that the outside leg is the load carrying limb. A concentration of loading on the outside ski pushes the ski into the snow surface creating a groove against which the lateral component of the ski reaction forces can act to push the skier into a curved trajectory. The inside ski is merely there to establish a wider contact area with the snow, optimizing lateral balance. However, excessive ski penetration into the snow surface is possible, particularly on soft snow. The even-loading philosophy promotes distributing pressure between the inside and outside skis to avoid excessive penetration and friction. In addition, engaging the inside ski may help to prevent it from skidding. Finally, a more even loading could allow better, smoother continuous contact in snow-ski interface and minimize the braking effect of skidding.

Vibration of the skis, which a skier's body must absorb during the loading phase is evident, and could be due to the lateral skidding in slalom (Müller & Schwameder, 2003). Federolf et al. (2009) support the notion of lateral skidding in tight slalom turns, but point out that the intensities of vibration varies depending on snow conditions, speed, equipment and skiing discipline. Determination of possible relation between ski impulse distribution and vibration (chattering) in the literature is lacking. Predominant loading of the outside ski could lead to more lateral skidding of the inside ski due to lower penetration into snow, and tighter turning radius of the inside ski.

The recent alpine skiing research in Norwegian School of Sport Sciences has been in association with the Norwegian Ski Federation lead by doctorate student Robert Reid. The present study was conducted to further participate in the bridge building between the "know-how" knowledge of the coaches and the athletes and the theoretical science community. Practical understanding and long-term experience of slalom skiing definitely lies in the hands of coaches and athletes, but philosophical practise remains speculative until evidence is raised either for or against it. In a continuously evolving sport, athletes and coaches act as a bank of the practical "know-how" while opposing theories are expected. It is natural that what works with one athlete, may not work with another. It is therefore preferred to evaluate as many athletes, equipments and external factors as possible to obtain a wide base of measurements, from which future theorems can be formed. The present biomechanical study was therefore conducted as part of the bridge being built between the practical expertise of coaches and the scientific community of alpine skiing.

The purpose of this study was to quantify and analyze ground reaction forces during unloading and loading phases in two course conditions and turn directions in elite slalom skiing. Possible relation between skill levels, defined as mean times of trials (short term) and FIS (the International Ski Federation) ranking (long term) and kinetic characteristics were evaluated.

The present biomechanical study is organized to give the reader basic understanding of slalom skiing technique, background of the recent research conducted, leading to the research questions and hypotheses of this study. Methods, results and discussion are followed by the conclusions drawn on the basis of the results and current literature in the field.

2 Theoretical background

Modern slalom technique is a complex movement and a complete theoretical description would require excessive space. Therefore, theory directly related to the aims of this study is presented in the following chapter. First, the mechanisms related to slalom skiing are described. Second, the recent research on the ground reaction forces in slalom skiing is introduced, and then lateral leg dominance theory is brought in. Finally, the validity of the plantar pressure measurements is evaluated based on the recent literature.

2.1 The mechanisms of slalom skiing

2.1.1 Slalom equipment geometry and functional implication

2.1.1.1 FIS regulations

The International Ski Federation (FIS) regulates the equipment and the rules for World Cup (WC) or Continental Cup (CC) races. Men's minimum length of slalom ski measured from the tip along the base of the ski to the tail is 165 ± 1cm. The minimum waist width allowed in slalom is 63 mm. The maximum height from the base sole of the ski to bottom of the boot sole is 50 mm; while maximum height of the boot sole is 43 mm. Side-cut radius for slalom skis is free (FIS, 2008). Slalom races must have a vertical difference of 100 to 180 meters. The number of turns must be related to the vertical difference, amounting usually to 30-35 % of the vertical difference (± 3 turns). Gates must be set up with a variety of distances; minimum of 0.75, maximum of 13 meters. Some of the sections of the race courses are rhythmical; some are technical while others require high speed. Gates are placed so that skiers execute complete turns and cross over the fall line of the course. Race courses are set up so that they challenge athletes but still do not require acrobatics.

2.1.1.2 The geometry of slalom skis

The shape of the slalom ski resembles an hourglass. The lateral curved edge of a ski is called the *side-cut,* see Figure 2.2 for an illustration of the ski geometry (LeMaster, 1999). The side-cut acts as a "railroad track" (Jentschura & Fahrbach, 2004) and determines the turn radius, Figure 2.1 (Lind & Sanders, 2004). The skier can alter the shape of the track by changing the edge degree of the skis, or the fore/aft pressure distribution (LeMaster, 1999). The side-cut radius (R_{SC}) is determined by the side-cut and the contact length of the ski, Figure 2.1 (Lind & Sanders, 2004). In slalom skis, the shovel is the widest part of the ski, followed by the tail. The waist is located either in the center of the skis running surface, or slightly behind it. The boot is positioned behind the waist which allows it to be released from the binding in case of high heel pressure as well as it helps to decrease the turn radius (Lind & Sanders, 2004).

The steering angle is the angle between the direction of travel of the ski's mid-body and the longitudinal axis of the ski, Figure 2.1. The steering angle must be differentiated from the *local steering angle* which varies along the ski's length and is the greatest at the tip, allowing the ski to turn itself when the ski is moved forward in an edged position. The local steering angle is what creates the ski's *self-steering effect* (LeMaster, 1999).

Varying the steering angle, the skier controls the effect of ground reaction forces on him; to turn the skis (>0˚) or to slow down the speed (at 90˚). Broad turn is achieved with small steering angles and a sharper turn with larger steering angle (LeMaster, 1999). At zero degree, there is no change in skier's momentum. In any angle between zero and 90, the forces act on the skier partly by slowing down, partly by changing the skier's path of movement (LeMaster, 1999). The steering angle is important in timing of the ski reaction forces during the loading phase.

The ski must penetrate into the snow in order to generate forces from it (LeMaster, 1999) and to turn. Penetration of the snow and the *edging angle* are important for the ski-snow interaction (LeMaster, 1999). A large distance from the edge of the ski to the binding allows a greater edging angle, and is therefore regulated. Edging angle plays an important role in turning, and will be further discussed later in the study.

2.1.1.1 The physical characteristics of slalom skis

In addition to the side-cut, the torsional and bending stiffness of the ski play an important part in overall ski performance (Federolf et al. 2009). Both torsion and length stiffness (ski camber) can play a role in vibrations. If a ski has high torsion stiffness, it is very aggressive on biting into the snow when it is edged (LeMaster, 1999). Skis with high torsion stiffness-twist and torque resistance- are easier to control as they need less reverse camber than skis with low stiffness. Bending stiffness (longitudinal stiffness) stands for the shovel-tail stiffness.

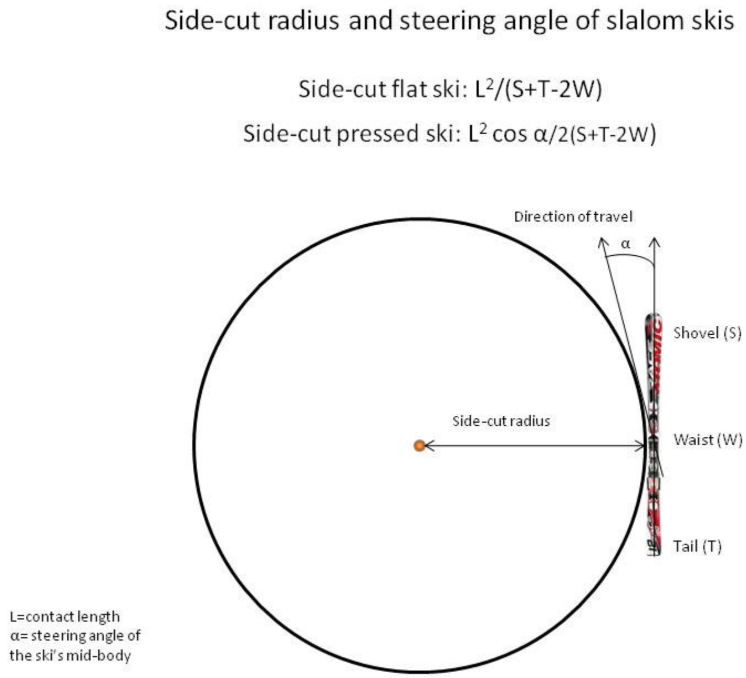

Figure 2.1: The side-cut radius and the steering angle of a modern slalom ski.

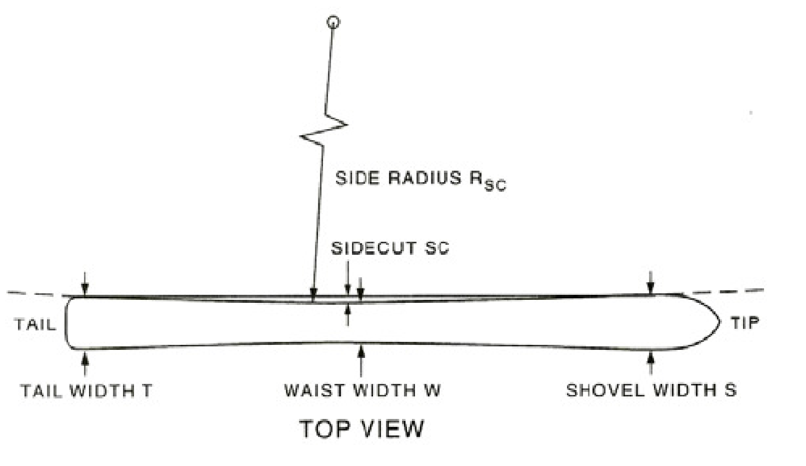

Figure 2.2: The top view of a modern slalom ski illustrating structural characteristics). Rsc: Turn radius determined by the steering angle of the ski. Lind, D. & Sanders, S., P (2004). The physics of skiing: Skiing at the triple point. 2nd ed., pp 45. New York, NY, USA: Springer-Verlag.

When the skier applies force to the ski, depending on the bending stiffness, a reverse camber is established, changing the difference between shovel and tail's relative steering angles. The larger this difference, the greater the ski's *self-steering effect* (LeMaster, 1999). Either deep side-cut or stiff torsional skis have larger self-steering effect taking advantage of greater biting into snow. Skis with high torsion stiffness allow a skier to better to control the edging and minimizes the attention needed to control the skis with considerable amount of chatter (Lind & Sanders, 2004).

2.1.1.2 The effect of ski boots on the skier-snow interaction

Alpine ski boots are considered the handle of the skis, transmitting the ground reaction forces to the skier, and movements by the athlete to the skis (LeMaster, 1999). As a skier controls the turn, the cuff is pressured against. The cuff wraps tightly around the lower leg. Lateral pressure controls edging of the skis, forward pressure transmits pressure to the shovel of the ski (initiate turning) and backward pressure transmits the pressure to the tail of the ski (stop turning) (LeMaster, 1999). Stiffness of the ski boots is crucial in transferring the motion control produced by the working muscles to skis, while flexibility allows the skier some movement and control of the interaction with the skis. The nature of the boots affects pressure measurements under the foot (Schaff et al. 1989, Hall et al. 1991). This will be discussed later in this study.

2.1.2 The external forces in slalom skiing

The mechanism allowing a skier to turn during slalom skiing was explained by LeMaster (1999) who stated that "the ski must turn before the skier can turn", meaning that the ski must be edged and in motion before the skier's centre of mass (CoM) starts to turn and the slalom turn is initiated. Taking advantage of the skis' geometry, the skier controls the forces. The skier's manipulation of the amount of edging, distribution of forces between the inside and the outside ski, inclination of CoM and fore/aft pressuring control the reaction forces acting on the skier, changing his momentum in a desired, controlled manner.

Figure 2.3 shows the external forces acting on the skier: *gravity* towards the centre of the earth, *ski reaction* and *air drag forces* all of which act on a skier from outside the body and collectively determine a skier's dynamic performance.

In skiing, gravity accelerates the skier down the slope, giving the skier momentum–the product of an objects' mass and its velocity. Newton's third law of motion implies that the skier applies a force to the snow, and the snow applies a reaction force on the skier (LeMaster, 1999). The reaction force from the snow can slow down, speed up, and turn the skier. Internal forces are produced by the skier's muscles to control the motion by directing limbs and the body in a desired manner, manipulating the equipment and pushing against the snow (LeMaster, 1999).

A skier's direction of travel is changed by the edging of the skis. The snow's properties allow the skier to glide on it by being slippery, and permit stopping by holding, resisting the skier's momentum (LeMaster, 1999). As the skier manipulates edging and inclines the CoM, the snow changes the skier's momentum by resisting compression (LeMaster, 1999) and making turning possible. Air drag acts opposite to the skier's instantaneous velocity of the CoM and snow friction acts opposite to the instantaneous velocity of the skis. The air drag is considered a small component compared to the ski-snow friction due to the low velocity in slalom skiing (Gilgien, 2008).

Figure 2.4 illustrates gravity and the reaction force components acting on the skier. Dynamic balance in slalom turns require that gravity must balance with the vertical component of the ski reaction force. In addition, due to the torque created about the CoM by the horizontal and vertical reaction forces, they must dynamically balance to control a skier's rotation about the CoM and avoid falls toward inside or outside of the turn.

2.1.1 Slalom turn phases

There are numerous definitions of the turning phases in the literature. Description of the phases in a slalom turn depends on who describes it- a variety of definitions are in use. LeMaster (1999) divided a turn into three phases; initiation, control and completion/transition phases. In the initiation phase, the edging and pressuring of the ski cause ski to penetrate into the snow. By pushing against the front cuff of the boot, the skier can re-distribute pressure to the ski, causing increased deformation of the ski fore-body and increased steering angle (LeMaster, 1999).

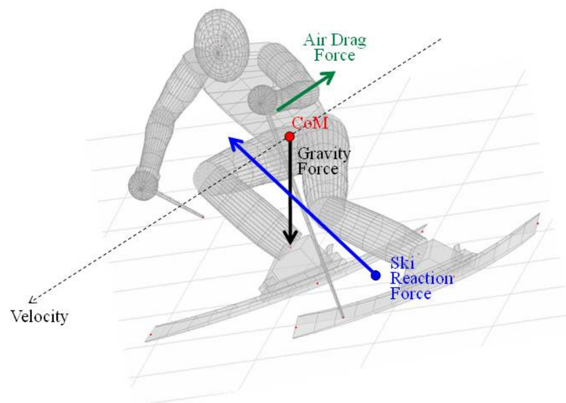

Figure 2.3: A free body diagram showing the external forces acting on the skier. Published with permission from Reid, 2009.

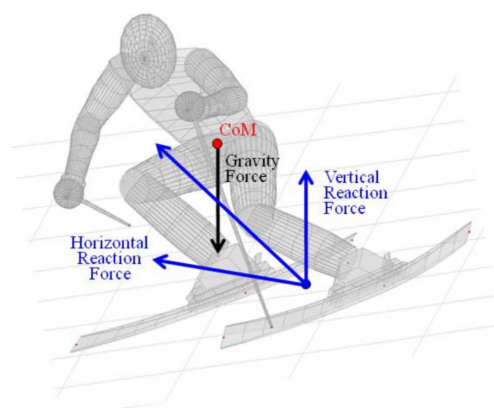

Figure 2.4: A simplified illustration of gravitation and reaction force components acting on the skier. Both skis have been combined into a single reaction force. The vertical reaction force component must counter gravity while the horizontal component creates centripetal acceleration and turning of the skier. Published with permission from Reid, 2009.

In the control phase, a horizontal force component between the ski and snow makes the ski turn while the skier controls edging of the skis and the fore/aft pressure distribution (front/back) on the ski to achieve the desired turn trajectory (LeMaster, 1999). Coming out of the turn, the pressure must be shifted slightly backwards because the aft pressure hinders the tip of the ski (with greater steering angle) to bite in the snow. With pressure in front, the ski would continue the turn (LeMaster, 1999), but when the pressure is shifted backwards, the ski starts to go straight forward. The lateral force component is eliminated by less edging of the ski, less inclination of the skier's body into the turn, vertical movement by the skier and slight backwards pressure of the ski, allowing skis to glide straight ahead. Completion phase is the end of the turn, and it often merges with the initiation phase of a new turn in elite skiers, particularly in short radius turns such as in slalom (LeMaster, 1999).

2.2 Measurements of ground reaction forces in skiing

2.2.1 Large loading forces in skiing

Ground reaction forces in alpine skiing have been measured by several research groups (Müller & Schwameder 2003, Krueger et al. 2006, Fauve 2009, Wolfram 2008,) since the first description by Möser in 1957 (Müller & Schwameder, 2003).

Ground reaction forces have been quantified in several different skiing techniques, slopes, ability levels, snow conditions and equipment. Slalom skiing is associated with considerable ground reaction forces around 2-3 times the skier's body weight. A Canadian research group, Lafontaine et al. (1998) report maximum pressures of 28-35 N/cm^2 (depending on the radius of the turn), and forces up to 3 BW (body weight) in high level recreational alpine skiing assessed with Pedar system with sampling frequency of 50 Hz. Utilizing Kistler force plates (Kistler Instruments Limited, UK) with a sampling frequency of 200 Hz, Klous et al. (2007) reported the reaction forces in the knee joint of the outside ski increased from 0.5 times BW to over 3 BW in a giant slalom turn. The inside leg forces were more steady and lower. Fauve et al. (2009) measured total forces of approximately 1500 N in giant slalom using 8 strain gauges at 200 Hz. Müller & Schwameder (2003) assessed two turns with the traditional parallel technique and the modern carving technique on a slope with 15° inclination with 14 m radii (carving) and 34 m radii (parallel). During the modern carving technique, they reported forces of 1000-1200 N. Typically, the forces have been reported as absolute forces in Newtons which does not allow comparisons of results between studies. Further, previous studies lack large base of measurements per subject and standardized course settings with possibility to compare two different course settings.

Brodie et al. (2009) used both kinematic and kinetic systems to assess performance and found that prompt establishment of maximal edging angle (leaning into the turn) was necessary to develop high forces, which were related to faster times. They found that if the skier was able to add pressuring around the apex of the turn (the point during the turn at which the ski impulse has the greatest effect on changing the skier's momentum), then the skier was able to accelerate during the turn. This leads to the temporal characteristics philosophies where the notion is that the apex should happen at the gate passage.

2.2.2 The temporal characteristics of ground reaction forces

The timing of pressuring is considered an important aspect of technique in slalom skiing. Skiers control the timing of pressuring by regulating ski edge angle, ski attack angle and vertical dynamics (Reid, personal communication, 2009). In practice, the skier's goal is to re-direct their momentum when passing the fall line during the turn. If the momentum is re-directed too early, less reaction force will be required, but the gate may be in the way of the skier's trajectory and the skier must stop turning, pass the gate and then end up with delayed timing of the forces. If the momentum is re-directed too late, more reaction force will be required to overcome the gravitational force. These larger reaction forces may exceed the strength of the snow's properties, resulting in skidding and braking of the skier's velocity. The challenge in slalom skiing is thus to time the apex at about the gate. Despite the obvious importance of the timing of the apex, it is surprising that the literature search unveiled the lack of information about it.

2.2.3 The lateral ski impulse distribution

Lateral ski impulse distribution refers to the force distribution (or ski loading) between the inside and outside skis, which is a topic of discussion in coaching circles. One of the wide-spread philosophies state that during the turn, the ground reaction forces are distributed predominantly on the outside ski, a contribution that is supported by the findings in several studies (Müller & Schwameder 2003, Klous et al. 2007, Fauve 2009 and Spitzenfeil et al. 2009). The alternative philosophy is the even loading of the inside and the outside skis. The supporting idea is that the even loading would minimize the ski-snow friction, as the total load would be divided on two skis instead of one (Reid, personal communication, 2009). Excessive ski penetration into the snow surface is associated with increased friction. Through distribution the load over both skis, the skier may reduce penetration and friction, particularly in soft snow conditions.

Müller & Schwameder (2003) reported continuous, equal increase of the ski impulse distribution between the inside and outside ski in the first steering phase in turns with a 13 meter radius. In the second steering phase, the outside ski was predominantly loaded until the initial phase took over with increasing ski impulse distribution on the inside ski (the new outside ski of the next turn). A study by Fauve et al. (2009) indicated that the distribution of load between the inside and the outside ski was 0.58 while in larger carving turns a study by Lüthi assessed force distribution of 0.41 indicating high degree of outside ski loading.

Spitzenfeil et al. (2009) studied seven male national level skiers and reported the loading of the inside ski as half of the loading of the outside ski. However, when considering the knee angles at specific time point when ground reaction forces were measured, the calculated muscular expenditure pointed to quite equal load of 80% of the individuals' maximum isometric strength on both legs. Discrepancy of mechanical loading ratio between the inside and the outside skis measured by the pressure insoles, and the experienced muscular loading of the skier due to different knee angles must be acknowledged. Although the inside leg may not carry as much load as the outside leg, the flexed inside leg contributes in almost equal amount in terms of energy consumption (Spitzenfeil et al. 2009)

In general, the inside ski contributes in skiing as fine tuning the lateral balance (Wolfram, 2008). In a study by Klous et al. (2007) the highest average and peak resultant forces were measured in the knee and ankle of the outside leg in a left skiing turn. The differences in the inside/outside ski loading can according to Klous et al. (2007) contribute to high degree of knee injuries with alpine skiers since high moments in the knee could injure ligaments. To determine whether the outside ski loading, or more even force distribution is prevailing, high national calibre skiers should be assessed for the inside/outside ski impulse ratio in slalom skiing.

In the recent research, the support for the even loading distribution is lacking. It is therefore preferable to measure ground reaction forces in a variety of snow conditions and subjects to further evidence for or against the alternative philosophy.

2.2.4 Vibrations

Substantial ski vibrations are evident in skiing. Skiing at high speed on an icy snow surface with repeated direction changes is associated with rapid changes in force, seen as vibrations, or chatter of the skis. The skier's body must deal with these vibrations in a way which minimizes vibration of the trunk and head, and is effectively done so by altering the angles of joints (Federolf, 2009). Although soft tissues absorb a great deal of the chatter, the skier is exposed to hazardous amount of vibration according to Federolf et al. (2009). Chatter increases the total load of skiing acting on the skier's body, and is an interesting kinetic characteristic in slalom skiing.

The vibrations were assessed as the fluctuations in resistance forces of snow observed when a metal plate was penetrated into hard snow (Federolf, 2005). These vibrations in slalom skiing could be caused by the snow's deformation under the ski (Federolf, 2005). Related to carving skiing the snow's resistance to compression is important. When the ski is edged, the compression caused by the weight of the skier and equipment, allows the penetration of the ski into the snow. It is assumed that as the ski penetrates the snow, the residual snow under the ski is either compacted under the ski or displaced (Federolf, 2005) out of the groove of the tracks or thrown into air. The snow's ability to resist under the ski determines how much skidding over the snow occurs (Federolf 2005). The fluctuations (vibrations) were explained by the nature of the snow deformation (physical deformation processes e.g. ductile and brittle compression) during turning. The mean resistance pressure of snow was found to depend on the edging angle of the skis as the resisting forces fluctuated specifically when the edging angle was increased. Federolf et al. (2009) speculated that the vibration is subject-specific and depends on skiing velocity, degree of carving, and differences in equipment characteristics. Fauve (2009) suggested another factor affecting the vibration; the torsional flex of the ski. Federolf et al. (2009) concluded that intensity of the vibration is highly snow condition (hardness and shear strength) dependent, since softer snow permits greater ski penetration, allowing larger area of the ski to bear the load, leading to a reduced torsional moment (Fauve 2009). The vibrations observed during slalom skiing, could reflect the deformation of snow as the ski penetrates into snow and the irregular deformation of the snow (Federolf 2005).

Mössner et al. (2009) claimed that only highly skilled skiers are able to execute turns without any skidding and that unless skiing in very hard snow conditions, there is always some skidding involved. Mössner et al. (2009) studied the effect of ski stiffness on the trajectory of the turns, and found that greater ski stiffness decreased the turn radii, and decreased skidding, although high speed increased the skidding found in the study by Mössner et al. In a study by Müller & Schwameder (2003), an uneven force-time relationship was reported to indicate frequent lateral skidding. According to the authors, lateral skidding could be caused by the difficulty of keeping a constant steering angle during the high loading. The “short turns” in slalom skiing require dynamic movements of the body with shortening muscles, while longer, more cleanly carving turns are executed with less body motion, force produced by the lengthening muscles (Federolf et al. 2009).

Descriptions of the chatter characteristics; frequency spectrum and mean amplitude in slalom skiing have been lacking from the recent literature. A recent study by Federolf et al. (2009) evaluated the intensity and frequency content of vibration in equipment (boot) level in short and carving turns during one day of testing. As acceleration sensors measured vertical vibrations, high vibrations were found in turn phase generally associated with great deal of ski skidding. Peak intensities of vibration were 5-30 Hz on hard snow, while a significant decrease was observed during softer snow conditions, where intensities above 15-20 Hz were damped. Knowledge of chatter which skiers are exposed to will add to the recent developments in the alpine skiing science and can help coach and athletes to understand the complete load skiers are exposed to.

2.3 Lateral leg dominance

All of us know which hand we use to write, but most of us are not aware which one is our dominant leg. Although the legs are perhaps used in more symmetric manner compared to the hands in our daily lives, one of the legs is always preferred in certain tasks. The preferable usage of limbs is dominated by either side of the brain and is called lateral preference in motor actions (Vaverka & Vodickova, 2009). Although our paired limbs (arms and legs) are anatomically symmetrical, one side is better accustomed than the other- approximately 90 %

of population is right-handed, 8-9 % left-handed and 2-3% are people who have the ability to use both hands equally (Vaverka & Vodickova, 2009). However, the preference of using the right hand does not necessarily mean that the subject also prefers to use the right leg.

Alpine ski turns are considered symmetrical movements (Vaverka & Vodickova, 2009) where load acts in a similar manner on both sides of the body, assuming that there are no side-to-side differences of the terrain. According to Vaverka & Vodickova (2009), most skiers prefer turns to the direction where their dominant leg is on the outside of the turn; right-leg dominant skier prefer to turn to left and vice versa for left-leg dominant. This suggestion needs to be studied more systematically. However, since the result of slalom races highly depend on the quality of executed turns in both directions, skiers must adapt and perform equally superior turns in order to achieve high total speed. Achieving motor coordination which eliminates the preferred turn direction must be the aim of long-term training.

The ability of coordinating and understanding (apprehension) complex movements may reduce physical and cognitive demand of complex movement execution (van der Wel & Rosenbaum, 2007). It is a clear advantage for any athlete to have developed means of automatic execution of a challenging motion, such as tight turns on the 10 meter course. The aim in technique training is to challenge and develop not only the physical abilities, but also the neural pathways of controlling complex locomotion and apprehension of motion. Van der Wel & Rosenbaum (2007) concluded that some kind of temporal planning of coordination of the body parts lead to final position where preferred support-leg is positioned for execution of task. Alpine athletes probably use similar apprehension planning. It is likely that most skiers have preferred turn direction which they feel is superior, or easier to turn toward.

According to Wolfram (2008), the inside leg is rather secondary factor in adapting to different skis while outside leg acts as the dominant adaptor. Vaverka & Vodickova, (2009) found substantial differences in turn directions in execution of slalom turns. The preferred turn direction (where the dominant leg was the outside limb) had more maximal force and force impulse, and was longer in duration. Also the timing of initiation and steering phases were different between the turn directions. Authors conclude that it is the dominant leg as the outside ski determining the speed, while the non-preferred turn directions only act as changing the movement direction. The authors did not mention side-to-side gradient of the slope affecting execution of turns, may affect the kinetic characteristics in slalom skiing.

Lin et al. (2008) found that the static balance control of one-leg standing was symmetric in the dominant and non-dominant legs in young healthy adults. The authors suggest that there are factors other than the leg dominance which influence the static balance control. The static balance may not be directly transferrable to alpine skiing, but the general notion is that leg dominance may not be a major factor in how a skier performs regarding the turn directions, while other factors such as slope gradient could affect the differences in kinetic variables in slalom turns.

2.4 Methods of measuring ground reaction forces in skiing

The recent alpine skiing research has estimated the ground reaction forces in alpine skiing utilizing three independent methods: kinematics, force transducer installed between the binding and ski and finally, plantar pressure measurement systems, such as Pedar (Novel GmbH, Munich, Germany). Many of the previous studies have assessed only a one or two turns per run. As any repeated motion (i.e. running, swimming) it is reasonable to think that slalom turns are in some degree dependent on the previous turn. Brodie et al. (2009) states that due to the temporal dependence of turn strategy, the performance cannot be predicted based on an isolated turn sequence. To build a base of measurements that would allow reliable comparison between subjects, it is vital to assess an adequate amount of turns per subject/trial/course condition.

2.4.1 Video based kinematics

Ground reaction forces estimated utilizing the video do not require expensive equipment, but is both time consuming in the analysis phase, and questionable in accuracy. The kinematic analysis falls short in evaluation of the force distribution between inside and outside leg.

2.4.2 Force transducers

Ground reaction forces have been assessed by diverse force transducers either between the ski and the binding, the binding and the boot or the boot and the foot. Force transducers typically consist of two to four force sensing cells, and measure forces in all three dimensions. Although force transducers are precise, accurate and reliable, installation to skiing equipment changes their characteristics substantially as they change the stiffness of the skis and standing height, inducing a validity dilemma. The force transducers are also expensive and do not allow personal equipment use by the athlete.

2.4.3 Pressure measurement systems

Plantar pressure measurement systems, such as Pedar have good reliability, but do not directly measure the ground reaction forces. The capacitive insoles only measure the pressure normal to the insole. However, they are easy to use in field studies and do not substantially change the ski equipment.

2.5 Validity of Pedar insoles

In the present study, we were interested in the ground reaction forces in slalom skiing with two different courses. The Pedar insoles measure the plantar pressure normal to the insole, and the pressure measurements was used to estimate a component of the ground reaction forces acting normal to the insoles. Related to estimated forces, the total error component according to Novel depends on the pressure threshold (15 kPa, discarding anything less), incompletely loaded insoles, bypassing forces, and the hardness of the ground on where insoles are used, as the calibration is done on soft ground. The soft ground calibration result in higher pressure measurements on harder ground. A study by Putti et al. (2007) reported the maximum coefficient of repeatability of 15.3 % during walking, and majority of the parameters in the study showed coefficients under 10%. Measuring the pressure, the accuracy of Pedar is adequate- however, there are factors which affect the estimation of ground reaction forces in slalom skiing.

A study to validate the Pedar system was assessed in alpine skiing by Lüthi et al. (2005) and a series of studies assessing Pedar have been conducted in running, walking, and other dynamic activities. Lüthi compared pressure measurements between Kistler three-component piezo sensor force plates installed between the skis and bindings and Pedar insoles. Results show that the force-time relation matched well with Kistler force plates and that in carved turn 90 % of the total ski force was verified of the vertical force component detected by Kistler force plates.

A study by Forner Cordero et al., (2004) validated the Pedar insoles during two-step walking. The error of vertical force component was under 10 % with good agreement in the measurements between AMTI force plate (1000 Hz) and Pedar insoles (100Hz) (r=0.95). The errors found in the study by Forner Cordero et al., (2004) occurred at the beginning and the end of the foot contact perhaps due to the folding of the insole inside the shoe. This error component would not be applicable in alpine skiing due to the stiff and tight fitting boot and due to the fact that the feet stay in contact with the snow (via bindings and skis) during the turn. The nature of the boots does not allow feet to slide in the boot, or the insole to fold in a same degree as during running. On the other hand, the stiffness of the boot may affect the measurements. When the skier is pressuring against the front of the cuff, the boot may act to absorb the pressure, thereby reducing the pressure measured by the insoles.

Another study validating the Pedar insoles provides reasonable evidence of their accuracy and reliability (Barnett et al., 1999). They found that the force-time relationship (duration of force) matched well with a Kistler force platform while the vertical force component was repeatedly measured significantly lower. Authors suggest that the non-sensing area may affect the vertical force measurements magnitude, and they highlight that Pedar insoles may underestimate the vertical force magnitude, but they are very accurate in temporal detection of pressure (Barnett et al., 1999).

Plantar pressure testing during slalom skiing last minimum of 2 minutes, while the skier is equipped with the insoles for a 1-2 hours if repeated trials are conducted. There are only a few studies assessing validity of Pedar system during prolonged activity. Arndt (2003) study measured long term accuracy of Pedar system in 3 hour long walking trial, where subjects stood still one minute after each hour of walking. They found increased total force (17%, 10%, 10% and 8 %) depending upon the mass of the subject and the boot model worn.

Assumptions were that the mass of the subject should stay stable over time (or decrease due to dehydration), which would reflect the Pedar measurements. Sensor creep[1] could possibly explain the increase of total force measured during static standing trials. Such a sensor creep was reasoned with temperature or moisture effects inside the shoes. Another explanation could be that while the force plate measured the weight of the boot, Pedar did not. The lower Pedar measurements may also lack the complete transferral of body weight to the insole. The anatomical structure of the leg, heel, foot and the length of the boot possibly transfer some of the weight around the insoles, similar to the alpine boots. The effect of the anatomy of the leg, heel and foot as well as the boot fitting to the total force measurement was evaluated by Arndt (2003) by static measurements without backpack or boots. The increase of total force from the start of the trial to 3 hours, force measured during static standing trials increased with 11 %, 8%, 22% and 3%, indicating that the boots affect the total force measurements.

Series of validating studies previously conducted by Reid in the Norwegian School of Sport Sciences (Appendix M) show that during dynamic squat jumps performed in running shoes with additional 50 kg mass, the Pedar insoles measured 3 to 7 % lower than the AMTI platform, while the force-time relationship matched well. Largest errors seemed to occur when the force increased or decreased rapidly. When jumps were performed with ski boots, the error component raised to 13 to 27 % (139 to 275 N) and the force-time relationship was characterized as delayed with rapid force changes. Larger error of the vertical force component could be due to the pressuring against the cuff of the boot, thus transferring part of the force to the shell of the boot instead of the insole inside the boot.

Schaff et al. (1989) assessed five boot models in different forward flexion positions with 10 subjects and found that a tightly closed and well-fitted boot lead to a substantial reduction in pressure measurements under the foot. Schaff et al. employed a customized capacitive mat

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[1] The gradual, permanent deformation of a body of material produced by a continued application of heat or stress. (www.dictionary.com)

with 72 measuring points and tightly and loosely positioned buckles in boots to the force measurement. Total forces during standing with tightly buckled boots were 36 % lower than when the boots were loosely buckled (320N / 500 N). It was reasoned that the reduction was due to force transmission along the shaft of the boot. They also reported decreased force measured under the foot during forward flexion when the boot was tightly fitted to subject's foot. These findings indicate that a tight-fitted-tight-buckled ski boot is important in injury prevention of the foot and ankle. On the other hand, it is important to take notice that Pedar, or other plantar pressure measurement systems are not able to estimate all of the ground reaction forces acting on the skier.

The reduction in total force estimations under the foot is part of the modern ski boot technology, reducing overloading of foot and ankle in skiing. An important injury preventive function of ski boots is that the force is transferred through the shell instead of through the foot sole. Additional validation studies assessing the pressuring of the cuff are necessary to further evaluate and validate the Pedar system as ski force estimation tool in alpine skiing.

2.5.1 The estimation of error

In summary, depending on the methods, the vertical force error component is estimated to deviate from true forces from 10 % to 30 %. In alpine skiing, the error component is probably closer to the latter due the fact that some of the true ground reaction forces are lost because Pedar only detects pressure normal to the insole, because of the ski and boot weight cannot be detected, as well as due to the dynamic pressuring of the cuff. Several national teams around the world currently use plantar pressure measurement systems in training. However, systematic evaluation of such a system is not available. A rational investment in plantar pressure measurement tools requires an analysis of both practicality and validity of plantar pressure system in slalom training. The system should be evaluated before such an engagement is done by the Norwegian Ski Federation. Therefore, it is necessary to establish wide knowledge about the Pedar system and it's applicability in various alpine skiing situations.

The ground reaction force was the object of interest in the present study. Ground reaction forces (or ski reaction forces) can be estimated through pressure measurements as force over an area, herein under the foot with capacitive insoles inserted in the skier's boots. With such a pressure measurement system, only pressure normal to the insoles is detected which limits the possibility to estimate the true ground reaction forces acting on the skier. It was therefore assumed that the components of the ground reaction forces normal to the insoles were measured with a pressure measurement system, and some of the true ground reaction forces were not detected.

The theory section has now introduced the slalom turning mechanisms, recent knowledge of the ground reaction forces, introduced the lateral leg dominance in skiing, and finally considered the validity of the Pedar plantar pressure system. Next, the rationale and specific research questions are introduced, leading to methods and followed by the results, discussion and the conclusion of the present study.

3 Rationale and specific objectives

The studies introduced here have examined various characteristics of modern slalom technique and biomechanics of slalom turns. Lack of relating force-time variables to gate passing, small sample sizes (amount of turns/subjects), and a lack of normalized ground reaction forces for inter-study comparisons contribute to the fact that there are gaps in the knowledge of alpine skiing. How the kinetic characteristics change during competitive slalom skiing and between the turn directions and the different gate settings is still not known.

Although plantar pressure measurement systems may be a common method used in the alpine skiing research, much of the published studies have been limited to descriptions of the methods and have stopped short of examining the research questions related to technique. The specific research questions of this study were:

1. What are the specific kinetic characteristics in unloading and loading phases in slalom turn in courses with 10 and 13 meter linear distance between gates? Are there significant differences in the kinetic characteristics between the courses and/or turn directions?
2. What is the ski impulse distribution between the inside and the outside ski? Are there significant differences in ski impulse distribution between courses and/or turn directions?
3. What is the quantity of chatter in the inside and the outside ski? Are there significant differences in the chatter characteristics between the courses and/or the turn directions?

The specific hypotheses were:

Are there significant differences in the kinetic characteristics, ski impulse distribution, or chatter characteristics between the courses and/or the turn directions?

H0: There are no significant differences in the kinetic characteristics, ski impulse distribution, or chatter characteristics between the course conditions, and/or the turn directions.

H1: There are significant differences in the kinetic characteristics, ski impulse distribution, or chatter characteristics between the course conditions, and/or the turn directions.

4 Methods

4.1 The choice of force instrumentation

The Pedar plantar pressure system was chosen due to the readiness for use in the field and due to the fact that the system does not change equipment characteristics and thus has a minimal impact on the athletes' performances. As we were interested in the technique aspects of slalom skiing, such as timing of the apex and the inside/outside ski impulse distribution, the Pedar system was considered the best method of assessment. It was assumed that the error associated with the system affect both legs similarly so that ratios of kinetic parameters between the inside and the outside legs would remain accurate. The temporal error component was considered to be small enough to not jeopardize the validity. Despite certain limitations in the system's accuracy in ground reaction force measurements, the Pedar system was chosen as the best-fit for the purpose of the present study.

4.1.1 The plantar pressure as a measurement tool

Ground reaction forces can be estimated from the pressure measurements between the foot and the boot. Pedar insoles are pressure sensitive insoles consisting of 99 small cells hooked in an electric circuit that reacts to deformation of the cells. They only measure the pressure normal to the cells, and have an inbuilt sensing threshold of 2 N/cm^2 as well as a non-sensing area around the insole. Kurpiers et al. (2009) mention that bending of the skis transmitted noise to the measurement unit. The threshold of pressure detection (converted to force) of 2 N/cm^2 may alter the pressure measurements as some cells measure zero pressure while in fact, cells were pressured with amount corresponding to 1.5 N/cm^2. Depending on the number of cells erroneously measuring zero could result in a substantial underestimation of actual ground reaction force. The advantage of such insoles is the freedom of measuring pressure under conditions where other force transducer or force platforms are impractical or invalid as they change the equipment characteristics. One of the limitations of the Pedar system is that it does not measure the weight of the skis, binding or boot. Although plantar pressure systems are accurate in measuring pressure under the foot, they fall short in estimating the real ground reaction forces due to the influence the boot has on the skier-snow interaction (Schaff et al., 1989).

Force platforms would be the gold standard due to their measurement accuracy and reliability. The disadvantage of force plates, however, is the fact that their static nature, size, and weight may interfere substantially with the performance characteristics of the athlete's equipment. In addition, with the Pedar system, the information is readily in hands of the athletes and the coaches once the analysis method is constructed.

4.2 The choice of design

Most research is generally conducted with a relatively large number of subjects, which allow findings to be applied to a larger population. However, it is not always possible to conduct research on a large number of subjects due to practical reasons, such as the subject availability and the external conditions during the data collection. The present study was conducted with close co-operation with a ski team for whom the information from each subject was valuable for the coach and the individual skiers. Therefore it was considered important in this study to use both group and single-subject information when the results were analyzed as these may include knowledge not readily available from the group analyses alone.

According to Bates (1994), single-subject analysis provides a foundation for research areas for the individual performance patterns and strategies. A founding assumption and the requirement for a valid single-subject design is adequate replication (Bates, 1994). A single-subject design has its limitations as it falls short on applying the results to any other subjects from the study. However, since slalom kinetics research is in its developing stages, single-subject designs can yield valuable information, especially for the coaches and the individual skiers. The research questions were the same as for the group analysis even though the results from single-subject analysis cannot be interpreted to affect a population of skiers. Single-subject studies are valuable research designs where the same task is executed in a different manner by the individuals resulting in an inter-subject variability (Bates, 1994).

In the present study, repetition of slalom turns adequately allowed the research team to investigate the effect of changing the gate settings over time as a natural trend instead of a random effect. The single-subject design detected the effect of changing the linear distance between gates on some subjects and provided information on variability of results between subjects that a group analysis did not show (Reboussin et al. 1996). Since results from two trials from a single subject are prone to be more similar than from two individuals, the within subject variability could detect changes between the courses and turn directions. A major limitation of single-subject designs is the lack of the application to larger populations, as it concludes the effect of changing gate settings on one single subject, thus falling short on saying anything about the effect of changing the gate settings on different subjects.

Multiple subject design resulted in a fictional “average skier”. Although the fictional average skier described kinetic variables for the group, the weakness of this kind of approach was that no single subject matched 100% with the average. However, as the sample size in this study was limited to nine subjects, applying the group results to a single subject may not have shown the reality. When some subjects showed an effect on changing the gate settings or the turn direction, others did not. It is therefore important to note that when interpreting the results of the present study, where individual differences existed, any modifications in technique training should be fine-tuned accordingly. While discarding the alternative hypothesis may be correct in group level, it may not be the right conclusion in a single-subject level. According to Bates (1994), individual task specific strategies often lead to increased inter-subject variability reducing statistical power of group design, and may lead to false approval of the null hypothesis. Also, considering the fact that significant differences existed in the preference of turn direction as an indication of lateral preference (Vaverka & Vodickova, 2009), the single subject design was considered appropriate. Since sufficient pieces of information were gathered, and the individual response was steady during the test time period, the individual’s performance was validly evaluated by the single-subject design.

Although an average skier approach was incomplete in recognizing the individual differences between the subjects in this study, it brought initial information about the kinetic characteristics in competitive slalom skiing. To cover the areas where the average skier approach was lacking, a single subject design added to the results, and suggested effects of changing the gate settings or turn directions in some level of consistency (Reboussin et al. 1996). The purpose of single-subject design was therefore to gain additional insight into the research questions in this study.

The aim of the present study was to provide knowledge with practical approach in slalom skiing. Therefore it was suggested that the combination of multiple-subject and single-subject design would provide a complete assessment of research questions and was therefore chosen in this study (Bates, 1994).

