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Ski Cross World Cup: Which course obstacles lead to high risk of injury, and which allow for overtaking? Is it different for men and women?

A systematic video analysis of the 2021/22 World Cup season

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Abstract

Purpose: The purpose of this study was to assess the risk of injury and to investigate which obstacles (Direction Changes, Jumps, Rollers, Start Straight) lead to an increased risk of injury in World Cup Ski Cross. It also investigated which obstacles allow athletes to overtake other skiers and contribute to attractive competitions.

Methods: The data was collected by video analysis of the 21/22 WC season for men and women. To measure injury risk, Surrogate measures of injury risk were assessed (Crash, Out of Balance, Contact, and Avoided Contact) and to measure overtaking, Rank Shifts were assessed. These Events were analysed using a standardised video rating process. Non-parametric tests were performed to assess differences between obstacles, venues, heats, and genders.

Results: Male athletes generally showed a higher occurrence of Events compared to female athletes. Crashes occurred equally often between the genders. For males, the occurrence of Crash, Out of Balance and Contact was significantly lower in Idre Fjäll compared to other venues. For females, the occurrence of Contact was significantly higher in semi-final 2 compared to quarter-final 1 and semi-final 1. Most Crashes occurred on Direction Changes for males, likely due to increased opponent Contact. For females, the Crashes were equal between obstacle categories. Out of Balance occurred most on jumps for both genders. A higher percentage of Out of Balance situations led to a Crash for females than males. The frequency of obstacles was equal between genders and between venues. Lasty, the possibility to overtake were equal between obstacle categories, suggesting that the course layouts were not a limiting factor for Rank Shifts.

Conclusion: Males generally exhibited more Events than females. For males, the occurrence of Crash was highest in Direction Changes, likely influenced by opponent Contact. For females, the occurrence of Crash was equal between obstacle categories, suggesting that females are Crashing due to the technicality of the course or the obstacles itself. The possibility to overtake was equal between obstacle categories but Rank Shifts may increase the risk of Contact in narrow course sections. This is highlighting the importance of designing accommodating courses with less narrow sections that is suitable for both genders.

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Acknowledgements

By submitting this thesis, I am finishing 5 years of studying at the Norwegian School of sport Sciences. These years have been filled with challenges, but also offered memorable experiences. With a strong interest in sports and physical activity, the opportunity to learn from leading experts in various research fields has brought me great joy. Each year has introduced new knowledge, and upon completing my education, I can reflect on these years and truly see the coherence of everything I have learned.

With this thesis, I am rounding up almost one year of consistent work. With that I must thank my supervisors Per Haugen and Matthias Felix Gilgien for their supports throughout this process, and for their ideas when things have been challenging. I also have to thank the "Swiss guys", Björn and Mara, for introducing me to the overall project and helping me with data collection in the early stages of the project.

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Håkon Furuseth Brusveen

1. Introduction

This project investigated the risk of injury in Ski Cross World Cup competitions, and assessed which obstacles lead to an increased risk of injury, by doing a systematic video analysis. This project is a sub-project of a larger ongoing project, initiated by FIS aimed at reducing injury risk in WC level Ski Cross. In addition to the present study, previous masters` work has been investigating this topic using the same approach and methodology described in this study. The overall aim is to contribute data and important knowledge to a research field that lacks information to make scientific-based measures regarding injury prevention and course design.

This thesis consists of a scientific article. In addition, there is an expanded theory part covering the research in Ski Cross and other relevant snow sports. The methods are described in the article. List of tables and figures are presented at the end of the article. Appendix 1 consists of descriptive tables and multiple statistical test results. Appendix 2 consists of a detailed course description for each venue.

2. Definition of terms

SX	Ski Cross.
SBX	Snowboard Cross.
WC	World Cup.
Event:	Crash, Out of Balance, Contact, Avoided Contact, Rank Shift.
SMoIR:	Surrogate Measures of Injury Risk.
Phr:	Per hour raced.
CR, OOB, CT, ACT, RS.	Crash, Out of Balance, Contact, Avoided Contact, Rank Shift.
EF, QF, SF, SmF, BF	Eighth-Final, Quarter-Final, Semi-Final, Small-Final, Big-Final.
Round of 64	First final heat with 64 skiers.
Heat level:	Different levels of final heats (QF, SF, SmF, BF).
Obstacle Category:	Direction Change, Jump, Roller, and Start Straight).

3. Theory

3.1 The sport of Ski Cross

Ski Cross (SX) is a fairly new freestyle discipline that has evolved from both freestyle and alpine skiing the recent years (Steenstrup et al., 2011, p. 1310). SX is closely related to Snowboard Cross (SBX), and it has distinctive characteristics when it comes to course design and competition format (Fédération Internationale de Ski, 2023, p. 142). SX was first included in the World Cup (WC) in the 2002/03 season, and Olympic Winter Games (OWG) in 2010 (Fédération Internationale de Ski, n.d.-a). In addition to SX, freestyle skiing consist of Aerials, Moguls, Dual Moguls, Halfpipe, Slopestyle, and Big Air (Fédération Internationale de Ski, 2023). SX is characterised by its unique course design including jumps, rollers, direction changes, and other freestyle inspired elements (Fédération Internationale de Ski, 2023, p. 141). SX competitions is usually divided into training day(s), qualification, and finals. The qualification is held either as an individually timed race or in groups (Fédération Internationale de Ski, 2023, p. 158). Generally, in WC competitions, the 32 quickest men and 16 quickest women qualify for the final knockout heats (Fédération Internationale de Ski, 2023, p. 158) The men usually start with eight finals and women with quarterfinals, based on the number of participants. Each SX heat generally starts with four skiers at the starting gate. The starting procedure involves a verbal command sequence, which consist of the instructions “skiers ready” and “attention”, followed by the mechanical drop of the gate. The gate is operated by the starter and will drop randomly within 1 to 4 seconds after the “attention” command (Fédération Internationale de Ski, 2023, p. 180). The first two athletes to cross the finish line advances on to the next round, until the winner is decided in the big final (Fédération Internationale de Ski, 2023, pp. 163, 164). Achieving success in cross disciplines requires a combination of effective starting technique, rapid acceleration, and choosing a favourable trajectory aligned with the course profile in order to maintain high speed throughout the race (Argüelles et al., 2011, p. 971).

When designing and constructing SX courses for use in WC competitions, adherence to both the Ski Cross Course Guidelines (Fédération Internationale de Ski, n.d.-b) and the Level A course standard (Fédération Internationale de Ski, 2023, p. 142) is required. The Ski Cross Course Guidelines are developed so that the athletes can compete at their best possible level in predictable and safe environments. The course should be built to provide a high level of excitement in a way that challenge the skiers' skills and technique. The course should be located so that the minimum requirements on course design is met. This includes e.g., total course length (800-1300m), vertical drop (70 – 260 m), track width (6 – 16 m), distance from start to the first direction change (100 m). The course should also include a variety of obstacles, including jumps, rollers, turns, and other technical features. This ensures that 4 – 6 opponents can race simultaneously down the course as quickly as possible, with the possibility to overtake, while maintaining the safety of the athletes (Fédération Internationale de Ski, 2023, pp. 141–143). However, the SX Course Guidelines does only give a framework for the course layout, and detailed rules on obstacle construction does not exist. SX is considered among the most dangerous professional snow sports, and is reported to come with high injury risk (Flørenes et al., 2010, p. 807; Soligard et al., 2015, p. 3, 2019, p. 3). The research on SX is limited and the mechanisms related to injuries are an ongoing research topic.

3.2 Epidemiology in snow sports

Snow sports, including skiing and snowboarding have become increasingly popular winter activities the recent years, attracting millions of participants each year (Flørenes et al., 2011, p. 196). Despite its popularity, snow sports are reported to come with high injury risk with potentially severe outcomes, in comparison to sports like football and handball, where less severe injuries are more common (Major et al., 2014, p. 4). Experienced athletes are likely to suffer from more severe time-loss injuries in comparison to recreational athletes who typically experience injuries from accidental falls caused by poor technique, resulting in e.g., wrist fractures (Fu et al., 2022, p. 6). In the following section, an epidemiological overview, type of injury, and differences in professional snow sports are presented.