4.3 Subjects

The main group included nine males selected by a convenient sample due to participant availability from "Edge"; a recruit team of the Norwegian Ski Federation. Two athletes from the same team formed the pilot group. The study was conducted in Juvass, a ski resort on a central Norwegian glacier during four consecutive days in September 2008. The team was on five-week training camp and agreed to be part of the study during the last week of their camp. The number of subjects who participated in this study was limited by the athlete availability and the location of the training camp. Since the fall is an important part of the preparation period before the first World Cup races in late October, it was not possible for some potential subjects to participate due to important training and equipment testing activities. Therefore, both the team coaches and skiers themselves were involved in deciding who participated. The daylight constraints and the availability of athletes determined the total number of subjects.

Table 4.1: A demographic description of the study population.

Demographics	Age	Effective Mass (kg) Mean ± SD	Height (cm)	FIS ranking Range
Pilot Group	28 ± 2	83 ± 3	176 ± 5	134 – 350
Main Group	20 ± 2	88 ± 7	181 ± 4	165 – 705

The subjects were assigned the test order by their coach. A random assignment was not considered possible as training was run parallel with the testing. The athletes were randomly assigned a test order of the course (either 10 or 13 meter course). Only subjects who regularly take part in the slalom discipline were asked to participate. Any member of the team who had an injury preventing them to maximally perform was not asked to participate. Subjects were informed about the purpose and procedures of the study and a written consent was obtained from all subjects prior the testing.

The demographics of the main study group were: Age 20 ± 1.6 years, height 181 ± 4.1 cm, mass 88 ± 4.1 kg, Table 4.1). Subjects had been members of the team for 1 ± 0.5 years. To appropriately describe subjects' long-term ability level, the previous season's FIS slalom ranking (www.fis-ski.com) was used. The FIS ranking reflects the two best rankings for the past 12 months. The latest season (2007/08) means of FIS ranking were 496 ± 190. The range of ranking in season was 165 and 705. The subjects' mass were measured with a weight scale as a mean of two trials, subjects fully equipped (race suit, boots, helmet, gloves, slalom leg pads, goggles and the Pedar system including carrying system) excluding skis and poles. The effective mass was calculated using fully equipped mass minus the mass of the boots. Eight subjects self-assessed right leg and three subjects the left leg dominance. Subjects also reported previous lower extremity injuries within the past 5 years.

4.4 Set up of the courses

Figure 4.1 shows the two slalom courses used in the present study; one with a linear distance between gates of 10 meters and a 3 meter off-set and the other course with 13 meters linear distance and a 4 meter off-set. These distances were chosen primarily because previous research had been conducted by the research group from Norwegian School of Sport Sciences in a similar set up and secondly because the 10 meter distance is widely practised in FIS slalom races, while 13 meter distance is the maximal allowed linear distance between gates and carved turns are usually allowed in this set up (Reid, personal communication, 2009). The courses were set up on a longer, rhythmical section on even terrain using two measuring tapes. First, the area of the hill was selected based on the even inclination and gradient profile. The inclination of the slope was 16°. Medium inclined terrain allowed rhythmical turning between the gates.

Ten consecutive turns were analysed to allow a long section of turns for each subject. The set up for this research was approved by the ski resort and the research team had complete control over the courses. Only the research team had access to courses during these four days. Courses were prepared by side slipping several times between each trial to ensure even conditions for each athlete.

The description of snow conditions and the hardness of snow are presented in Table 4.2. Snow was a combination of natural and man-made. Temperature measurements were obtained with a thermometer (Thermo Electra, Pijnacker, Netherlands) in the shadow of a backpack placed in the vicinity of the courses. Categories of the description of course conditions were "Ice, Hard/Ice, Hard, and Soft".

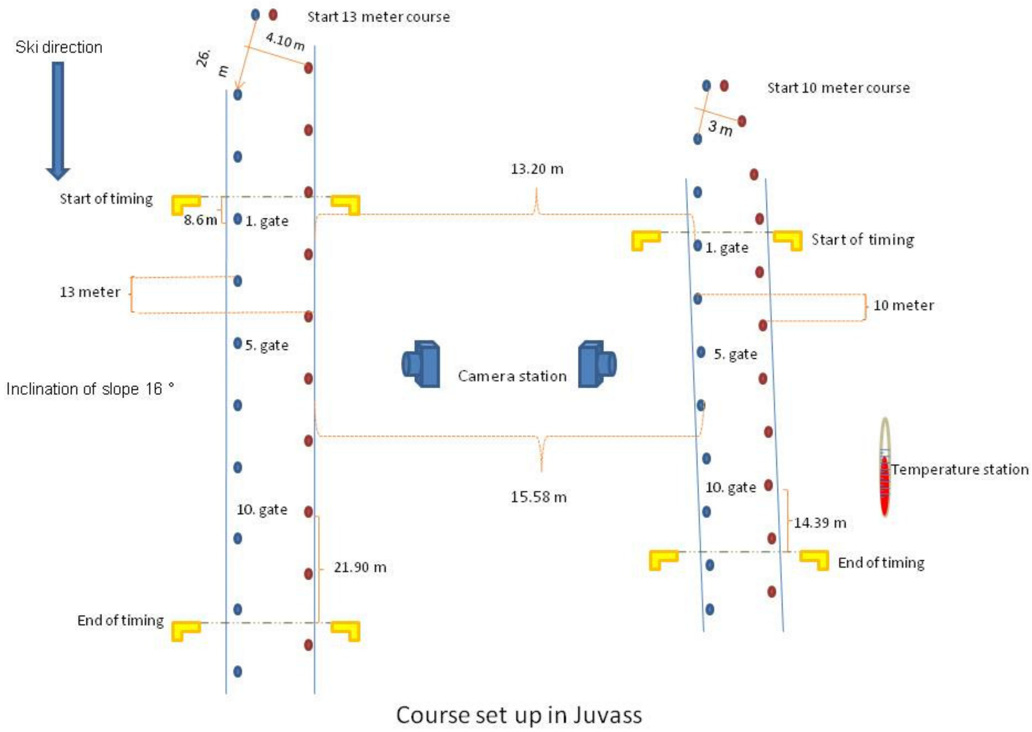


Figure 4.1: The course set-up of the two courses, timing, camera and temperature stations, direction of travel, slope gradient, inclination and specific measurements for the courses.

Table 4.2: The external conditions; snow and air temperature described for each day. A subjective evaluation of course condition and visibility is given as % of number of trials.

Snow type	**Snow temperature (˚C)**	**Air temperature (˚C)**	**Course condition**	**Visibility**
Main group	**Mean ± SD**			
Transformed, old, frozen	-2.7 ± 1.3	0.9 ± 1.9	Hard 33%	Excellent 83 %
			Hard/Ice 67 %	Good 11 % OK 6 %
Day 1	-1.8 ± 0.9	2.0 ± 1.5		
Day 2	-3.3 ± 1.3	1.3 ± 1.8		
Day 3	-3.2 ± 1.0	-0.5 ± 1.6		
Pilot group				
Transformed, old, frozen	-2.4 ± 1.2	1.1 ± 0.8	Soft 82% Soft but hard after side slipping 18 %	Excellent 90 % Good 10 %

4.5 The ski equipment

Each subject used his preferred slalom equipment. The characteristics of the skis; contact length, side-cut radius, minimum width and standing height were measured, recorded and provided in Table 4.3. The skis were manufactured by Atomic (4), Völkl (3), Elan (1), Fischer (1), Rossignol (1) and Dynastar (1).

Table 4.3: A summary of the equipment characteristics used in the study.

Ski characteristics	
Contact length (cm)	142 ± 1.2
Side-cut radius (m)	13 ± 0.4
Minimum width (mm)	64 ± 0.8
Standing height (mm)	49 ± 2.3

The ski widths were measured in every 10 cm along the longitudinal axis of the ski's contact length when the ski was pressed flat. The method allowed estimation of the side cut radius. The height of the binding was measured twice from the base of the ski to the top of the binding at the heel and the toe. The characteristics of the skis (means of two measurements) were reported to allow future research to compare results from this study.

4.6 The procedure

The subjects were asked to warm up as they normally do prior to competition. They were asked to focus as if they were in a competition situation. Figure 4.2 shows an athlete outfitted with the Pedar plantar pressure measurement system. This system involved inserting thin pressure sensitive insoles into the subject's boots, while thin cables ran along the lateral side of the legs inside the competition suit from the insoles to the data logger. The data logger and power supply – measuring 10 cm x 15 cm x 4 cm and 6 cm x 11 cm x 3 cm, respectively – were carried in a customized back protection gear specifically designed to both minimize interference with the subject's performance and to protect the subject in case of a fall. The whole carrying system had a mass of 1.8 kg, and was included in the effective mass of each athlete.

Figure 4.2: An athlete carrying the Pedar system; data log, battery and cables inside the ski pants.

The subjects performed three maximal trials on each course. Each analyzed trial contained 20 full turns, but only the middle 10 turns were analyzed. After the first performed run, the subjects were asked to return to the top of the course for the second run with the different gate settings. Subjects were allowed to fully recover between the runs. The mean recovery time between the trials runs was 11 ± 3 minutes, in which the athletes were allowed to rest and intake liquid or snacks.

To synchronize the video input with the pressure measurements, a specific starting procedure was repeated at the start of each trial. This procedure included unloading of the insoles by lifting the foot with buckled boot and ski after the data log was turned on, and stomping each foot twice. After each finished trial, subjects underwent a specific finish procedure (one jump) which ensured the synchronizing.

4.7 Data analysis

4.7.1 Recording and processing of data

The kinetic variables of interest were measured with the Pedar insoles at a sampling frequency of 50 Hz. During the pilot study, a 100 Hz sampling frequency was tested, but due to the long duration of the measurements, the increased sampling frequency exceeded the data log’s memory capacity (8 Mb). It was likely that with a 50 Hz sampling frequency, the

Pedar system was unable to detect the highest and the lowest of the data points of the original signal, excluding the highest peak values of the ground reaction forces. Typically, a slalom turn lasts under a second where ground reaction force was assumed to be relatively low compared to activities such as jumping on a hard floor. Therefore a sampling frequency of 50 Hz was considered appropriate, as it allowed the general trend of the ground reaction forces to be estimated. Calibration of the Pedar insoles was done by the Pedar manufacturer in Munich, Germany prior to testing.

The measurements from the Pedar data log were immediately downloaded into a laptop with Pedar X-Online program (Novel) between the testing of the subjects. For processing, the input files were converted into three different formats (.sol, .fgt and .asc), imported to Microsoft Excel (Microsoft Inc., Redmond, WA, USA) to be checked and cleaned, then further analysed in custom developed program in MatLab (Math Works Inc, Natick, USA). A back up of the raw Pedar and video inputs were immediately taken and stored in another computer at the Norwegian School of Sport Sciences. The performance times (appendix F) were measured with photocells (Microgate SRL, Bolzano, Italy), initiated by the passing of the first photocell before the first analyzed gate and finalized by the passing of the second photocell located after the last analyzed, 10th gate. To determine subject's position relative to a turn cycle, the subjects were video recorded with a camera (Sony Handycam DCR-TRV950E) located in between the courses (Figure 4.1). To synchronize the video input with the Pedar measurements, the video from each trial was first de-interlaced to 50 Hz using Dartfish (Dartfish, Fribourg, Switzerland). Then each switch and gate passage were visually *tagged* (marking of the picture frame in the video) in the MatLab programme.

4.7.2 The method of estimating ground reaction forces

Figure 4.3 demonstrates the analyzing process using the custom-built MatLab programme. The program allowed selection of the specific trial, a left or a right turn, and a plot of the force-time relation.

a) *Synchronization:* After the video input was synchronised with the Pedar measurements, the 10 consecutive turns were chosen by tagging the start and the finish. To synchronize the Pedar measurements with the video input, subjects were asked to stomp their feet twice while a radio connection transmitted the stomping audio to the video recording. When the audio band was imported to the MatLab programme, the spikes in the audio file were then synchronized with force spikes visible at the Pedar measurements. It was assumed that when audio was captured on film via radio connection, there was a short delay of 0.02 seconds and spikes from audio were positioned accordingly with the Pedar measurements.

b) *Turn selection*: A start was determined by a passing of the first photocell visible on the video film. Following selection of ten complete consecutive turns, the tagging of each switch and gate passing was done manually.

c) *A switch* was determined as the picture frame where the skier's center of mass was in the midpoint of the path of skiing. In cases where the midpoint was between two frames a MatLab function was used to tag a time point between two specific frames (±0.01 seconds).

d) *The gate passing* was determined as the frame where a skier's center of mass passed the gate, which was assumed to be approximately two frames after the initial contact with the gate. A full turn cycle started with a switch and ended with the next switch minus one frame.

e) *Selection of turns:* The whole area of analysis for one trial with all switches (red vertical line) and gate passing (purple dashed line).

f) Screen of *raw data:* this was the main screen for the calculation process.

4.7.1 Definitions and calculations of the kinetic variables

The first, main part of this study analyzed the kinetic characteristics of slalom skiing (dependent variables). The independent variables in this study were the linear distances between the gates; short linear distance (10 meter) and long linear distance (13 meter).

The kinetic variables were analyzed as a total force: a summation of measurements from the left and the right insoles. The turn cycle phases were defined as the unloading and the loading, where estimated forces were either below one effective body weight (*unloading phase*) or above one effective body weight (*loading phase*).

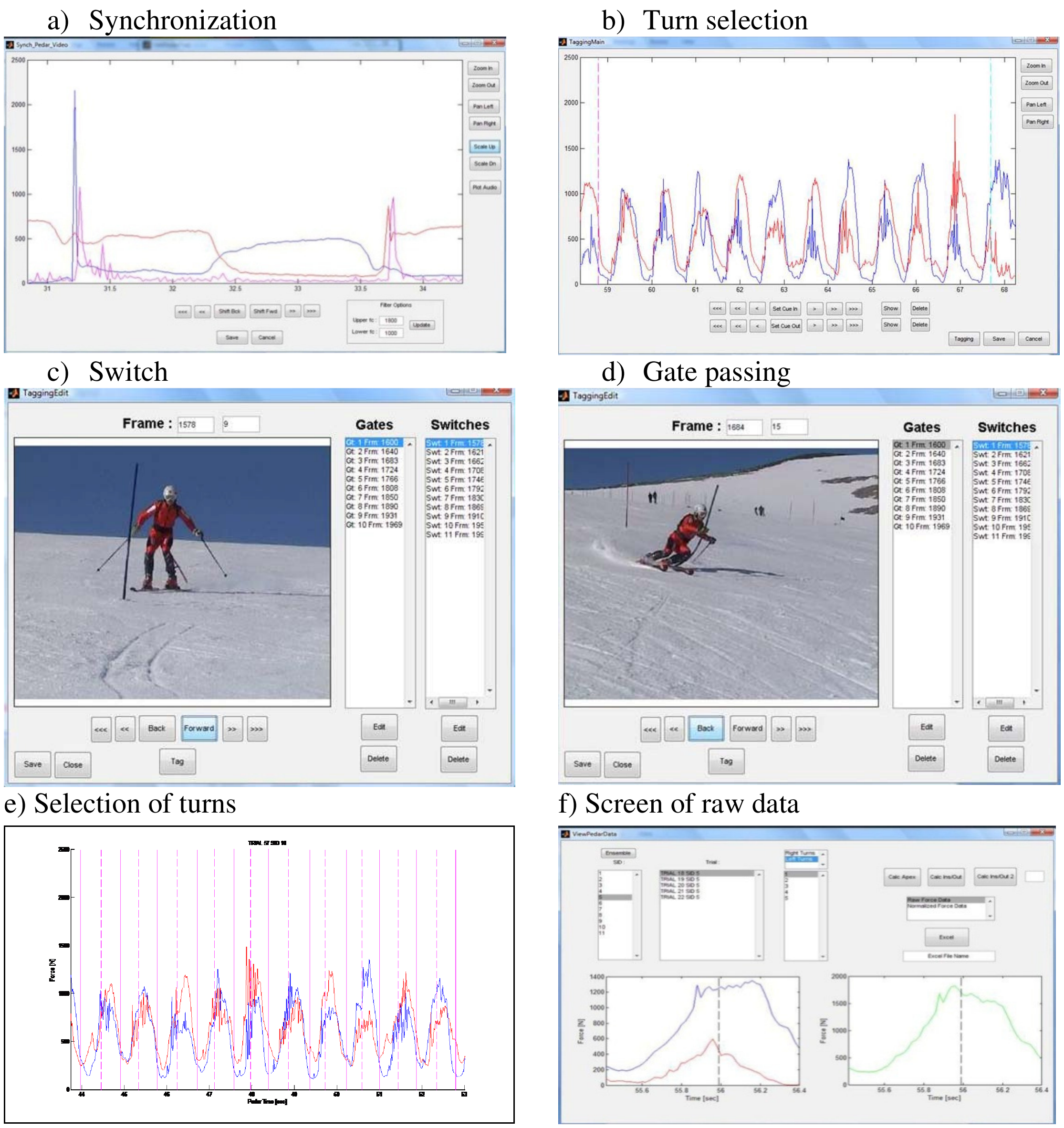


Figure 4.3: Screenshots of the synchronizing process, turn selection, switch, and gate tagging and force calculation process in the MatLab programme.

The apex of turn was defined as the 10 % region of the loading phase, where the impulse (force applied with respect to time) was the greatest, thereby identifying the phase of the turn where the skier's momentum was most effectively changed, Figure 4.4. Since the insoles only measure the component of the ground reaction force acting normal to the insole, an important assumption for accurate estimation of the timing of the apex is that the angle between the normal to the insole and the total ground reaction force remains relatively constant during the loading phase. The definition of apex here was likely different from the apex that has the most effect on changing the skiers momentum, due to the measurement tool. The time point which apex occurred was defined as the middle of the 10% interval defined as apex.

Each turn was analyzed for *mean unloading force*, *minimum unloading phase, unloading duration, unloading-loading duration ratio* (proportion of unloading and loading phases as % of turn cycle in time), *mean loading force*, *mean apex force*, *peak force*, *gate passing* and *gate to apex* (as % of turn cycle). The mean loading force was calculated from the start of the loading phase to the peak of the apex, while the mean unloading force was calculated as the mean force for a turn in the unloading phase. Gate passage was defined as the time point where skier's CoM passed the gate, Figure 4.3. *The inside/outside ski impulse ratio (Inside/outside SIR)* was calculated as the ratio of the inside ski to the outside ski impulse calculations in the loading phase. A ratio of 1.0 indicated an even loading between the inside and the outside skis. A ratio of 0.5 indicated predominantly loading of the outside ski, where the inside ski carries half of the force carried by the outside ski.

During skiing, specifically when skidding, skis typically *chatter*, inconsistently vibrating. In the alpine skiing literature, the chattering of high frequencies 20-30 Hz is referred to as vibrations (Federolf, 2009). To characterize force in the time domain, mean residuals of chatter reflect the size of the "spikes"/chatters of force-time relationship, Figure 4.6. The mean residuals for both the inside and the outside ski, and the *inside/outside chatter ratio* (Inside/outside CR) were calculated. The mean residuals were calculated as the difference between the raw force-time curve and the smoothed force-time curve. For the chatter analysis, a low-pass Butterworth filter with a cut-off frequency of 4 Hz was used to filter the raw data to generate a smoothed trend of the force-time data. Normally, low-pass filtering is used to remove random errors/noise to obtain an appropriate signal, as the random errors are associated with higher frequencies. However, in the present study, we were interested in separating the raw force data from the high frequency chattering associated with vibrations due to ski equipment. In the present study, the chatter was derived from the plantar pressure measurements, while snow conditions and ski equipment were reported and skiing velocity was assessed by timing of subjects. The degree of carving was controlled with two courses with different linear gate set up. It was anticipated that the shorter distance course (10 m) would require a greater degree of skidding.

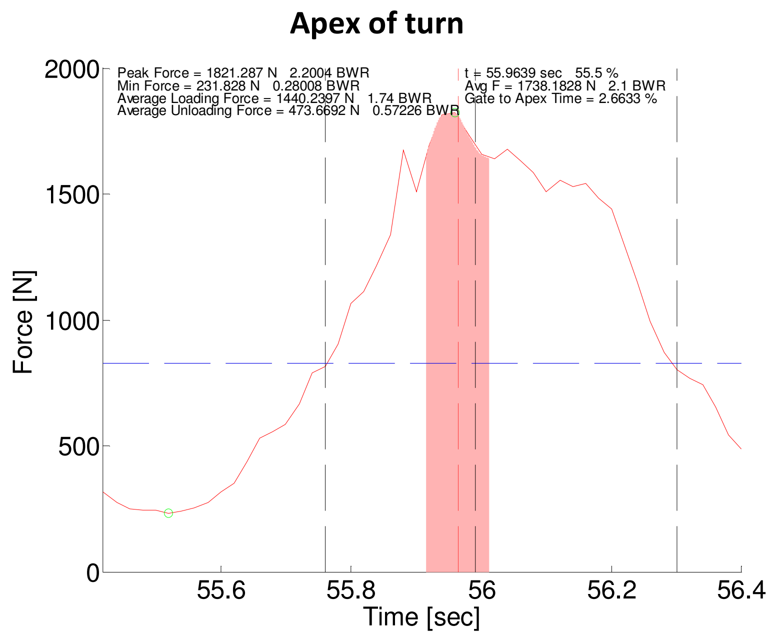


Figure 4.4: A Screenshot of the apex. The blue horizontal line reflects 1 BW, black vertical line indicates the gate passing, and the red vertical line indicates the middle apex. Force calculations for the turn provided at the upper part of the figure.

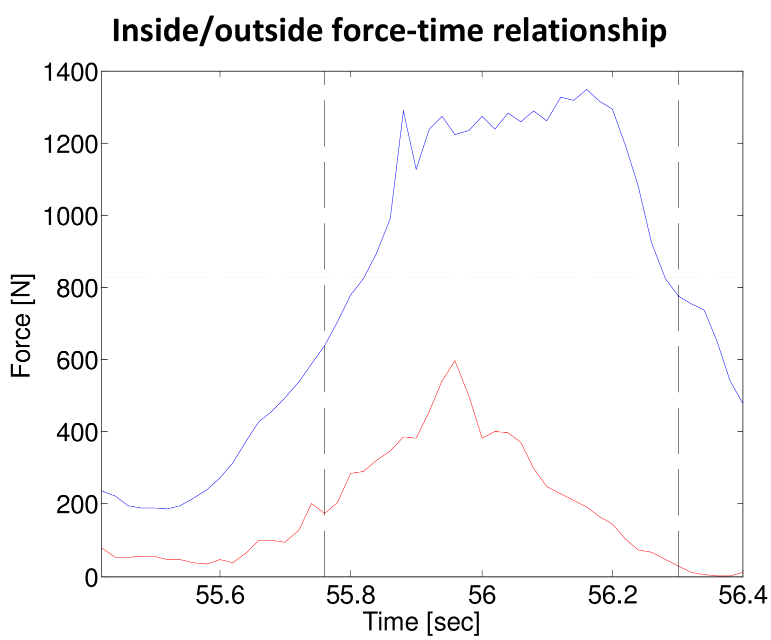


Figure 4.5: The inside/outside force-time relationship. The loading phase indicated with the black vertical lines, 1 BW indicated with red horizontal line, blue and red lines indicate the outside and the inside force calculations, respectively.

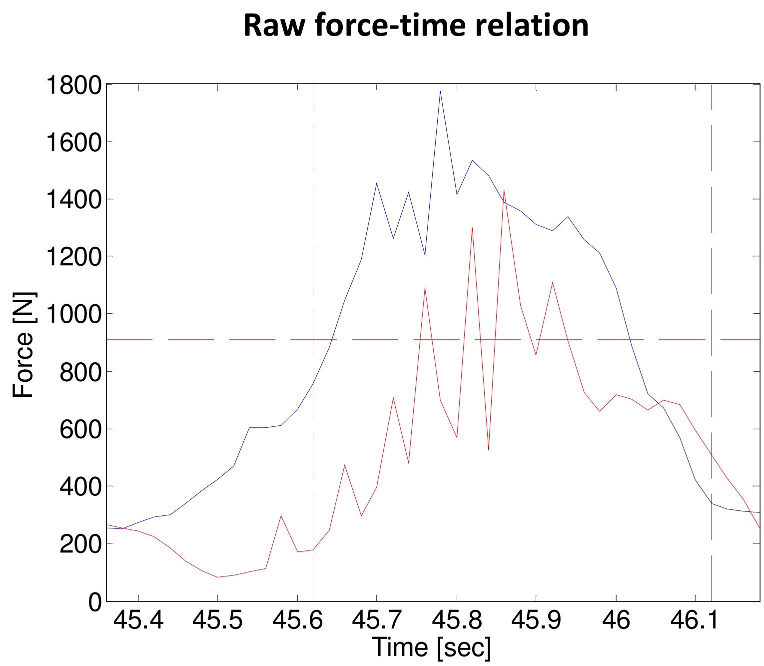


Figure 4.6: An example of the force-time relation and the mean residual size of the chatter for the outside ski (blue line) and the inside ski (red line).

All forces were reported relative to either the mean body weight (BW) of the group or subject's BW in the single subject results. Relative forces allow proper comparison of forces in competitive slalom skiing with future research. The dependent variables were further typed in to MS Excel and in Statistical Package for the Social Sciences (SPSS Inc, IL, USA) for statistical analysis.

4.7.2 Statistics

The data-analysis for both the single-subject and the group analyses was conducted in MatLab, MS Excel and SPSS. All variables are presented as means ± SDs. Standard errors of means are presented in all figures. For the single-subject analysis, the unpaired, two-tailed t-tests were used for the total kinetic variables, and for the mean inside and outside chatter, and paired, one-tailed t-tests for the inside/outside ski impulse and the inside/outside chatter ratio to determine significant differences between the courses and the turn directions. For the group analysis, unpaired t-tests were utilized for the total kinetic variables and a two-way repeated measure of analysis of variance (ANOVA) to determine potential differences in the inside/outside ski impulse and chatter ratios. Statistical significance level was set to $p < .05$. Values up to $p = .20$ were reported in the results. When the two-way repeated measures ANOVA analysis indicated that the turn directions or the courses were significantly different, post hoc tests were conducted with Bonferroni's adjustment (alpha level divided by number of comparisons). In the present study, alpha level .05 was divided by four and the new corrected alpha level of 0.013 was determined. A weak but significant correlation between subject test order and performance time was observed (later subjects had slightly slower times). Therefore, partial product-moment coefficients of correlation controlling for test order were used to assess possible relationships between variables; inside/outside ski impulse ratio (X) and FIS ranking (Y) variables corrected for a third factor, order of testing (Z) in the two courses. A partial correlation provided a clearer explanation of the nature of relationships between variables excluding the effect of testing order (Portney & Watkins, 2009).

The statistical null hypothesis was that there were no differences in the means of any of the kinetic characteristics between the two gate settings, or turn directions. H_0: $\mu_1 = \mu_2$. Alternative hypothesis was that the two means differ. H_1: $\mu_1 \neq \mu_2$. If there was a significant difference between the gate settings or the turn directions, the null hypothesis was rejected, and there was something other than chance causing the differences.

4.7.3 Sources of error

To minimize the random error component, ten turns from each trial were analyzed. Repeated turns permitted the most accurate representation of the turns. Averaging the scores of data summarized the random errors from each individual score and produced a zero total sum of error. Five analyzed right and five left turns per trial acted as a control for variance itself. It must be stated, that analyzing the mean values may have reduced information and ignored individual turns.

Pedar insoles only detect pressure perpendicular to the insoles. Studies presented previously found that the Pedar system had at least about 150 N errors in estimation of ground reaction forces. First, the error component due to the inability of Pedar to detect the mass of the boots (mean 5.1 ± 0.31 kg and skis 7.7 ± 0.38 kg/ski) was estimated to 125 N. Secondly, the pressure detection threshold of 2 N/m^2 could contribute to the total error. Thirdly, dynamic pressuring against boot cuff was assumed to add to the total error component with an unknown amount.

According to the sampling theorem "The process of signal must be sampled at a frequency greater than twice as the highest frequency present in the signal itself" (Robertson et al. 2004,

p. 232), this is also called the Nyquist sampling frequency. Human locomotion is generally associated with frequencies under 10 Hz (Robertson et al. 2004). In the present study, a sampling frequency of 50 Hz was used. Usually, 5 to 100 times higher sampling frequencies are used in biomechanics, warranting that the signal is represented in the time domain without ignoring the peak values (Robertson et al. 2004). In the present study, it was therefore assumed that the true peak force values as well as the higher frequency vibrations may have been missed.

The synchronizing process was conducted by one investigator, ruling out any inter-researcher variability. However, a subjective determination of the switches and the gate passing possibly led to small temporal deviations of 1/100 to 4/100 seconds in the total force and the temporal calculations in either direction. Although a minor temporal error component, the error would affect the whole sequence of turns if not detected, or only few turns if detected early. Controlling of this type of error was challenging and depended fully on the investigator's ability to consistently determine the switches and the gate passing.

4.8 The pilot study

A pilot study was conducted with two members from Edge Team. The aim of the pilot study was to practice the test protocol and gather useful initial information. Based on the pilot study, some expectations about the research events were obtained. The set up of the pilot study followed the main study set up of the main study group. However, the course was set up in a slightly different placement of the hill where the snow conditions were considerably harder than in the pilot study. The results from the pilot study are presented with the main study.

4.9 Assumptions

The Pedar insole system measures the normal pressure distributed over the area of a footprint, between the foot and the shoe. Due to the nature of the Pedar plantar pressure measurement system, and based on the current validation studies conducted by other researchers and in the motion lab in the Norwegian School of Sport Sciences, it was assumed that ground reaction force magnitudes estimated using Pedar deviated from true ground reaction forces acting on the skier by 10-30%. Since the force-time relationship was repeatedly reported to match well the relationship measured with force plates between skis and bindings, or with force platforms, the temporal estimates of kinetic variables as well as the inside/outside impulse and chatter ratios were assumed to correlate well with the true ground reaction forces. The error component was not adjusted in the measurements, but the readers are encouraged to take the total error component into consideration when interpreting the results of this study

4.10 Limitations

The present, descriptive biomechanical study did not involve randomization of the sample population, or manipulation of the variables, and was therefore considered as "weaker" study design than a randomized trial. The study design was chosen because the knowledge of the relationship between ground reaction forces in competitive slalom skiing with different gate settings is limited, if not minimal. There was no direct measurement of the individual turn radius, and therefore this study did not predict or find correlation in the force characteristics between the actual skier's turn radii. Using two courses with two different linear distances between gates, this study only evaluated whether there were any changes that happened in the kinetic characteristics during the skier's performance with different gate settings.

4.10.1 The sample population

A small sample size was a limitation, as it directly lowered the power of the statistical test in the study. Due to a small sample size, significant differences were difficult to find, if they truly existed. It was therefore accepted that there was a risk for type II error; a failure to reject a false null hypothesis. Since ten consecutive turns were analysed per subject, and subjects performed three trials for each course, the amount of trials and turns acted as a control itself. In addition, the test days (weather, snow and course conditions) for this study turned out to be very constant, which is unlikely in racing/most training camp situations. The number of subjects was highly dependent on the subject availability and the location of the hill. It was desirable for the sample to consist of at least 10 athletes, where 5 are males and 5 are females. Since artificial lighting was not available, the day light was a constraint for the time available for the testing. Furthermore, the hill in question opened lifts at 9 am and closed at 3 pm, leaving 5 hours for the course set up and testing.

Since the snow conditions change fast, it was desirable and optimal to test all the subjects during the same day to minimize any measurement bias. However, only two or three subjects each day were realistic due to the time constraint and also in order to allow appropriate time to follow the protocol optimally. The changes in the snow conditions between subjects were uncontrollable, and therefore spreading the subjects over several testing day was necessary.

4.10.2 The order of subject testing

The order of the course subject first performed was randomized by the flip of the coin to minimize any bias. Practical issues, such as switching the measurement equipment from subject to subject, and the day light related time constraints hindered a random assignment between the subjects. If a subject was first randomly assigned to one course and then another subject was randomly assigned to the same (or the other course) immediately after the first subject, it would have required extensive amount of time to shift the equipment from one subject to another. Therefore, one subject was tested before next subject was ready. Other possible limitations of this study were the practice and carry-over effects which may have influenced the dependent variables. Since all the subjects were elite skiers, it was unlikely that the practice or carry-over effect affected the dependent variables. It was therefore assumed that the practical order of subject testing did not put the generality of the measurements in jeopardy.

4.10.3 External factors

Another limitation of this study was the snow conditions during the data collection. Subjects tested in during different days experienced changed snow conditions, which may have led to large inter-subject variations. Icier course may have promoted faster times, more total force and make skis chatter more. During competitions, there may be rapid changes in the snow and weather conditions. Keeping that in mind, the spreading of subjects on several days was a minor limitation. Limitations in the control of external factors such as the snow and weather conditions may have influenced the outcome of the present study. This weakens the generality of the findings. However, the research design was chosen due to the overall effectiveness and its applicability to the real world situation.

4.11 Ethics

All subjects were informed of the purpose and the protocol of the study and given enough time to familiarize themselves to the measurement tool before testing. All subjects were asked to sign and hand in their informed consent forms prior testing (Appendix B). The information was handled with confidentiality and subjects were given an identification key. The list of identification keys was created manually (not electronically) and kept locked in a safe in the department chair's office to keep the personal information of the subjects in the study anonymous and safe from outsiders. Anonymity of the subjects was secured by destroying all personal information and the identification key list after the present study was completed at the end of May 2009.

All subjects were informed that their participation was voluntary, and that they were free to withdraw from the study at any point in time without having to give any reason for their withdrawal. All the information obtained was handled according to the Norwegian regulations for obtaining, assessing and storing personal electronic information. An application was submitted to Norsk samfunnvitenskapelig datatjeneste AS (Appendix C). Another application to the National Committees for Research Ethics (REK) in Oslo was obtained and their approval was gained for the present study (Appendix D).

The increase in injury risk over what is normally associated with training and competition was minimal. There was a risk of injury if the subject were to fall and land on the data logger and power supply. Therefore, the carrying device used was padded to ensure the safety of the subjects. To prevent that the cords were to attach to gates or ski equipment, they were secured with tape and held close to skier's leg, thigh and back. The cords were covered with a layer of ski clothes, which decreased the risk of attachment to the gates and inhibition of normal ski movement. Any discomfort or inhibition of normal movement was registered in the protocol. Subjects were informed of this risk before they were asked to sign and hand in the informed consent forms.

Subjects were offered to obtain their individual results as well as the overall results and conclusions from this study.

4.12 The significance

The present study brings indirect, practical information of the magnitude and time course of ground reaction forces acting on a skier and how these variables differ from a shorter linear distance between the gates to a longer linear distance between the gates. Understanding the events and characteristics of the dependent variables and how they change with the different gate settings or the turn directions is useful for skiers to optimize their technique. The importance of the present study is the insight it brings to the competitive skiers and their coaches, helping them to understand the performance related to the slalom technique and the tactical advantages of the slalom turn.

5 Results

There are two main sections of the results chapter; the group results and the single-subject results by kinetic variable. Results for the subjects of the pilot group (subjects 1 and 2) are presented in the single subject analysis (Appendix I) and the pilot group results (Appendix H). The single-subject analysis which follows the group results consists of all subjects and presents each kinetic variable within an individual skier.

5.1.1 “Average slalom skier” – an overview of the group results

5.1.2 Total ground reaction force

“Average slalom skier” results presented in Table 5.2 and illustrated in Figure 5.1, show the kinetic characteristics based on the mean values for 10 and 13 meter course, and left and right turns of the main group in this study. Any single skier from the group deviates from the “average skier”.

Table 5.2 presents the results for the left and the right turns in the 10 and the 13 meter courses for the kinetic variables, as well as the comparison of the means analysis. Two comparisons were carried out; first, the comparison of means between the turn directions, as the mean of the left turns on the 10 meter course was compared to the mean of the right turns on the 10 meter course (p value indicated with “10”). Secondly, the comparison of the means between the courses, the mean of the left turns on the 10 meter course was compared to the mean of the left turns on the 13 meter course (“L”). In a similar manner the mean of the right turns were compared to the mean of the left turns on the 13 meter course (“13”) and the mean of the right turns on the 10 meter course were compared to the mean of the right turns on the 13 meter course (“R”).

Table 5.1: Unloading-loading duration ratio, n= 9.

Unloading-loading duration ratio	10 meter course		13 meter course	
	Left turn	Right turn	Left turn	Right turn
Mean ± SD	38/62	38/62	37/63	36/64

Table 5.2: The kinetic variables related to the bodyweight (BW) and the timing as % of the turn cycle in time for the main group, n=9. Means ± SD and comparisons of the means in the 10 meter and the 13 meter courses.

Kinetic variable		10 meter course		13 meter course		
		Left	Right	Left	Right	Comparison of means
		Mean ± SD				(p)
Mean unloading force	BW	0.62 ± 0.10	0.64 ± 0.10	0.59 ± 0.08	0.62 ± 0.09	$.102_{L}$ $.170_{13}$
Minimum unloading force	BW	0.38 ± 0.09	0.40 ± 0.11	0.34 ± 0.09	0.37 ± 0.11	$.04_{L}$
Unloading duration	%	38 ± 6	38 ± 7	37 ± 5	36 ± 6	-
Mean loading force	BW	1.86 ± 0.13	1.81 ± 0.14	1.80 ± 0.11	1.77 ± 0.11	-
Mean apex force	BW	2.34 ± 0.17	2.29 ± 0.19	2.32 ± 0.15	2.24 ± 0.17	$.182_{13}$
Peak force	BW	2.68 ± 0.28	2.62 ± 0.29	2.64 ± 0.24	2.70 ± 0.27	-
Gate passing	%	51 ± 3	51 ± 3	54 ± 3	53 ± 2	$.031_{L}$ $.049_{R}$
Timing of apex	%	58 ± 6	61 ± 4	63 ± 4	67 ± 4	$.024_{L}$ $.003_{R}$ $.039_{10}$ $.013_{13}$
Gate to apex time	%	7 ± 6	11 ± 5	9 ± 1	14 ± 5	$.078_{R}$ $.042_{10}$ $.009_{13}$
Inside/outside SIR		0.59 ± 0.22	0.67 ± 0.13	0.54 ± 0.21	0.63 ± 0.14	$.077_{10}$ * $.096_{13}$ *
Inside/outside CR		1.72 ± 0.27	1.86 ± 0.27	1.16 ± 0.25	1.20 ± 0.23	$.0004_{L}$ * $.0003_{R}$ *
Chatter outside	N	15 ± 4	17 ± 4	16 ± 4	16 ± 3	-
Chatter inside	N	23 ± 7	24 ± 4	17 ± 5	17 ± 4	$.0006_{L}$ * $.001_{R}$ *

** A Two-way repeated measure ANOVA was used to determine significant differences between courses and/or turns directions. Unpaired t-tests were used on the rest of the kinetic variables in the group level.*

Table 5.2 shows that the unloading phase covered on average 38 % of the turn cycle in time. The unloading-loading duration ratio describes the duration of the phases and was calculated from unloading duration results, Table 5.1. The unloading-loading duration ratio was 37:63% with no significant differences between courses or turn directions.

Table 5.2 illustrates that there were no significant differences in the mean unloading force, which was in average 0.62 BW. The mean minimum force was 0.38 BW, with significantly less minimum force in the left turns on the 13 meter course than on the 10 meter course (p=.040).

Figure 5.1 shows the ensemble average force-time relationship on the 10 meter and the 13 meter courses for the main group. Turns to the left and to the right were both included in the graphs. Total of 270 turns on the 10 meter course and 228 turns on the 13 meter course were analysed. Figure 5.1 show the differences between the courses; delayed gate passing and timing of the apex on the 13 meter course. Due to the great subject-specific results, none of the individual skier's ensemble average force-time relation graphs appear to exactly match these graphs. For ensemble average graphs for each subject and for further details, see appendices for single-subject results (Appendix I).

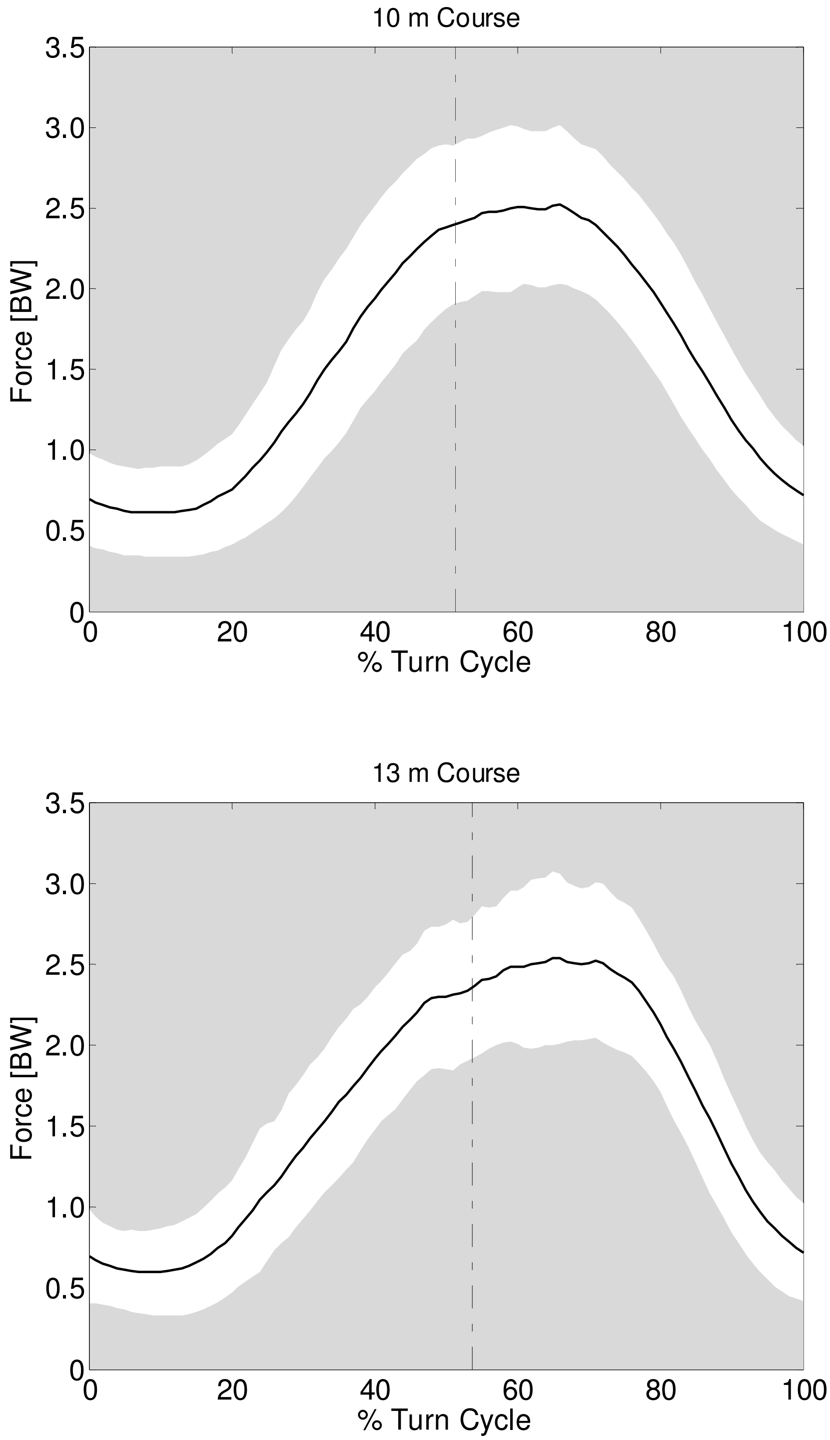


Figure 5.1: The ensemble average force-time relation for the main group in the 10 meter (upper graph), n= 270 turns and the 13 meter courses (lower graph), n = 228 turns related to the mean body weight. The vertical dashed line reflects the gate passing.

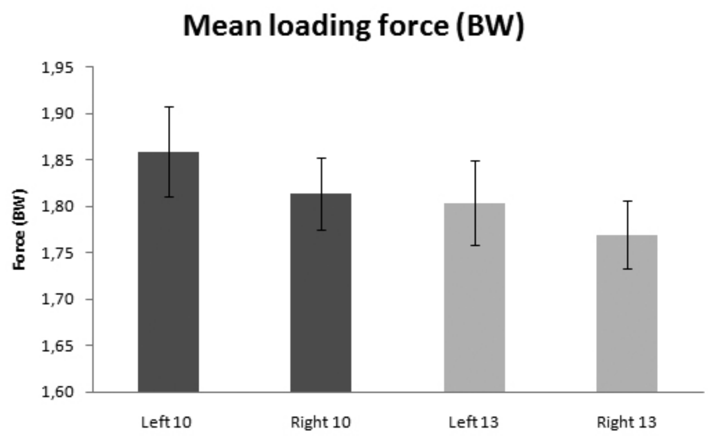


Figure 5.2: The mean relative loading force, means and standard error of means (SEM), n=9.

A considerable amount of loading was evident in both courses; the mean loading force was 1.81 ± 0.13 BW. In the turns to the left on the 13 meter course, the force was higher, Table 5.1 and Figure 5.1. The mean apex force was considerable 2.30 ± 0.31 BW, and the peak force was 2.62 ± 0.37 BW.

Figure 5.3 shows a significantly delayed timing of the apex on the 13 meter course compared to the 10 meter course (p=.024 and p=.003 in left and right turns). Figure 5.3 illustrates delayed timing of apex in the right turns, compared to the left turns regardless of the course (p=.039 and p=.013 on 10 and 13 meter courses).

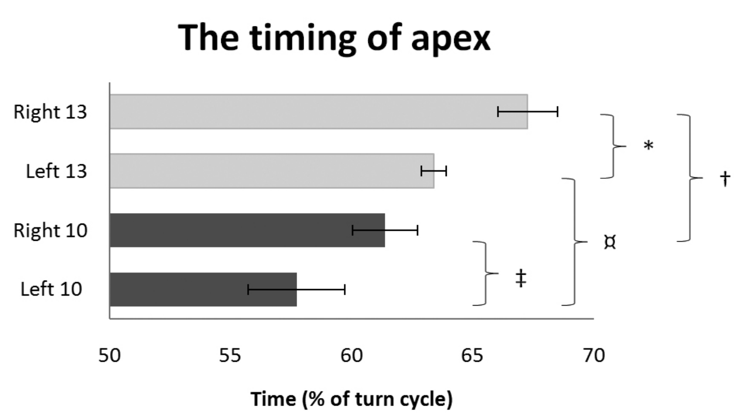


Figure 5.3: The timing of the apex as % of turn cycle. Means and SEM, n=9. ‡: p=.039 ¤: p=.024 *: p=.013 and †: p=.003.

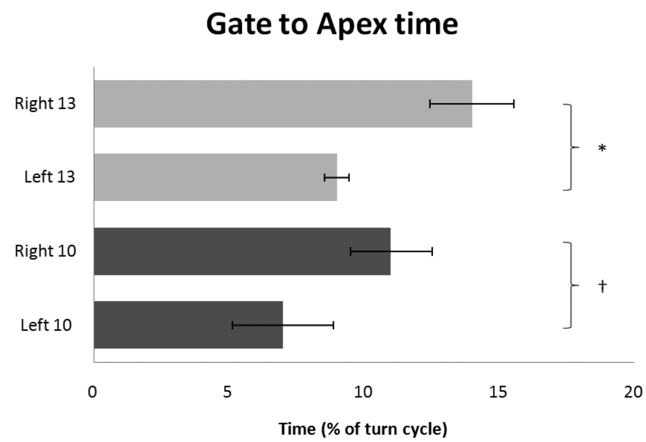


Figure 5.4: The means and SEM of gate to apex time as % of turn cycle, n=9.*: p=.009 and †: p=.042.

Table 5.2 shows that the time between the gate passing and mid-apex was approximately 7 to 11 % in the 10 meter and 9 to 14 % on the 13 meter course. Figure 5.4 illustrates a delay on the turns to the right in both courses (p=.042 and p=.009 for the 10 and the 13 meter courses respectively).

In general, skiers passed the gate at 52 % of the turn cycle in time. Figure 5.5 show that in both turn directions the gates were passed significantly later on the 13 meter course than on the 10 meter course (p=.005 and p=.037 for left and right turns, respectively).

The ratio of the inside to the outside ski impulse showed that a typical skier predominantly loaded the outside ski. The inside ski was in average loaded with a weight corresponding to half to two-thirds of the load on the outside ski. Table 5.2 and Figure 5.6 show a trend of a greater outside ski loading in the left turns (F=6.3 p=.077 and p=.096 for 10 and 13 meter courses, respectively).

Figure 5.7 indicate that the inside/outside SIR was subject-specific (the single-subject analysis and the discussion for more details). The figure illustrates the altering inside/outside ratios between the subjects. Some subjects predominantly loaded the outside ski in the turns to the left regardless of the course (SID 5,7,8,9,11), while others predominantly loaded the outside ski in the turns to the right (SID 3,4,10). One subject showed no difference between the turn directions (SID 6).

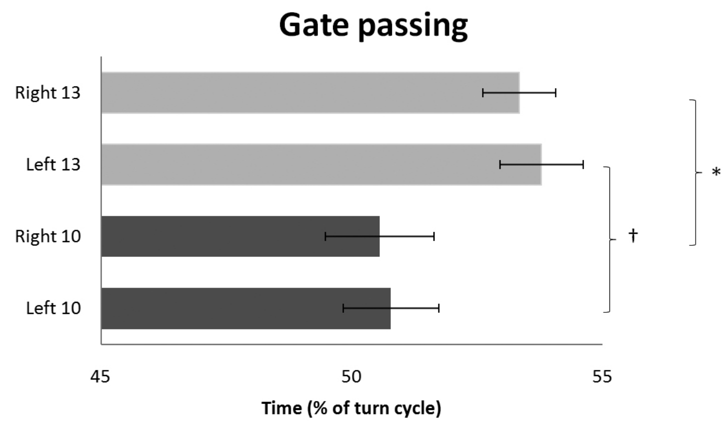


Figure 5.5: The mean gate passing for the two courses and the turn directions, mean and SEM, n=9.*: p=.049 †: p=.031.

The rapid changes in the force presented as the mean residuals, showed a significantly greater amplitude of the inside ski chatter than the outside ski on the 10 meter course, Table 5.2. Figure 5.9 shows that the mean amplitude of the outside ski chatter was alike regardless of the courses or the turn directions, while the inside ski chatter was significantly higher in both turn directions in the 10 meter than on the 13 meter course ($F = 51.8$ with $p<.001$ for left turns and $p<.006$ for right turns).

Figure 5.8 demonstrates the individual variability of the inside and the outside ski chatter.

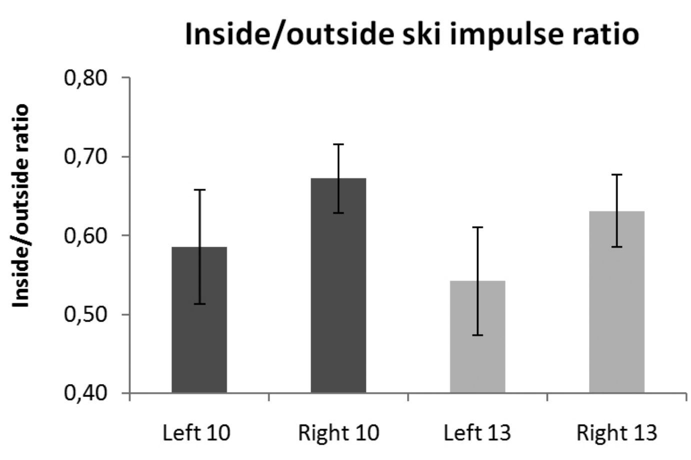


Figure 5.6: The inside/outside SIR, means and SEM, n=9.

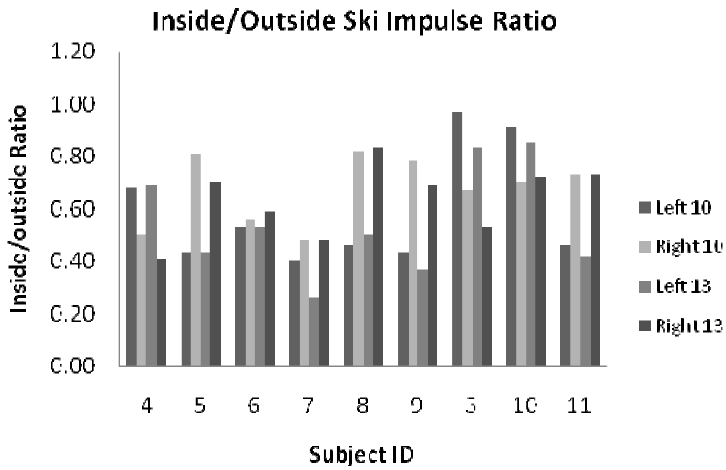


Figure 5.7: The inside/outside SIR in both turn directions and courses, n=9.

Figure 5.8 shows that the mean residuals showed a large variability between the courses and the between the subjects (inter-individual variability). The figure shows that the outside ski chatters were smaller than the inside ski chatters for almost all subjects. Some intra-individual variability was evident, for example SID 3, while subject 5 showed consistent magnitude of the mean residuals of the outside ski on the 10 and 13 meter courses and the inside chatter of the 10 meter course and larger mean residuals at the 13 meter course.

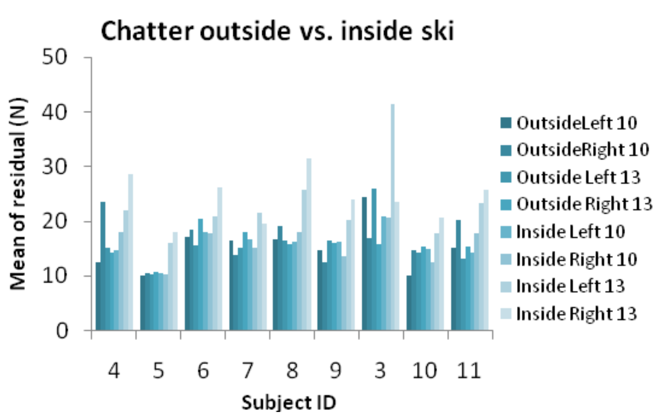


Figure 5.8: The individual inside and outside ski chatter in the left and right turns in the two courses.

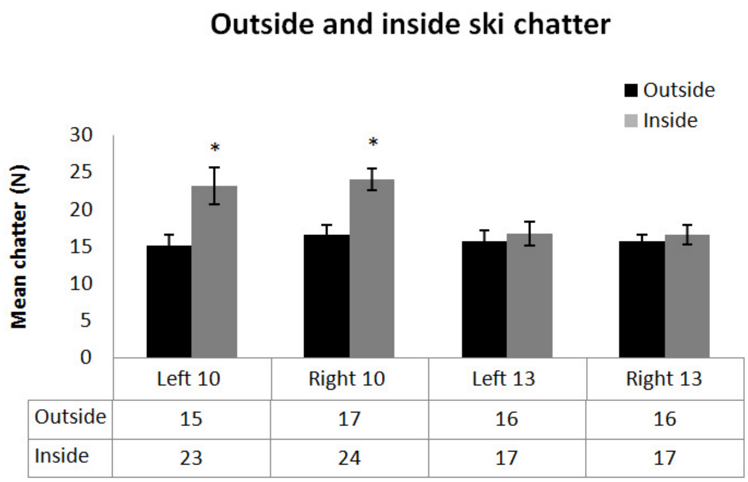


Figure 5.9: The mean amplitude of the outside and the inside chatter. Means and SEM, a two-way repeated measures, n=9.*: p=.0006 and †: p=.001.

Figure 5.9 illustrates the ratio of the inside to the outside ski chatter. The ratio was significantly larger in the left and right turns on the 10 meter course compared to the 13 meter course.

Figure 5.10 shows that inside/outside CR was significantly higher on the 10 meter course (both turn directions) than on the 13 meter course (F= 78.7, p=.0004$_L$ and .0003$_R$).

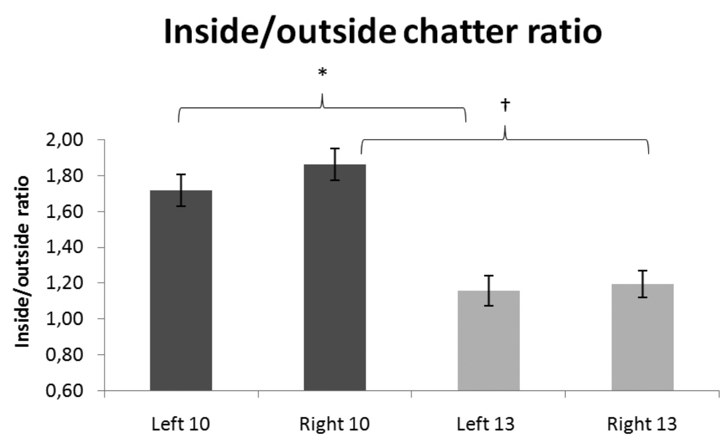


Figure 5.10: The inside/outside CR with means and SEM, n=9.*: p=.0004 †: p=.0003.

5.1.3 The correlation

One of the main findings was the absence of the relationships between the chatter and the inside/outside ski impulse ratio as well as the relationships between the ability level and the chatter or inside/outside SIR. The second finding was that the inside/outside SIR was not correlated with the ability level (FIS ranking) (r=-.433 p=.28 n=9 on the 10 meter course and r=-.384 p=.347 n=9 on the 13 meter course).

Correlation between the inside/outside SIR and trial times was not considered justified because the testing was conducted over 3 days which was likely to affect the external factors such as course condition. A weak relationship was found between the mean trial times and inside/outside SIR. The relationship was based on 8 subjects due to a subject's outlier values of the inside/outside SIR. The outlier which was excluded from the correlation analysis (a subject with the inside/outside ratio of 0.40 and 0.37) should have fallen beyond 3 standard deviations away from the mean in order to be justifiably discarded (Portney & Watkins, 2008). In both courses the outliers fell within the ± 3 standard deviation limit (-1.7 and -1.9 SD). This finding must be evaluated carefully, since the discarded "outlier" fell within the recommended 3 SD limit. Including the inside/outside SIR information could distort the relationship, while exclusion of the information could indicate relationship which may or may not be true. Considering all the above mentioned factors and factors influencing the performance (ski-snow friction, motivation, equipment, strategy, and training) it would be speculative to conclude that the more one loads the outside ski, the faster one skis.

5.1.4 The variability

The relative magnitude of the variability of the kinetic variables in the present study was assessed with a calculation of the coefficient of variation. The coefficient of variation assessed the response stability across repeated trials (Portney & Watkins, 2009) and was a sign of the extent of the measurement error. The results presented in the Table 5.3 show that the mean unloading, the mean loading, the mean apex, and even the peak force were reproduced steadily. In a similar manner the timing of apex and gate passing were stable measures of the temporal characteristics. The gate to apex, the inside/outside SIR, and the chatter variables were reproduced in a less stable manner.

Table 5.3: Coefficient of variation (CV) for the kinetic variables.

Kinetic variable	Coefficient of variation (CV) (%)
Mean unloading force (BW)	1
Min unloading force (BW)	17
Unloading duration (%)	21
Mean loading force (BW)	7
Mean apex force (BW)	7
Peak Force (BW)	10
Timing of apex (%)	6
Gate to apex time (%)	41
Gate passing (%)	5
Inside/outside SIR	29
Chatter outside (N)	17
Chatter inside (N)	23
Inside/Outside CR	25

5.1.5 Single-subject results per kinetic variable

The single-subject results for each kinetic variable are presented in the following part of the results chapter. The aim of presenting results per variable was to demonstrate the range and the direction of the individual values of the kinetic variables and to illustrate the variability within and between the individual sets of scores. See appendices for single-subject results per subject (Appendix I).

5.1.5.1 The mean unloading force

Table 5.4: The mean unloading force (BW) means ± SD, unpaired t-tests.

Mean unloading	10 meter course		13 meter course		
force (BW)	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	0.78 ± 0.08	0.71 ± 0.27	0.75 ± 0.05	0.76 ± 0.08	-
2	0.58 ± 0.07	0.60 ± 0.07	0.56 ± 0.06	0.58 ± 0.08	-
3	0.60 ± 0.07	0.67 ± 0.06	0.55 ± 0.08	0.62 ± 0.07	$.093_{L}$ $.062_{R}$ $.006_{10}$ $.020_{13}$
4	0.50 ± 0.03	0.52 ± 0.07	0.45 ± 0.08	0.48 ± 0.03	$.079_{L}$
5	0.55 ± 0.08	0.51 ± 0.05	0.57 ± 0.05	0.54 ± 0.05	$.158_{R}$
6	0.60 ± 0.09	0.60 ± 0.12	0.55 ± 0.18	0.59 ± 0.21	-
7	0.67 ± 0.11	0.65 ± 0.06	0.67 ± 0.05	0.67 ± 0.09	-
8	0.47 ± 0.09	0.56 ± 0.07	0.52 ± 0.10	0.62 ± 0.10	$.12_{L}$ $.073_{R}$ $.004_{10}$ $.017_{13}$
9	0.78 ± 0.10	0.77 ± 0.11	0.69 ± 0.08	0.71 ± 0.07	$.009_{L}$ $.094_{R}$
10	0.73 ± 0.05	0.70 ± 0.04	0.68 ± 0.05	0.63 ± 0.07	$.012_{L}$ $.005_{R}$ $.086_{10}$ $.031_{13}$
11	0.66 ± 0.15	0.77 ± 0.10	0.64 ± 0.07	0.67 ± 0.11	$.019_{R}$ $.021_{10}$

The individual results for the mean unloading force are presented in Table 5.4 for the left and right turns in both courses. Two out of nine subjects had significantly more unloading force on the 10 meter course, and three out of eleven had significantly more force in the right turns. The range of the mean unloading force score was 0.45 BW to 0.78 BW. The mean variability for the main group was 0.09 BW; the range of individual SD scores was 0.03 to 0.21 BW, indicating that some scores are more variable than others around the mean. Despite the individual variability, all scores fell within 3 SD which was set as cut off value for data outliers.

5.1.5.2 The minimum unloading force

The individual results for the minimum unloading force are presented in Table 5.5 for turns to the left and to the right in both courses. Three out of nine subjects had significantly more minimum unloading force on the 10 meter course, and two out of nine subjects had significantly more force in turns to the right, while one subject had significantly more minimum unloading force in the left turns.

There was a spread of the mean scores in the minimum unloading forces compared to the mean unloading forces; the range of minimum force scores was 0.15 BW to 0.72 BW. The mean SD was 0.11 BW and the range was 0.03 BW to 0.20 BW. The mean scores show a variability between the subjects, one outlier score was found (0.72). The minimum unloading force represented means of the minimum values that the Pedar system detected; variability was therefore expected due to the low sampling frequency.

Table 5.5: The minimum force (BW), means ± SD, unpaired t-tests.

Min unloading	10 meter course		13 meter course		
force (BW)	Left	Right	Left	Right	Unpaired t-tests
Subject	Mean ± SD				(p)
1	0.58 ± 0.13	0.62 ± 0.14	0.53 ± 0.08	0.57 ± 0.12	-
2	0.31 ± 0.10	0.36 ± 0.11	0.30 ± 0.08	0.33 ± 0.09	$.14_{13}$
3	0.31 ± 0.04	0.44 ± 0.09	0.28 ± 0.07	0.40 ± 0.09	$.00005_{10}$ $.001_{13}$
4	0.25 ± 0.04	0.23 ± 0.06	0.15 ± 0.05	0.15 ± 0.05	$.002_{L}$ $.03_{R}$
5	0.30 ± 0.07	0.26 ± 0.04	0.29 ± 0.03	0.27 ± 0.07	-
6	0.32 ± 0.14	0.33 ± 0.12	0.34 ± 0.14	0.40 ± 0.16	$.18_{R}$
7	0.46 ± 0.16	0.42 ± 0.10	0.42 ± 0.07	0.44 ± 0.09	-
8	0.16 ± 0.09	0.28 ± 0.09	0.18 ± 0.10	0.34 ± 0.16	$.20_{R}$ $.002_{10}$ $.003_{13}$
9	0.72 ± 0.17	0.70 ± 0.20	0.59 ± 0.12	0.57 ± 0.10	$.02_{L}$ $.02_{R}$
10	0.59 ± 0.05	0.49 ± 0.07	0.50 ± 0.07	0.42 ± 0.11	$.0004_{L}$ $.06_{R}$ $.0002_{10}$ $.03_{13}$
11	0.40 ± 0.15	0.51 ± 0.19	0.37 ± 0.11	0.42 ± 0.14	$.12_{R}$ $.07_{10}$

5.1.5.3 The unloading duration

Table 5.6: The unloading duration (% of turn cycle in time), means ± SD, unpaired t-tests.

Unloading duration	10 meter course		13 meter course		
(%)	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	24 ± 7	24 ± 3	33 ± 5	31 ± 5	$.033_{L}$ $.008_{R}$
2	40 ± 4	40 ± 7	38 ± 6	38 ± 6	$.19_{L}$
3	38 ± 4	36 ± 5	38 ± 3	31 ± 6	$.023_{R}$ $.001_{13}$
4	46 ± 3	47 ± 3	46 ± 6	46 ± 8	-
5	46 ± 4	45 ± 6	43 ± 6	46 ± 6	$.18_{13}$
6	38 ± 11	39 ± 11	38 ± 9	37 ± 9	-
7	36 ± 9	39 ± 5	32 ± 9	33 ± 8	$.022_{R}$
8	43 ± 4	46 ± 4	38 ± 7	37 ± 8	$.02_{L}$ $.001_{R}$ $.067_{10}$
9	29 ± 8	26 ± 8	31 ± 6	31 ± 5	$.059_{R}$
10	34 ± 4	37 ± 6	33 ± 6	32 ± 8	$.052_{R}$ $.043_{10}$
11	32 ± 8	30 ± 15	32 ± 8	34 ± 10	-

Table 5.6 presents the unloading duration for all subjects. Some subjects had longer duration in the left turns, while others had longer duration in the right turns; therefore no trend was found supporting either turn direction. Similar variation was evident regarding the courses; some subjects had a longer duration of the unloading phase on the 10 meter course, while others had a longer duration on the 13 meter course.

The mean unloading duration of 37 % of the turn cycle in time was calculated. The SD was 6 % for the main group. The range of mean scores was 26 to 47 % of the turn cycle in time. The range of individual SD scores was 3 to 15 % of the turn cycle in time, indicating variability around the mean scores. No outlier scores were found.

5.1.5.4 The mean loading force

The mean loading force is presented in the Table 5.7. The individual significant differences found between the turn directions and the course showed no consistent trend for specific course or turn direction.

The mean loading force for the main group was 1.81 BW. The range of mean loading force scores was 1.55 to 2.06 BW. The mean standard deviation was 0.13 BW; the range of individual scores was 0.05 to 0.24 BW, demonstrating individual variability around the means. No outlier scores were found.

Table 5.7: The mean loading force (BW), means ± SD and unpaired t-tests.

Mean loading force (BW)	10 meter course		13 meter course		
	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	2.19 ± 0.12	2.08 ± 0.09	2.15 ± 0.06	2.35 ± 0.07	$.018_{L}$ $.0001_{R}$ $.0001_{10}$ $.018_{13}$
2	1.94 ± 0.10	1.96 ± 0.09	2.06 ± 0.07	2.03 ± 0.14	$.001_{L}$ $.15_{R}$
3	2.02 ± 0.17	1.96 ± 0.14	1.85 ± 0.12	1.87 ± 0.11	$.005_{L}$ $.056_{R}$
4	1.82 ± 0.07	1.73 ± 0.10	1.82 ± 0.11	1.55 ± 0.10	$.007_{R}$ $.032_{10}$ $.004_{13}$
5	1.74 ± 0.05	1.65 ± 0.05	1.65 ± 0.11	1.68 ± 0.09	$.019_{L}$ $.002_{10}$
6	1.77 ± 0.23	1.73 ± 0.14	1.73 ± 0.10	1.71 ± 0.12	-
7	1.79 ± 0.18	1.67 ± 0.20	1.78 ± 0.11	1.79 ± 0.18	$.09_{R}$ $.111_{10}$
8	1.83 ± 0.11	1.71 ± 0.14	1.80 ± 0.12	1.69 ± 0.11	$.20_{R}$ $.014_{13}$
9	2.06 ± 0.13	2.05 ± 0.08	2.02 ± 0.11	1.98 ± 0.09	$.042_{R}$
10	1.77 ± 0.06	1.86 ± 0.24	1.70 ± 0.07	1.73 ± 0.10	$.014_{L}$ $.09_{R}$ $.17_{10}$
11	1.93 ± 0.14	1.96 ± 0.17	1.89 ± 0.15	1.93 ± 0.12	-

5.1.5.5 The mean apex force

Table 5.8 presents the mean apex force for all subjects. Significant differences were found, while the direction of the difference was inconsistent; some subjects showed a larger mean apex force in the right turns while others showed a larger force in the left turns, and some subjects showed a larger mean apex force on the 10 meter course while others showed the larger mean apex force on the 13 meter course.

The mean apex force for the main group was 2.30 BW and the range of individual scores was 1.85 to 2.79 BW. The mean SD was 0.17 BW and the range was 0.09 to 0.29 BW, showing a variability of the mean apex force scores around the individual means. No outliers were found.

Table 5.8: The mean apex force (BW), means ± SD, unpaired t-tests.

Mean apex force (BW)	10 meter course		13 meter course		
	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	3.01 ± 0.18	2.86 ± 0.14	3.01 ± 0.16	3.32 ± 0.16	$.001_{R}$ $.003_{10}$ $.015_{13}$
2	2.39 ± 0.10	2.47 ± 0.18	2.53 ± 0.13	2.53 ± 0.21	$.002_{L}$ $.14_{10}$
3	2.57 ± 0.18	2.50 ± 0.23	2.40 ± 0.20	2.38 ± 0.20	$.023_{L}$ $.124_{R}$
4	2.24 ± 0.16	2.16 ± 0.19	2.22 ± 0.09	1.85 ± 0.14	$.008_{R}$ $.001_{13}$
5	2.08 ± 0.11	2.03 ± 0.09	2.06 ± 0.15	2.08 ± 0.13	-
6	2.15 ± 0.27	2.14 ± 0.23	2.23 ± 0.19	2.17 ± 0.16	-
7	2.20 ± 0.18	2.05 ± 0.17	2.40 ± 0.09	2.27 ± 0.19	$.001_{L}$ $.003_{R}$ $.03_{10}$ $.019_{13}$
8	2.35 ± 0.13	2.10 ± 0.22	2.28 ± 0.17	2.10 ± 0.18	$.006_{10}$ $.008_{13}$
9	2.79 ± 0.21	2.77 ± 0.22	2.70 ± 0.09	2.57 ± 0.17	$.13_{L}$ $.009_{R}$ $.011_{13}$
10	2.23 ± 0.10	2.23 ± 0.09	2.08 ± 0.12	2.20 ± 0.14	$.004_{L}$ $.034_{13}$
11	2.49 ± 0.19	2.66 ± 0.28	2.49 ± 0.29	2.58 ± 0.19	$.065_{10}$

5.1.5.6 The peak force

Table 5.9: The peak force (BW), means ± SD, unpaired t-tests.

Peak Force (BW) Subject	10 meter course Left	10 meter course Right	13 meter course Left	13 meter course Right	Unpaired t-tests (p)
		Mean ± SD			
1	3.11 ± 0.19	3.00 ± 0.16	3.15 ± 0.21	3.52 ± 0.25	$.005_R$ $.035_{13}$
2	2.55 ± 0.12	2.75 ± 0.41	2.66 ± 0.17	2.77 ± 0.27	$.054_L$ $.084_{10}$ $.194_{13}$
3	3.12 ± 0.38	2.73 ± 0.28	2.90 ± 0.28	2.69 ± 0.26	$.073_L$ $.003_{10}$ $.044_{13}$
4	2.49 ± 0.22	2.66 ± 0.31	2.46 ± 0.10	2.11 ± 0.39	$.011_R$ $.166_{10}$ $.092_{13}$
5	2.36 ± 0.18	2.24 ± 0.27	2.29 ± 0.29	2.25 ± 0.15	-
6	2.44 ± 0.36	2.43 ± 0.31	2.44 ± 0.22	2.47 ± 0.16	-
7	2.55 ± 0.39	2.18 ± 0.20	2.66 ± 0.18	2.66 ± 0.27	$.0001_R$ $.027_{10}$
8	2.74 ± 0.23	2.54 ± 0.27	2.65 ± 0.32	2.51 ± 0.27	$.074_{10}$
9	3.04 ± 0.27	3.16 ± 0.22	3.12 ± 0.09	3.04 ± 0.17	-
10	2.49 ± 0.17	2.51 ± 0.15	2.37 ± 0.20	2.60 ± 0.25	$.176_R$ $.035_{13}$
11	2.89 ± 0.33	3.17 ± 0.46	2.89 ± 0.33	2.87 ± 0.31	$.063_R$ $.062_{10}$

Table 5.9 presents the peak force for all subjects. Significant differences were found between the turn directions and the courses; the trend of the direction was inconsistent.

The mean peak force for the main group was 2.62 BW and the range of individual peak force scores was 2.11 to 3.17 BW. The mean SD was 0.27 and the range of individual SD scores was 0.15 to 0.46 BW, indicating large variability in the individual scores around the mean scores. No outliers were found.

The peak force represents means of the maximum values that the Pedar system detected; variability was therefore expected due to the low sampling frequency, consistent with the minimum unloading force.

5.1.5.7 The timing of the apex

Table 5.10 presents the timing of the apex. For three subjects on the 10 meter course, the right turns had significantly delayed timing of the apex. On the 13 meter course, the significantly delayed right turns were evident in three subjects as well. Five subjects had a significantly delayed right turns on the 13 meter course compared to the 10 meter course. Three subjects had significantly delayed left turns on the 13 meter course compared to the 10 meter course.

Table 5.10: The timing of the apex (% of turn cycle in time), means ± SD, unpaired t-tests.

Timing of apex (%) Subject	10 meter course Left	Right	13 meter course Left	Right	Unpaired t-tests (p)
		Mean ± SD			
1	67 ± 3	62 ± 8	71 ± 3	72 ± 3	$.036_L$ $.015_R$ $.11_{10}$
2	60 ± 8	58 ± 7	68 ± 7	59 ± 9	$.003_L$ $.003_{13}$
3	56 ± 7	57 ± 7	61 ± 9	61 ± 9	$.096_L$ $.19_R$
4	54 ± 10	63 ± 7	63 ± 13	68 ± 6	$.17_L$ $.027_{10}$
5	47 ± 12	55 ± 10	65 ± 8	66 ± 6	$.0001_L$ $.001_R$ $.11_{10}$
6	52 ± 11	60 ± 8	62 ± 8	67 ± 6	$.009_L$ $.011_R$ $.024_{10}$ $.051_{13}$
7	60 ± 6	67 ± 7	63 ± 10	65 ± 9	$.005_{10}$
8	65 ± 12	62 ± 12	65 ± 10	72 ± 9	$.012_R$ $.045_{13}$
9	58 ± 8	58 ± 10	65 ± 9	65 ± 6	$.033_L$ $.051_R$
10	63 ± 7	65 ± 8	62 ± 9	73 ± 7	$.006_R$ $.001_{13}$
11	64 ± 7	64 ± 7	64 ± 10	69 ± 6	$.094_R$

The mean timing of the apex for the main group was 62 % of the turn cycle and the range was 47 to 73 % of the turn cycle in time. The mean SD was 8 % of the turn cycle, and the range was 6 to 13 % of the turn cycle in time. No outliers were found.

5.1.5.8 The time from the gate to the apex

Table 5.11 shows that four out of nine subjects had significantly later timing of the gate to the apex-time in the right turns compared to the left turns on the 10 meter course. Also, two out of nine had significantly later timing of gate to apex in right turns compared to the left turns on the 13 meter course. Two out of nine subjects had a significantly later timing of the gate to the apex in the left turns on the 13 meter course compared to the 10 meter course. Three subjects had significantly later timing of the gate to apex in the right turns on the 13 meter course compared to the 10 meter course. A trend was clear; right turns in both 10 meter and 13 meter course had a delay, which was also evident between the courses.

The mean gate to apex time for the main group was 10 % of the turn cycle in time. The range in the main group was -4 to 22 % of the turn cycle in time. The mean SD was 4 % of the turn cycle in time and the range was 4 to 12 % of the turn cycle in time. A great variability between the individuals was evident. The mean gate to apex time score -4 % of the turn cycle in time fell above the 3 SD cut off (-3.5).

Table 5.11: Time from the gate to the apex (% of turn cycle), means ± SD, unpaired t-tests.

Gate to apex time	10 meter course		13 meter course		
(%)	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	23 ± 4	18 ± 6	18 ± 4	19 ± 2	$.031_{L}$ $.10_{10}$
2	15 ± 8	12 ± 6	21 ± 8	11 ± 9	$.046_{L}$ $.003_{13}$
3	8 ± 8	8 ± 4	9 ± 8	7 ± 9	-
4	8 ± 8	19 ± 7	8 ± 9	15 ± 5	$.003_{10}$
5	-4 ± 10	5 ± 9	9 ± 8	11 ± 5	$.002_{L}$ $.05_{R}$ $.054_{10}$
6	3 ± 9	11 ± 8	9 ± 6	15 ± 10	$.027_{L}$ $.20_{R}$ $.018_{10}$ $.071_{13}$
7	6 ± 6	13 ± 8	7 ± 10	11 ± 8	$.024_{10}$
8	14 ± 9	10 ± 12	12 ± 9	19 ± 11	$.046_{R}$ $.061_{13}$
9	4 ± 7	6 ± 8	9 ± 10	10 ± 8	$.15_{L}$
10	14 ± 5	16 ± 8	10 ± 8	22 ± 8	$.14_{L}$ $.043_{R}$ $.0004_{13}$
11	9 ± 6	10 ± 8	9 ± 8	14 ± 8	$.083_{13}$

5.1.5.9 The gate passing

Table 5.12 shows the gate passing as % of turn cycle in time for all subjects. It was noticeable that four out of nine subjects had significantly later gate passing on the 13 meter course than on the 10 meter course.

The mean gate passing was at 52 % of the turn cycle in time. The range was 44 to 56 % of the turn cycle in time. The mean SD was 5 and the range was 3 to 15 % of the turn cycle in time. Except for one subject (subject 6 at the 13 meter course), the individual variability was low. No outliers were found.

Table 5.12: The gate passing (% of turn cycle in time), means ± SD, unpaired t-tests.

Gate passing	10 meter course		13 meter course		
(%)	Left	Right	Left	Right	Unpaired t-tests
Subject		Mean ± SD			(p)
1	44 ± 14	44 ± 2	53 ± 2	53 ± 2	$.000001_{L}$ $.00001_{R}$
2	45 ± 3	45 ± 4	48 ± 3	48 ± 3	$.035_{L}$ $.031_{R}$
3	49 ± 5	49 ± 5	52 ± 5	54 ± 6	$.044_{L}$ $.026_{R}$
4	46 ± 4	44 ± 3	54 ± 5	53 ± 3	$.006_{L}$ $.001_{R}$
5	51 ± 3	50 ± 3	56 ± 4	56 ± 5	$.004_{L}$ $.007_{R}$
6	49 ± 3	50 ± 3	49 ± 15	49 ± 14	-
7	54 ± 4	55 ± 5	56 ± 5	54 ± 4	-
8	51 ± 4	52 ± 5	53 ± 3	53 ± 4	$.14_{L}$
9	53 ± 4	52 ± 4	56 ± 6	55 ± 5	$.092_{R}$
10	49 ± 3	49 ± 3	52 ± 5	51 ± 5	$.012_{L}$
11	55 ± 3	54 ± 4	56 ± 4	55 ± 4	-

5.1.5.10 The inside/outside ski impulse ratio

Table 5.13: The inside/outside SIR, means ± SD and paired t-tests.

Inside/outside SIR	10 meter course		13 meter course		
	Left	Right	Left	Right	Paired t-tests
Subject	Mean ± SD				(p)
1	0.75 ± 0.23	1.10 ± 0.29	0.60 ± 0.09	0.86 ± 0.13	$.065_L$ $.062_R$ $.048_{10}$ $.01_{13}$
2	0.69 ± 0.31	0.59 ± 0.15	0.43 ± 0.15	0.57 ± 0.18	$.009_L$ $.14_{10}$ $.039_{13}$
3	0.97 ± 0.12	0.67 ± 0.17	0.83 ± 0.15	0.53 ± 0.18	$.013_L$ $.009_R$ $.0008_{10}$ $.0007_{13}$
4	0.68 ± 0.20	0.50 ± 0.12	0.69 ± 0.22	0.41 ± 0.18	$.18_R$ $.021_{10}$ $.073_{13}$
5	0.43 ± 0.13	0.81 ± 0.18	0.43 ± 0.17	0.70 ± 0.19	$.15_R$ $.0003_{10}$ $.0002_{13}$
6	0.53 ± 0.19	0.56 ± 0.16	0.53 ± 0.19	0.59 ± 0.13	$.18_{13}$
7	0.40 ± 0.18	0.48 ± 0.15	0.26 ± 0.11	0.48 ± 0.10	$.007_L$ $.12_{10}$ $.0002_{13}$
8	0.46 ± 0.23	0.82 ± 0.19	0.50 ± 0.17	0.83 ± 0.17	$.001_{10}$ $.0002_{13}$
9	0.43 ± 0.09	0.78 ± 0.19	0.37 ± 0.06	0.69 ± 0.11	$.041_L$ $.044_R$ $.0001_{10}$ $.0000005_{13}$
10	0.91 ± 0.19	0.70 ± 0.11	0.85 ± 0.15	0.72 ± 0.07	$.0006_{10}$ $.012_{13}$
11	0.46 ± 0.08	0.73 ± 0.15	0.42 ± 0.13	0.73 ± 0.18	$.12_L$ $.00006_{10}$ $.0001_{13}$

Table 5.13 shows the inside/outside SIR for all subjects. There was a clear trend of significant turn direction differences in the loading ratio. Three subjects had higher degree of the outside ski loading in the left turns on the 13 meter course than on the 10 meter course. One subject had a higher degree of the outside ski loading in the right turns on the 13 meter course than on the 10 meter course. Three subjects had a significantly higher degree of the outside ski loading in the right turns compared to the left turns, and 4 subjects had a significantly higher degree of the outside ski loading in the left turns compared to the right turns on the 10 meter course. Two subjects had a significantly higher outside ski loading in the right turns compared to the left turns, and five subjects had a significantly higher degree of the outside ski loading in the left turns compared to the right turns on the 10 meter course. The mean inside/outside SIR for the main group was 0.61 and the range was 0.26 to 0.97. The mean SD of the inside/outside SIR was 0.17 and the range was 0.07 to 0.23. No outlier scores were found.

5.1.5.11 The chatter of the outside ski

Table 5.14 shows the chatter of the outside ski for all subjects. Two subjects had significantly more outside ski chatter on the 10 meter course than on the 13 meter course, one subject had more outside ski chatter in the right turns, and the other in the left turns. Two subjects had more outside ski chatter in the right turns than in the left turns on the 10 meter course, while one subject had more outside ski chatter in the left turns compared to the right turns.

Table 5.14: The chatter of the outside ski (N), means ± SD and unpaired t-tests.

Chatter outside ski (N)	10 meter course		13 meter course		Unpaired t-tests
	Left	Right	Left	Right	
Subject	Mean ± SD				(p)
1	6 ± 2	6 ± 2	7 ± 1	7 ± 2	$.12_L$
2	8 ± 2	13 ± 3	11 ± 2	14 ± 3	$.002_L$ $.0001_{10}$ $.004_{13}$
3	24 ± 11	17 ± 6	26 ± 10	16 ± 8	$.03_{10}$ $.005_{13}$
4	12 ± 6	23 ± 20	15 ± 10	14 ± 14	$.11_{10}$
5	10 ± 2	10 ± 8	10 ± 3	11 ± 3	-
6	17 ± 6	18 ± 10	15 ± 3	20 ± 7	$.031_{13}$
7	16 ± 10	14 ± 6	15 ± 6	18 ± 7	$.10_L$
8	17 ± 8	19 ± 15	16 ± 6	16 ± 6	-
9	15 ± 3	12 ± 4	16 ± 4	16 ± 6	$.06_R$ $.15_{10}$
10	10 ± 3	15 ± 8	14 ± 4	15 ± 4	$.004_L$ $.044_{10}$
11	15 ± 8	20 ± 14	13 ± 7	15 ± 6	-

On the 13 meter course, two subjects had significantly more outside ski chatter in the right turns compared to the left turns and one had significantly higher outside ski chatter in the left turns compared to the right turns. The mean chatter of the outside ski was 16 N and the range was from 10 to 26 N. The mean SD was 4 N and the range was 2 to 20 N. There was a high degree of individual variability in the chatter of the outside ski. No outlier scores were found.

5.1.5.12 The chatter of the inside ski

Table 5.15 presents the chatter of the inside ski for all subjects. A great deal of variation was evident. Five subjects showed a significantly higher amount of inside ski chatter in the left turns on the 10 meter course compared to the 13 meter course. Five subject showed also a significantly higher amount of the inside ski chatter in the right turns on the 10 meter course compared to the 13 meter course.

Table 5.15: The chatter of the inside ski (N), means ± SD and unpaired t-tests.

Chatter inside ski (N)	10 meter course		13 meter course		Unpaired t-tests
	Left	Right	Left	Right	
Subject	Mean ± SD				(p)
1	6 ± 2	7 ± 2	6 ± 3	5 ± 1	$.007_R$
2	15 ± 7	19 ± 9	8 ± 2	10 ± 4	$.0003_L$ $.001_R$ $.061_{13}$
3	41 ± 12	23 ± 6	24 ± 12	19 ± 7	$.0005_L$ $.067_R$ $.00002_{10}$ $.16_{13}$
4	22 ± 7	23 ± 20	18 ± 10	13 ± 6	$.0003_R$ $.033_{10}$
5	16 ± 7	18 ± 6	12 ± 6	10 ± 3	$.12_L$ $.0001_R$
6	21 ± 9	26 ± 10	12 ± 4	16 ± 3	$.003_L$ $.001_R$ $.14_{10}$ $.011_{13}$
7	21 ± 13	20 ± 6	13 ± 4	16 ± 6	$.028_L$ $.13_R$ $.12_{13}$
8	26 ± 10	31 ± 13	22 ± 8	20 ± 6	$.005_R$ $.17_{10}$
9	20 ± 7	24 ± 10	21 ± 10	22 ± 6	-
10	18 ± 5	20 ± 5	13 ± 6	18 ± 6	$.029_L$ $.17_R$ $.19_{10}$ $.048_{13}$
11	23 ± 5	26 ± 8	16 ± 6	16 ± 4	$.001_L$ $.0002_R$

The mean inside ski chatter for the main group was 20 N and the range was 12 to 41 N. The mean SD for the inside ski chatter was 5 N and the range was 3 to 20 N, indicating a high degree of individual variability of the scores around the means of inside ski chatter. The inside ski chatter score of 41 N was found to fall beyond the 3 SD cut off limit from the mean.