3.2.1 Injury incidence in snow sports

By doing a systematic meta-analysis, Fu et al. 2022 estimated the incidence of injuries in professional snow sports, including alpine skiing, freestyle skiing, nordic skiing, and snowboard. A total of 22 studies were included for injury incidence calculations. In their report, it was observed an overall injury incidence of 3.49 injuries per 1000 athlete-days (95% CI: 2.97 – 4.01) for all snow sports combined. Further, they reported that the highest injury incidence was found in freestyle skiing (6.83 per 1000 athlete-days, 95% CI: 4.00-9.66), then snowboarding (3.99 per 1000 athlete-days, 95% CI: 2.86-5.12), alpine skiing (3.57 per 1000 athlete-days, 95% CI: 2.77-4.36), and Nordic skiing (2.70 per 1000 athlete-days, 95% CI: 1.94-3.46).

3.2.2 Injury type, location, and mechanisms

In alpine skiing, the predominant injury type observed is lower-extremity injuries, with anterior cruciate ligament (ACL) sprain being the most frequent injury type (Fu et al., 2022, p. 10). In addition, injuries to the lower-back, head/face, shoulder, and hands/fingers are also common (Flørenes et al., 2009, p. 975). Most of the reported injuries were moderate to severe, caused by both contact and non-contact mechanisms (Fu et al., 2022, p. 10). Injuries did for the most part occur during World Cup or World Championship competitions (45%). The remaining injuries occurred during official competition training (16.2%), training on snow (25.1%), other competitions/official training (12.6%), and during off-snow training (1.0%) (Flørenes et al., 2009, p. 975).

For snowboard, Fu et al. (2022) reported that injuries to the lower-extremities were most common, followed by injuries to the upper-extremities. The predominant injury types were conclusions, sprains, and fractures. This was largely caused by contact situations (Fu et al., 2022, p. 10).

Freestyle skiing had the highest incidence of severe injuries, with injuries to the head and neck being frequently reported (Fu et al., 2022, p. 10). The aerial manoeuvring performed in freestyle lead to a higher risk of impacts to critical body parts compared to other sports (Flørenes et al., 2010, p. 807; Steenstrup et al., 2014, p. 3). Additionally, lower-extremity sprains and fractures were also common, often caused by contact situations (Fu et al., 2022, p. 10).

In Nordic skiing, severe injuries are less common compared to alpine skiing, freestyle skiing, and snowboard. Athletes who participate in typical aerobic snow sports, such as cross-country skiing, are more prone to develop injuries related to overuse (Soligard et al., 2015, p. 3). In addition, respiratory illness caused largely by infections are more common in these sports (Soligard et al., 2015, p. 4).

3.3 Ski Cross course obstacles and injury risk

Alpine skiing, freestyle skiing and snowboard are different in its nature. However, they also share some similarities. All disciplines involve competing in challenging courses containing either turns, aerial features and/or high speed. Given that SX involve a mix of these elements, the factors causing injuries may be a combination of those observed in other snow sports.

In the following sections, SX characteristics and the distinct element categories (jumps, direction changes, and rollers) will be described and expanded upon knowledge from alpine skiing, snowboard, and other freestyle disciplines. Further, injury risk in SX specific races will be addressed and how the use of surrogate measures can serve as valid variables for injury risk to increase statistical power.

3.3.1 Jumps

Jumping elements are important features in SX courses. These aerial elements come in different shapes and sizes, like Wu-tangs, spines, corner jumps, step-ups/downs, and kickers (Fédération Internationale de Ski, n.d.-b, p. 5). However, jumping is reported to come with high injury risk. Previous studies have shown that disciplines containing jumps are likely to have a higher risk of injury compared to disciplines without jumps (Major et al., 2014, p. 4; Torjussen, 2006, p. 233). At the recreational level, severe injuries to the head, face, and back are common on aerial features in terrain parks compared to regular ski slopes where less severe injuries are more frequent (Brooks et al., 2010, p. 119).