5.1.5.13 The inside/outside chatter ratio

Table 5.16 shows the inside/outside chatter ratio for all subjects. Due to the greater inside ski chatter, the ratio was also found significantly greater on the 10 meter course for most of the subjects. Five subjects had a greater ratio in the right turns on the 10 meter course than on the 13 meter course, and four subjects had a greater ratio in the left turns on the 10 meter course than on the 13 meter course.

The mean inside/outside chatter ratio for the main group was 1.48 and the range was 0.80 to 2.31. The mean SD for the ratio was 0.64 and the range was 0.26 to 1.42, indicating a large individual variability of the scores around the means.
No outlier scores were found.

Table 5.16: The inside/outside chatter ratio, means ± SD and paired t-tests.

Inside/outside CR	10 meter course		13 meter course		
	Left	Right	Left	Right	Paired t-tests
Subject		Mean ± SD			(p)
1	1.20 ± 0.55	1.26 ± 0.23	0.88 ± 0.33	0.69 ± 0.17	.16L .03R
2	1.86 ± 0.85	1.48 ± 0.52	0.72 ± 0.20	0.73 ± 0.25	.0003L .0002R .1010
3	1.94 ± 0.72	1.46 ± 0.39	1.00 ± 0.47	1.34 ± 0.58	.001L .04910 .09613
4	2.14 ± 1.42	1.98 ± 1.25	1.28 ± 0.26	1.22 ± 0.56	.071L .035R
5	1.69 ± 0.91	2.31 ± 1.28	1.14 ± 0.43	0.97 ± 0.29	.14L .014R .1810 .1813
6	1.34 ± 0.64	1.70 ± 1.03	0.80 ± 0.34	0.86 ± 0.28	.027L .012R
7	1.41 ± 0.69	1.70 ± 0.90	0.96 ± 0.41	0.97 ± 0.37	.048L .016R
8	1.72 ± 0.89	2.03 ± 1.25	1.53 ± 0.86	1.44 ± 0.55	.12R
9	1.49 ± 0.73	2.11 ± 1.14	1.30 ± 0.55	1.54 ± 0.58	.10R .1413
10	1.86 ± 0.93	1.60 ± 0.48	0.95 ± 0.42	1.24 ± 0.57	.006L .11R .1913
11	1.89 ± 0.93	1.88 ± 1.22	1.46 ± 0.87	1.18 ± 0.62	.05R

6 Discussion

The aim of this study was to describe, quantify and analyze ground reaction forces during unloading and loading phases in two course conditions typical of competitive slalom skiing.

The results showed a highly subject-specific variability in the kinetic characteristics, indicating individual adaptations to the two courses and turn directions. The single subject approach used in this study show that subjects are different although some group relationships were also evident. Most of the group relationships were not significant, but are nevertheless of interest for the team coach and the subjects. It is not clear whether these individual adaptations are due to individual technical differences or random effects.

The results of the group analysis showed that the apex of the turn was delayed in turns to the right turns. Turn apex was also delayed on the 13 meter course compared to the 10 meter course for both turn directions. There was a trend of greater loading of the outside ski in turns to the left, although the difference was not statistically significant. The degree of the outside ski loading was highly subject-dependent. Finally, there was a greater degree of inside ski chatter on the 10 meter course.

6.1 Total ground reaction forces

6.1.1 The magnitude of ground reaction forces in slalom turns

The peak forces illustrated the sudden, fast changes in the force-time relationship. Although the peak values were reported in this study, the mean apex force better described the overall momentum changing forces acting on the subject, see methods p. 44. The magnitude of peak forces in the present study were about 2.6 BW, and are lower than both Klous et al. (2007) who reported 3.5 BW with Kistler force plates at a sampling frequency of 200 Hz in carved giant slalom turn, and Lafontaine et al. (1998) who reported 3.0 BW using plantar pressure measurement at a sampling frequency of 50 Hz during recreational skiing with short turn radii. The mean loading forces of 1.81 BW and a mean apex force of 2.3 BW are supported by previous studies which found mean forces in the steering phase of approximately 1500 N (Fauve et al. 2009, Lafontaine et al. 1998). Fauve estimated mean forces during giant slalom turns of 1317 N (or 1.7 BW based on an average skier weighing 88 kg) utilizing strain gauges at a sampling frequency of 200Hz on hard and soft snow.

In a kinematic study carried out by the research group from the Norwegian School of Sport Sciences, the mean peak of ground reaction forces were estimated to 3.3 BW on the 10 meter course and 3.5 BW on the 13 meter course, Figure 6.1. The minimum forces were 0.2 BW and 0.2 BW in the 10 and 13 meter courses respectively. The set up of the courses, the skiers' ability level and the slope gradient were all similar with the present study. The findings of the kinematic study are in a good agreement, although the maximum force was higher than in the present study regarding the magnitude and the temporal characteristics.

Unloading forces in the present study were; minimum 0.38 BW and mean unloading phase force 0.62 BW, which corresponded well with the minimum forces reported by Klous et al. (0.3-0.5 BW). The different method of estimation of the magnitude of ground reaction forces may explain some of the difference, for example the sampling frequency, and the definition of unloading phase. It was therefore not surprising that the minimum force in the present study was lower than in the study by Klous, as it is known that due to the boots' characteristics and the around 200 N error component of Pedar, the results of the present study probably are lower than what were the true ground reaction forces acting on the skier.

In agreement with the Vaverka & Vodickova (2009) study, in turns with the right-dominant-leg as the outside limb, we found a higher mean loading and mean apex force. The majority of the kinetic characteristics examined were not significantly different between the courses or turn directions at a group level although significant differences between courses and/or turn directions were evident for some individual skiers. The large variability between individuals in slalom turns was also confirmed by Vaverka & Vodickova (2009), who reasoned the large variability to the general requirements of slalom turns; the frequency of the turn connections (left and right repeated after each other), total duration of turns, radius of turning, speed of movement and all above mentioned factor in relation to the outer factors, such as inclination, and snow surface.

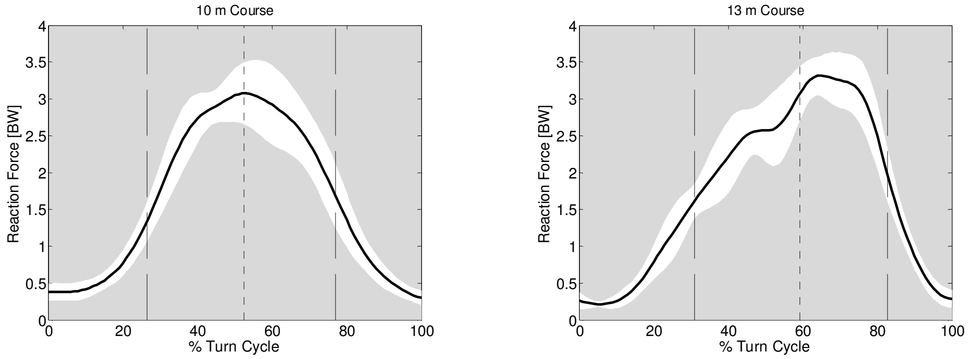


Figure 6.1: The ensemble averages (black line) and SDs (white area) of ground reaction forces for 10 meter (left) and 13 meter (right) courses based on a kinematic analysis. Graphs are based on 6 subjects, 2 turns each. Graphs published with permission from Reid, 2009.

6.1.2 Temporal characteristics of slalom turns

Timing of the apex was significantly delayed in right turns in both courses, and delayed on the 13 meter course compared to the 10 meter course. In addition, the gate passing (% of turn cycle in time) occurred later on the 13 meter course than on the 10 meter course. No significant differences in the gate passing were found between the turn directions.

A great example of the timing challenge on the 13 meter course can be seen with subject 5, see appendices for single-subject analysis (Appendix I) (Figure 9.20). The ensemble average force-time relationship is theoretically optimal on the 10 meter course, occurring at the gate passing (Reid and Johnsen[2], personal communication, 2009). In contrast, the force-time relationship of the 13 meter course showed that the timing of apex was delayed. A possible explanation for the delayed apex on the 13 meter course could be the tactical choices skiers face. Fast skiers may find it difficult to time the initiation perfectly when the gate distance is long and speeds are high (Johnsen, S., Personal communication, 2009. This explanation may be speculative, although in practice, it could aid the skier with initiation of the turns. Another possibility was that the difference in temporal characteristics was due to the nature of the two

[2] Johnsen, S., coach of the Edge Team.

courses. Figure 6.2 shows the ensemble average ski attack angles for both courses for the outside and inside skis from the Reid kinematic study. Judging based on these results; it is likely that a greater degree of skidding was required on the 10 m course in the present study. Therefore, the later timing of apex on the 13 meter course seen in this study could somehow be related to differences in the kinetic characteristics of the carving and skidded turns.

Figure 6.2 shows how in a 10 meter course, the angle of attack of the outside ski first increases, then decreased faster and closer to the gate passing than on the 13 meter course. The angle of the inside ski appeared to increase faster, and then decreased faster than the outside ski attack angle. The gate was passed at 53 % of the turn cycle in time on the 10 meter course and in 59 % on the 13 meter course, which in fact corresponds remarkably with the results from the present study. From the Figure 6.1 the apex of turn appeared to be delayed as it was determined undoubtedly slightly after the gate passing, while on the 13 meter course the trend appeared to be a delay of the apex relative to the gate passing.

Another possible explanation for differences between the turn directions could be the side-to-side gradient. The effect of side-to-side gradient has not been examined in the recent literature, but Lafontaine et al. (1998) reason that the lower forces in a turn direction with the side-to-side gradient could have influenced by the outside foot drifting out from under the skier's bodies. In the present study the side-to-side was controlled for during course setting and was later determined to be minimal based on direct measurement. Therefore, differences between turn directions due to a side-to-side gradient difference were not considered as a likely explanation. Future research should be conducted to examine the effect of side-to-side gradient to the kinetic characteristics in slalom skiing.

Due to different definitions of the turn phase, it was difficult to relate findings from this study to previous research regarding the temporal characteristics in slalom turns. Vaverka & Vodickova (2009) found right turns considerably shorter, and the initiation phase shorter while the steering phase longer in the left turns. We found no differences in the duration of unloading and loading phases, but earlier timing of the apex in left turns. The earlier apex in left turns (right-dominant leg outside) could indicate shorter turn duration, which would be in contradiction to the findings of Vaverka & Vodickova. However, the temporal characteristics of turns are highly situation and skier dependent, and factors such as snow, course profile and ski radius are likely to affect them.

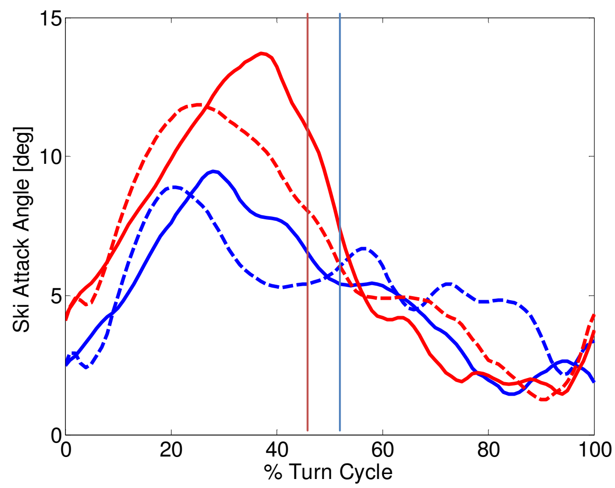


Figure 6.2: The ensemble average of ski attack angle for 10 meter (red solid line: outside ski, dashed line inside ski) and for 13 meter course (blue: solid line outside ski, dashed line inside ski) for 6 athletes, 2 turns each. Gate passing on the 10 meter course: red solid vertical line and 13 meter course: blue solid vertical line. Graph published with permission from Reid, 2009.

6.1.3 Examples of subject-specific variations

Some of the subject-specific variations are illustrated with subjects five and six. Subject five was recognized by his coach as an exceptional slalom skier. The force-time relationship graph (Figure 9.20) supported the coach's judgment of the subject. On the 10 meter course, the subject passed the gate at 50 % of the turn cycle in time, and the timing of the apex corresponded the gate passage or even slightly before (timing of left turns 4 % before the gate and right turns 5 % of the turn cycle after the gate passing). The timing of the apex with the gate passage was in good agreement with coaching philosophies.

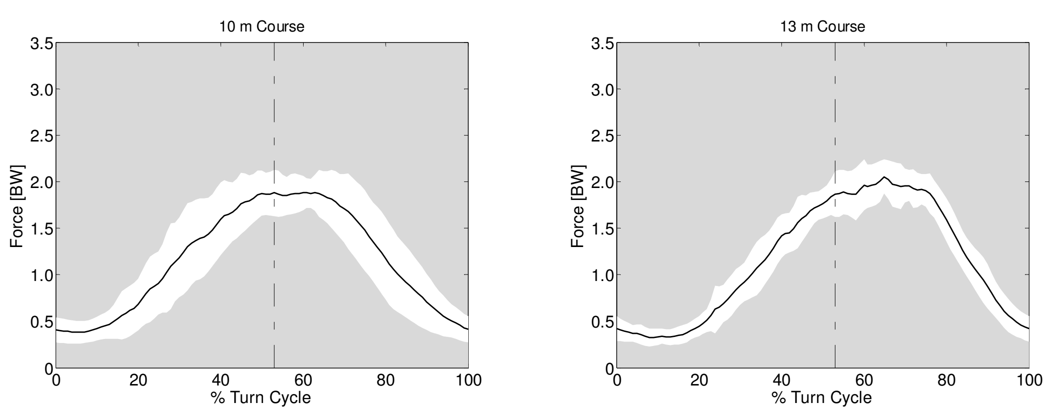


Figure 6.3: The ensemble average force-time relation for subject 5.

Although subject 5's timing of reaction force appeared optimal on the 10 meter course, his fast execution of turns appeared to be more challenged on the 13 meter course where his gate passing and timing of apex were significantly delayed (gate passing: p=.004 left turns and p=.007 right turns, timing of apex: p=.0001 left turns and p=.001). There were no differences between turn directions or courses in the mean apex force or peak force, but the mean loading force was significantly greater in the left turns on the 10 meter course. The general stability of the kinetic characteristics supports the remark of an excellent slalom skier.

The kinetic characteristics of subject five showed no differences in the magnitude of forces between turn directions on the 10 meter course. There was also no difference in the gate passing (49 % of the turn cycle) between turn directions or courses. On the 10 meter course, the timing of the apex was significantly delayed for right turns compared to the left turns (p=.024). The timing of the apex was significantly delayed on the 13 meter course for both turn directions when compared to the 10 meter course (52 and 60 % on the 10 meter course vs. 62 and 67 % of the turn cycle in time, p=.009 for left turns and p=.011 for right turns). This indicated that the skier was challenged in the timing of the apex in the right turns on the 10 meter course and in both turn directions on the 13 meter course. According to the team coach, the subject was in excellent slalom condition during the time of testing.

Based on these two good skiers, it was concluded that the 13 meter course somehow challenged skier's ability to time the apex of the turn. Similar timing on the 10 meter course of subject 5 and 6 indicates that good skiers were able to time the apex simultaneously or even before the gate passing. Generally it was concluded that good skiers should be able to adjust to the turn directions and distances between the gates without significant differences in the magnitude of the kinetic characteristics.

6.2 The Inside/Outside Ski Impulse Ratio

Although skiers must move laterally to balance against the ground reaction force during turning, they can control the force distribution between the inside and outside ski through fine-tuning of the lateral balance (LeMaster, 1999). Traditional philosophies describe a lateral balance where the force distribution occurs predominantly on the outside ski (Müller & Schwameder 2003, Klous et al. 2007, Fauve 2009 and Spitzenfeil et al. 2009) which was confirmed by the present study as the predominant loading of the outside ski was found.

However, with the recent developments in the slalom equipment, philosophies have emerged promoting a more even distribution. While this may reduce the ski-snow friction when carving, it may also result in greater skidding and chatter.

The results of the present study indicated greater relative loading of the outside ski in the left turns. An individual, dynamic variation in the loading of the inside/outside ski was evident; some skiers loaded heavily the outside ski in left turns (ratio 0.4) and engaged the inside ski in right turns (ratio 0.8). Others acted in the opposite way; they engaged the inside ski in left turns, and loaded heavily on the outside in right turns.

Possible explanations for these differences could be the leg dominance and the injury history. The leg dominance was previously determined to affect the kinetics of slalom skiing by Vaverka & Vodickova (2009). Subjects self-reported leg dominance and previous injuries within the past 5 years.

Table 6.1: An overview over the leg dominance.

Dominant foot	Subject ID	Turn direction with dominant outside ski loading
Right	1,3,6,7,8,9,10,11	Left: 6/7 Right 1/7
Left	2, 5, 4	Left: 1/3 Right: 1/3 Inconsistent 1/3

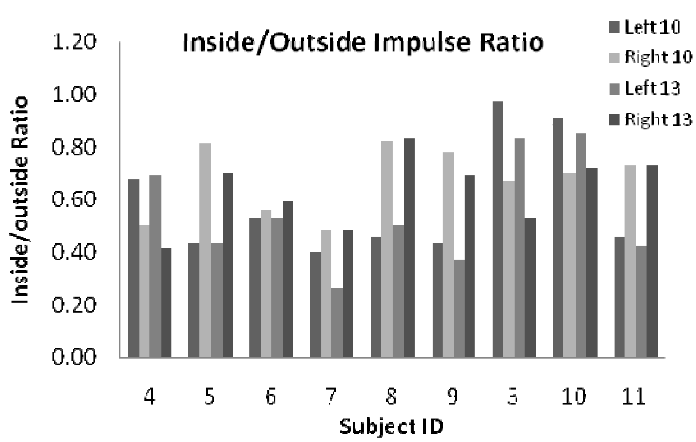


Figure 6.4: The inside/outside SIR for the main group in the order of testing.

A prevailing trend of dominant outside ski loading in left-hand turns was found for right leg dominant athletes (5 of 6 cases for non-injured subjects). This trend was not as clear for left leg dominant athletes possibly since two of the three subjects who were left-leg dominant had previous injuries to the left limb, Table 6.1.

Individuals with previous injuries clearly decreased the engagement of the injured leg by loading the healthy leg more regardless of turn direction. An example of this was subject one, who loaded the inside ski more than the injured outside ski on the 10 meter course (right turns, Table 9.7: ratio 1.1). Skiers with dominant-leg injuries could compensate for weakness, limitations in range of motion, and/or experienced pain by engaging the healthy, inside leg in turns where the injured leg is the outside ski (subjects 3 and 5). However, it is speculative to conclude that even loading automatically was due to compensation.

These findings were in good agreement with what one would naturally expect, i.e. that the turns, where the strongest leg is the outside ski, are executed loading dominantly on the outside ski. When the weaker leg is the outside ski, one would accordingly expect that the inside ski will be engaged to increase the contact with snow for better balance. Although a trend of the leg dominance was found, it is important to point out that a cause-effect relationship cannot be established based on these results. It is therefore suggested that future research examine this.

There was no strong evidence of correlation between performance and the inside/outside SIR. It should be noted that the correlation between trial times and the inside/outside SIR ought to be carefully evaluated due the fact that performance was assessed over several days, with changing external factors. Although the actual courses remained set throughout the data collection, the snow conditions changed slightly from the first day's -1.8 to -3.7 and to -3.2 °C of the last day, and the courses were repeatedly slide slipped, making them icier. Although with harder/icier snow one might expect a faster course, the wear and tear of the snow surface due to previous skiers' tracks may have influenced skiers of the last day forcing them to change their choice of line or by increased chatter. The order of the subject testing did not affect the mean trial times on the 10 meter course ($r=.38$, $n=9$), but did so on the 13 meter course ($r=.69$, $p<.05$ $n=9$). In addition, training was run parallel to the testing, which may have affected some skiers as fatigue developed.

Several factors affect the inside/outside distribution of ski impulse depending on the turn phase. In the initiation phase, even loading could ease the steering of the skis. In the loading phase (or the steering phase), there must be enough loading on the outside ski to make penetration of the ski into the snow possible. However, with excessive penetration a risk of increased friction as well as the fracturing of the snow which would lead to skidding are augmented. In the completion phase, the transfer of loading to the inside ski is thought to be important which establishes the contact with the new outside ski. Future analyses of the ski impulse distribution in the different turning phases should be conducted.

6.2.1 Example of subject-specific variations in force distribution

Subject 1 was chosen to show how injuries may affect the force-time relationship. His injured left foot clearly affected his skiing during testing. To compensate for the injury, he loaded the healthy inside leg in right turns (seen as high inside/outside SIR in the right turns of 10 meter course). Subject 1 only had one successful trial on the 13 meter course. The differences in the kinetic characteristics between turn directions reported in the single-subject analysis may partly be due to small number of trials on the 13 meter course. It was obvious that the subject was careful loading the left, injured leg on the 10 meter course.

Plantar pressure measurement could be beneficial in researching both healthy and injured skiers and the inside/outside ski loading in various situations. Such assessment could confirm if the skier is able to load both skis and/or the injured leg maximally. Technique training with such pressure measuring systems could assist coaches in identification of problems associated with the ski impulse distribution between inside and outside ski.

6.3 The chatter

In general, the greater outside ski loading was evident, and the inside ski was loaded with half to two-thirds of the load of the outside ski. Larger mean amplitude of inside ski chatter (24 N) on the 10 meter course was evident compared to both the inside ski of the 13 meter course and to the outside ski on the 10 meter course. The amplitude of the chatter for the outside ski was stable, about 16 N, regardless of course or turn direction, but the frequency analysis conducted on the same set of measurements showed that the frequency spectrum for right turns was significantly greater (Smith et al., 2009, not published). The amplitude of the inside ski chatter for the 10 meter course was significantly higher relative to the outside ski on the 10 meter course as well as both skis on the 13 meter course for both turn directions. The ratio of inside/outside ski chatter was therefore greater on 10 meter course than on the 13 meter course, regardless of turn direction. It should be pointed out that large individual differences were evident.

Assuming that the estimated chatter would reflect skidding, the findings of more inside ski chatter in the present study partly support the statement that on the 10 meter course, there would be more lateral skidding of the skis, while on the 13 meter course one would expect a greater degree of carving (Reid, personal communication, 2009). Due to the relatively low sampling frequency used in the present study, only lower frequency chatter could be detected, and the results may therefore not describe all the vibrating motion occurring during slalom skiing.

The frequency analysis conducted by Smith et al. 2009 provides a novel knowledge of chattering in slalom skiing. A frequency analysis of ski chatter based on the measurements from the 10 meter course of the present study showed that the amplitude of the inside ski was higher than the amplitude of the outside ski. Chattering of skis showed amplitudes of 10 to 20 Hz, this is in good accordance with the findings of Federolf et al. (2009). Nevertheless, the lower frequency chatter observed was probably due to the snow-ski interaction, where as the high frequency chatter could be torsional vibration of the skis.

Although the cause of the chatter is unclear, Federolf et al. (2009) speculates that the vibration differs between subjects and skiing styles due to different speeds, and ski-snow interface (for example degree of carving), differences in equipment character such as torsional flex of the ski which was found to vibrate more in hard snow conditions (Fauve 2009). Federolf et al. (2009) conclude that intensity of the vibration is highly dependent upon the snow condition (the hardness and the shear strength of snow) as in softer snow the ski penetrates it easier, allowing a greater area of the ski to bear the load leading to reduced torsional moments (Fauve 2009).

Higher chatter of the inside ski could also be caused by lesser loading of the inside ski during slalom turns. If the inside ski is loaded less, it would decrease the edge penetration into the snow, and therefore the snow underneath the edge could give in under the ski, and skidding would occur. Also, the inside ski must turn with a smaller radius and a typically smaller edge angle than the outside ski, making skidding more likely. However, the low inside/outside SIR was not associated with increased chatter in the present study. Large variability in force characteristics are evident, making it challenging to find any possible relationships in group level. Three out of nine skiers had a greater inside/outside impulse ratio, and a greater inside/outside chatter ratio in the left turns, 4 out of nine skier had a greater inside/outside impulse ratio and a greater inside/outside chatter ratio in right turns, 1 skier had greater inside/outside impulse in right turns, but no difference in chatter between left and right turns, and 1 skier had no difference inside/outside impulse ratio but greater inside/outside chatter in right turns. It was apparent that greater chatter may be related to the greater loading of the inside ski - but no relationship between Inside/outside SIR and the inside/outside CR was found on either course. It is therefore proposed that the future research is engaged into explaining the higher chatter of the inside ski.

Another feasible explanation of the higher inside ski chatter in the present study was the gate possibly hitting the inside ski immediately after the gate passage. In tight turns, the skier knocks down the gate, which can hit the inside ski, causing large vibrations of the ski. This kind of vibration could possibly be detected by the Pedar system. In the present study, the possibility was not examined, and is therefore recommended in the future research.

Not only is the skier's body the object for relatively high loads due to ground reaction forces (2-3 BW), but in addition, the chattering must be absorbed. According to Federolf et al. (2009), the chatter is effectively absorbed, and damped by the working muscles as maintaining the motion of skiing by keeping the correct joint angle, or when the muscle stiffness is needed to damp the chatter. The exposure to high chattering which according to Federolf et al. (2009) surpasses the international standards for work place safety (ISO 2631-1) for whole body vibrations, directly transmitted to the body is clearly a physical health hazard- but the effect of such chatter and the absorption is subject specific. Although the typical injuries associated with alpine skiing are ligament injuries in the knee joint, being exposed to a long-term chatter could injure the sensory organs, specifically in the eyes and ears (Federolf et al. 2009). Some of the observed sensations due to exposure may be nausea, discomfort or irritation according ISO 2631-1 (Federolf et al. 2009). It is possible that under extreme muscle fatigue and continued skiing under high chatter circumstances, a skier may develop a stress fracture in lower limbs.

The present study presents a novel approach of evaluation of common slalom technique problems associated with ski impulse distribution and chattering of skis. Influence of the factors that might have an effect on the degree of chatter, snow conditions, ski equipment characteristics and performance times of each skier were not controlled but are reported. To control the degree of carving, this study compared the kinetic characteristics between one course allowing clean carving (13 meter course) to a course which did not allow clean carving and which are typically used in FIS races.

6.4 The validity of the method

The results for the coefficient of variation presented in the Table 5.3 indicated that the magnitude of forces as well as the timing of the apex and gate passing were estimated in a stable, repeated manner (CV < 10%), while the precision in estimations of the inside/outside SIR and chatter characteristics were lower (CV 17-29 %), reflecting the error component due to method, or other factors affecting the large inter-subject variability. Although coefficient of variation permits comparison between two variables with different units, the limitation is that the closer the zero the mean value is, the more sensitive the CV is to variation in the standard deviation (Portney & Watkins, 2009).

The quantification of the timing and magnitude of the force which changes the skier's momentum was assessed by the timing of the apex and mean force of apex. The apex of the turn was chosen to describe the phase of the turn where the skiers' momentum was most effectively changed, because the peak force most likely won't describe the momentum change, but rather one of the peaks in the force-time curve caused by chattering. Since the peak forces were assumed to be associated with chattering-with a lot of inter-subject (and even turn-by-turn) variation in timing and magnitude, it was reasonable to design a tool to assess what really has an impact on the skier during turns. In addition, Pedar measurements were sampled at 50 Hz, which most likely affected the magnitude of the peak force, as some of the peaks would not have been detected by the insoles in such a low sample frequency.

Another possible error component of the present study included the identification of the switch and the gate passing. The investigator identified the picture frames from video input manually, which may have led to unsystematic error in the phase identification. Although small error margins of .01 or .02 seconds would have affected the temporal characteristics of ground reaction forces (the duration of unloading and loading phases, the time from gate to the apex), the tagging was conducted by the same investigator with a constant evaluation of positioning of the skier in switches and gate passages, which would lead to a random error rather than to a systematic error.

It was assumed that the results of the present study underestimated the true ground reaction forces. The mean magnitude of the total error component associated with Pedar insoles in alpine skiing remains unidentified. The literature estimates a 10 to 30 % reduction of total ground reaction forces assessed with the Pedar insoles (Barnett et al. 1999, Arndt 2003, Forner Cordero et al. 2004, Lüthi et al. 2005). Adding the 30 % error component to the mean loading, mean apex and peak forces result in 2.3/2.4 BW (10/13 meter courses), 3.0 BW and 3.4/3.5 BW, which corresponds with the results from Reid study (Figure 6.1) obtained from kinematic analysis of external forces on the skier in similar two conditions as the present study. The corrected mean peak values were also supported by the similar results from the study by Klous et al. (2007). Difficulty in quantifying the true error component was partly due to skier-via boot- to ski interaction, partly due the nature of insoles; threshold of pressure cells, bypassing forces, incapacity of measuring the shear forces, the calibration procedure, and also possible sensor creep. Lüthi et al. (2005) estimated the difference between Kistler force plates between the skis and bindings and Pedar insoles to 150 N when the skier stands centered on the ski. In reality, a static mid-stance position is unrealistic. This will affect the pressure measurements negatively, therefore it was justified to think that the discrepancy between the measurements by Pedar deviate even more. The quantification of the reduction caused by force transmission along the cuff of the boot must be conducted in future research.

Arndt (2003) reported increased total force (sensor creep) measurement during a prolonged walking trials study. The authors explained the sensor creep due to temperature or moisture effects inside the shoes. In the present study, since the subject wore the boots with Pedar insoles inserted for 2 hours during the testing, the insoles were inserted between the ski boot insole and the base of the boot and covered with plastic wrap in order to protect the insoles from humidity. It was assumed that this moisture protection avoided sensor creep, but protecting the insoles could have lead to alterations in the measurements as less pressure could have been detected due to the additional material between the foot and the Pedar insole.

The Pedar system certainly has validity issues regarding the estimations of the true ground reaction forces in slalom skiing, as it is only possible to estimate a component of the true ground reaction force acting on the skier. Based on the static and dynamic validation studies in the lab at the Norwegian School of Sport Sciences, as well as within literature, it was estimated that Pedar insole measurements underestimate the true ground reaction forces with an error component between 10 and 30 %, corresponding to a minimum absolute force of 198 N or relative absolute force of 0.23 BW. The 10 % error component was probably an underestimation of the true error component. The true error component was expected to be even larger depending on maximum forces during skiing, sampling frequency, the hardness of snow conditions, calibration of the insoles, and the fit of the boot.

According to Bates (1994), individual task specific strategies often lead to increased inter-subject variability reducing statistical power of group design, and may lead to false approval of the null hypothesis.

Regarding the temporal characteristics and the inside/outside ski impulse ratio, it was concluded that the results and conclusions from this study were valid for the specific population sample. Due to the limitations in the Pedar system, the magnitudes of forces were likely underestimations. Based on the present study it would be speculative to draw conclusions to apply for rest of the alpine skiing racing community. Future research conducted with larger populations in altering external conditions is necessary. It is preferable that research groups agree to implement definitions of variables which allow comparison of results from different studies. Plantar pressure distribution systems such as used in this study provide useful information about inside/outside ski impulse distribution and the temporal characteristics, which may better enable alpine skiing coaches to give precise technique suggestions to their athletes.

7 Conclusion

The aim of the present study was to estimate the kinetic characteristics in competitive slalom skiing in two courses typical to competitions. The results based on a set of 498 turns and described the kinetic characteristics between the turn directions and the different gate settings. The estimated ground reaction forces were related to the gate passing and to the weight of the skiers to permit comparisons with the future research. A major limitation of the study was the validity of the pressure measurement system, as it only measured pressure normal to the insoles, thereby not measuring some component of the true ground reaction forces.

> **RESEARCH QUESTION 1:**
> What are the specific kinetic characteristics in unloading and loading phases in slalom turn in courses with 10 and 13 meter linear distance between gates? Are there significant differences in kinetic characteristics between courses and/or turn directions?

No significant differences were found in the magnitude of the kinetic characteristics in the unloading and loading phases between the two courses, or turn directions. Significant differences in the timing of kinetic characteristics were found in timing of the apex, gate passing and the timing of gate to apex. Timing of apex was delayed on the 13 meter course and in turns to right, gate passing was delayed on the 13 meter course, and the gate to apex time was delayed in the turn to right.

Based on non-significant findings, the zero hypothesis was failed to reject regarding magnitude of the kinetic characteristics.

Based on the significant findings, the null hypothesis was rejected and the alternative hypothesis was supported regarding the timing of kinetic characteristics.

> **RESEARCH QUESTION 2:**
> What is the ski impulse distribution between the inside and outside ski during the loading phase? Are there significant differences in ski impulse distribution between courses and/or turn directions?

Statistically non-significant greater outside-ski-loading was found in the left turns. Inside/outside ski impulse ratio was subject-specific.

Based on the non-significant findings, the zero hypothesis was failed to reject.

RESEARCH QUESTION 3:

What is the quantity of chatter in inside and outside ski during loading phase? Are there significant differences in chatter characteristics between courses and/or turn directions?

Significant differences in the mean residual of chatter as well as in the frequency of the chatter of the inside ski was found in the10 meter course

Based on the significant findings, the zero hypothesis was rejected and the alternative hypothesis was supported.

8 References

Arndt, A. (2003). Correction of sensor creep in the evaluation of long-term plantar pressure data. *J Biomech, 36*, 1813-1817.

Bahr, R. & Mæhlum, S. (2003). *Idrettskader*. (2nd edition). Oslo, Norway: Gazette bok.

Barnett, S., Cunningham, J., Hunter, G., McDowell, N. & West, S. (1999). A comparison of vertical force and temporal parameters produced by an in shoe pressure measuring system and a force platform. *Clin biomech, 14*, 552-566.

Bates, B., T. (1996). Single-subject methodology: an alternative approach. *Med & Sci in Sports & Exercise, 28*, 631-638.

Brodie, M., Walmsley, A. & Page, W. (2009). How to ski faster: art or science? In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 162-174. Maidenhead, UK: Meyer & Meyer Sport.

Brown, C., A. (2009). Modeling edge-snow interactions using machining theory. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. Pp. 175-182. Maidenhead, UK: Meyer & Meyer Sport.

Fauve, M., Auer, M., Lüthi, A., Rhynes, H. & Meier, J. (2009). Measurement of dynamical ski behaviour during alpine skiing. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 195-206. Maidenhead, UK: Meyer & Meyer Sport.

Federolf, P., A. (2005). Finite element simulation of a carving snow ski. Doctoral degree dissertation. Swiss federal institute of technology, Zurich, Switzerland.

Federolf, P.A., von Tscharner, V., Haeufle, D., Nigg, B., Gimpl, M. & Müller, E. (2009). Vibration exposure in alpine skiing and consequences for muscle activation levels. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 19-25. Maidenhead, UK: Meyer & Meyer Sport.

Forner Cordero, A., Koopman, H., J., F., M. &, van der Helm, F., C., T. (2004). Use of pressure insoles to calculate the complete ground reaction forces. *J Biomech, 37*, 1427-1432.

Gilgien, M., Reid, R., Tjørhom, H., Moger, T., Haugen, P., Kipp, R. et al. (2007). Energy dissipation and slalom turn radius. *4th international congress on science and skiing, 2007. Tirol, Austria.*

Gilgien, M. (2008). External forces acting in direction of travel and their relation to energy dissipation in slalom. Unpublished Master's Thesis, Norwegian School of Sports Sciences, Oslo, Norway.

Hall, B., Schaff, P. & Nelson, R., C. (1991). Dynamic displacement and pressure distribution in alpine ski boots. Skiing Trauma and Safety: Eight International Symposium. Pp.186-189. Philadelphia, USA: American Society for Testing and Materials.

Haugen,P., Reid, R., Tjørhom, H., Moger, T. , Gilgien, M., Kipp, R. et al. (2007). Center of mass velocity and the turn cycle in slalom. *4th international congress on science and skiing. Tirol, Austria.*

Heinrich, D., Kaps, P., Mössner, M., Schretter, H. & Nachbauer, W. (2009). Calculation of pressure distribution between ski and snow. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 229-241. Maidenhead, UK: Meyer & Meyer Sport.

International Ski Federation (2008). *Specifications for competition equipment and commercial marking: 2008/09.*

Jentschura, U., D., & Fahrbach, F. (2004). Physics of skiing: the ideal-carving equation and its applications. *Can J Phys, 82,* 249-261.

Klous, M., Müller, E. & Schwameder, H. (2007). Lower extremity joint loading in carved ski and snowboard turns. *XXV ISBS Symposium,* pp. 91-94, Ouro Preto, Brazil.

Krueger, A., Edelmann-Nusser, J., Spitzenpfeil, P., Huber, A., Waibel, K.-H. & Witte, K. (2006). A measuring method for the combined determination of the edging angle and the ground reaction force in alpine skiing. *ISBS Salzburg. Germany.*

Kurpiers, N., Kersting, U., G. & McAlpine, P., R. (2009). Effects of mock-up force plate on riding technique and perception-a prerequisite for comprehensive biomechanical analyses in mogul skiing. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 327-336. Maidenhead, UK: Meyer & Meyer Sport.

Lind, D. & Sander, S., P. (2004). *The Physics of Skiing: Skiing at the Triple Point.* 2nd ed. New York, NY, USA: Springer-Verlag.

Lafontaine, D., Lamontagne, M., Dupuis, D. & Diallo, B. (1998). Analysis of the distribution of pressure under the feet of elite alpine ski instructors. *XVI International Symposium on Biomechanics in Sports: Proceedings.* Germany.

LeMaster, R. (1999). *The Skier's Edge.* Champaign, IL, USA: Human kinetics.

Lešnik, B. & Žvan, M., (2007). The best slalom competitors-kinematic analysis of tracks and velocities. *Kinesiology, 39*, 40-48.

Lin, W.-H., Liu, Y.-F., City C.-C. H. & Alex, J., Y., L. (2008). Ankle eversion to inversion strength ratio and static balance control in the dominant and non-dominant limbs of young adults. *J Sci Med Sport*, doi: 10.1016/j.jsams.20077.10.001.

Loland, S. (1992). The mechanics and meaning of alpine skiing: methodological and epistemological notes on the study of sport technique. *J phil sport*, *XIX*, 55-77.

Loland, S. (2009). Alpine skiing technique-practical knowledge and scientific analysis. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 43-58. Maidenhead, UK: Meyer & Meyer Sport.

Lüthi, A., Federolf, P., Fauve, M., Oberhofer, K., Rhyner, H., Ammann, W., et al. (2005). Determination of forces in carving using three independent methods. In E. Müller, D. Bacharach, R. Klika, H. Schwameder (Eds.). Science and Skiing III, pp. 96-106. Oxford, UK: Meyer & Meyer Sport.

Moger, T. (2007). Kan en ved hjelp av en 3 dimensjonal kinematisk analyse beskrive tyngdepunktsbanen til SL-løpere nøyaktig nok til å belyse viktige prestasjonskarakteristika. Unpublished Master's Thesis, Norwegian School of Sport Sciences, Oslo, Norway.

Molinari, A. & Moufki, A. (2008). The merchant's model of orthogonal cutting revisited: A new insight into the modeling of chip formation. *Int J Mech Sci, 50*, 124-131.

Mössner, M., Heinrich, D., Kaps, D., Schretter, H. & Nachbauer W. (2009). Effects of ski stiffness in a sequence of ski turns. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 374-388. Maidenhead, UK: Meyer & Meyer Sport.

Müller, E. (1994). Analysis of the biomechanical characteristics of different swinging techniques in alpine skiing. *J Sport Sci*, *12*, 261-278.

Müller, E. & Schwameder, H. (2003). Biomechanical aspects of new techniques in alpine skiing and ski-jumping. *J Sport Sci, 21*, 679-692.

Portney, L., G. & Watkins, M., P. (2008). *Foundation of Clinical Research Applications to Practice.* (3rd edition). New Jersey, USA: Pearson Prentice Hall.

Putti, A.,B., Arnold, G.,P., Cochrane, L. & Abboud, R.J. (2007). The Pedar in-shoe system: Repeatability and normal pressure values. *Gait & Posture, 25,* 401-405.

Reboussin, D., M. & Morgan, T., M. (1996). Statistical considerations in the use and analysis of single-subject designs. *Med & Sci in Sports & Exercise, 28,* 639-644.

Robertson, D., G., E., Caldwell, G., E., Hamill, J., Kamen, G., Whittlesey, S., N. (2004). *Research Methods in Biomechanics.* Champaign, IL, USA: Human Kinetics.

Schaff, P., Schattner, R., Kulot, M. & Hauser, W. (1989). Influences on the foot pressure pattern in ski boots. *Skiing Trauma and Safety: Seventh International Symposium*. pp. 137-145. Philadelphia, USA: American Society for Testing and Materials.

Schöllhorn, W., I., Hurth, P., Kortmann, T. & Müller, E. (2009). Biomechanical basis for differential learning in alpine skiing. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 454-463. Maidenhead, UK: Meyer & Meyer Sport.

Spitzenpfeil, P., Huber, A. & Waibel, K. (2009). Mechanical load and muscular expenditure in alpine ski racing and implications for safety and material considerations. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 479-486. Maidenhead, UK: Meyer & Meyer Sport.

Tjørhom, H. (2007). Beskrivels av tyngdepunktets frem/bak dynamikk i slalåm sett opp mot prestasjon ved hjelp av en 3 dimensjonal kinematisk analyse. Unpublished Master's Thesis, Norwegian School of Sport Sciences, Oslo, Norway.

Tjørhom, H., Reid, R., Moger, T., Haugen, P., Gilgien, M., Kipp, R. Et al. (2007). Fore/aft dynamics and performance in slalom. *4th international congress on science and skiing,* 2007. Tirol, Austria.

Van der Wel, R., P., R., D. & Rosenbaum, D., A. (2007). Coordination of locomotion and prehension. *Exp Brain Res*, *176*: 281-287.

Vaverka, F., & Vodickova, S. (2009). The influence of the laterality of the lower limbs on the symmetry of connected carving turns. In E. Müller, S. Lindinger, T. Stöggl (Eds.), Science and Skiing IV. pp. 523-531. Maidenhead, UK: Meyer & Meyer Sport.

Wolfram, S. (2008). Influence of the ski geometry and the role of inside leg in the carving turn in alpine skiing. Unpublished Master's degree thesis. University of Jyväskylä, Finland.

Retrieved from:

"FIS-SKI – ALPINE SKIING – FIS POINTS" http://www.fis-ski.com/uk/disciplines/alpineskiing/fispoints.html. (September 24th 2008).

"CREEP" www.dictionary.com (May 9th 2009)

Multimedia resources:

US Ski Team and USSA Coaching, (2005). *Alpine Ski Fundamentals II.* Sport Performance Series.

9 APPENDICES

9.1 APPENDIX A: GLOSSARY

Glossary

Apex	A region of the loading phase with the largest impulse and thus represented the loading phase where a skier’s momentum was most effectively changed. The impulse was calculated in 10 % intervals until the largest impulse was found.
BW	Body weight; skier’s mass * gravity.
Chatter	Mean residuals mean the size of each “spikes”/chatter when raw force-time curve was subtracted from the smoothed force-time curve.
CoM	Center of mass.
Effective weight	The weight of the skier and the equipment exclusive weight of the skis and boots.
FIS ranking	A ranking system by the International Ski Federation which ranks skiers based on the two best results within the last 12 months.
Gate passing	CoM passing the gate.
Inside/Outside Impulse ratio	Calculated as the ratio of inside ski impulse to outside ski impulse measurements. Ratio 1.0 means even distribution of impulse between the inside and the outside ski, and 0.5 means predominantly loading of the outside ski, where inside ski carries half of the force by the outside ski.
Loading phase	Part of the turn where measured forces are greater than 1 body weight.
SID	Subject ID
Side-to-side slope gradient	Lateral inclination of the slope, related to longitudinal direction of the hill.
Switch	Instantaneous position of the turn where trajectory of COM is located in the middle of the skis.
Unloading phase	Part of the turn where measured forces are less than 1 body weight.

9.2 APPENDIX B: AN INFORMED CONSENT FORM

Informed consent form

”Kinetic characteristics of competitive slalom skiing”

Bakgrunn og hensikt

Dette er et spørsmål til deg om du er villig til å delta i en forskningsstudie som beregner og analyserer trykket mot underlaget under et slalomrenn. I tillegg, vil studien vurdere om bruk av trykksåler kan brukes som et treningsverktøy.

Du er valgt ut som mulig kandidat i denne studien på grunn av din rolle som toppalpinist i Norge. Om du bestemmer deg for å delta i studien, vil data innsamlingen skje under en treningsleir i løpet av høsten 2008.

Denne studien er Marjaana Lappis mastergrads oppgave ved Norges Idrettshøgskole.

Hva innebærer studien?

Studien innebærer at du blir utstyrt med trykksåler (Pedar ”plantar pressure” - såler laget av Novel Gmph, Tyskland) inne i skistøvlene som måler trykket på ulike områder av fotsålen. For din egen trygghet, vil du også ha på deg en beskyttende polstret ryggplate. En datalogg og en batteripakke er festet til utsiden av ryggplaten. Fra sålene går det ledninger under drakten til dataloggen.

Du skal varme opp slik du gjør før konkurranser. Du skal deretter utføre fire maksimale renn i to ulike løyper (to renn per løype), der avstanden mellom portene er på 10 og 13 meter. Du vil bli gitt tilstrekkelig tid til å restituere deg mellom løpene. Løpene blir filmet med et kamera som er satt parallelt til løypen. Video data blir brukt til å identifisere i hvilken fase av svingen du beveger deg i. Totalt sett vil data innsamlingen ta ca 2 timer.

Mulige fordeler og ulemper

Noe ubehag kan oppleves på grunn av ledningene og ryggplaten som du bærer, men normale slalåmbevegelser vil ikke være hindret. For å hindre at ledningene fester seg i skiutstyr eller portene, blir de festet med tape under en konkurransedrakt som forskningsteamet bruker i denne studien. Eventuelle løse ledninger i ryggplaten blir festet med tape. Ryggplaten er polstret slik at om du skulle falle og lande oppå ryggplaten, er risikoen for å bli skadet på grunn av dataloggen og batteriet liten. Data logg og batteri måler 10cmx15cmx4cm og 6cmx11cmx3cm.

Siden denne studien innebærer maksimal innsats, vil skaderisiko være lik den du utsetter deg for i en konkurranse. Dette må vurderes nøye før samtykke gis.

Fordeler av denne studien er økt kunnskap om trykk fordeling og hvor store krefter som virker under de forskjellige fasene av et slalåmløp. Du vil motta dine individuell data, i tillegg til resultatene fra hele gruppen og konklusjon fra denne studie. Vi håper du vil kunne få bruk for denne kunnskapen i din idrettskarriære. Det vil ikke være noen økonomiske fordeler for noen av partene (Norges Skiforbundet eller forskning team) i denne studien.

Hva skjer med informasjonen om deg?

Informasjon som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet konfidensielt uten navn og fødselsnummer eller andre direkte gjenkjennbare opplysninger. En kode knytter deg til dine opplysninger gjennom en navneliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Navnelisten, video data, og alle skjema vil bli oppbevart i låste skap på Seksjon for Fysisk Prestasjonsevne ved Norges Idrettshøgskole. Alle personlige data, inkludert video data vil bli makulert når denne studien avsluttes i mai 2009. Etter det vil det være umulig å finne tilbake til dine personlige data. Det vil heller ikke være mulig å identifisere deg i publisert materiale. Dersom video data blir benyttet for å illustrere studien på noe som helst tidspunkt, også etter at studien er avsluttet, vil ansiktet ditt være sladdet.

Alle data som registreres om deg behandles konfidensielt og etter Norsk Samfunnsvitenskapelig Datatjenestes regler. Norsk Samfunnsvitenskapelig Datatjeneste har godkjent prosjektet i september 2008. Studien har fått etisk godkjenning fra De regionale komiteer for medisinsk og helsefaglig forskningsetikk i september 2008. Denne studien vil bli utført i henhold til retningslinjene i Helsinkideklarasjonen.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dette vil ikke medføre noen negative konsekvenser for deg. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke. Dersom du senere ønsker å trekke deg eller har spørsmål om studien, kan du kontakte min veileder Robert Reid, NIH, Tlf 971 84 528.

Utdypende forklaring av hva studien innebærer

Rekruttering av deltakere: Utøvere fra Norges alpinlandslag og utviklingslaget vil bli spurt om å delta i denne studien. Rekruttering av utøvere skjer i samarbeid med landslagets og utviklingslagets trenere og Norges Skiforbund. Hovedkontakt skjer via hovedveileder, Robert Reid, NIH.

Datainnsamling: Pedar såler, som settes inn i utøverens skistøvler registrerer trykk under føttene til utøverne. Deretter analyseres trykkfordeling og ”ground reaction” krefter. Utøverne blir i tillegg filmet med ett videokamera mens de gjennomfører løpene. Filming av utøvere med videokamera vil bli brukt for å illustrere i hvilke fase av slalom sving utøveren befinner seg i, og er synkronisert med Pedar sålene. Alle innsamlede data er nødvendige for å analysere og for å kunne gi svar på forskningspørsmålet.

Forsøkspersonenes identitet blir beskyttet mot innsyn fra uvedkommende ved bruk av et referansenummer system. En manuell navneliste i papir med navn og referansenummer blir lagret i et låst skap ved avdelingens fagadministrasjon. Ved prosjektets slutt i mai 2009 blir alt personlig data materiale makulert. Video opptak blir nedlåst i et skap ved bevegelseslaboratoriet, og på en PC tilhørende avdelingen og vil bli makulert ved prosjektets avslutning. Om det skulle være nødvendig å bruke video opptak for presentasjon av resultater fra dette studiet, blir utøverens ansikt sladdet slik at det ikke vil være mulig å identifisere utøveren.

Norges idrettshøgskole finansierer meste parten av prosjektet, søknad for videre finansiering er sendt til Norges Skiforbund og Olympiatoppen.

Personvern, biobank, økonomi og forsikring

Opplysninger som registreres om deg er navn, alder, vekt, sko tørrelse, kjønn, høyde og hvor mange år du har tilhørt i laget. I tillegg samles det informasjon om skiutstyret: ski, bindinger, støvler. Se vedlegg. Alle som får innsyn har taushetsplikt. Norges Idrettshøgskole ved leder for FAD Hans Tranekjer Andresen er databehandlingsansvarlig.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi og Norges Idrettshøgskolens rolle

Denne studien er et mastergrads oppgave ved Norges Idrettshøgskole. Studien er finansiert gjennom tildelte forskningsmidler fra Norges Idrettshøgskole.

Forsikring

Alle deltakere i dette prosjektet er dekket av NIHs fellesforsikring.

Informasjon om utfallet av studien

Du vil motta dine individuelle data samt generelle resultater og konklusjon fra denne studien.

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

9.3 APPENDIX C: A NOTICE TO NORSK SAMFUNNSVITENSKAPELIG DATATJENESTE

A notice to Norsk Samfunnsvitenskapelig Datatjeneste

1. Prosjekttittel *

The plantar pressure distribution and ground reaction forces in competitive slalom skiing

1. Prosjekttittel

Prosjekttittel er en kort beskrivende tittel på prosjektet.

2. Behandlingsansvarlig institusjon *

Norges idrettshøgskole

Seksjon for fysisk prestasjonsevne

2. Behandlingsansvarlig institusjon

Velg den institusjon du er tilknyttet. Alle nivå må oppgis. Ved studentprosjekt er det studentens tilknytning som er avgjørende. Dersom din institusjon ikke finnes på listen, ta kontakt med personvernombudet.

3. Daglig ansvarlig (forsker, veileder) *

Fornavn *	Etternavn *
Robert	Reid
Akademisk grad/utdanning	**Stilling**
Doktorgrad	Doktorgrad student
Arbeidssted *	
Norges Idrettshøgskole	
Adresse arbeidssted *	
P.O. Box 4014 Ullevål stadion	
Postnummer *	**Poststed ***
0806	Oslo
Telefon *	**Mobil**
23262000	97184528
Faks	**Epost ***
	robert.reid@nih.no

3. Daglig ansvarlig

Før opp navn på den som har det daglige ansvaret for prosjektet. For studentprosjekt er daglig ansvarlig vanligvis veileder. Veileder og student må være tilknyttet samme institusjon.

Dersom studenten har ekstern veileder kan for eksempel biveileder eller fagansvarlig stå som daglig ansvarlig.

Akademisk grad
Velg akademisk grad til daglig ansvarlig.

Stilling
Før opp stilling ved behandlingsansvarlig institusjon.

Arbeidssted
Arbeidssted må være i tilknytning til behandlingsansvarlig institusjon, f.eks. underavdeling, institutt etc.

NB! Brev etter endt saksbehandling av prosjektet og senere korrespondanse blir sendt til arbeidsstedsadresse.

4. Student

☑ **Kryss av for studentprosjekt**

Fornavn *	Etternavn *
Marjaana	Lappi
Akademisk grad/utdanning	
Høyere grad	
Privatadresse	
10800 Clay road apt 11202	
Postnummer *	**Poststed ***
77041	Houston, Texas, USA
Telefon *	**Mobil**
12813839743	17133072823
Faks	**Epost ***
	marjaana_78@hotmail.com

4. Studentprosjekt

Fyll ut feltene dersom prosjektet gjennomføres som et studentprosjekt med faglig veileder. Prosjekter på høyere nivå enn master, f.eks. PhD er ikke studentprosjekt.

Akademisk grad
Velg pågående akademisk grad.

NB! Tilrådning av prosjektet og senere korrespondanse blir sendt til privatadresse.

5. Formål med prosjektet *

The purpose of this study is twofold: 1) to quantify and analyze plantar pressure

5. Formål

Redegjør kort for prosjektets formål, problemstilling, forskningsspørsmål e.l.

distribution and ground reaction forces during varying situations in elite slalom skiing and 2) to assess the efficacy of the plantar pressure measurement as a training tool for the Norwegian Alpine Ski Team. Although plantar pressure measurement may be a common method used in alpine skiing research, much of the published studies have been limited to descriptions of methods and have stopped short of examining research questions related to technique. This study will assess the following questions using athletes of high national and international calibre: What is the magnitude and time-course of ground reaction forces through slalom turns with different linear distance between gates? What is the distribution of ground reaction forces between the inside and outside ski? What are the medial-lateral, and fore-aft distribution of the plantar pressure during competitive slalom turn?

6. Prosjektomfang

(•) Enkelt institusjon ( ) Nasjonal multisenterstudie[1] ( ) Internasjonal multisenterstudie[1]

6. Prosjektomfang

Kryss av for Nasjonal multisenterstudie dersom prosjektet er et samarbeid mellom norske institusjoner.

Kryss av for Internasjonal multisenterstudie dersom utenlandske institusjoner er involvert.

Les mer om hva som defineres som multisenterstudier

7. Utvalgsbeskrivelse

Beskrivelse av utvalget

Utøvere fra Norsk alpinlandslaget og utviklingslaget vil bli spurt til å delta i dette studie.

Rekruttering og trekking

Rekruttering av utøvere skjer i samarbeid med landslagets og utviklingslagets trenere og Norges Skiforbund. Hovedkontakt skjer via hovedveilederen, Robert Reid.

Førstegangskontakt

Førstekontakt skjer via landslag trenere.

Alder på utvalget

[ ] Barn (0-15 år) [ ] Ungdom (16-17 år) [x] Voksne (over 18 år)

Antall personer som inngår i utvalget:

10-20

7. Utvalgsbeskrivelse

Beskrivelse av utvalget
Beskriv hvem som deltar i undersøkelsen, f.eks. et representativt utvalg av befolkningen, barn, skoleelever med lese- og skrivevansker, pasienter, innsatte etc. Dersom utvalget har spesielle kjennetegn, gjør rede for dette.

Rekruttering og trekking
Gjør rede for hvordan utvalget trekkes og rekrutteres. Gjør også rede for hvem som foretar trekkingen/rekrutteringen. Skal utvalget trekkes fra bestemte registre (Folkeregisteret, pasientregister, registre ved sosialkontor etc.), eller rekrutteres fra ett eller flere miljø (f.eks en bedrift, skole, idrettsmiljø eller eget nettverk), eller er det andre måter forsker skal komme i kontakt med utvalget på?

Førstegangskontakt
Førstegangskontakt er første gang utvalget blir kontaktet og får kjennskap til prosjektet.

Oppgi hvem det er som oppretter førstegangskontakt, f.eks. lærer, behandlende lege, prosjektleder etc.

Antall personer
Anslå hvor mange personer som totalt skal inngå i utvalget

Inkluderes det personer med redusert eller manglende samtykkekompetanse?

○ Ja ◉ Nei

8. Informasjon og samtykke

- [x] Det gis skriftlig informasjon (legg ved kopi av informasjonsskriv)
- [x] Det gis muntlig informasjon

Redegjør for hvilken informasjon som gis.

muntlig informasjon om prosjektet gis til utøvere gjennom hovedveilederen og landslags og utviklingslag trenere. Se prosjektbeskrivelse Vedlegg C.

- [ ] Det gis ikke informasjon

Innhentes samtykke fra den registrerte?

- [x] Ja
- [ ] Nei

Hvis ja, oppgi hvordan samtykke innhentes og i hvilken form:

Alle deltakende utøvere bes om å lese, gjøre seg forstått med og underskrive og innlevere informert samtykke form før prosjektets datainnsamling påbegynnes. Se vedlegg B.

9. Metode for innsamling av personopplysninger

Kryss av for hvilke datainnsamlingsmetoder og datakilder som skal benyttes:

- [x] Spørreskjema
- [ ] Personlig intervju
- [ ] Observasjon
- [ ] Gruppeintervju
- [ ] Psykologiske/pedagogiske tester
- [ ] Medisinske undersøkelser/tester
- [ ] Journaldata
- [ ] Registerdata
- [ ] Biologisk materiale
- [ ] Utprøving av legemidler
- [x] Annen innsamlingsmetode

Oppgi hvilken innsamlingsmetode

Pedar Insoles, som settes inn i utøverens skistøvler og som registrerer trykk under føttene av utøvere. Utøvere blir i tilledd til filmet med en videokamera parallelt til løype mens de gjennomfører løypene.

Kommentar til metode for innsamling av personopplysninger:

Samtykkekompetanse
Dersom det inkluderes personer med redusert eller manglende samtykkekompetanse, beskriv denne delen av utvalget nærmere. Redegjør for hvorfor det er nødvendig å inkludere personer uten samtykkekompetanse.

8. Informasjon og samtykke

Som hovedregel skal det gis informasjon og innhentes samtykke fra den registrerte. Et gyldig samtykke er en frivillig, uttrykkelig og informert erklæring fra den registrerte om at han eller hun godtar behandling av personopplysninger om seg selv.

Les mer om hva som er et gyldig samtykke

Les mer om hva et informasjonsskriv bør inneholde

Muntlig informasjon kan supplere eller erstatte skriftlig informasjon. Dersom informasjonen gis muntlig, redegjør for hvilken informasjon som vil bli gitt.

Dersom det benyttes andre former for samtykke, f.eks. generelt/bredt samtykke, passivt samtykke, stedfortredende samtykke, samtykke innhentet etter at behandlingen har funnet sted eller dispensasjon fra taushetsplikten, skal dette oppgis her.

9. Metode for innsamling av personopplysninger

Personopplysningene kan innhentes på flere måter. De kan innhentes direkte fra den registrerte gjennom f.eks. personlig intervju, postale spørreskjema, deltakende observasjon, medisinske undersøkelser/tester. Personopplysninger kan også innhentes fra eksisterende registre (f.eks. Kreftregisteret, Medisinsk fødselsregister) eller fra ulike journaler; pasientjournaler, PPT-journal etc.)

Ved spørreskjema hentes det informasjon om følgende: Alder, vekt, skostørrelse,kjønn, høyde, år med laget. Samt informasjon om skiutstyret: ski, bindinger, støvler. Vedlegg A.

10. Datamaterialets innhold

Gjør rede for hvilke opplysninger som samles inn.

Ved spørreskjema hentes det informasjon om følgende: Navn, alder, vekt, skostørrelse,kjønn, høyde, år med laget. Samt informasjon om skiutstyret: ski, bindinger, støvler. Vedlegg A. Med Pedar Insoles innsamles det trykket under føttene som deretter analyseres som plantar pressure distribusjon og ground reaction forces. Filming av utøvere med videokamera vil bli brukt for å sette utøvere i sammenheng med hvilket fase av et sving utøveren befinner seg i. Videokamera settes parallelt til løype og er synkronisert med Pedar Insoles. All innsamlet data er nødvendig for å analysere data og for å kunne svare på forskningspørsmål.

Registreres det direkte personidentifiserbare opplysninger?

(●) Ja ( ) Nei

Hvis ja, oppgi hvilke:

- [x] Navn, adresse, fødselsdato
- [ ] 11-sifret fødselsnummer

Registreres det indirekte personidentifiserbare opplysninger?

(●) Ja ( ) Nei

Hvis ja, oppgi hvilke:

Video opptak av utøvere under testløype.

Behandles det sensitive personopplysninger?

( ) Ja (●) Nei

Hvis ja, oppgi hvilke:

- [ ] Rasemessig eller etnisk bakgrunn, eller politisk, filosofisk eller religiøs oppfatning
- [ ] At en person har vært mistenkt, siktet, tiltalt eller dømt for en straffbar handling
- [ ] Helseforhold
- [ ] Seksuelle forhold
- [ ] Medlemskap i fagforeninger

Behandles det opplysninger av tredjeperson?

( ) Ja (●) Nei

11. Informasjonssikkerhet

Registrering og oppbevaring av datamaterialet

- [x] Direkte personidentifiserende opplysninger erstattes med et referansenummer som viser til en navneliste som oppbevares atskilt fra det øvrige datamaterialet.

10. Datamaterialets innhold

Redegjør kort for hvilke opplysninger som samles inn. Spørreskjema, intervjuguide, forskningsprotokoll m.m. kan legges ved meldeskjemaet til slutt. Det er imidlertid ikke tilstrekkelig å kun vise til disse.

Direkte personidentifiserende opplysninger

En person vil være direkte identifiserbar via navn, personnummer eller andre personentydige kjennetegn.

Indirekte personidentifiserende opplysninger

Indirekte personidentifiserende opplysninger er opplysninger som kan identifisere den registrerte uavhengig av om dataene er tilknyttet direkte personidentifiserbare opplysninger. En person vil være indirekte identifiserbar dersom det er mulig å identifisere vedkommende gjennom bakgrunnsopplysninger som for eksempel bostedskommune eller institusjonstilknytning kombinert med opplysninger om alder, kjønn, yrke, diagnose, etc.

Opplysninger om tredjeperson

Med opplysninger om tredjeperson menes opplysninger som kan spores tilbake til personer som ikke inngår i utvalget. Eksempler på opplysninger om tredjeperson er opplysninger om spesifiserte familiemedlemmer til en registrert, som mor, far, onkel, bestemor.

11. Informasjonssikkerhet

Redegjør for hvordan datamaterialet registreres og oppbevares. Direkte personidentifiserende opplysninger bør ikke registreres sammen med det

Oppgi hvordan listen lagres og hvem som har tilgang til denne:

Identifikasjons liste som inneholder liste over forsøkspersoner og deres id-nummer for dette studie blir laget manuelt (ikke elektronisk) og innelåst i en safe hos Norges Idrettshøgskole, avdeling for fysisk prestasjonsevne. Ved prosjektets slutt, blir denne listen makulert. Listen over forsøkspersoner og id nummerer blir lagret manuelt (ikke elektronisk) og blir beholdt låst i et skap på kontoret til prosjektlederen. Denne listen blir ødelagt når prosjektet er avsluttet.

- [ ] Direkte personopplysninger lagres sammen med det øvrige materialet.
- [ ] Annet

øvrige datamaterialet.

Merk av for hvordan datamaterialet registreres og oppbevares.

- [x] Fysisk isolert PC tilhørende virksomheten
- [x] PC i nettverkssystem tilhørende virksomheten
- [x] PC i nettverkssystem tilknyttet Internett tilhørende virksomheten
- [ ] Fysisk isolert privat PC
- [x] Privat PC tilknyttet Internett
- [x] Videoopptak/fotografi
- [ ] Lydopptak
- [ ] Manuelt/papir
- [x] Annen registreringsmetode

Beskriv nærmere:

direkte personidentifiserbar informasjon blir kun lagret manuelt i en safe uten tilgang til uvedkommede i dette prosjektet.

Behandles/lagres lyd/videoopptak på PC?

(•) Ja ( ) Nei

Her skilles det mellom om lyd- og bildeopptaket overføres til, oppbevares på eller avspilles fra pc, eller om det holdes atskilt fra pc-basert utstyr.

Sikring av konfidesialitet

Sikring av konfidensialitet

Daglig ansvarlig og student plikter å holde oversikt over hvilke personopplysninger som skal behandles med elektroniske hjelpemidler og som må sikres spesielt mot at uvedkommende får adgang til dem. Den behandlingsansvarlige skal også vurdere sannsynligheten for at sikkerhetsbrudd kan forekomme: Er f.eks. pc-tilgangen beskyttet med brukernavn og passord og står pc-en i et låsbart rom?

Beskriv hvordan datamaterialet er beskyttet mot at uvedkommende får innsyn i opplysningene?

Forsøkspersonenes identifikasjon blir beskyttet for innsyn fra uvedkommede ved å bruk av en referanse nummer system. En manuel liste i papir med navn og referanse nummer blir lagret i et låst skap på kontoret til prosjektets hovedveileder – kun prosjektlederen har nøkkel til dette skapet. Ved prosjektets slutt i Mai 2009 blir denne listen makulert. Video opptak materiale blir lagret i samme safe i tillegg til PC tilhørende avdelingen og vil bli makulert ved prosjektets utgang. Om videomateriale blir brukt som en del av presentasjon, blir utøverens ansikt dekket med svart strek slik at det er umulig å identifisere utøveren.

Skal prosjektet ha prosjektmedarbeidere som skal ha tilgang til datamaterialet på lik linje med daglig ansvarlig/student?

( ) Ja (•) Nei

Innhentes eller overføres personopplysninger ved hjelp av e-post/Internett?

( ) Ja (•) Nei

E-post/Internett
Med dette menes om personopplysningene skal samles inn eller overføres til andre gjennom eksternt datanett, f.eks. via e-post fra respondenten, spørreskjema som besvares via web m.m.

Vil personopplysniger blir utlevert til andre enn prosjektgruppen?

( ) Ja (•) Nei

Skal opplysninger samles inn/bearbeides ved hjelp av databehandler?

( ) Ja (•) Nei

Databehandler
En databehandler er en som behandler personopplysninger på vegne av den behandlingsansvarlige. En

12. Vurdering/godkjenning av andre instanser

Er prosjektet fremleggelsespliktig for Regional komité for medisinsk og helsefaglig forskningsetikk (REK)?

(•) Ja ( ) Nei

Kommentar:

Søknad blir levert til REK 5.august.

Er det søkt REK om opprettelse av forskningsbiobank?

( ) Ja (•) Nei

Er det nødvendig å søke om dispensasjon fra taushetsplikt for å få tilgang til data?

( ) Ja (•) Nei

Kommentar:

Er det nødvendig med melding til Statens legemiddelverk?

( ) Ja (•) Nei

Kommentar:

[ ] **Andre**

13. Prosjektperiode *

Prosjektstart (ÅÅÅÅ-MM-DD) * 2008-09-10

Prosjektslutt (ÅÅÅÅ-MM-DD) * 2009-05-31

Gjør rede for hva som skal skje med datamaterialet ved prosjektslutt.

[x] **Datamaterialet skal anonymiseres**

Gi en redegjørelse for hvordan datamaterialet anonymiseres

Referanseliste og video opptak materiale blir makulert og dermed er det umulig å identifisere enkelte forsøkspersoners data. Dessuten blir utøverens ansikt dekket med svart stripe om det skulle være nødvengig å bruke video opptak materiale for presentasjon av resultater fra dette studiet.

[ ] **Datamaterialet skal oppbevares med personidentifikasjon**

14. Finansiering

Før opp den/de institusjoner som finansierer prosjektet

databehandler kan f.eks. være en ekstern person eller firma/institusjon som på oppdrag samler inn data. Eksempler på ofte brukte databehandlere er Questback, Synovate MMI, Norfakta etc.

12. Vurdering/ godkjenning av andre instanser

REK
All medisinsk og helsefaglig forskning som involverer mennesker (inkludert personopplysninger og humant materiale) skal fremlegges for en regional komité for medisinsk og helsefaglig forskningsetikk. Se www.etikkom.no for flere opplysninger.

Taushetsbelagte opplysninger
For å få utlevert taushetsbelagte opplysninger fra offentlige forvaltningsorgan, sykehus, trygdekontor, sosialkontor m.m., må det søkes om dispensasjon fra taushetsplikten. Dispensasjon søkes vanligvis fra aktuelt departement.

Legemiddelutprøving
Det skal sendes melding til Statens legemiddelverk ved utprøving av legemidler. Statens legemiddelverk vurderer meldinger om klinisk utprøving i henhold til Forskrift om klinisk utprøving av legemidler til mennesker. Se www.legemiddelverket.no for flere opplysninger.

Annet
Det kan også være aktuelt å søke tillatelse hos f. eks registereier for utlevering av data, rektor for tilgang til forskning på skole etc.

13. Prosjektperiode

Prosjektstart
Tidspunkt for når datainnsamlingen starter.

Prosjektslutt
Oppgi når formålet med behandlingen er oppfylt og prosjektet skal avsluttes. Dette sammenfaller gjerne med publisering og ferdigstilling av oppgave, avhandling, rapport.

Datamaterialet anonymiseres
Dersom datamaterialet skal anonymiseres etter prosjektslutt skal alle personopplysninger, både direkte og indirekte, slettes eller skrives om/kategoriseres, slik at det ikke lenger er mulig å føre opplysningene tilbake til enkeltpersoner i datamaterialet.

Datamaterialet oppbevares videre med personidentifikasjon
Data kan oppbevares med personidentifikasjon etter prosjektslutt i påvente av eventuelle

kjema - Personvernombud for forskning https://pvoportal.nsd.no/Meldeskjema/index.cfm?mid=9

Norges idrettshøgskole finansierer meste parten av prosjektet, søknad for videre finansiering er sent til Norges Skiforbund og Olympiatoppen.

oppfølgingsundersøkelser og for historiske, statistiske og vitenskapelige formål.

15. Tilleggsopplysninger

9.4 APPENDIX D: THE REK APPROVAL

UNIVERSITETET I OSLO
DET MEDISINSKE FAKULTET

Professor Gerald Smith
Norges Idrettshøgskole
Pb. 4014 Ullevål stadion
0806 Oslo

Regional komité for medisinsk og helsefaglig forskningsetikk Sør-Øst A (REK Sør-Øst A)
Postboks 1130 Blindern
NO-0318 Oslo

Telefon: 22 84 46 66
Telefaks: 22 85 05 90
E-post: jorgen.hardang@medisin.uio.no
Nettadresse: www.etikkom.no

Dato: 03.09.08
Deres ref.:
Vår ref.: S-08591a saksnummer: 2008/15041

S-08591a Plantar pressure distribusjon og ground reaction forces i elite slalom ski [1.2008.1791]

Vi viser til søknad mottatt til fristen 5. august.

Komiteen behandlet søknaden i sitt møte onsdag 27. august 2008. Prosjektet er vurdert etter lov om behandling av etikk og redelighet i forskning av 30. juni 2006, jfr. Kunnskapsdepartementets forskrift av 8. juni 2007 og retningslinjer av 27. juni 2007 for de regionale komiteer for medisinsk og helsefaglig forskningsetikk.

Prosjektet er en masteroppgave hvor formålet er todelt; å kvantifisere og analysere distribusjon og "ground reaction"-krefter under varierende situasjoner hos slalåmkjørere på landslag, og å vurdere effektivitet av "plantar pressure"-såler som treningsverktøy hos de samme. Til prosjektet rekrutteres 10 deltagere, fem kvinner og fem menn, fra landslaget.

Drøftingen er knyttet til rekruttering og frivillighet som forutsetninger. Det kan diskuteres i hvilken grad dette påvirkes av den relasjon potensielle deltakere er i. Det vektlegges at ingen som er skadet forespørres, og at deltakere kan ha fordel av å delta.

Søknaden er underskrevet av flere, bl.a. av prosjektleder. Komiteen understreker at det er prosjektleder alene som er ansvarlig i forhold til søknaden.

Komiteen har følgende merknader til informasjonsskriv og samtykkeerklæring:

1. Informasjonsskrivet bør gjennomgås med tanke på den språklige utformingen.
2. Referanse til at det å trekke seg ikke får konsekvenser for videre behandling må strykes eller omformes til at det ikke får noen konsekvenser i forhold til det å være utøver.
3. Det er i denne studien ikke aktuelt med stedfortredende samtykke, og dette må tas ut av samtykkeerklæringen.

<u>Vedtak:</u>

Prosjektet godkjennes under forutsetning av at de merknadene som er anført ovenfor, blir innarbeidet før prosjektet settes i gang.

Med vennlig hilsen

Kristian Hagestad
Fylkeslege cand.med., spes. i samf.med
Leder

Jørgen Hardang
Komitésekretær

Kopi: Robert Reid, Norges Idrettshøgskole, Pb. 4014 Ullevål stadion, 0806 Oslo

9.5 APPENDIX E: THE SKI EQUIPMENT CHARACTERISTICS

Equipment characteristics

SID ___

Ski brand ___________________________________

Ski model __________________________________

Ski length (cm) ______________________________

Ski width (mm) Tip ___________ Tail ___________

Binding brand _______________________________

Binding model_______________________________

Height of the binding (from the bottom of the ski base to the top of binding) (mm)

Back ______________ Front ___________________

Weight of the ski and binding (kg) _______________ Weight of the boot (kg) __________

Boot brand _________________________________ Sole length (mm) _______________

Boot model_________________________________

Comments: _________________________________

Ski width measured in sections of 10 cm over the entire length of the ski contact

0 10 20 30 40 50 60 70 80 90 100 110

120 130 140 150 160 170

9.6 APPENDIX F: THE PERFORMANCE TIMES

The performance times

Table 9.1: Performance times for the 10 meter and the 13 meter courses.

Subject	Trial	Time 10 m (sec)	Trial	Time 13 m (sec)
1	1	7.03	2	14.63
1	3	7.21	4	8.10
1	5	7.05		
2	6	7.04	7	8.02
2	8	6.96	9	7.89
2	10	6.84	11	8.00
3	47	7.80	48	-
3	49	7.79	50	9.10
3	51	7.70	52	9.09
4	13	8.14	12	8.75
4	15	7.52	14	8.74
4	17	7.58	16	8.72
5	19	7.77	18	9.00
5	21	7.61	20	8.89
5	-	-	22	9.09
6	23	7.69	24	8.57
6	25	7.60	26	8.63
6	27	7.46	28	8.61
7	29	8.03	30	8.88
7	31	7.81	32	8.78
7	33	7.83	34	8.92
8	35	7.73	36	8.87
8	37	7.57	38	9.00
8	39	7.52	40	8.96
9	41	7.45	42	8.94
9	43	7.57	44	8.87
9	45	7.50	46	8.87
10	47	7.80	48	-
10	49	7.79	50	9.10
10	51	7.70	52	9.09
11	60	7.78	59	8.94
11	62	7.61	61	9.02
11	64	7.62	63	9.11

9.7 APPENDIX G: AN OVERVIEW OF THE GROUP RESULTS

An overview of the group results

Table 9.2: The mean kinetic variables, the inside/outside SIR, the inside/outside chatter ratio for the main group, the inside and outside chatter for the 10 meter and the 13 meter course, for turns to the left and to the right relative to the mean bodyweight (BW), timing as % of the turn cycle in time, n=9.

Kinetic variable		10 meter course		13 meter course		
		Left	Right	Left	Right	Total mean
		Mean ± SD				Mean ± SD
Mean unloading force	BW	0.63 ± 0.13	0.61 ± 0.11	0.61 ± 0.11	0.63 ± 0.10	0.62 ± 0.09
Minimum unloading force	BW	0.39 ± 0.16	0.36 ± 0.13	0.37 ± 0.15	0.39 ± 0.13	0.38 ± 0.11
Unloading duration	%	38 ± 7	37 ± 6	37 ± 6	37 ± 7	37 ± 6
Mean loading force	BW	1.84 ± 0.20	1.79 ± 0.20	1.83 ± 0.19	1.79 ± 0.21	1.81 ± 0.13
Mean apex force	BW	2.31 ± 0.18	2.28 ± 0.16	2.33 ± 0.16	2.27 ± 0.16	2.30 ± 0.17
Peak force	BW	2.64 ± 0.28	2.61 ± 0.25	2.65 ± 0.26	2.60 ± 0.28	2.62 ± 0.27
Gate passing	%	51 ± 4	54 ± 6	52 ± 5	52 ± 5	52 ± 5
Timing of apex	%	60 ± 8	65 ± 8	61 ± 8	64 ± 8	62 ± 8
Gate to apex time	%	9 ± 5	11 ± 3	8 ± 4	12 ± 5	10 ± 4
Inside/outside SIR		0.63 ± 0.17	0.59 ± 0.23	0.56 ± 0.21	0.65 ± 0.13	0.61 ± 0.17
Inside/outside CR		1.79 ± 0.85	1.18 ± 0.44	1.44 ± 0.64	1.53 ± 0.64	1.48 ± 0.64
Chatter outside	N	16 ± 4	16 ± 3	15 ± 5	16 ± 4	16 ± 4
Chatter inside	N	24 ± 6	17 ± 4	20 ± 7	20 ± 4	20 ± 5

Table 9.2 show the average kinetic variables for the 10 and the 13 meter course, where both left and right turns were included on the value for the 10 meter course and the 13 meter courses. Similarly, the average kinetic variables for the left and right turns include left turns from the 10 and the 13 meter courses. The right turns were estimated in a similar manner.

The mean loading 1.81 BW, the mean apex 2.30 BW and the peak force 2.62 BW showed a considerable amount of loading in both courses. During the unloading phase, the mean unloading force was 0.62 BW, and minimum force was 0.38 BW. The unloading duration was 37 % of turn cycle in time, and the gate was passed at 52 % of turn cycle in time.

The inside/outside SIR was 0.61, which indicated that the group predominantly loaded the outside ski more than the inside ski. There was more inside than outside ski chatter: the inside/outside CR was 1.48.

9.8 APPENDIX H: RESULTS FOR THE PILOT GROUP

Results for the pilot group

The pilot group subjects were FIS ranked between 134 and 350 in the 2007/08 season. The pilot group was tested on a similar course setting but on a different location of the same hill than the main group. They also had softer snow conditions, with snow temperature which increased from 0 ˚ C to + 2.5 ˚ C.

The unloading phase was characterized by low unloading force, about 66 % of subjects' body weight, and by short duration, 32 % of the turn cycle in time. There was a significant amount of mean loading force during the loading phase (2.09 BW). The mean apex force (2.77 BW) and the peak force (2.94 BW) indicated the high loading for the pilot group. Timing of the apex was 60/63 and 70/66 % of turn cycle in time for 10 meter course (left/right turns) and 13 meter course respectively. The gate passage was 45 % of the turn cycle in time for the 10 meter course, and 50/51 % of turn cycle in time for the 13 meter course, which was slightly earlier than in the main group (48 vs. 52).

The inside/outside impulse ratio showed relatively even force distribution, in average 0.70. The inside ski was loaded about half to two-thirds of the load of the outside ski. On the 10 meter course, there was a trend of more even loading, with a ratio 0.78 while on the 13 meter course, there was a tendency of more loading of the outside ski, ratio 0.62. Mean chatter was small in both courses, and there were no clear differences in turn directions.

Table 9.3: Mean kinetic variables, the inside/outside SIR, the inside/outside chatter ratio, the inside and outside chatter for the 10 meter and the 13 meter course, for the turns to the left and to the right, relative to the mean bodyweight (BW), timing as % of the turn cycle in time, n=2.

Kinetic variable		10 meter	13 meter	Left turn	Right turn	Total mean
			Mean ± SD			Mean ± SD
Mean unloading force	BW	0.67 ± 0.09	0.66 ± 0.10	0.68 ± 0.11	0.65 ± 0.09	0.66 ± 0.01
Minimum unloading force	BW	0.47 ± 0.16	0.43 ± 0.13	0.43 ± 0.14	0.47 ± 0.15	0.43 ± 0.03
Unloading duration	%	32 ± 9	35 ± 3	34 ± 7	33 ± 7	33 ± 2
Mean loading force	BW	2.04 ± 0.12	2.15 ± 0.15	2.08 ± 0.10	2.11 ± 0.20	2.09 ± 0.07
Mean apex force	BW	2.68 ± 0.30	2.85 ± 0.39	2.74 ± 0.32	2.80 ± 0.39	2.77 ± 0.12
Peak force	BW	2.86 ± 0.25	3.03 ± 0.39	2.87 ± 0.31	3.01 ± 0.36	2.94 ± 0.14
Gate passing	%	45 ± 1	51 ± 3	47 ± 4	48 ± 4	48 ± 3
Timing of apex	%	62 ± 4	68 ± 6	66 ± 5	63 ± 7	65 ± 4
Gate to apex time	%	17 ± 4	17 ± 4	19 ± 4	15 ± 4	17 ± 2
Inside/outside SIR		0.78 ± 0.22	0.62 ± 0.18	0.62 ± 0.14	0.78 ± 0.25	0.70 ± 0.14
Inside/outside CR		1.40 ± 0.30	1.07 ± 0.08	1.12 ± 0.39	1.03 ± 0.50	1.08 ± 0.38
Chatter outside	N	8 ± 3	9 ± 3	8 ± 2	10 ± 4	9 ± 1
Chatter inside	N	12 ± 6	10 ± 2	9 ± 4	10 ± 6	10 ± 3

Table 9.3 show the average kinetic variables for the 10 and the 13 meter course, where both left and right turns were included on the value for the 10 meter course and the 13 meter courses. Similarly, the average kinetic variables for the left and right turns, include left turns from the 10 and the 13 meter courses. The right turns were estimated in a similar manner.

Table 9.4: The kinetic variables for the pilot group related to the bodyweight (BW) and the timing as % of the turn cycle in time, means ± SD, comparisons of means for the 10 meter and the 13 m courses, n=2.

Kinetic variable		**10 meter course**		**13 meter course**	
		Left	**Right**	**Left**	**Right**
		Mean ± SD			
Mean unloading force	BW	0.68 ± 0.14	0.65 ± 0.08	0.67 ± 0.13	0.66 ± 0.13
Minimum unloading force	BW	0.45 ± 0.19	0.49 ± 0.18	0.41 ± 0.18	0.45 ± 0.17
Unloading duration	%	32 ± 11	32 ± 11	35 ± 4	34 ± 5
Mean loading force	BW	2.07 ± 0.17	2.02 ± 0.09	2.10 ± 0.06	2.19 ± 0.23
Mean apex force	BW	2.70 ± 0.44	2.66 ± 0.27	2.77 ± 0.34	2.93 ± 0.56
Peak force	BW	2.83 ± 0.40	2.88 ± 0.18	2.91 ± 0.34	3.15 ± 0.53
Gate passing	%	45 ± 1	45 ± 1	50 ± 4	51 ± 4
Timing of apex	%	63 ± 5	60 ± 3	70 ± 2	66 ± 10
Gate to apex time	%	19 ± 6	15 ± 4	19 ± 2	15 ± 6
Inside/outside SIR		0.72 ± 0.04	0.84 ± 0.37	0.52 ± 0.12	0.72 ± 0.21
Inside/outside CR		1.45 ± 0.61	1.35 ± 0.16	0.79 ± 0.09	0.71 ± 0.00
Chatter outside	N	7 ± 1	9 ± 5	9 ± 3	11 ± 5
Chatter inside	N	11 ± 6	13 ± 8	7 ± 1	8 ± 4

The mean unloading force was 67 % and the minimum unloading force was 45 % of the effective body weight during unloading phase. Mean unloading phase was 32 % of the turn cycle in time on the 10 meter course, and 35 % of the turn cycle in time on the 13 meter course.

The mean loading force was 2.1 times effective body weight. On the 10 meter course, the mean force was slightly less than on the 13 meter course. The timing of the apex was earlier on the 10 meter course than on the 13 meter course, and earlier in the right turns than in the left turns. The mean apex force was 2.8 times effective body weight. It was slightly less on the 10 meter course than on the 13 meter course. The peak force was 2.9 times effective body weight and was slightly less on the 10 meter course than on the 13 meter course. The peak force was higher in the right turns than in the left turns.

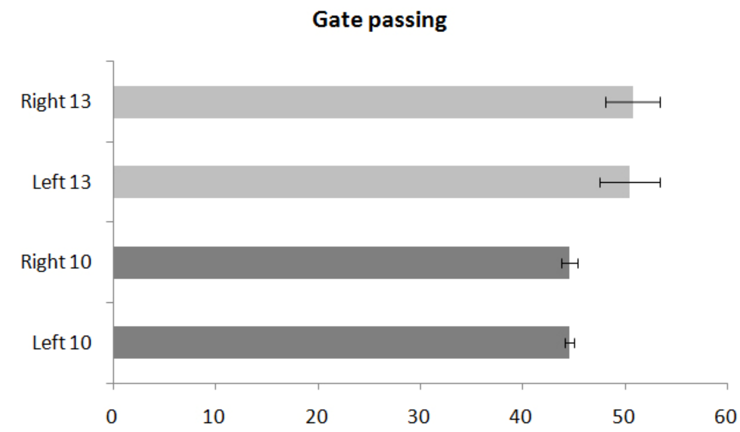


Figure 9.1: The gate passing, means and SEM, n=2.

Timing from the gate passage to the apex was 17 % of the turn cycle and there were no differences between courses or turn directions. The mean gate passing for the pilot group occurred at 48 % of the turn cycle in time. Figure 9.1 show the gate passing which was delayed on the 13 meter course than on the 10 meter course.

Inside/outside impulse ratio for pilot group was 0.70. More outside ski loading was present in the left turns compared to right turns, Figure 9.2. On the 13 meter course, there was more outside ski loading than on the 10 meter course. The standard error of the mean in the Figure 9.2 was large, possibly because subject 1 loaded the inside ski extensively in the right turns.

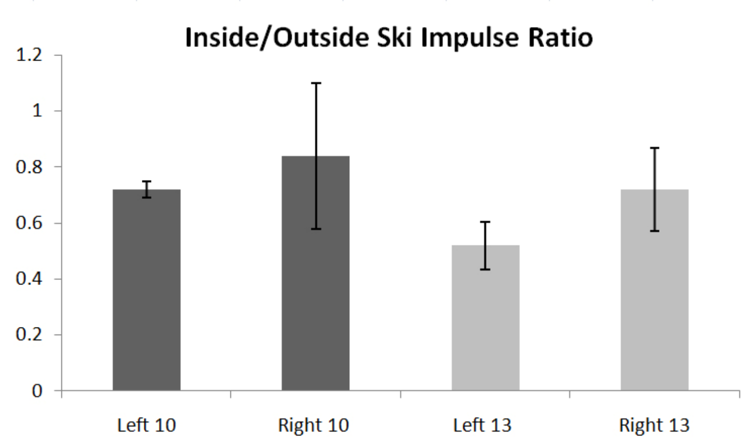


Figure 9.2: The inside/outside impulse ratio, mean ± SEM, n=2.

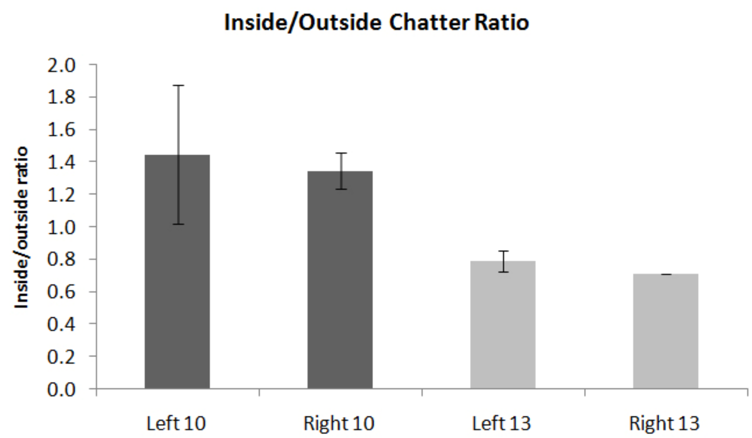


Figure 9.3: The inside/outside CR, mean ± SEM, n=2.

The mean chatter of the outside ski was 9 N, and mean chatter of the inside ski was 10 N. There was a trend of more inside ski chatter on the 10 meter course than on the 13 meter course, which led to higher the inside/outside CR on the 10 meter course in both turn directions, Figure 9.3.

9.9 APPENDIX I: THE SINGLE-SUBJECT RESULTS

Single-subject results

9.9.1 Subject 1 (Pilot Group)

Due to severe injury to the left foot, the subject was forced to retire from skiing.

9.9.1.1 Total kinetic variables

Table 9.5 show that subject one had a short unloading phase on the 10 meter course, only 24 % of the turn cycle in time. The unloading phase lasted significantly longer on the 13 meter course than on the 10 meter course (p=.03 and p=.008 for left and right turns). Timing of the apex was significantly earlier on the 10 meter course in both turn directions (p=.036 in left and p=.015 in right turns). Even though significant differences were found between the turn directions in both courses (p=.0001 and p=.018 for 10 and 13 m course), there was no clear trend of the direction; mean loading force was larger in left turns on the 10 meter course, but larger in right turns on the 13 meter course. Timing of apex and from the gate to the apex time, the mean apex and the peak force showed the same trend: there was more force, and/or later timing in the left turns on the 10 meter course, but more force and/or later timing in the right turns on the 13 meter course, Figure 9.4. Both the mean apex and the peak force were higher than the pilot group average in both courses (mean apex force 3.05 vs. 2.77 BW and peak force 3.20 vs. 2.94).The subject had a base of 9 turns each direction on the 10 meter course and only 5 on the 13 meter course due to limitation of the data log capacity. The small amount of trials analyzed may explain the inconsistency of the results.

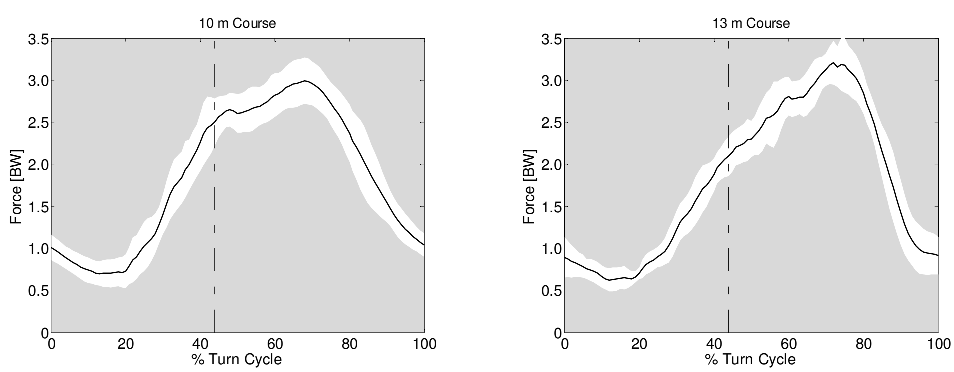


Figure 9.4: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, SID 1, ± SD (white area).

Table 9.5: The kinetic variables, means ± SD, unpaired t-tests, n=9 in the 10 meter and n=5 on the 13 meter course, SID 1. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		**10 meter course**		**13 meter course**		**Unpaired**
		Left	**Right**	**Left**	**Right**	**t-tests**
Subject 1		**Mean ± SD**				**(p)**
Mean unloading force	BW	0.78 ± 0.08	0.71 ± 0.27	0.75 ± 0.05	0.76 ± 0.08	-
Minimum unloading force	BW	0.58 ± 0.13	0.62 ± 0.14	0.53 ± 0.08	0.57 ± 0.12	-
Unloading duration	%	24 ± 7	24 ± 3	33 ± 5	31 ± 5	$.033_L$ $.008_R$
Mean loading force	BW	2.19 ± 0.12	2.08 ± 0.09	2.15 ± 0.06	2.35 ± 0.07	$.018_L$ $.0001_R$ $.0001_{10}$ $.012_{13}$
Mean apex force	BW	3.01 ± 0.18	2.86 ± 0.14	3.01 ± 0.16	3.32 ± 0.16	$.0001_R$ $.003_{10}$ $.015_{13}$
Peak force	BW	3.11 ± 0.19	3.00 ± 0.16	3.15 ± 0.21	3.52 ± 0.25	$.0005_R$ $.005_{10}$ $.035_{13}$
Gate passing	%	44 ± 1	44 ± 2	53 ± 2	53 ± 2	$.000001_L$ $.000001_R$
Timing of apex	%	67 ± 3	62 ± 8	71 ± 3	72 ± 3	$.036_L$ $.015_R$ $.11_{10}$
Gate to apex time	%	23 ± 4	18 ± 6	18 ± 4	19 ± 2	$.031_L$ $.10_{10}$

9.9.1.2 The inside/outside ski impulse ratio

In average, the subject one had an even force distribution in both skis, Figure 9.5. Subject one loaded the skis quite evenly, mean ratio 0.85. In the right turns on the 10 meter course, the inside ski was heavily loaded, mean ratio 1.10.

There was significantly more loading of the outside ski in the left turns than in the right turns in both courses (p=.048 and p=.010 for 10 and 13 m course), Figure 9.6.

Table 9.6: The inside/outside SIR. Means ± SD, paired t-tests, SID 1.

Inside/Outside SIR	**10 meter course**		**13 meter course**		
	Left	**Right**	**Left**	**Right**	**Paired t-tests**
Subject 1	**Mean ± SD**				**(p)**
	0.75 ± 0.23	1.10 ± 0.29	0.60 ± 0.09	0.86 ± 0.13	$.065_L$ $.062_R$ $.048_{10}$ $.01_{13}$

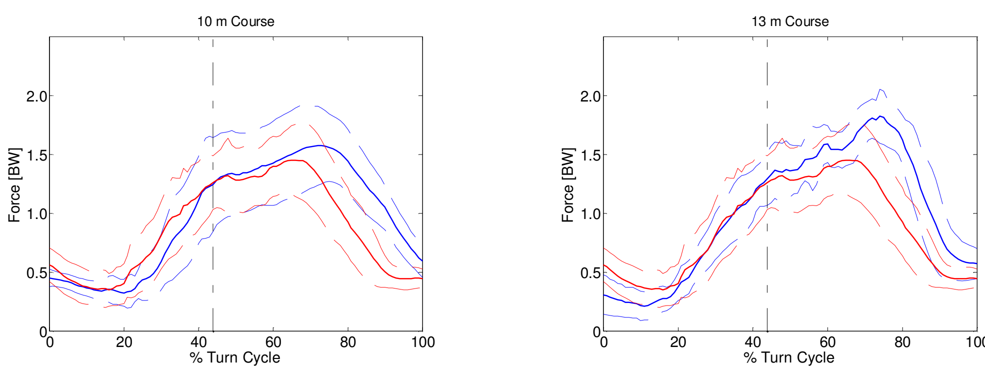


Figure 9.5: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 1.

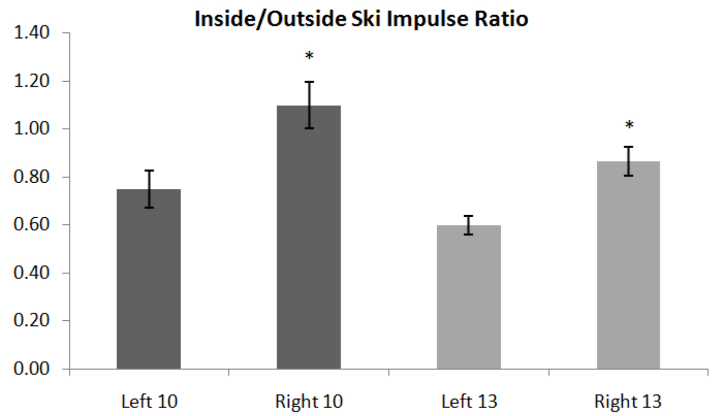


Figure 9.6: The inside/outside SIR, means and SEM, SID 1.

9.9.1.3 The chatter

Subject one had relatively diminutive mean residuals (chatter) both the outside and the inside ski compared to the other subject in the pilot group. There was more inside ski chatter on the 10 meter course than on the 13 meter course. Significantly more inside ski chatter in the right turns was evident on the 10 meter course than on the 13 meter course (p=.007) and a greater inside/outside CR in the right turns (p=.03). There was a trend of more inside/outside CR in the left turns as well (Table 9.7).

Table 9.7: The chatter variables of the outside and the inside ski, means ± SD, unpaired t-tests used in the inside and the outside ski chatter, paired t-tests used in the inside/outside CR, SID 1.

Subject 1 Chatter	10 meter course Left	Right	13 meter course Left	Right	T-tests (p)
	Mean ± SD				
Chatter outside (N)	6 ± 2	6 ± 2	7 ± 1	7 ± 2	$.117_L$
Chatter inside (N)	6 ± 2	7 ± 2	6 ± 3	5 ± 1	$.007_R$
Inside/Outside CR	1.20 ± 0.55	1.26 ± 0.23	0.88 ± 0.33	0.69 ± 0.17	$.159_L$ $.03_R$

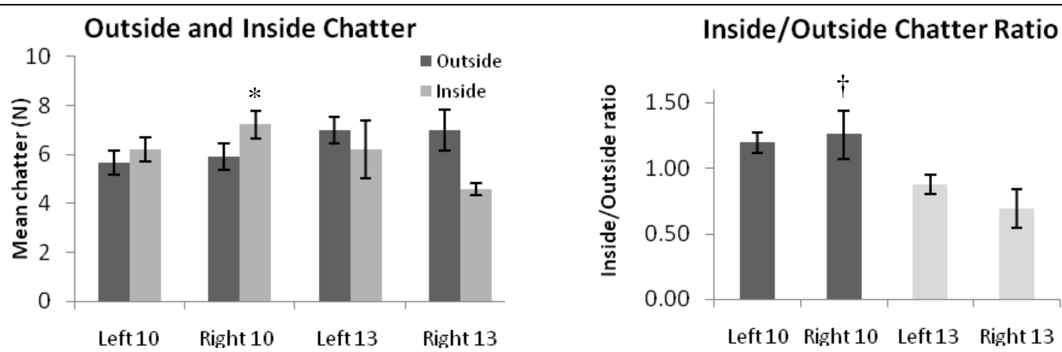


Figure 9.7: The outside and inside chatter and the inside/outside CR, means and SEM, SID 1.

9.9.2 Subject 2 (pilot group)

Subject 2 is left leg dominant, with a previous injury on the right foot.

9.9.2.1 Total kinetic variables

Subject 2 had a longer unloading phase and lower mean and minimum unloading forces. In the loading phase, the subject had lower forces and earlier timing of the apex in comparison to the other subject of the pilot group.

For subject 2, there was significantly more force and a later timing of the apex and timing of the gate passage on the 13 meter course than on the 10 meter course, Table 9.8 and Figure 9.7. The mean loading force in turns to the left was significantly larger on the 13 meter course than on the 10 meter course (2.06 vs. 1.94 BW, p=.001). The mean apex force was significantly larger in left turns on the 13 meter course than on the 10 meter course (2.39 vs. 2.53 BW, p=.002). Timing of the apex was significantly later in the left turns on the 13 meter course than on the 10 meter course (60 vs. 68 % of turn cycle time, p=.003), and it was also significantly later in the left turns than in the right turns on the 13 meter course (68 vs. 59 % of turn cycle in time, p=.003). Gate passing was later on the 13 meter course than on the 10 meter course regardless of the turn direction (p=.035 and p=.031).

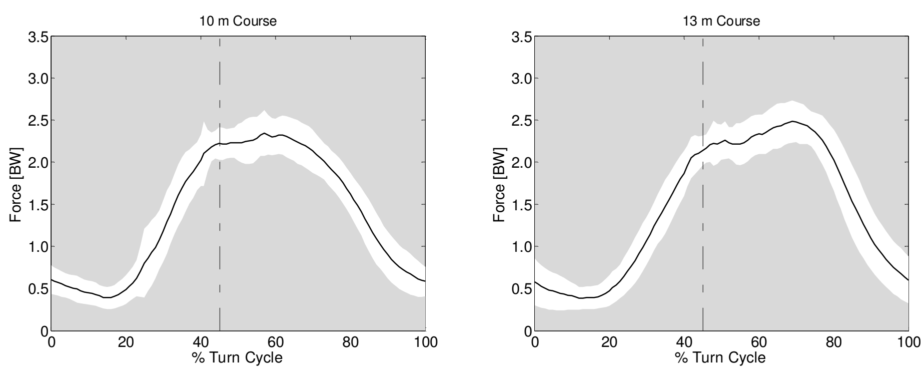


Figure 9.8: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 2.

Table 9.8: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 2. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 2		Mean ± SD				(p)
Mean unloading force	BW	0.58 ± 0.07	0.60 ± 0.07	0.56 ± 0.06	0.58 ± 0.08	-
Minimum unloading force	BW	0.31 ± 0.10	0.36 ± 0.11	0.30 ± 0.08	0.33 ± 0.09	.14$_{13}$
Unloading duration	%	40 ± 4	40 ± 7	38 ± 6	38 ± 6	.19L
Mean loading force	BW	1.94 ± 0.10	1.96 ± 0.09	2.06 ± 0.07	2.03 ± 0.14	.001$_{L}$ .15$_{R}$
Mean apex force	BW	2.39 ± 0.10	2.47 ± 0.18	2.53 ± 0.13	2.53 ± 0.21	.002$_{L}$ .14$_{10}$
Peak force	BW	2.55 ± 0.12	2.75 ± 0.41	2.66 ± 0.17	2.77 ± 0.27	.054$_{L}$ .084$_{10}$ .19$_{13}$
Gate passing	%	45 ± 3	45 ± 4	48 ± 3	48 ± 3	.035$_{L}$ .031$_{R}$
Timing of apex	%	60 ± 8	58 ± 7	68 ± 7	59 ± 9	.003$_{L}$ .003$_{13}$
Gate to apex time	%	15 ± 8	12 ± 6	21 ± 8	11 ± 9	.046$_{L}$ .003$_{13}$

9.9.2.2 The inside/outside ski impulse ratio

The mean inside/outside SIR for subject 2 was 0.57, indicating that the subject loaded more on the outside ski than the inside ski, which was loaded with half of the load of the outside ski, Table 9.9 and Figure 9.9. Compared to the other subject of the pilot group, subject 2 distributed the ski force mainly on the outside ski.

There was more outside ski loading in the left turns on the 13 meter course than on the 10 meter course (0.43 vs. 0.69, p=.009) Figure 9.9. On the 13 meter course, the subject loaded the outside ski more in the left turns than in the right turns (0.57 vs. 0.43, p=.039).

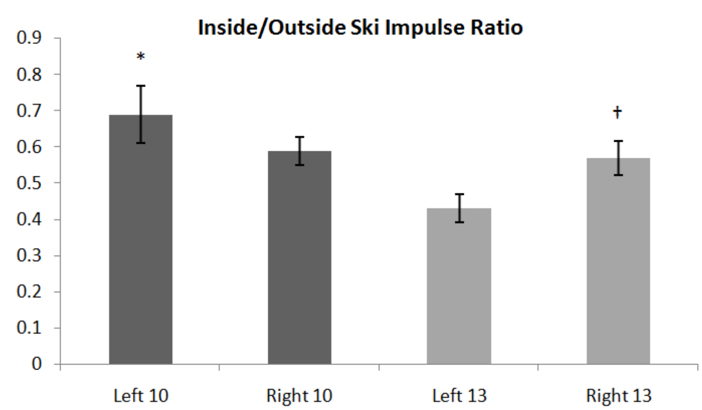


Figure 9.9: The inside/outside SIR, means and SEM, SID 2.

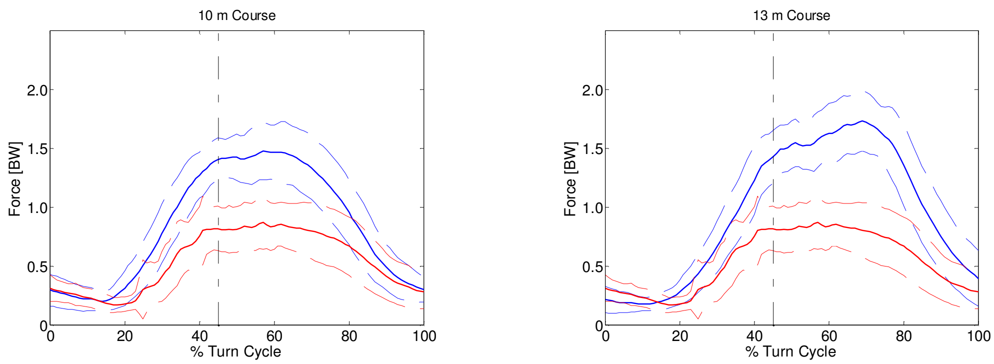


Figure 9.10: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 2.

Table 9.9: The inside/outside SIR. Means ± SD, paired t-tests, SID 2.

Subject 2	**10 meter course**		**13 meter course**		**Paired t-test (p)**
	Left	**Right**	**Left**	**Right**	
	Mean ± SD				
Inside/outside SIR	0.69 ± 0.31	0.59 ± 0.15	0.43 ± 0.15	0.57 ± 0.18	$.009_L$ $.144_{10}$ $.039_{13}$

9.9.2.3 The chatter

A high degree of chatter of the inside ski characterizes subject 2 on the 10 meter course, Figure 9.11. There was significantly more outside ski chatter in the left turns on the 13 meter course than on the 10 meter course (p=.002) and there was significantly more outside chatter in the right turns than in the left turns in both courses (p=.0001 and p=.004 for 10 and 13 meter courses). Large inside ski chatter on the 10 meter course than on the 13 meter course was evident in both turn directions (p=.0003 and p=.001 for left and right turns Figure 9.11). The inside/outside CR was significantly larger on the 10 meter course than 13 meter course (p=.0003 and p=.0002 for left and right turns).

Table 9.10: Chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 2.

Subject 2 Chatter	**10 meter course**		**13 meter course**		**T-tests (p)**
	Left	**Right**	**Left**	**Right**	
	Mean ± SD				
Chatter outside (N)	8 ± 2	13 ± 3	11 ± 2	14 ± 3	$.002_L$ $.0001_{10}$ $.004_{13}$
Chatter inside (N)	15 ± 7	19 ± 9	8 ± 2	10 ± 4	$.0003_L$ $.001_R$ $.061_{13}$
Inside/Outside CR	1.86 ± 0.85	1.48 ± 0.52	0.72 ± 0.20	0.73 ± 0.25	$.0003_L$ $.0002_R$ $.096_{10}$

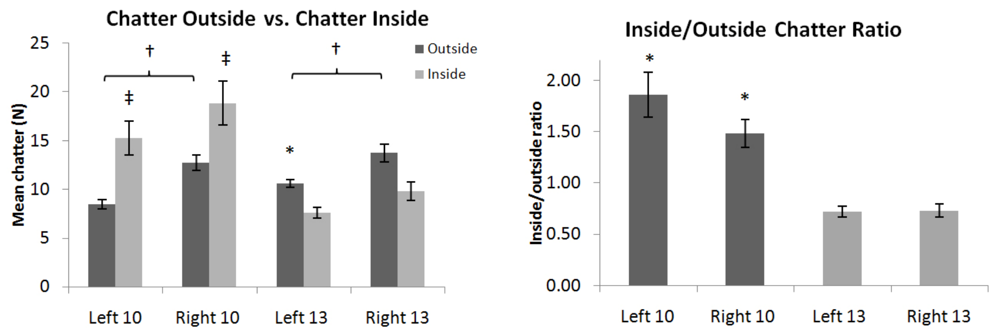


Figure 9.11: The outside and inside chatter and the inside/outside CR, means and SEM, SID 2.

9.9.3 Subject 3

Subject 3 is right leg dominant, with injuries in the ACL and the menisci of the right knee.

9.9.3.1 Total kinetic variables

Table 9.11 shows that the total kinetic variables for subject 3 were similar to the "average skier" which represent the average skier of the main group. The mean apex and the peak forces were larger (2.46 vs. 2.30 BW and 2.86 vs. 2.62 BW respectively). There was significantly less unloading in the right turns than in the left turns in both courses i.e. higher unloading force (p=.006 and p=.020 for 10 and 13 meter courses). This was also apparent in the minimum unloading force (larger in the right turns in both courses p=.00005 and p=.001 for 10 and 13 meter courses).

The unloading duration was significantly shorter in the right turns on the 10 meter course than on the 13 meter course (31 vs. 36 % of turn cycle in time, p=.023). There was also significantly less loading, as the mean loading force was lower in the right turns on the 10 meter course than on the 13 meter course (1.85 vs. 2.02 BW, p=.005). The peak force was lower in the right turns than in the left turns in both courses (2.73 vs. 3.12 BW, p=.003 on the 10 meter course and 2.69 vs. 2.90 BW, p=.044 on the 13 meter course). The gate passing was significantly delayed on the 13 meter course than on the 10 meter course (p=.044 and p=.026 for left and right turns), Figure 9.12.

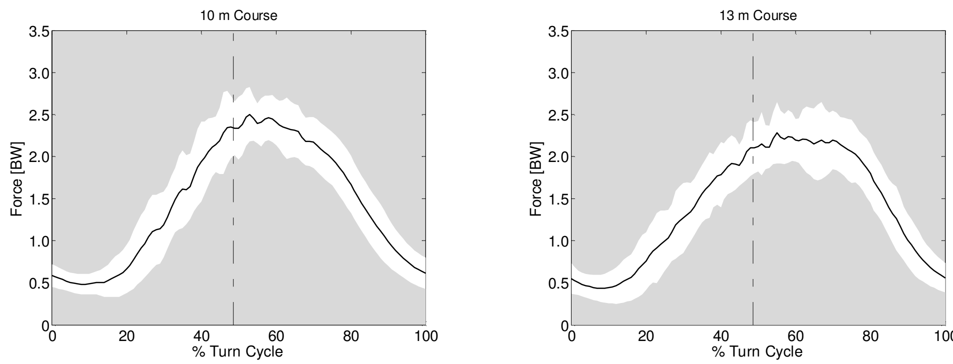


Figure 9.12: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 3.

Table 9.11: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 3. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 3		Mean ± SD				(p)
Mean unloading force	BW	0.60 ± 0.07	0.67 ± 0.06	0.55 ± 0.08	0.62 ± 0.07	$.093_L$ $.062_R$ $.006_{10}$ $.02_{13}$
Minimum unloading force	BW	0.31 ± 0.04	0.44 ± 0.09	0.28 ± 0.07	0.40 ± 0.09	$.00005_{10}$ $.001_{13}$
Unloading duration	%	38 ± 4	36 ± 5	38 ± 3	31 ± 6	$.023_R$ $.001_{13}$
Mean loading force	BW	2.02 ± 0.17	1.96 ± 0.14	1.85 ± 0.12	1.87 ± 0.11	$.005_L$ $.056_R$
Mean apex force	BW	2.57 ± 0.18	2.50 ± 0.23	2.40 ± 0.20	2.38 ± 0.20	$.023_L$ $.12_R$
Peak force	BW	3.12 ± 0.38	2.73 ± 0.28	2.90 ± 0.28	2.69 ± 0.26	$.073_L$ $.003_{10}$ $.044_{13}$
Gate passing	%	49 ± 5	49 ± 5	52 ± 5	54 ± 6	$.044_L$ $.026_R$
Timing of apex	%	56 ± 7	57 ± 7	61 ± 9	61 ± 9	$.096_L$ $.19_R$
Gate to apex time	%	8 ± 8	8 ± 4	9 ± 8	7 ± 9	-

9.9.3.2 The inside/outside ski impulse ratio

The mean inside/outside SIR (0.75) was larger than the average skier (0.61). The inside/outside SIR indicated greater loading of outside ski in the right turns compared to the left turns, Table 9.12 . A greater degree of loading of both skis was evident on the 10 meter course than on the 13 meter course, regardless of the turn direction (p=.013 and p=.009 left and right turns), Figure 9.13. In the right turns, a greater outside ski loading was apparent compared to the turns to the left in both courses (p=.00008 and p=.007 for 10 and 13 meter course respectively) Figure 9.14.

Table 9.12: The inside/outside SIR, means ± SD, paired t-tests, SID 3.

Subject 3	10 meter course		13 meter course		Paired
	Left	Right	Left	Right	t-test
	Mean ± SD				(p)
Inside/Outside SIR	0.97 ± 0.12	0.67 ± 0.17	0.83 ± 0.15	0.53 ± 0.18	$.013_L$ $.009_R$ $.00008_{10}$ $.007_{13}$

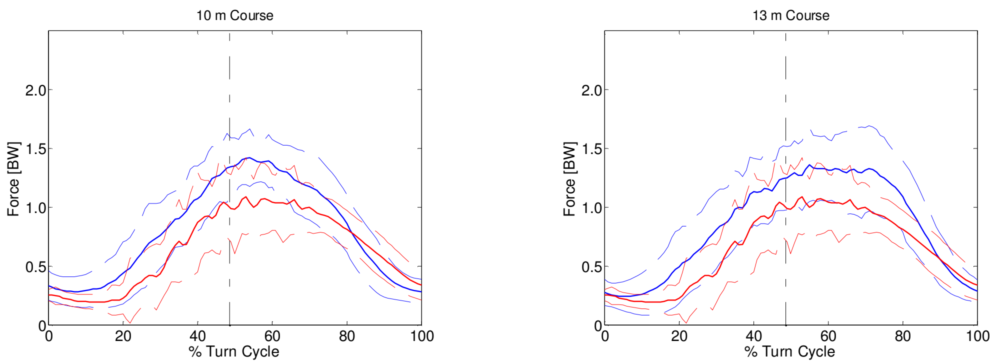


Figure 9.13: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 3.

9.9.3.1 The chatter

Compared to the group average, subject 3 had greater amount of chatter; the mean outside chatter was 21 vs. 16, the inside chatter was 27 vs. 20, Table 9.13. However, the inside/outside CR was alike the average skier (1.44 vs. 1.48). Subject's two first trials for each course were characterized by large mean chatter, especially in the turns to the left. The outside ski chatter was greater in the left turns than in the right turns in both courses (p=.03 and p=.005 for 10 and 13 meter courses respectively) Figure 9.15. The inside chatter in the left turns was also significantly greater on the 10 meter course than on the 13 meter course (p=.0005). There was significantly more inside ski chatter in the left turns on the 10 meter course, Figure 9.15.

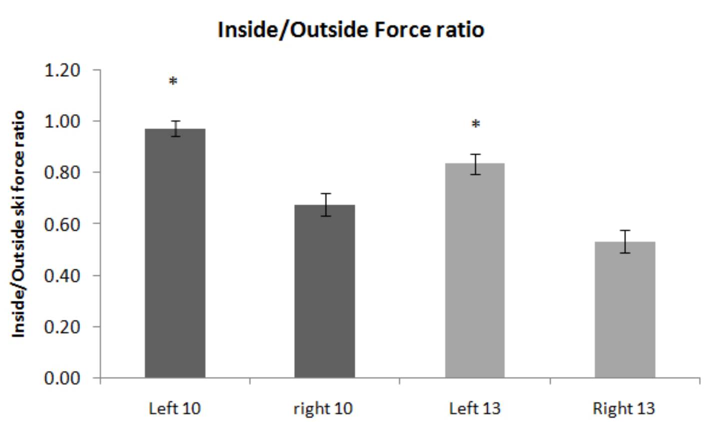
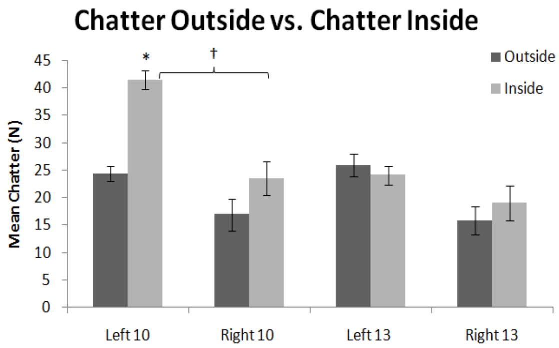


Figure 9.14: The inside/outside SIR, means and SEM, SID 3.



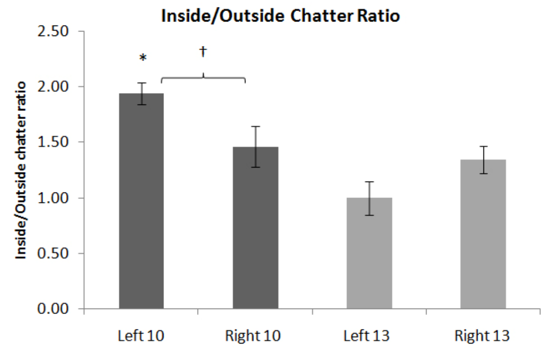


Figure 9.15: The outside and inside chatter and the inside/outside CR, means and SEM, SID 3.

Table 9.13: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 3.

Subject 3	**10 meter course**		**13 meter course**		**T-tests (p)**
Chatter	**Left**	**Right**	**Left**	**Right**	
		Mean ± SD			
Chatter outside (N)	24 ± 11	17 ± 6	26 ± 10	16 ± 8	$.030_{10}$ $.005_{13}$
Chatter inside (N)	41 ± 12	23 ± 6	24 ± 12	19 ± 7	$.0005_{L}$ $.067_{R}$ $.00002_{10}$ $.162_{13}$
Inside/Outside CR	1.94 ± 0.72	1.46 ± 0.39	1.00 ± 0.47	1.34 ± 0.58	$.001_{L}$ $.049_{10}$ $.096_{13}$

9.9.4 Subject 4

Subject 4 is left leg dominant, with no injuries within the last 5 years.

9.9.4.1 Total kinetic variables

Compared to the group average, subject 4 had less mean unloading and minimum force (0.62 vs. 0.49 BW, 0.38 and 0.19 BW), longer unloading phase (37 vs. 46 % of turn cycle in time), and less mean loading force (1.81 vs. 1.73 BW), mean apex (2.30 vs. 2.12 BW) and peak force (2.62 vs. 2.43 BW), Table 9.14. There was more loading force in the right turns on the 10 meter course than on the 13 meter course, Figure 9.16. The loading force, the apex force and the peak force were all significantly larger in the right turns on the 10 meter course than on the 13 meter course (p=.007, p=.008 and p=.011, respectively). Timing of the apex was significantly delayed in right turns than in left turns on the 10 meter course (54 vs. 63 % of turn cycle in time, p=.027).

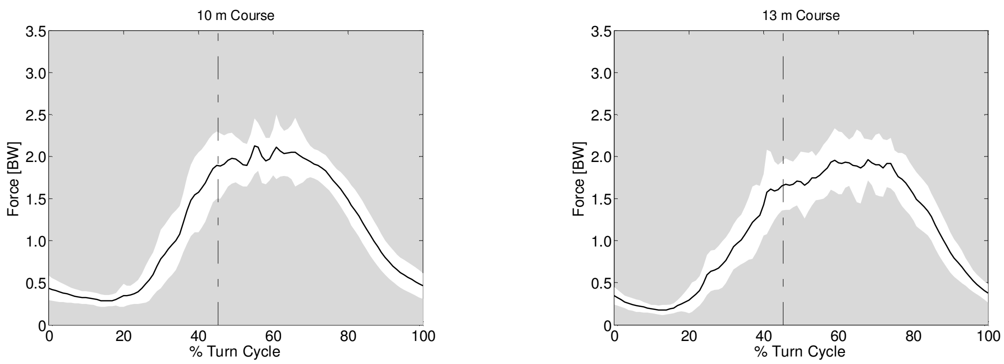


Figure 9.16: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 4.

Table 9.14: The kinetic variables, means ± SD, unpaired t-tests, n=10 in the 10 meter and 5 on the 13 meter course, SID 4. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 4		Mean ± SD				(p)
Mean unloading force	BW	0.50 ± 0.03	0.52 ± 0.07	0.45 ± 0.08	0.48 ± 0.03	$.079_{L}$
Minimum unloading force	BW	0.25 ± 0.04	0.23 ± 0.06	0.15 ± 0.05	0.15 ± 0.05	$.002_{L}$ $.03_{R}$
Unloading duration	%	46 ± 3	47 ± 3	46 ± 6	46 ± 8	-
Mean loading force	BW	1.82 ± 0.07	1.73 ± 0.10	1.82 ± 0.11	1.55 ± 0.10	$.007_{R}$ $.032_{10}$ $.004_{13}$
Mean apex force	BW	2.24 ± 0.16	2.16 ± 0.19	2.22 ± 0.09	1.85 ± 0.14	$.008_{R}$ $.001_{13}$
Peak force	BW	2.49 ± 0.22	2.66 ± 0.31	2.46 ± 0.10	2.11 ± 0.39	$.011_{R}$ $.166_{10}$ $.092_{13}$
Gate passing	%	46 ± 4	44 ± 3	54 ± 5	53 ± 3	$.006_{L}$ $.001_{R}$
Timing of apex	%	54 ± 10	63 ± 7	63 ± 13	68 ± 6	$.17_{L}$ $.027_{10}$
Gate to apex time	%	8 ± 8	19 ± 7	8 ± 9	15 ± 5	$.003_{10}$

9.9.4.2 The inside/outside ski impulse ratio

Table 9.15 shows that subject 4 loaded the outside ski more than the average skier. The mean inside/outside SIR for subject 4 was 0.57, which was slightly less than the group mean (0.61). The greater outside ski loading was apparent in the right turns (lower ratio) in both courses, Figure 9.18.

Table 9.15: The inside/outside SIR. Means ± SD, paired t-tests, SID 4.

Subject 4	10 meter course		13 meter course		Paired t-test
	Left	Right	Left	Right	(p)
	Mean ± SD				
Inside/outside SIR	0.68 ± 0.20	0.50 ± 0.12	0.69 ± 0.22	0.41 ± 018	$.178_{R}$ $.021_{10}$ $.073_{13}$

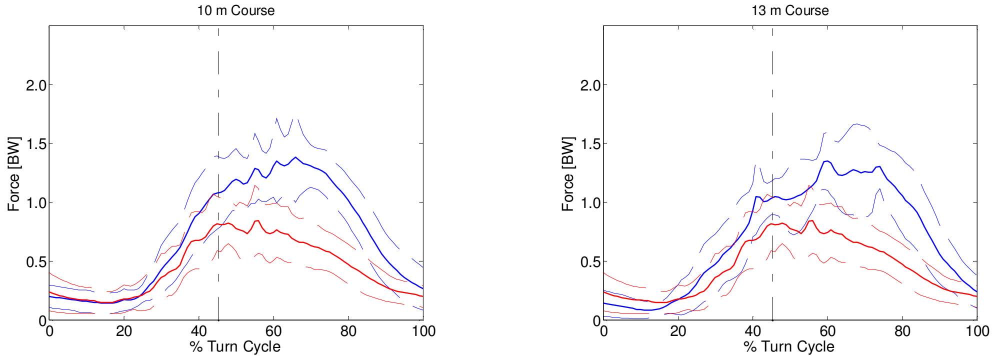


Figure 9.17: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 4.

9.9.4.1 The chatter

The mean inside/outside CR was larger than for the average skier (1.66 vs. 1.48). Both the mean outside and inside chatter were identical to the group average. There was significantly more inside ski chatter in the right turns on the 10 meter course than on the 13 meter course (p=.0003), contributing to the higher chatter ratio in right turns (p=.035). Similar trend was apparent in the left turns (p=.071), Figure 9.19. The chatter of the inside ski was significantly larger in the right turns than in the left turns on the 10 meter course (p=.033) Figure 9.19.

Table 9.16: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 4.

Subject 4 Chatter	**10 meter course Left**	**Right**	**13 meter course Left**	**Right**	**T-tests (p)**
		Mean ± SD			
Chatter outside (N)	12 ± 6	23 ± 20	15 ± 10	14 ± 14	$.105_{10}$
Chatter inside (N)	22 ± 7	29 ± 6	18 ± 10	13 ± 6	$.0003_{R}$ $.033_{10}$
Inside/Outside CR	2.14 ± 1.42	1.98 ± 1.25	1.28 ± 0.26	1.22 ± 0.56	$.035_{R}$ $.071_{L}$

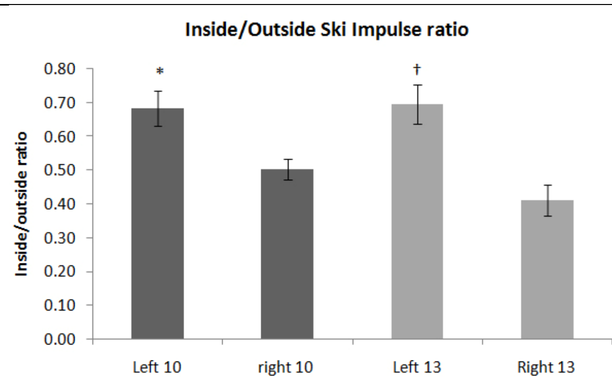


Figure 9.18: The inside/outside SIR, means and SEM, SID 4.

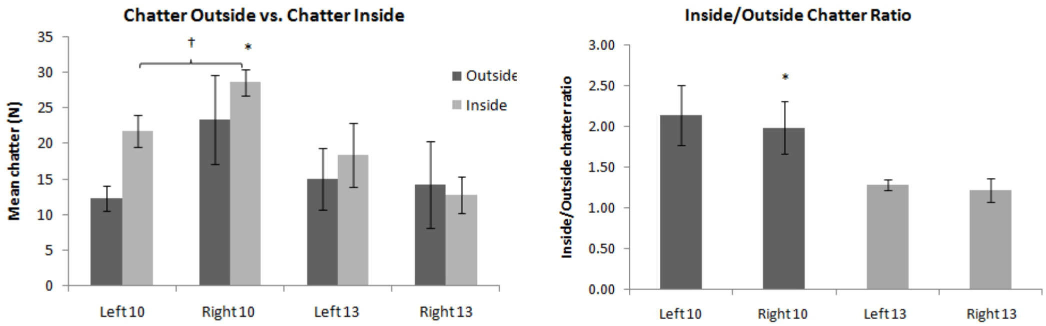


Figure 9.19: The outside and inside chatter and the inside/outside CR, means and SEM, SID 4.

9.9.5 Subject 5

Subject 5 is left leg dominant. The subject had an ACL ligament tear of the left knee during the season 07/08.

9.9.5.1 Total kinetic variables

There was less loading force for subject 5 than the average skier; mean loading force (1.68 vs. 1.81 BW), mean apex force (2.06 vs. 2.30 BW) and peak force (2.29 vs. 2.62), Table 9.17. The subject had a longer unloading phase (45 vs. 37 % of turn cycle in time) and lower unloading force (0.54 vs. 0.62 BW) and lower minimum force (0.28 vs. 0.38 BW). Earlier timing of apex on the 10 meter course was apparent regardless of the turn direction (p=.0001 and p=.001 for left and right turns) Figure 9.20.

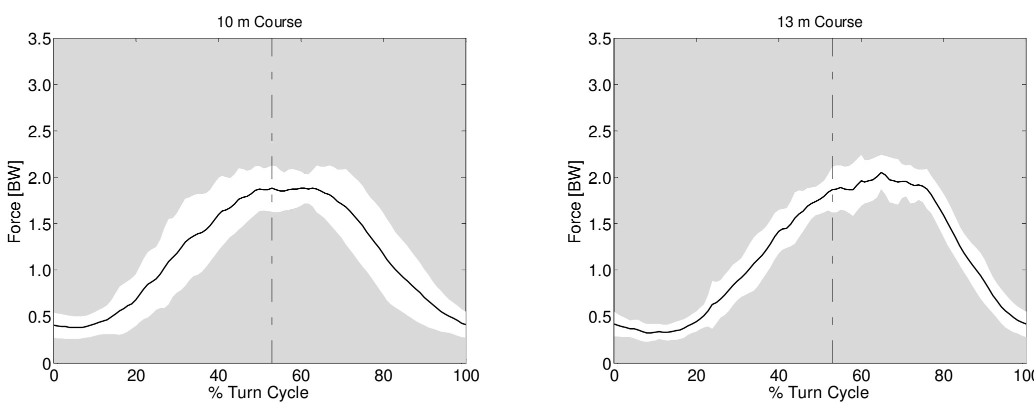


Figure 9.20: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 5.

Table 9.17: The kinetic variables, means ± SD, and unpaired t-tests, n=10 in the 10 meter, n=15 on the 13 meter course SID 5. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 5		Mean ± SD				(p)
Mean unloading force	BW	0.55 ± 0.08	0.51 ± 0.05	0.57 ± 0.05	0.54 ± 0.05	$.16_{R}$
Minimum unloading force	BW	0.30 ± 0.07	0.26 ± 0.04	0.29 ± 0.03	0.27 ± 0.07	-
Unloading duration	%	46 ± 4	45 ± 6	43 ± 6	46 ± 6	$.18_{13}$
Mean loading force	BW	1.74 ± 0.05	1.65 ± 0.05	1.65 ± 0.11	1.68 ± 0.09	$.019_{L}$ $.002_{10}$
Mean apex force	BW	2.08 ± 0.11	2.03 ± 0.09	2.06 ± 0.15	2.08 ± 0.13	-
Peak force	BW	2.36 ± 0.18	2.24 ± 0.27	2.29 ± 0.29	2.25 ± 0.15	-
Gate passing	%	51 ± 3	50 ± 3	56 ± 4	56 ± 5	$.004_{L}$ $.007_{R}$
Timing of apex	%	47 ± 12	55 ± 10	65 ± 8	66 ± 6	$.0001_{L}$ $.001_{R}$ $.11_{10}$
Gate to apex time	%	-4 ± 10	5 ± 9	9 ± 8	11 ± 5	$.002_{L}$ $.05_{R}$ $.05_{10}$

9.9.5.2 The inside/outside ski impulse ratio

There was a significant difference in the turn directions with a greater loading of the outside ski in the left turns, and loading of both skis in the right turns (p=.0003 and p=.0002 for 10 and 13 meter courses) Table 9.18. The mean inside/outside SIR was lower than for the average skier (0.59 vs. 0.61).

Table 9.18: The inside/outside SIR. Means ± SD, paired t-tests, SID 5.

Subject 5	10 meter course		13 meter course		Paired t-test (p)
	Left	Right	Left	Right	
	Mean ± SD				
Inside/outside SIR	0.43 ± 0.13	0.81 ± 0.18	0.43 ± 0.17	0.70 ± 0.19	$.148_{R}$ $.0003_{10}$ $.0002_{13}$

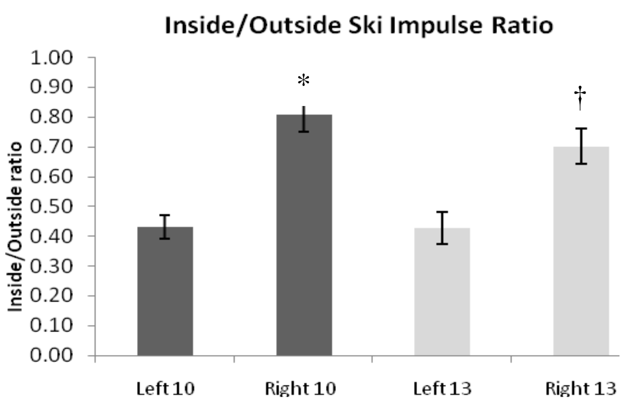


Figure 9.21: The inside/outside SIR, means and SEM, SID 5.

Subject 5 had a greater loading of the outside ski in turns to the left and higher ratio than the average skier in the right turns, Figure 9.21.

9.9.5.3 The chatter

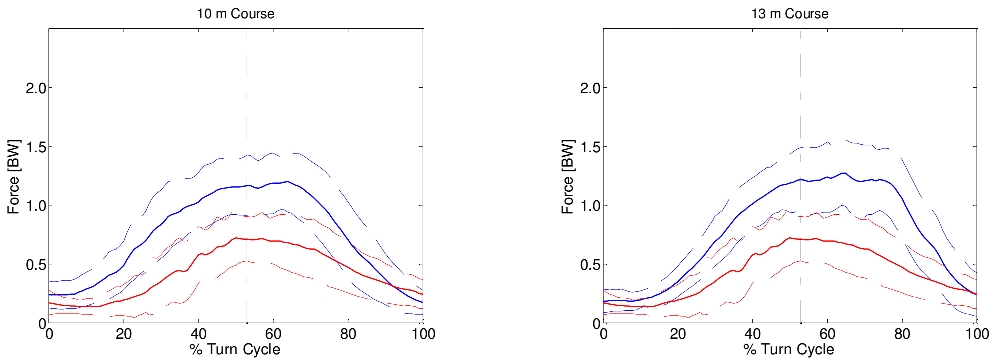


Figure 9.22: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 5.

There was larger inside ski chatter on the 10 meter course than on the 13 meter course, although the difference was only significant in the right turns (p=.0001), Figure 9.23.

Table 9.19: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 5.

Subject 5 Chatter	10 meter course Left	Right	13 meter course Left	Right	T-tests (p)
	Mean ± SD				
Chatter outside (N)	10 ± 2	10 ± 8	10 ± 3	11 ± 3	-
Chatter inside (N)	16 ± 7	18 ± 6	12 ± 6	10 ± 3	.122L .0001R
Inside/Outside CR	1.69 ± 0.91	2.31 ± 1.28	1.14 ± 0.43	0.97 ± 0.29	$.137_L$ $.014_R$ $.175_{10}$ $.182_{13}$

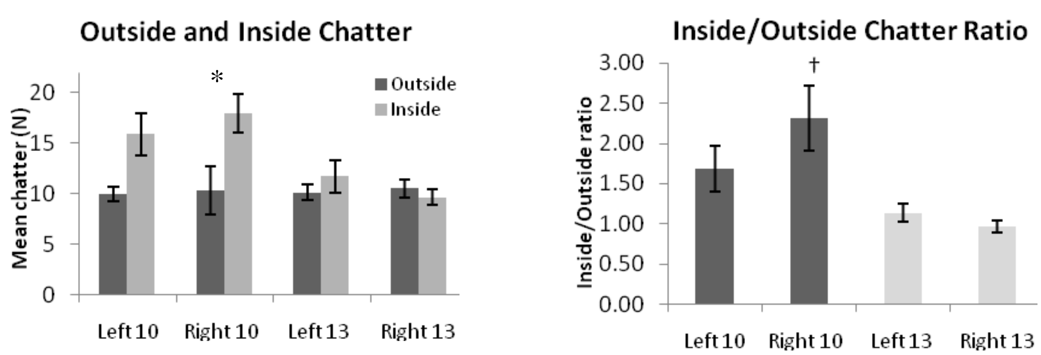


Figure 9.23: The outside and inside chatter and the inside/outside CR, means and SEM, SID 5.

Subject 5 had less inside and outside ski chatter than the average skier. The mean inside/outside CR was similar to the average skier (1.53 vs. 1.48), Table 9.19.

9.9.6 Subject 6

Subject 6 is right leg dominant. Previous injuries include a tear of both ACL ligament and menisci 5 years ago and repeat of the tear of menisci 1.5 years ago.

9.9.6.1 Total kinetic variables

The total kinetic variables for the subject were alike the group average, Table 9.20. The timing of the apex was significantly delayed in both turn directions on the 13 meter course compared to the 10 meter course (p=.009 and p=.011) Figure 9.24. Delayed timing of the apex was apparent in the right turns compared to the left turns on the 10 meter course (p=0.24 and p=0.051).

Table 9.20: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 6. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 6		Mean ± SD				(p)
Mean unloading force	BW	0.60 ± 0.09	0.60 ± 0.12	0.55 ± 0.18	0.59 ± 0.21	-
Minimum unloading force	BW	0.32 ± 0.14	0.33 ± 0.12	0.34 ± 0.14	0.40 ± 0.16	$.18_R$
Unloading duration	%	38 ± 11	39 ± 11	38 ± 9	37 ± 9	-
Mean loading force	BW	1.77 ± 0.23	1.73 ± 0.14	1.73 ± 0.10	1.71 ± 0.12	-
Mean apex force	BW	2.15 ± 0.27	2.14 ± 0.23	2.23 ± 0.19	2.17 ± 0.16	-
Peak force	BW	2.44 ± 0.36	2.43 ± 0.31	2.44 ± 0.22	2.47 ± 0.16	-
Gate passing	%	49 ± 3	50 ± 3	49 ± 15	49 ± 14	-
Timing of apex	%	52 ± 11	60 ± 8	62 ± 8	67 ± 6	$.009_L$ $.011_R$ $.024_{10}$ $.051_{13}$
Gate to apex time	%	3 ± 9	11 ± 8	9 ± 6	15 ± 10	$.027_L$ $.20_R$ $.018_{10}$

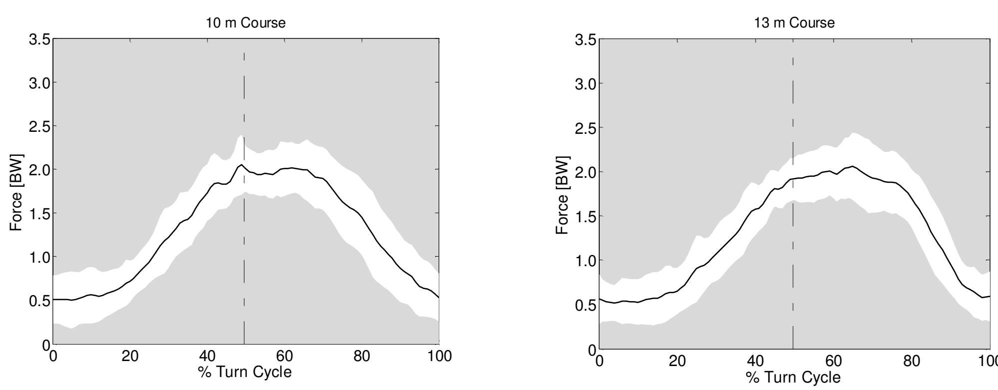


Figure 9.24: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 6.

9.9.6.2 The inside/outside ski impulse ratio

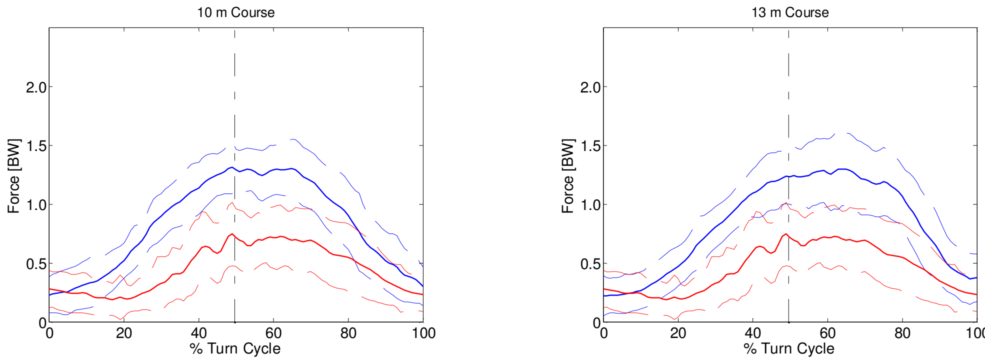


Figure 9.25: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 6.

Subject 6 loaded predominantly the outside ski regardless of the turn direction or course, Table 9.21. The mean inside/outside SIR was 0.55 (slightly lower than the group average), Table 9.21 and Figure 9.26.

Table 9.21: The inside/outside SIR. Means ± SD, paired t-tests, SID 6.

Subject 6	**10 meter course**		**13 meter course**		**Paired t-test (p)**
	Left	**Right**	**Left**	**Right**	
	Mean ± SD				
Inside/Outside SIR	0.53 ± 0.19	0.56 ± 0.16	0.53 ± 0.19	0.59 ± 0.13	$.184_{13}$

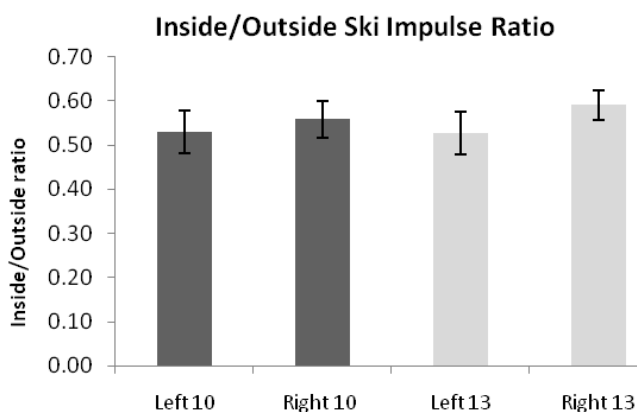


Figure 9.26: The inside/outside SIR, means and SEM, SID 6.

9.9.6.3 The chatter

The mean inside and outside chatter were 17 and 19 N, similar to the group averages (16 and 20), Table 9.22. The mean inside/outside CR was lower than the average skier (1.18 vs. 1.48). A significantly greater outside and inside chatter was detected in the right turns than in the left turns of the 13 meter course (p=.031 and p=.011 for outside and inside chatter) Figure 9.27.

Table 9.22: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 6.

Subject 6 Chatter	**10 meter course Left**	**10 meter course Right**	**13 meter course Left**	**13 meter course Right**	**T-tests (p)**
	Mean ± SD				
Chatter outside (N)	17 ± 6	18 ±10	15 ±3	20 ± 7	$.031_{13}$
Chatter inside (N)	21 ± 9	26 ± 10	12 ± 4	16 ± 3	$.003_{L}$ $.001_{R}$ $.144_{10}$ $.011_{13}$
Inside/Outside CR	1.34 ± 0.64	1.70 ± 1.03	0.80 ± 0.34	0.86 ± 0.28	$.027_{L}$ $.012_{R}$

A greater inside ski chatter was evident in both turn directions on the 10 meter course compared to the 13 meter course (p=.003 and p=.001 for left and right turns). The ratio was higher on the 10 meter course than on the 13 meter course (p=.027 and p=.012 for left and right turns), Figure 9.27.

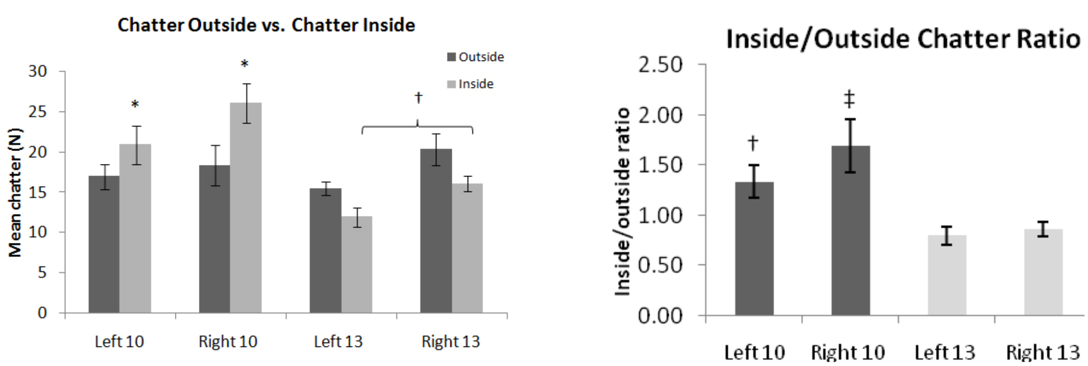


Figure 9.27: The outside and the inside chatter and the inside/outside CR, means and SEM, SID 6.

9.9.7 Subject 7

Subject 7 is right leg dominant.

9.9.7.1 Total kinetic variables

Table 9.23: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 7. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course		13 meter course		Unpaired
		Left	Right	Left	Right	t-tests
Subject 7		Mean ± SD				(p)
Mean unloading force	BW	0.67 ± 0.11	0.65 ± 0.06	0.67 ± 0.05	0.67 ± 0.09	-
Minimum unloading force	BW	0.46 ± 0.16	0.42 ± 0.10	0.42 ± 0.07	0.44 ± 0.09	-
Unloading duration	%	36 ± 9	39 ± 5	32 ± 9	33 ± 8	$.022_R$
Mean loading force	BW	1.79 ± 0.18	1.67 ± 0.20	1.78 ± 0.11	1.79 ± 0.18	$.09_R$ $.11_{10}$
Mean apex force	BW	2.20 ± 0.18	2.05 ± 0.17	2.40 ± 0.09	2.27 ± 0.19	$.001_L$ $.003_R$ $.025_{10}$ $.02_{13}$
Peak force	BW	2.55 ± 0.39	2.18 ± 0.20	2.66 ± 0.18	2.66 ± 0.27	$.0001_R$ $.027_{10}$
Gate passing	%	54 ± 4	55 ± 5	56 ± 5	54 ± 4	-
Timing of apex	%	60 ± 6	67 ± 7	63 ± 10	65 ± 9	$.005_{10}$
Gate to apex time	%	6 ± 6	13 ± 8	7 ± 10	11 ± 8	$.024_{10}$

Subject 7 had less loading force; the mean loading, the mean apex and the peak forces were all lower than the average skier. The timing of the apex was significantly delayed in the right turns than in the left turns on the 10 meter course (p=.005), Figure 9.28.

The mean apex force was significantly larger on the 13 meter course than on the 10 meter course (p=.001 and p=.003 for left and right turns), and it was larger in the left turns than in the right turns in both courses (p=.025 and p=.019).

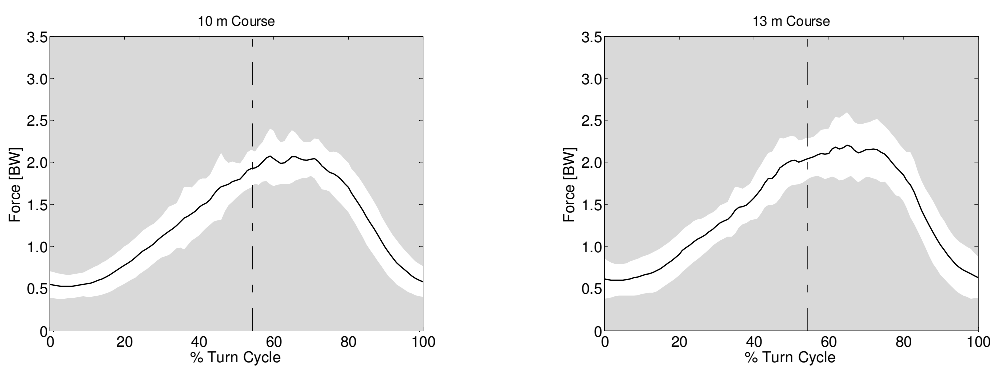


Figure 9.28: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 7.

9.9.7.2 The inside/outside ski impulse ratio

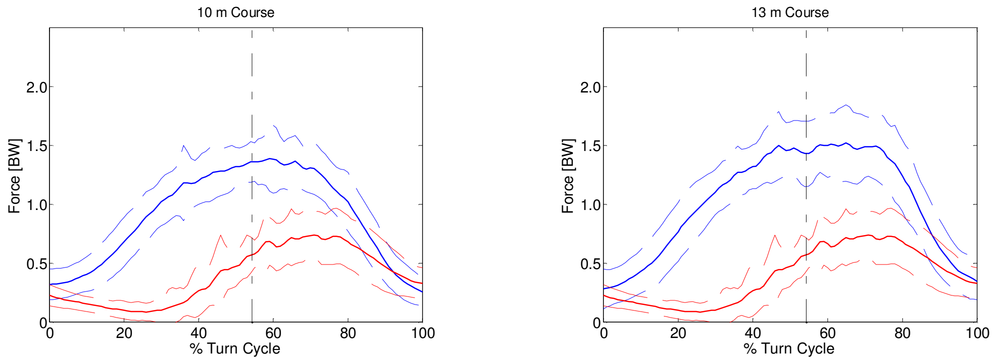


Figure 9.29: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 7.

Table 9.24: The inside/outside SIR. Means ± SD, paired t-tests, SID 7.

Subject 7	10 meter course		13 meter course		Paired t-test (p)
	Left	Right	Left	Right	
	Mean ± SD				
Inside/Outside SIR	0.40 ± 0.18	0.48 ± 0.15	0.26 ± 0.11	0.48 ± 0.10	$.007_L$ $.120_{10}$ $.00002_{13}$

A greater outside ski loading was evident for the subject 7 compared to the average skier (0.41 vs. 0.61). An extreme loading of the outside ski was evident in the left turns on the 13 meter course (0.26) and were significantly different from the left turns on the 10 meter course (p=.007), Figure 9.29 and Table 9.24. The loading of the outside ski in the left turns were also significantly greater than in the right turns on the 13 meter course (p=.00002), Figure 9.30.

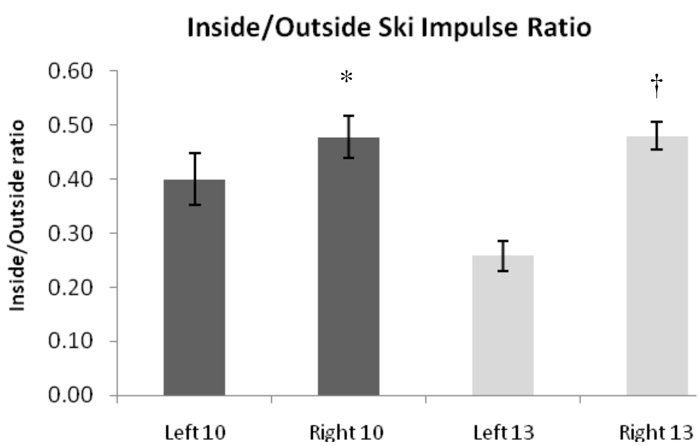


Figure 9.30: The inside/outside SIR, means and SEM, SID 7.

9.9.7.3 The chatter

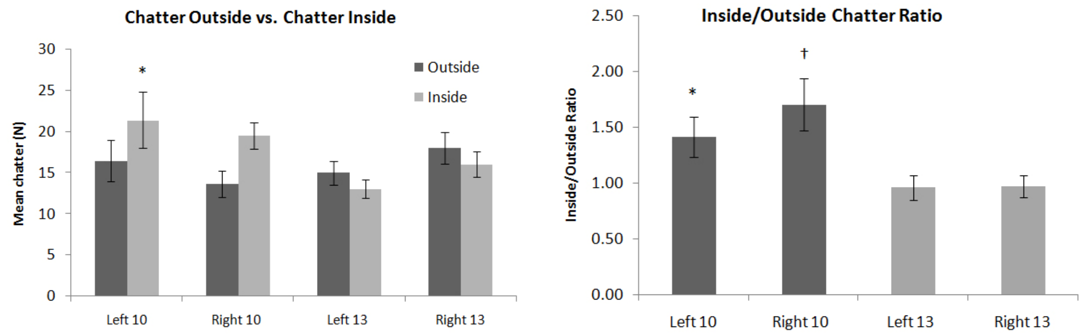


Figure 9.31: The outside and inside chatter and the inside/outside CR, means and SEM, SID 7.

The outside ski chatter was alike to the average skier, although the chatter of the inside ski was lower for the subject 7(mean inside/outside CR 1.26 vs. 1.48). On the 10 meter course, there was significantly more inside chatter than on the 13 meter course (p=.028). Compared to the 13 meter course, there was a greater degree of the inside ski chatter on the 10 meter course as the ratio was higher on the 10 meter course (p=.048 and p=.016 for the left and the right turns), Figure 9.32.

Table 9.25: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 7.

Subject 7	**10 meter course**		**13 meter course**		**T-tests (p)**
Chatter	**Left**	**Right**	**Left**	**Right**	
	Mean ± SD				
Chatter outside (N)	16 ± 10	14 ± 6	15 ± 6	18 ± 7	$.095_R$
Chatter inside (N)	21 ± 13	20 ± 6	13 ± 4	16 ± 6	$.028_L$ $.125_R$ $.122_{13}$
Inside/Outside CR	1.41 ± 0.69	1.70 ± 0.90	0.96 ± 0.41	0.97 ± 0.37	$.048_L$ $.016_R$

9.9.8 Subject 8

Subject 8 is right leg dominant.

9.9.8.1 Total kinetic variables

Subject 8 had more unloading (0.54 vs. 0.62 and 0.24 vs.0.38) and longer unloading phase (41 vs. 37 %) than the average skier. Timing of the apex was delayed compared to the average skier (62 vs. 66 % of turn cycle in time), Table 9.25. The right turns differed significantly with the higher mean unloading (p=.004 and p=.017 for 10 and 13 meter courses) and the minimum force (p=.002 and p=.003) from the left turns.

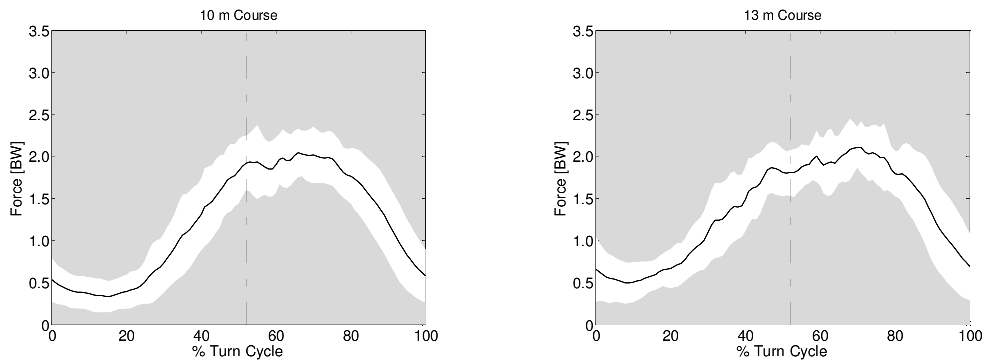


Figure 9.32: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 8.

Delayed apex was evident on the 13 meter course in right compared to left turns directions (p=.045), and in the right turns compared to the 10 meter course (p=.012). A greater mean apex force in the left turns was evident in both courses (p=.006 and p=.008 for 10 and 13 meter courses).

Table 9.26: The kinetic variables, means ± SD, and unpaired t-tests, n=15, SID 8. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		**10 meter course**		**13 meter course**		**Unpaired**
		Left	**Right**	**Left**	**Right**	**t-tests**
Subject 8		**Mean ± SD**				**(p)**
Mean unloading force	BW	0.47 ± 0.09	0.56 ± 0.07	0.52 ± 0.10	0.62 ± 0.10	.12$_L$ .073$_R$ .004$_{10}$ .017$_{13}$
Minimum unloading force	BW	0.16 ± 0.09	0.28 ± 0.09	0.18 ± 0.10	0.34 ± 0.16	.20$_R$ .002$_{10}$ .003$_{13}$
Unloading duration	%	43 ± 4	46 ± 4	38 ± 7	37 ± 8	.017$_L$ .001$_R$ .067$_{10}$
Mean loading force	BW	1.83 ± 0.11	1.71 ± 0.14	1.80 ± 0.12	1.69 ± 0.11	.20R .01413
Mean apex force	BW	2.35 ± 0.13	2.10 ± 0.22	2.28 ± 0.17	2.10 ± 0.18	.006$_{10}$ .008$_{13}$
Peak force	BW	2.74 ± 0.23	2.54 ± 0.27	2.65 ± 0.32	2.51 ± 0.27	.074$_{10}$
Gate passing	%	51 ± 4	52 ± 5	53 ± 3	53 ± 4	.14$_L$
Timing of apex	%	65 ± 12	62 ± 12	65 ± 10	72 ± 9	.012$_R$ .045$_{13}$
Gate to apex time	%	14 ± 9	10 ± 12	12 ± 9	19 ± 11	.046$_R$ .061$_{13}$

9.9.8.2 The inside/outside ski impulse ratio

The mean inside/outside SIR was similar to the average skier (0.61 vs. 0. 65), Table 9.27 and Figure 9.34. Subject 8 loaded the outside ski more in the left turns (ratio 0.46 and 0.50) on both courses, while in the right turns, more even loading was apparent (ratio 0.82 and 0.83) in both courses (p=.001 and p=.0002 for 10 and 13 meter courses).

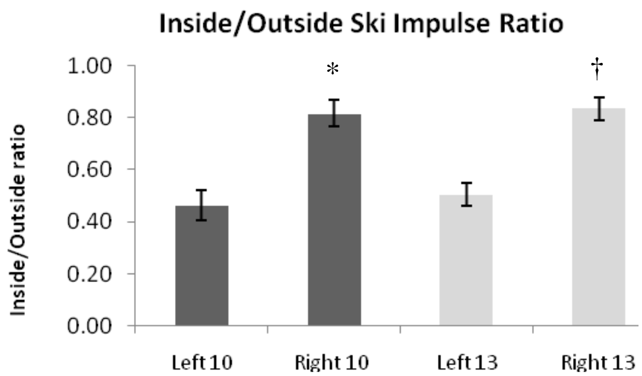


Figure 9.33: The inside/outside SIR, means and SEM, SID 8.

The dynamic range of the inside/outside SIR was evident (0.46 / 0.50 and 0.82 / 0.83) Figure 9.33, where the outside ski was predominantly loaded in the left turns compared to the right turns.

Table 9.27: The inside/outside SIR. Means ± SD, paired t-tests, SID 8.

Subject 8	10 meter course		13 meter course		Paired t-test (p)
	Left	Right	Left	Right	
	Mean ± SD				
Inside/Outside SIR	0.46 ± 0.23	0.82 ± 0.19	0.50 ± 0.17	0.83 ± 0.17	$.001_{10}$ $.0002_{13}$

9.9.8.1 The chatter

There was larger inside ski chatter for the subject 8 than the average skier (25 vs. 20). A larger inside ski chatter was apparent in right turns on the 10 meter course than on the 13 meter course (p=.005).

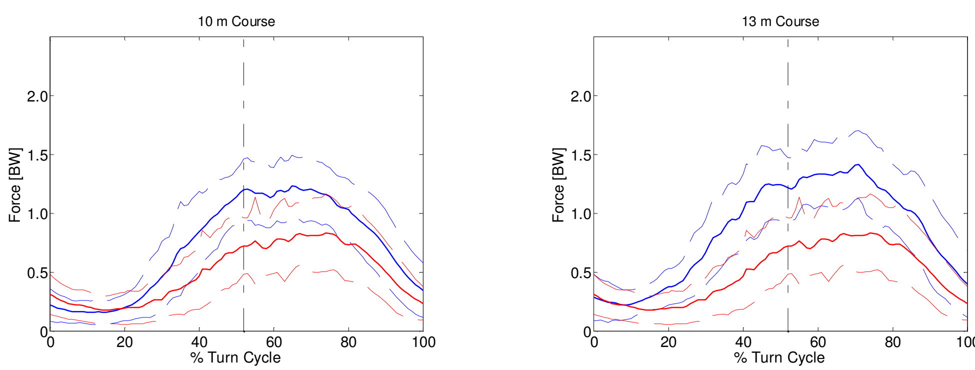


Figure 9.34: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 8.

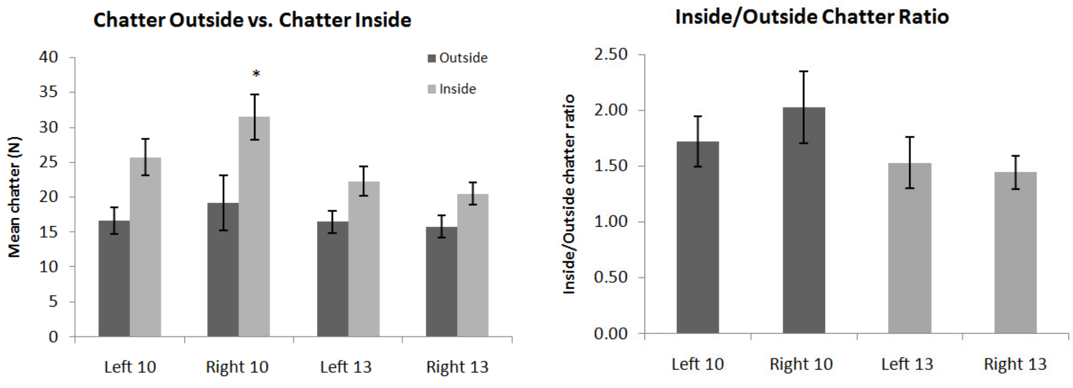


Figure 9.35: The outside and inside chatter and the inside/outside CR, means and SEM SID 8.

Table 9.28: The chatter variables, means ± SD, unpaired t-tests were used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 8.

Subject 8 Chatter	**10 meter course Left**	**Right**	**13 meter course Left**	**Right**	**T-tests (p)**
	Mean ± SD				
Chatter Outside (N)	17 ±8	19 ± 15	16 ± 6	16 ± 6	-
Chatter Inside (N)	26 ± 10	31 ± 13	22 ± 8	20 ± 6	$.005_R$ $.174_{10}$
Inside/Outside CR	1.72 ± 0.89	2.03 ± 1.25	1.53 ± 0.86	1.44 ± 0.55	$.118_R$

9.9.9 Subject 9

Subject 9 is right leg dominant.

9.9.9.1 Total kinetic variables

A shorter unloading phase and higher unloading force, larger mean loading, apex and peak force than the average skier characterized subject 9, Table 9.29.

Table 9.29: The kinetic variables, means ± SD, and unpaired t-tests, n=15, SID 9. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		**10 meter course Left**	**Right**	**13 meter course Left**	**Right**	**Unpaired t-tests**
Subject 9		**Mean ± SD**				**(p)**
Mean unloading force	BW	0.78 ± 0.10	0.77 ± 0.11	0.69 ± 0.08	0.71 ± 0.07	$.009_L$ $.094_R$
Minimum unloading force	BW	0.72 ± 0.17	0.70 ± 0.20	0.59 ± 0.12	0.57 ± 0.10	$.02_L$ $.024_R$
Unloading duration	%	29 ± 8	26 ± 8	31 ± 6	31 ± 5	$.059_R$
Mean loading force	BW	2.06 ± 0.13	2.05 ± 0.08	2.02 ± 0.11	1.98 ± 0.09	$.042_R$
Mean apex force	BW	2.79 ± 0.21	2.77 ± 0.22	2.70 ± 0.09	2.57 ± 0.17	$.13_L$ $.009_R$ $.011_{13}$
Peak force	BW	3.04 ± 0.27	3.16 ± 0.38	3.12 ± 0.31	3.04 ± 0.31	-
Gate passing	%	53 ± 4	52 ± 4	56 ± 6	55 ± 5	$.092_R$
Timing of apex	%	58 ± 8	58 ± 10	65 ± 9	65 ± 6	$.033_L$ $.051_R$
Gate to apex time	%	4 ± 7	6 ± 8	9 ± 10	10 ± 8	$.15_L$

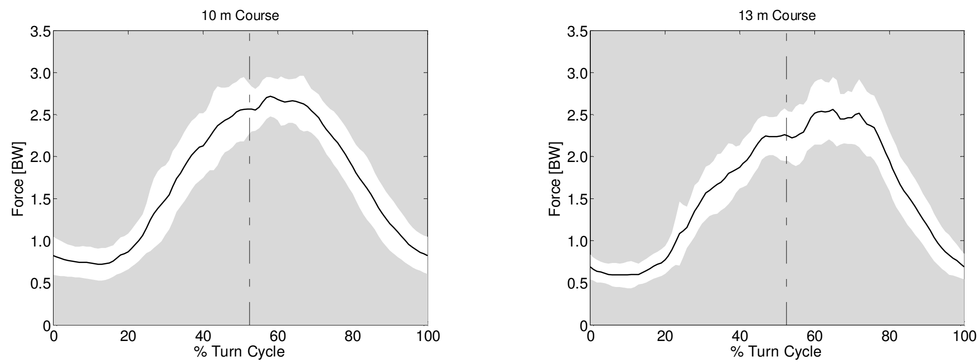


Figure 9.36: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 9.

Significantly lower mean unloading force, and more loading force in the right turns on the 10 meter course (p=.009 for unloading force, p=.042 for loading force). Delayed timing of apex was found on the 13 meter course for both turns (p=.033 and p=0.51) Figure 9.36.

9.9.9.2 The inside/outside ski impulse ratio

A greater loading of outside ski was evident for subject 9 (0.57 vs. average skier of 0.61). A predominant outside ski loading in the left turns differed from the loading of both skis in the right turns in both courses (p=.00001 and p=.00000005), Figure 9.37. The lower ratio on the 13 meter course than on the 10 meter course in both turn directions (p=.041 and p=.044 for left and right turns) evidenced of differentiation, **Error! Reference source not found.**.

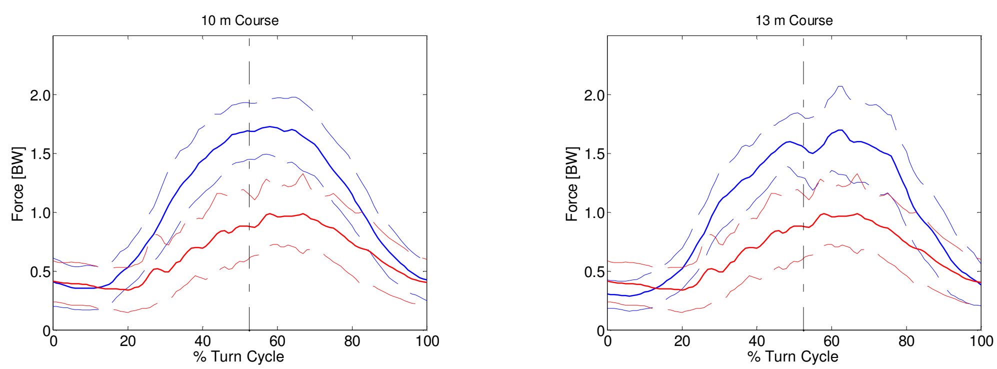


Figure 9.37: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 9.

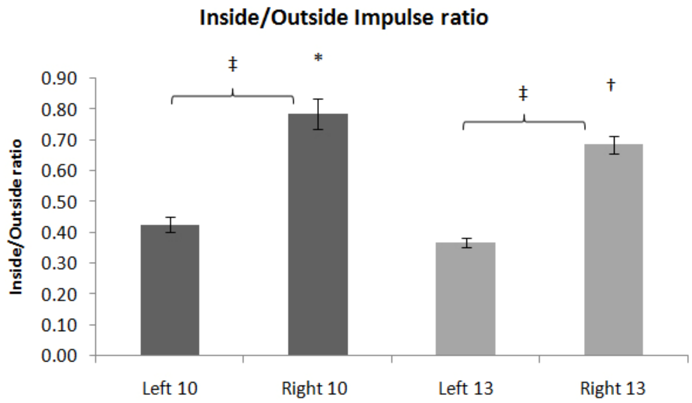


Table 9.30: The inside/outside SIR. Means ± SD, paired t-tests, SID 9.

Subject 9	10 meter course		13 meter course		Paired t-test (p)
	Left	Right	Left	Right	
	Mean ± SD				
Inside/Outside SIR	0.43 ± 0.09	0.78 ± 0.19	0.37 ± 0.06	0.69 ± 0.11	$.041_L$ $.044_R$ $.00001_{10}$ $.00000005_{13}$

9.9.9.1 The chatter

The mean inside/outside CR was above the average skier, Table 9.31. There were no significant differences in the chatter variables between the turn directions or courses. Right turns on the 13 meter course appeared to have more outside ski chatter than on the 10 meter course (p=.060), Figure 9.38.

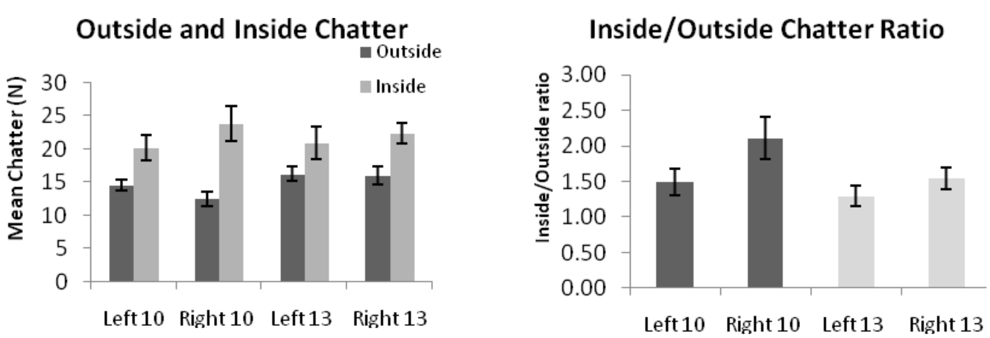


Figure 9.38: The outside and inside chatter and the inside/outside CR, means and SEM, SID 9.

Table 9.31: The chatter variables, means ± SD, unpaired t-tests used in the inside or the outside chatter, paired t-tests used in the inside/outside CR, SID 9.

Subject 9 Chatter	10 meter course Left	 Right	13 meter course Left	 Right	T-tests (p)
	Mean ± SD				
Chatter outside (N)	15 ± 3	12 ±4	16 ±4	16 ± 6	$.060_R$ $.151_{10}$
Chatter inside (N)	20 ± 7	24 ±10	21 ±10	22 ± 6	-
Inside/Outside CR	1.49 ± 0.73	2.11 ± 1.14	1.30 ± 0.55	1.54 ± 0.58	$.099_R$ $.138_{10}$

9.9.10 Subject 10

Subject 10 is right leg dominant.

9.9.10.1 Total kinetic variables

There was a shorter unloading phase, with more unloading force for the subject 10 than for the average skier. The mean unloading force was significantly larger in both turn directions on the 10 meter course than on the 13 meter course (p=.012 and p=.005 for left and right turns) Table 9.32 and Figure 9.39. There was a longer unloading phase in the right turns than in the left turns on the 10 meter course (p=.043). The delayed timing of apex was evident in the right turns on the 13 meter course than on the 10 meter course (p=.006) or when compared to the left turns on the 13 meter course (p=.001). A lower mean apex force in left turns differed from the right turns on the 13 meter course (p=.034) and from left turns on the 10 meter course (p=.004).

Table 9.32: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 10. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course Left	 Right	13 meter course Left	 Right	Unpaired t-tests
Subject 10		Mean ± SD				(p)
Mean unloading force	BW	0.73 ± 0.05	0.70 ± 0.04	0.68 ± 0.05	0.63 ± 0.07	$.012_L$ $.005_R$ $.086_{10}$ $.031_{13}$
Minimum unloading force	BW	0.59 ± 0.05	0.49 ± 0.07	0.50 ± 0.07	0.42 ± 0.11	$.0004_L$ $.062_R$ $.0002_{10}$ $.029_{13}$
Unloading duration	%	34 ± 4	37 ± 6	33 ± 6	32 ± 8	$.052_R$ $.043_{10}$
Mean loading force	BW	1.77 ± 0.06	1.86 ± 0.24	1.70 ± 0.07	1.73 ± 0.10	$.014_L$ $.091_R$ $.17_{10}$
Mean apex force	BW	2.23 ± 0.10	2.23 ± 0.09	2.08 ± 0.12	2.20 ± 0.14	$.004_L$ $.034_{13}$
Peak force	BW	2.49 ± 0.17	2.51 ± 0.15	2.37 ± 0.20	2.60 ± 0.25	$.18_R$ $.035_{13}$
Gate passing	%	49 ± 3	49 ± 4	52 ± 5	51 ± 5	$.12_L$
Timing of apex	%	63 ± 7	65 ± 8	62 ± 9	73 ± 7	.006R .00113
Gate to apex time	%	14 ± 5	16 ± 8	10 ± 8	22 ± 8	$.14_L$ $.043_R$ $.0004_{13}$

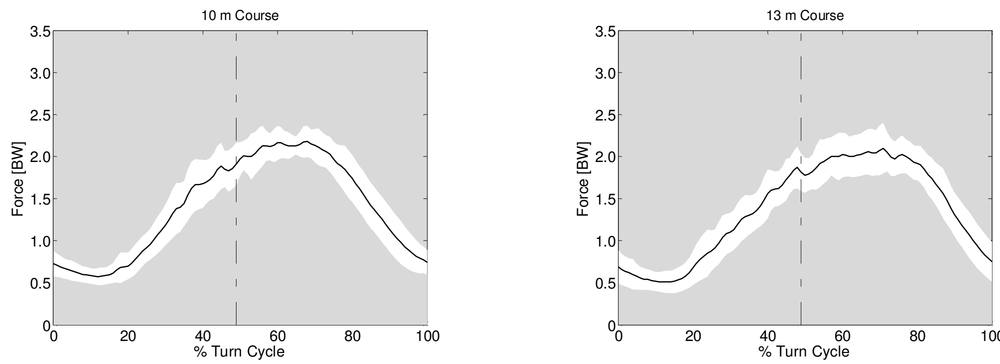


Figure 9.39: The ensemble average of reaction force-time relation in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 10.

9.9.10.2 The inside/outside ski impulse ratio

A higher inside/outside SIR indicated that subject 10 loaded both skis more equally than the average skier did (0.80 vs. 0.63), Table 9.33. On the 10 meter course, both skis were more equally loaded in left turns and the same trend was apparent on the 13 meter course, Figure 9.40.

Table 9.33: The inside/outside SIR. Means ± SD, paired t-tests, SID 10.

Subject 10	**10 meter course**		**13 meter course**		**Paired t-test (p)**
	Left	**Right**	**Left**	**Right**	
		Mean ± SD			
Inside/Outside SIR	0.91 ± 0.19	0.70 ± 0.11	0.85 ± 0.15	0.72 ± 0.07	.0006$_{10}$ .012$_{13}$

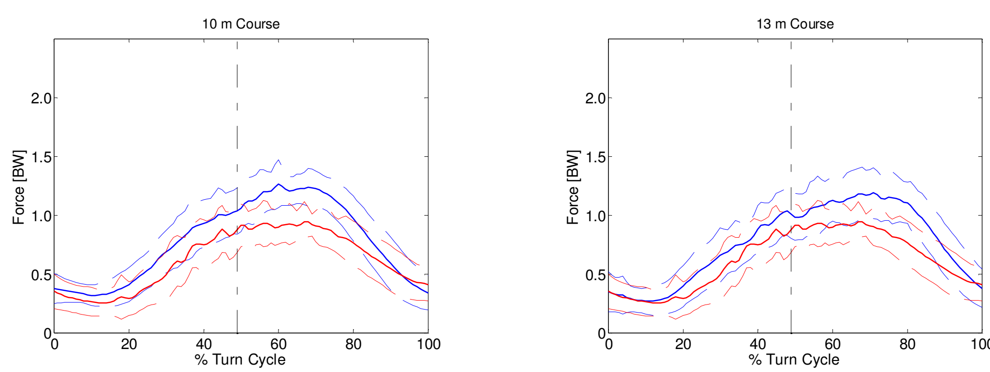


Figure 9.40: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 10.

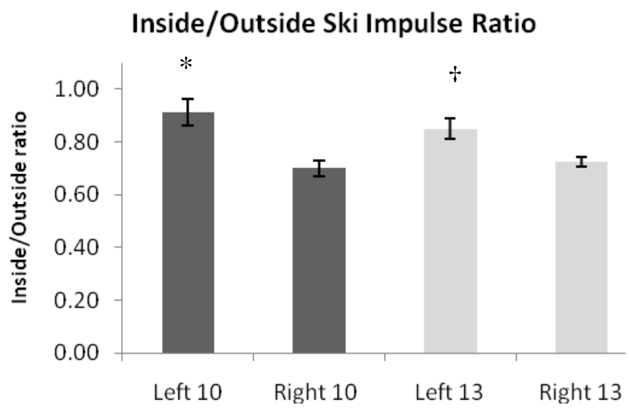


Figure 9.41: The inside/outside SIR, means and SEM, SID 10.

Although the equal loading of both skis was apparent for subject 10, the right turns were loaded with more outside ski loading (p=.0006 for 10 meter course and p=.012 for 13 meter course).

9.9.10.3 The chatter

There were lower mean inside and outside chatter than for the average skier, while the mean inside/outside CR was nearly the same (1.41 vs. 1.48), Table 9.34. There was more outside ski chatter in the right turn on the 10 meter course (p=.044), and less chatter in the left turns on the 10 meter course than on the 13 meter course (p=.004).

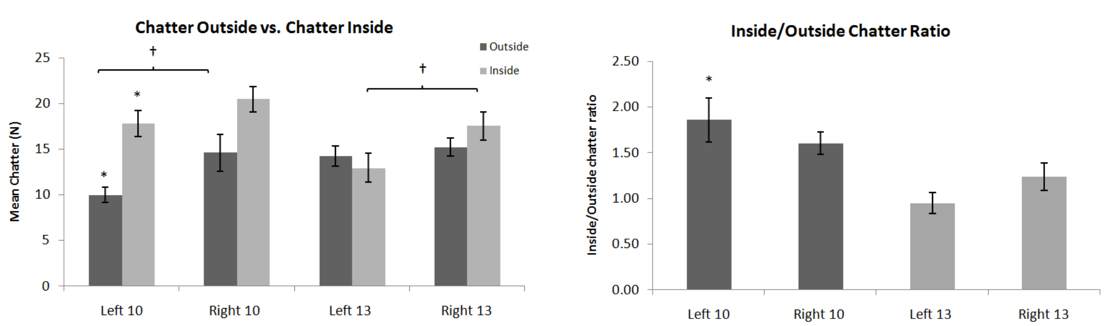


Figure 9.42: The outside and inside chatter and the inside/outside CR, means and SEM, SID 10.

On the 10 meter course, the mean inside chatter was larger than on the 13 meter course in the left turns (p=.029), Figure 9.42. The mean ratio was significantly larger in the left turns on the 10 meter course compared to the 13 meter course (p=.006).

Table 9.34: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 10.

Subject 10 Chatter	10 meter course Left	Right	13 meter course Left	Right	T-tests (p)
	Mean ± SD				
Chatter outside (N)	10 ± 3	15 ± 8	14 ± 4	15 ± 4	$.004_L$ $.044_{10}$
Chatter inside (N)	18 ± 5	20 ± 5	13 ± 6	18 ± 6	$.029_L$ $.171_R$ $.186_{10}$ $.048_{13}$
Inside/Outside CR	1.86 ± 0.93	1.60 ± 0.48	0.95 ± 0.42	1.24 ± 0.57	$.006_L$ $.112_R$ $.188_{13}$

9.9.11 Subject 11

Subject 11 is right leg dominant.

9.9.11.1 Total kinetic variables

A shorter loading phase and larger mean apex and peak forces differed from the average skier (2.56 vs. 2.30 and 2.95 vs. 2.63 BW), Table 9.35. The mean unloading force was significantly higher in the right turns on the 10 meter course than on the 13 meter course (p=.019), and higher than in the left turns on the 10 meter course (p=.021) Figure 9.43.

Table 9.35: The kinetic variables, means ± SD, unpaired t-tests, n=15, SID 11. (%): % of turn cycle in time. (BW): body weight.

Kinetic variable		10 meter course Left	Right	13 meter course Left	Right	Unpaired t-tests
Subject 11		Mean ± SD				(p)
Mean unloading force	BW	0.66 ± 0.15	0.77 ± 0.10	0.64 ± 0.07	0.67 ± 0.11	$.019_R$ $.021_{10}$
Minimum unloading force	BW	0.40 ± 0.15	0.51 ± 0.19	0.37 ± 0.11	0.42 ± 0.14	$.12_R$ $.073_{10}$
Unloading duration	%	32 ± 8	30 ± 15	32 ± 8	34 ± 10	-
Mean loading force	BW	1.93 ± 0.14	1.96 ± 0.17	1.89 ± 0.15	1.93 ± 0.12	-
Mean apex force	BW	2.49 ± 0.19	2.66 ± 0.28	2.49 ± 0.29	2.58 ± 0.19	$.065_{10}$
Peak force	BW	2.89 ± 0.33	3.17 ± 0.46	2.87 ± 0.33	2.89 ± 0.31	$.063_R$ $.062_{10}$
Gate passing	%	55 ± 3	54 ± 4	56 ± 4	55 ± 4	-
Timing of apex	%	64 ± 7	64 ± 7	65 ± 10	69 ± 6	$.094_R$
Gate to apex time	%	9 ± 6	10 ± 8	9 ± 8	14 ± 8	$.083_{13}$

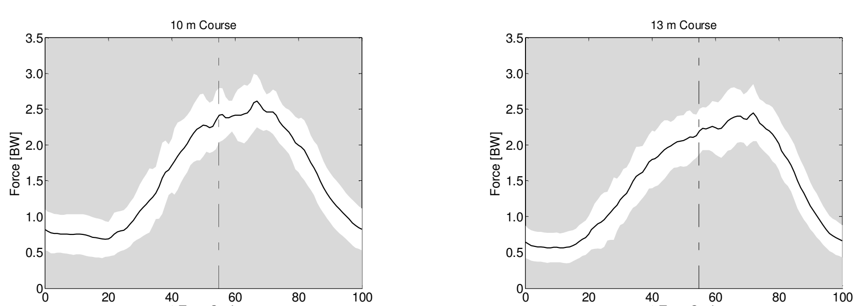


Figure 9.43: The ensemble average of reaction force-time relation time in the 10 meter (left) and the 13 (right) meter courses, ± SD (white area), SID 11.

9.9.11.2 The inside/outside ski impulse ratio

A greater loading of the outside ski for the subject 11 was alike the average skier's ski impulse ratio (0.59 vs. 0.61), Table 9.36 and Figure 9.45. The outside ski was loaded significantly more in the left turns than in the right turns in both courses (p=.000006 and p=.00001).

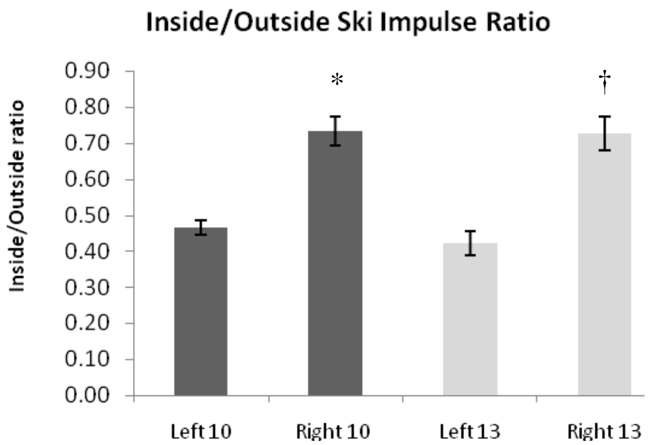


Table 9.36: The inside/outside SIR. Means ± SD, paired t-tests, SID 11.

Subject 11	10 meter course		13 meter course		Paired t-test (p)
	Left	Right	Left	Right	
	Mean ± SD				
Inside/Outside SIR	0.46 ± 0.08	0.73 ± 0.15	0.42 ± 0.13	0.73 ± 0.18	$.119_{L}$ $.000006_{10}$ $.00001_{13}$

Figure 9.44: The inside/outside SIR, means and SEM, SID 11.

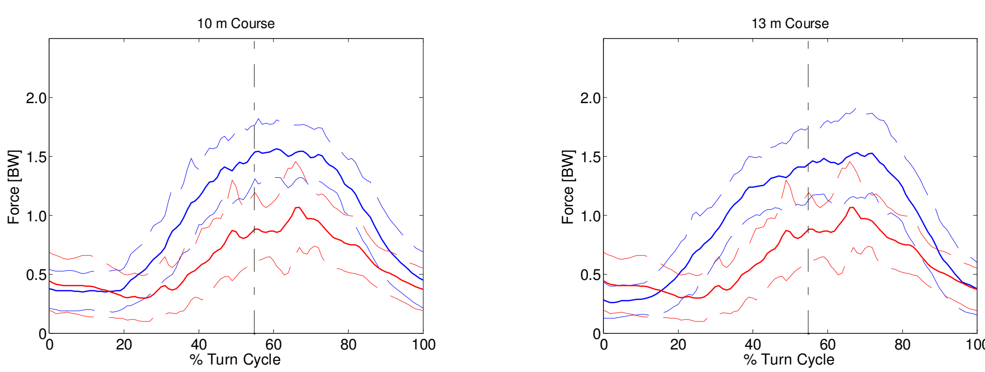


Figure 9.45: The ensemble averages of the force-time relation of the outside (blue solid line) and the inside (red solid line) skis in the 10 meter (left) and the 13 meter (right) courses, means ± SD, (dashed lines), SID 11.

9.9.11.3 The chatter

The mean chatter variables for the subject 11 were similar to the group average, Table 9.37. There was a larger inside ski chatter on the 10 meter course than on the 13 meter course regardless of the turn direction (p=.001 and p=.002 for left and right turns) Figure 9.46. There was a significantly higher chatter ratio in the right turns on the 10 meter course than on the 13 meter course (p=.05).

Table 9.37: The chatter variables, means ± SD, unpaired t-tests used in the inside and the outside chatter, paired t-tests used in the inside/outside CR, SID 11.

Subject 11 Chatter	10 meter course Left	10 meter course Right	13 meter course Left	13 meter course Right	T-tests (p)
	Mean ± SD				
Chatter outside (N)	15 ± 8	20 ± 14	13 ±7	15 ± 6	-
Chatter Inside (N)	23 ± 5	26 ± 8	16 ± 6	16 ± 4	$.001_L$ $.0002_R$
Inside/Outside CR	1.89 ± 0.93	1.88 ± 1.22	1.46 ± 0.87	1.18 ± 0.62	$.05_R$

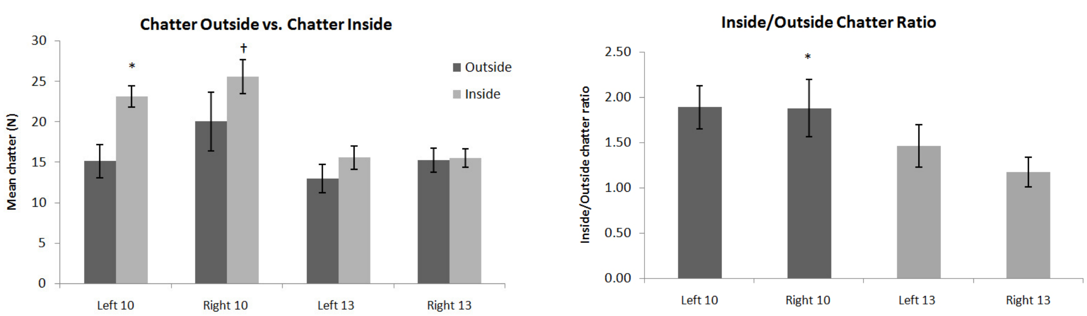


Figure 9.46: The outside and inside chatter and the inside/outside CR, means and SEM, SID 11.

9.10 APPENDIX J: ABSTRACT BY SMITH, G., LAPPI, M., REID, R. THE AMERICAN SOCIETY OF BIOMECHANICS CONGRESS (2009)

FREQUENCY ANALYSIS OF SKI CHATTER IN SLALOM SKIING: COMPARISON OF INSIDE AND OUTSIDE SKI RESPONSES

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INTRODUCTION

Alpine ski racing involves a careful balancing of the forces acting on a skier to obtain an interaction with the environment which optimizes performance. Ski reaction forces are the largest of the external forces acting on a skier and are the most important for determining the path of the skier through a race course. However such reaction forces are difficult to measure under race-like conditions.

Several previous projects have built mobile force plates for attachment between skis and bindings [1,2]. Such devices require mounting on a unique pair of skis rather than on the finely tuned equipment to which a racer is accustomed. In addition they change ski stiffness, increase binding height along with increasing mass of the system all of which affect a skier's technique. Thus such equipment may alter the technique characteristics which are being studied. An alternative approach is to use instrumented insoles for measurement of pressure distributions between foot and boot using a skier's personal equipment. Reaction forces acting on skis can be estimated by summing across the insole surface.

In this study, snow reaction force characteristics during slalom turns were evaluated to better understand relationships of force distribution between skis and their interactions with the under-lying snow. In particular, ski "chattering" (which is low frequency, inconsistent grabbing of a ski during skidding) was characterized and related to loading distribution between inside and outside skis.

METHODS

Ski reaction forces were determined using Novel Pedar insoles placed between foot and boot bed. Pedar's mobile data logger recorded pressure distribution for right and left insoles at 50 Hz. Force from each sensor was summed to obtain a total force on each side vs. time.

High level Norwegian skiers (n=9, with FIS rankings between 165 to 705) were tested over 3 consecutive days during a September training camp on a glacier with nearly ideal, firm surface conditions. A rhythmical slalom course was set with 10 m spacing between gates. Ten turns (5 left, 5 right) near the middle of the course were analyzed. Right and left turns were not combined as there was a slight side-to-side slope gradient. The continuous force data for a run through the slalom course were separated turn by turn from transition point to next transition point. A typical force-time response is shown below in Figure 1. The five turns for each direction were separately analyzed but ultimately combined for a mean response of the skier on right or left turns.

Chattering characteristics were determined through a fourier analysis of the frequency amplitudes for the ski reaction forces. Mean amplitude in the 10-20 Hz range was determined for each turn. The response in this relatively low frequency range is distinct from other ski vibration of higher frequency.

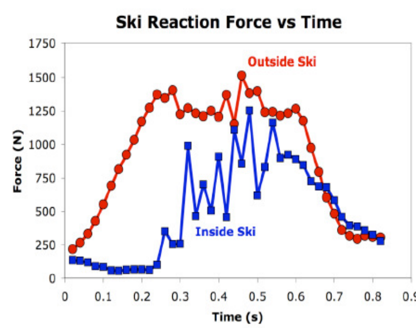


Figure 1. Representative ski reaction force curves during a single slalom turn. The outside ski typically had greater force than the inside ski. "Chattering" of the inside ski is apparent in the graph with rapid changes of force occurring while the ski was loaded during mid-turn.

RESULTS AND DISCUSSION

Ski reaction forces were considerably greater on the outside compared to the inside ski which had about two-thirds of outside forces. This is in good agreement with the force data described by Federolf [1]. Easily visible on force-time graphs, many skiers exhibited chatter of the inside ski. This effect was captured in the frequency distribution data (Figures 2A and 2B) in the 10 to 20 Hz range where inside ski amplitudes were 30 to 50% greater than outside ski amplitudes ($p < 0.01$).

Turn direction affected chattering characteristics for the outside skis (Figure 3). Right turns which were across the side-to-side gradient were associated with increased chatter compared to left turns with the gradient ($p = 0.009$). Inside skis had similar chattering for left or right turns which was greater than either direction outside skis.

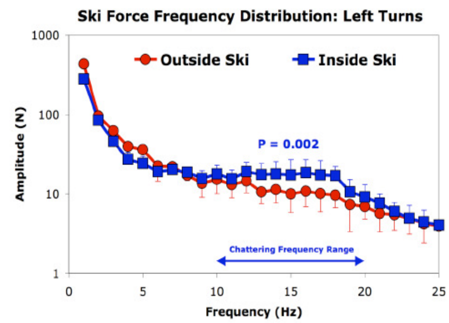
Mechanical origins of chattering cannot be definitively determined from this study however these momentary discontinuities of force are likely due to shearing of snow under the ski [1]. Inside skis were typically loaded about two-thirds of outside skis, and would likely have less snow penetration making shearing of the snow layer under the edge, more likely. Also affecting penetration is ski edging angle where the inside leg geometry disadvantages ski edging compared to the outside leg. Finally, the inside ski must turn with a smaller radius of curvature (compared to the outside ski) making carving more difficult and skidding with potential chattering, more likely.

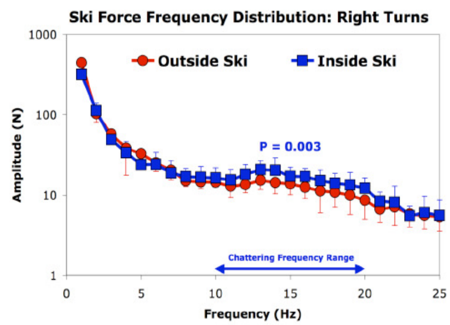
CONCLUSIONS

Ski chattering can be detected through spectral analysis of ski reaction force data. Greater chattering of inside skis was observed. This may be due in part to reduced loading of inside compared to outside skis in tight slalom turns.

REFERENCES

1. Federolf PA. *Finite Element Simulation of a Carving Snow Ski*. Swiss Federal Institute of Technology Zurich, 2005.
2. Klous M et al. *Lower extremity joint loading in carved ski and snowboard turns*. ISBS Proceedings, 91-94, 2007.





Figures 2A and 2B: Frequency spectrum for ski reaction forces during left and right turns. Chattering of the skis had frequencies in the range of about 10 to 20 Hz. Comparison of mean amplitudes in this range found significant differences for skis on the inside vs. outside of each turn.

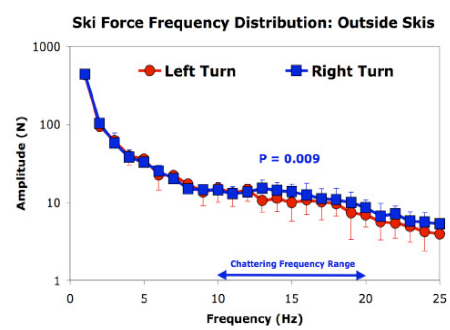


Figure 3. Frequency spectrum for ski reaction forces of the outside ski in left and right turns. Chattering was significantly greater for right turns perhaps due to a slight gradient across the direction of the slalom course.

9.11 APPENDIX K: ABSTRACT BY LAPPI, M., SMITH, G., REID, R. AMERICAN SOCIETY OF BIOMECHANICS CONGRESS (2009)

INSIDE/OUTSIDE FORCE RATIO AND SKI CHATTER IN SLALOM SKIING

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INTRODUCTION

Although skiers must move laterally to balance against the ground reaction forces (GRF) during turning, they can control the force distribution between the inside and the outside ski through fine-tuning of lateral balance [1]. This force distribution is important for performance, yet it is a topic of debate in coaching circles.

Traditional philosophies describe a lateral balance where the GRF loading occurs predominantly on the outside ski. However, with recent developments in equipment, philosophies have emerged promoting a more even distribution. While this may reduce ski-snow friction when carving, it may also result in greater skidding and chatter. The purpose of this study was to describe and compare ground reaction forces in slalom skiing between two courses typical of competition.

METHODS

Nine male Norwegian skiers (body weight 859 ± 71 N) and FIS ranked between 165 and 705 (2007/08) were tested over 3 consecutive days. Kinetic characteristics were analyzed for 2 rhythmical course settings with linear distances of 10 and 13 m between gates. The middle 10 turns of each trial were analyzed to determine GRF using 50 Hz plantar pressure insoles (Novel GmbH, Germany) and associated data logging instrumentation shown in Figures 1 & 2.

Right and left turns were separately analyzed due to differences in the side-to-side slope gradient. Inside/Outside force ratio was calculated based on force impulse during each turn. The mean residual between raw force measurements and a smoothed force-time curve (cut-off frequency 5 Hz) was used to quantify chatter for each ski. Repeated measures ANOVA was used to compare turn directions and courses and Pearson's correlation to assess the relationship between chatter and force distribution.

Figure 1. Data logging was accomplished with a portable acquisition system carried in a small backpack. Cables to the insole system were routed underneath a skier's standard suit.

Figure 2. Data were collected under simulated race conditions during a glacier training camp with hard snow surface conditions comparable to competition.

RESULTS AND DISCUSSION

Inside ski forces averaged about half to two-thirds of outside ski forces. This can be seen in the example trial shown in Figure 3. Inside/Outside ratios were on average greater for right-hand turns on both courses, but these differences were not statistically significant (Table 1). That right turns tended to have loading forces more evenly distributed between skis was perhaps due to the slight side-to-side gradient difference or perhaps due to leg dominance.

The inside ski of turns tended to chatter more than the outside ski in the tight turns of the 10 meter course. This larger mean chatter may be due to the shorter turn radius required of the inside ski.

Better performance was related to greater outside ski force distribution (lower ratio), as performance times correlated well with the Inside/Outside Force Ratio on both courses ($r = 0.81$, $p < 0.02$ for the 10 m course and $r = 0.73$, $p < 0.05$ for the 13 m course, n=8). No significant correlation was found between chatter and ski force distribution.

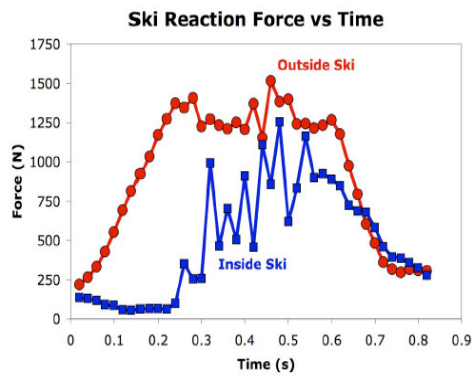

Figure 3. Representative ski reaction force curves during a single slalom turn. The ski to the outside of the turn typically had greater force than the inside ski. The rapid changes of force seen for the inside ski of this turn reflect "chattering" of the ski on the surface.

CONCLUSION

This study presents a novel approach to evaluating common slalom technique problems associated with ski force distribution and chattering of skis. Magnitude of chattering was not clearly related to the inside/outside force distribution. Technique training with such force measuring systems could potentially assist coaches in identification of problems associated with the ski force distribution between inside and outside skis.

REFERENCES

1. LeMaster R. *The Skier's Edge*. Human Kinetics: Champaign, IL.

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Table 1: Means ± SD Inside/Outside Force Ratio, Chatter Inside, Chatter Outside and Inside/Outside Chatter Ratio (n=9).

Course:	10 meter		13 meter		Course Compare
Turn Direction:	**Left**	**Right**	**Left**	**Right**	**L / R (p)**
Inside/Outside Force Ratio	0.59 ± 0.22	0.67 ± 0.13	0.54 ± 0.21	0.63 ± 0.14	.077 / .096
Chatter Inside (N)	23 ± 7	24 ± 4	17 ± 5	17 ± 4	.0006 / .001
Chatter Outside (N)	15 ± 4	17 ± 4	16 ±4	16 ±3	.559 / .645
Inside/Outside Chatter Ratio	1.72 ± 0.27	1.86 ± 0.27	1.16 ± 0.25	1.20 ± 0.23	.0004 / .0003

9.12 APPENDIX L: VALIDATION OF THE PEDAR SYSTEM AS A PLANTAR PRESSURE MEASUREMENT TOOL AND ESTIMATION OF GROUND REACTION FORCES

Validation of the Pedar system as a plantar pressure measurement tool and estimation of ground reaction forces.

Lappi, M. (2009). Norwegian School of Sport Sciences.

Concurrent validity was assessed by comparing the magnitude of ground reaction forces form Pedar measurements to AMTI force platform data. The purpose of the pilot study was to evaluate reliability and validity of Pedar system and quantify the possible systematic error associated with Pedar insoles. It was assumed that due to the fact that Pedar system measure only forces perpendicular to the pressure cells, and would not measure the weight of the ski boots, and may not detect all forces due to active pressuring against the cuff of the ski boots, the pressure measured by the Pedar insoles deviate from the actual force acting on the skier. It was important to establish how much of the pressure would be lost by the Pedar system to quantify magnitude of ground reaction forces. In addition, since skier control the skis by edging and pressuring of the cuff of the stiff boots, it was important to estimate deviation due to pressuring of the boot.

Methods

Pilot testing included 3 subjects. They were recruited from the alpine coach studies in Norwegian School of Sports Science. First, the subjects wearing their own ski boots, jumped on the platform, stood on a force platform and shifted their weight from the right foot to the left foot. Second, simple up-down movement with light pressure on the cuff of the ski boot was assessed. Third, shifting pressure back and forth with knees bent on the platform was assessed.

Insole calibration was done in the factor of Novel GmbH, Germany according to their recommendations. The measurements were done at 100 Hz for Pedar and 200 Hz for platform. The measurements were first checked and cleaned in Excel. Then, the maximum value from landing was highlighted as a starting point and to be used as point to synchronize Pedar to the AMTI platform measurements. Pedar measurements were interpolated, and compared. This method clearly presents source of error due to identifying exact time point from platform measurements. Interpolating may cut off the information and therefore not matching perfectly with the platform measurements. However, this study was not interested in high force values, but rather an average force activity during the movements. The middle three movements thought to represent average movement typical for the subject, were found, and analyzed against same time period (11 seconds) of platform measurements. Means, standard deviation (SD) and paired, one-tailed t-tests were calculated between the insole and platform measurements. Statistical significance level was set to $p < .05$.

Results

Pedar Insoles measured significantly less force in all three tasks (side-to-side, up-down and backward – forward movements) than the AMTI platform (p=.0009, p=.0003 and p=.006 respectively). The difference corresponds to 31-24-25% of the mean force measured by the force platform.

Table 1: Mean force measured simultaneously with AMTI platform (200Hz) and Pedar Insoles (100Hz). Means ± SD n=3.

Mean force (N)	**Side-side**	**Up-down** **Mean ± SD**	**Back-forward**
Force platform	682 ± 29	682 ± 25	683 ± 28
Pedar Insoles	472 ± 41	515 ± 59	512 ± 118
Paired t-tests (p)	.0009	.0003	.006

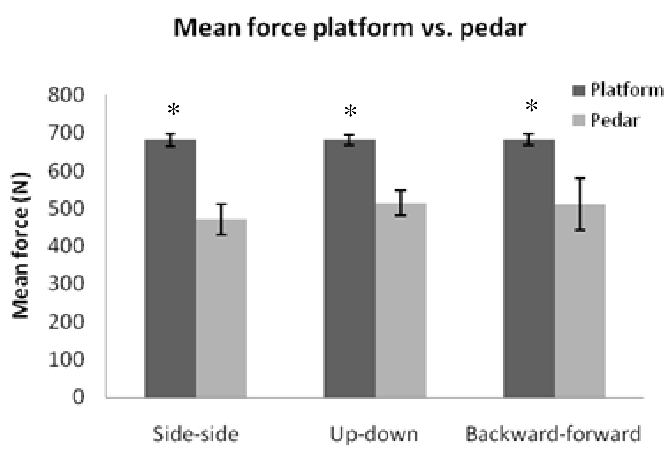

Figure 1: Mean force measured by platform and Pedar Insole, three tasks were performed by3 subjects. Means and SEMs are reported.

Conclusion

Pedar do not measure all forces when subjects wore their own ski boots weighting approximately 5 kg. With some pressuring against the shell of the boot, Pedar failed to measure 24 to 31 % of the mean forces measured by AMTI platform. Pedar reports standard error margin of 5 %, which would equal 34 N (3.5 kg) here. Since the calibration was recently done by Novel, there was no obvious reason to expect larger error margin.

Absolute mean difference was as 183 N which corresponds well with the difference previously found in the same laboratory with dynamic squat jumps with additional 50 kg weights on, which found an error component of 139 to 275 N (13 to 27 % of the total force) (Reid, not published). Also Lüthi et al. (2005) report an error component of 150 N when compared to force transducers implanted between skis and bindings. In both of these studies, the force-time relation matches well with the force platform/ force transducers, although some deviations are apparent when high forces are measured quickly, indicating that Pedar responds slower to the force change. The slower respond was perhaps natural phenomena. When lifting off the ground, it is reasonable to think that toes would pressure the insole after the boot is airborne. The light pressure could be detected by the cells and show up in the measurements after airborne state when platform measures zero values.

A great deal of the force was not measured by Pedar. To estimate how much is lost due to pressuring against the cuff during slalom skiing, it is necessary to simulate skiing on the platform with skis on and subject imitating movements natural to slalom skiing.

9.13 APPENDIX M: A STUDY OF THE VALIDITY OF THE NOVEL PEDAR CAPACITIVE INSOLE SYSTEM IN MEASURING THE VERTICAL COMPONENT OF THE GROUND REACTION FORCE UNDER DYNAMIC LOADING

A study of the validity of the Novel Pedar capacitive insole system in measuring the vertical component of the ground reaction force under dynamic loading.

Reid, R.C.

Introduction

In-shoe pressure measuring systems, such as the Pedar capacitive insole system developed by Novel (Munich), have been a popular tool for studying ground reaction forces in alpine skiing (e.g., Eriksson, 1978; Frick et al., 1997; Lafontaine et al., 1998; Müller & Schwameder, 2003; Raschner et al., 1997; Raschner et al., 2001; Schaff, Senner, & Kaiser, 1997; Schollhorn et al., 2001). Although a number of studies have examined the validity and reliability of in-shoe pressure measurement in clinical applications (Hurkmans, 2004; Nicolopoulos & Barnett, unpublished; Martinelli et al., 2004; Rosenbaum & Kersting, 2004), few have examined the validity of its use in alpine skiing. One notable exception is the study by Lüthi et al. (2004) who compared forces determined from Pedar's capacitive insole system with the vertical force component measured by force plates mounted between binding and ski. They found that forces measured by the two systems matched well, with an absolute difference between the two systems of 150 N. Schaff et al. (1997) have used an in-shoe system extensively in studying pressures and forces in alpine skiing. However, they did not report any specific findings in regards to validity other than claiming that the method is valid based on experience.

In a previous pilot study, the validity of the Pedar system to measure a constant load was examined. It was found that the measurement error for the vertical component of the ground reaction force ranged from 0 to 30 N greater than the reference force plate. Three separate pairs of insoles were tested and it was found that the magnitude of the error varied from insole to insole as well as from portion to portion within each insole. The fact that measurement errors were relatively constant for each insole raises the question of how well the insoles were initially calibrated at the factory after production.

The purpose of this study is to examine the validity of force measurements under dynamic loading using skiing-specific movements in both running shoes and ski boots.

Methods

Data collection

Two subjects participated in the study. Only the medium insoles were used. For each trial, the subject completed a series of squat jumps with 50 kg of weight. Subjects completed two trials for each foot in running shoes followed by two trials for each foot using ski boots. To examine each individual insole separately, only one foot was placed on the platform for each trail. At the beginning of each trial, the subject completed a jump onto the platform. This created a spike in the force data that would be used later to synchronize the force platform data and the Pedar data. Measurements were taken at 50 Hz by both the force platform and the Pedar system while the subject completed 5 squat jumps.

Data analysis

Force data from both the Pedar system and the force platform were exported to Microsoft Excel for analysis. The measurements were synchronized using the spike in force data created when the subject jumped onto the force platform. Absolute error magnitude was calculated for each measurement and then averaged for the entire 5 squat jump sequence.

Results

Measurements from each trial are plotted in the figures in Appendix A and Appendix B for running shoes and ski boots, respectively. The ground reaction force dynamics of the squat jump exercise closely match those of skiing, although the forces were somewhat lower in comparison - 1000 N for squat jumps relative to 1500-1700 N for skiing (Lafontaine et. al., 1998; Müller & Schwameder, 2003; Scott, 2004).

Running Shoes

In running shoes, the average trial error ranged from 36 N to 72 N (approximately 3 to 7 percent of the total force). Although there were some variations, the force – time curves from the Pedar system and the platform seemed to correspond very well (see, for example, Figure 1). The largest errors seemed to occur during rapidly changing forces (see arrows Figure 1).

Figure 1. Force-time curves for Pedar and force platform measurements of a subject wearing running shoes. Arrows indicate largest sources of error.

Ski Boots

In ski boots, the average trial error ranged from 139 N to 275 N (approximately 13 to 27 percent of the total force). The force-time curves from the Pedar system and the force platform did not match as well for the ski boots as they did for the running shoes (see Figure 2). Similar to the running shoes, the largest errors seemed to occur during rapidly changing forces (see arrows in Figure 2).

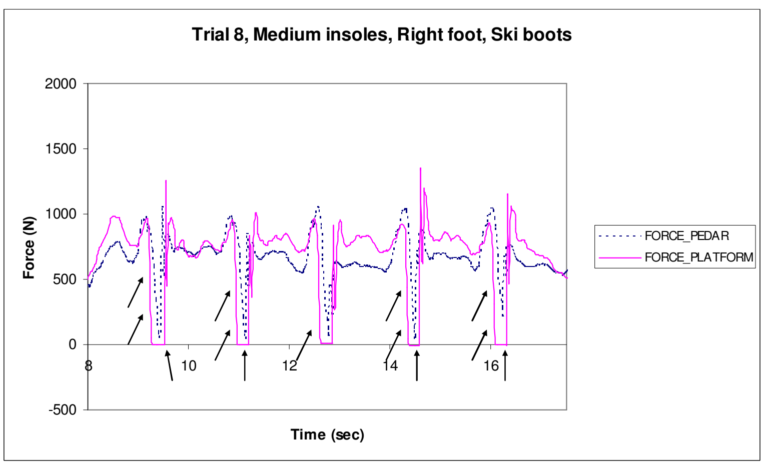

Figure 2. Force-time curves for Pedar and force platform measurements of a subject wearing ski boots. Arrows indicate larges sources of error.

Discussion

Pedar measurements seemed to match force platform measurements quite well when used in running shoes during a squat jump type of activity. The 3 to 7 percent error measured in this study is slightly more than the 2 percent error measured by Martinelli et al. (2004).

Measurement errors in ski boots were considerably larger than that for running shoes. However, the average error we found for ski boots is quite similar to that reported earlier for the Pedar system being used in skiing (Lüthi et al., 2004). In this study, the Pedar system was primarily underestimating the total force when used with ski boots. This could be due to a certain portion of the force being transmitted through the shell of the boot to the floor instead of through the sole of the foot.

When examining the force-time curves for the Pedar system used with ski boots and the force plate, one gets the impression that the Pedar system is slightly slower to respond to changes in force relative to the platform. This could explain why the largest errors seem to occur under rapidly changing forces.

Based on the results of this and the previous pilot studies, I would like to propose the following line of research for further validation of the Pedar system:

Studies 1 & 2. A repetition of the first and second pilot studies with the following two adjustments: a) more stringent methods to quantify the test-retest reliability of the system and b) calibration of the insoles prior to data collection.

Study 3. A study to determine the limitations that the constraining effect of an alpine ski boot has on in-shoe pressure measurement. As shown in this study, a considerable amount of the ground reaction force is not measured by the insoles. To examine this problem more closely, we measured pressure distributions while one of the subjects stood in ski boots with the Pedar system. The subject varied between standing in mid-balance, leaning slightly forward, leaning far forward, leaning slightly back and leaning far back. The pressure distributions for each position are presented in Figure 3. The pressure distributions changed substantially depending on the for-aft balance of the subject. However, the distribution changed unexpectedly if the subject leaned on the shell of the ski boot. For example, if the subject leaned forward normally, the pressure distribution shifted forwards as expected. But if the subject leaned forward and rested his weight on the shell of the ski boot, the pressure distribution was shifted backwards, not forwards. The significance this has for using the Pedar system for alpine skiing needs to be determined.

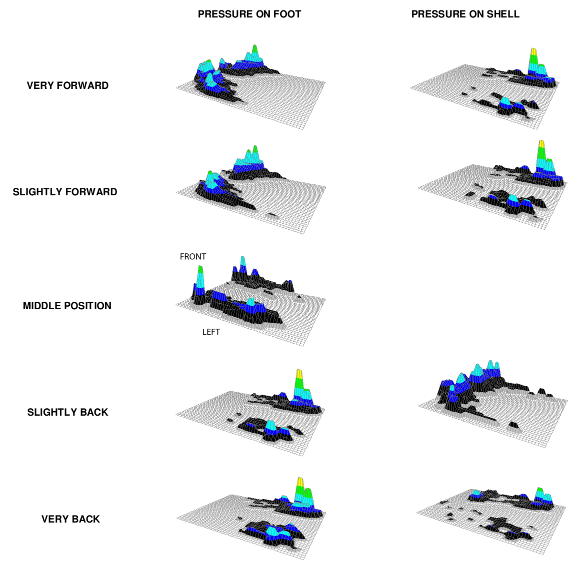

Figure 3. Pressure distributions as measured by Pedar for different for-aft positions of a subject wearing ski boots.

References

Eriksson, A., Forsberg, A, Nilsson, J, & Karlsson, J. (1978). Muscle strength, EMG activity, and oxygen uptake during downhill skiing. *Biomechanics VI-A*, 54-61.

Frick, U., Schmidtbleicher, D., Raschner, C., & Muller, E. (1997). Types of muscle action of leg and hip extensor muscles in slalom. In E. Muller, H. Schwameder, E. Kornexl, & C. Raschner (Eds.), *Science and Skiing* (pp. 262-271). London: E & FN Spon.

Hurkmans, H.L.P., Bussman, J.B.J., Selles, R.W., Horemans, H.L.D., Benda, E., Stam, H.J., & Verhaar, J.A.N. (2004). Validity of the pedar mobile system of vertical force measurement during a long-term period. EMED Scientific Community Proceedings. Leeds, U.K. July 29 – Aug 1. p. 60.

Lafontaine, D., Lamontagne, M., Dupuis, D., & Diallo, B. (1998). Analysis of the distribution of pressure under the feet of elite alpine ski instructors. In H.J. Riehle & M.M. Vieter (Eds) XVI

International Sympiosium on Biomechanics in Sports: Proceedings I. Universitätsverlag Konstanz, GmbH.

Lüthi, A., Federolf, P., Fauve, M., Oberhofer, K., Rhyner, H., Ammann, W., Stricker, G., Schiefermüller, C., Eitzlmair, E., Schwameder, H., & Müller, E. (2004). Determination of forces in carving using three independent methods. In D. Bacharach & J. Seifert (Eds.) 3rd International Congress on Skiing and Science: Abstract Book. March 28- April 3, 2004. Snowmass, CO USA. p 3-4.

Martinelli, L., Rosenbaum, D., & D'Alessio, T. (2004). Evaluation of a capacitive pressure sensor for joint contact stress measurements. EMED Scientific Community Proceedings. Leeds, U.K. July 29 – Aug 1. p. 60.

Müller, E. & Schwameder, H. (2003). Biomechanical aspects of new techniques in alpine skiing and ski-jumping. Journal of Sport Sciences, 21: 679-692.

Nicolopoulos, C & Barnett, S. (unpublished). Plantar pressure review using the FSCAN system.

Orlin, M.N. & McPoil, T.G. (2000). Plantar pressure measurement. Physical Therapy. 80(4), 399-409.

Raschner, C., Muller, E., & Schwameder, H. (1997). Kinematic and kinetic analysis of slalom turns as a basis for the development of specific training methods to improve strength and endurance. In E. Muller, H. Schwameder, E. Kornexl, & C. Raschner (Eds.), *Science and Skiing* (pp. 251-261). London: E & FN Spon.

Raschner, C., Schiefermuller, C., Zallinger, G., Hofer, E., Muller, E., & Brunner, F. (2001). Carving turns versus traditional parallel turns - a comparative biomechanical analysis. In E. Muller, H. Schwameder, C. Raschner, S. Lindinger, & E. Kornexl (Eds.), *Science and Skiing* (Vol. 2, pp. 203-217). Hamburg: Verlag Dr. Kovac.

Rosenbaum, D & Kersting, U. (2004). Between-day reliability of repeated plantar pressure distribution measurements in a normal population. EMED Scientific Community Proceedings. Leeds, U.K. July 29 – Aug 1. p. 21.

Schaff, P., Senner, V., & Kaiser, F. (1997). Pressure distribution measurements for the alpine skier - from the biomechanical high tech measurement to its application as swingbeep - feedback system. In E. Muller, H. Schwameder, E. Kornexl, & C. Raschner (Eds.), *Science and Skiing* (pp. 159-172). London: E & FN Spon.

Schollhorn, W., Muller, E., Lindinger, S., Raschner, C., Schwameder, H., & Benko, U. (2001). Individuality and generality in ski turn techniques. In E. Muller, H. Schwameder, C. Raschner, S. Lindinger, & E. Kornexl (Eds.), *Science and Skiing* (Vol. 2, pp. 69-83). Hamburg: Verlag Dr. Kovac.

Scott, N.W. (2004). Measurement of joint motion and acting forces on a top athlete skiing. In M. Hubbard, R.D. Mehta, & J.M. Pallis (Eds.) The Engineering of Sport 5, vol. 1. International Sports Engineering Association. Sheffield, GB.