To investigate the construction of jumps, recent studies have examined the design of terrain park jumps to increase the safety of the users (Hubbard & Swedberg, 2012; Levy et al., 2015; McNeil et al., 2012). Traditionally, local terrain park groomers rely on their own experience to construct jumps, often with "table-top" design, without any analysis or help from engineering personnel (Hubbard & Swedberg, 2012, p. 2). With this approach, both jump characteristics, the lack of standardisation between venues, as well as changes due to snow conditions can cause dangerous jumping situations (McNeil et al., 2012, p. 2). The traditional table-top design often has a "sweet-spot" past the knuckle where athletes seek to land. However, this is only true under certain snow conditions, meaning that the landing impact will vary (McNeil et al., 2012, p. 12).

Landing on the flat part, or the so called “deck” before the knuckle, or overshooting the table-top must be avoided, since the impacts here can be dangerously high (Levy et al., 2015, p. 2; McNeil et al., 2012, p. 10). This means that the take-off velocity of the jumper must be precisely executed to avoid large impacts upon landing (McNeil et al., 2012, p. 12). Since table-top designs does not control for landing impact, researchers have suggested the incorporation of engineering design principles (Hubbard & Swedberg, 2012; Levy et al., 2015; McNeil et al., 2012). By doing so, the risk of injury may decrease as a result of designing the jump with a wider and more forgiving landing area, with less pronounced “knuckle”, known to largely increase the injury risk (McNeil et al., 2012, pp. 9, 10).

To make terrain park jumps safer, the concept of Equivalent Fall Height (EFH) has been used as an important parameter to calculate landing impact (Hubbard & Swedberg, 2012, p. 3; Levy et al., 2015, p. 12; McNeil et al., 2012, p. 9). The landing impact from a jump is determined by the magnitude of energy the jumper must absorb upon landing (McNeil et al., 2012, p. 6). Since EFH is dependent on the velocity normal to the landing surface, manipulating the angle of the landing to align with the flight angle of the jumper can dramatically reduce EFH, thus reduce the risk of severe injury (Hubbard & Swedberg, 2012, p. 3).

In competitive freestyle and snowboard disciplines, like big air and slopestyle, aerial features associated with high injury risk are important elements of the sports (Soligard et al., 2015, p. 3, 2019, p. 3; Steenstrup et al., 2014, p. 3). In competitive settings, the course design must typically undergo extensive evaluation and testing based on existing rules and guidelines as opposed to terrain park features constructed based on local experience (Hubbard & Swedberg, 2012, p. 2). Given the aim of competitive athletes to optimise performance, the advanced manoeuvres performed are likely the more prominent risk factor compared to recreational settings where suboptimal technique and poorly designed jumps are the main risk factors. However, by reducing the EFH, the injury outcome of a miscalculated jump would be less severe regardless of skill level or setting (McNeil et al., 2012, p. 14).

The injury incidence in aerial disciplines differ slightly (Flørenes et al., 2010, p. 807; Soligard et al., 2015, p. 3, 2019, p. 3). Some of this variability can likely be explained by some disciplines are in a more controlled format than others. In big air, athletes focus on mastering one jump and trick per run, as opposed to slopestyle where multiple features needs to be linked together, including rails and jumps, to score points (Steenstrup et al., 2014, p. 3). As a result, less factors are needed to be accounted for in big air compared to slopestyle. In aerial skiing, however, the injury incidence tends to be higher compared to big air, slopestyle and moguls (Soligard et al., 2015, p. 3, 2019, p. 3). Aerial skiing is characterised by high take-off speeds with inclination angles up to 70°. This, are known to cause so-called “slapback” situations where skiers gaining to much backward rotation while air born, leading to large impacts to the back and head upon landing (Mecham et al., 1999, p. 28). The substantial hights obtained by the skiers, as well as the complexity of the manoeuvres performed are likely important factors causing severe injuries in aerial skiing (Mecham et al., 1999, p. 27).

In alpine skiing, poor technique and incorrect strategy are considered important risk factors when jumping (Bere et al., 2011, p. 1423; Gilgien et al., 2014, p. 4; Heinrich et al., 2014, p. 185). Heinrich et al. (2014) investigated the relationship between jump landing kinematics and peak ACL force in downhill skiing. They reported that the posture of the skier prior to the landing had a significant predictive value for the peak ACL force. Meaning that poor jumping technique (e.g., backward lean, hip flexion, knee extension, and ankle dorsiflexion) can largely influence the landing forces to the knee, and consequently, the risk of ligament injury (Heinrich et al., 2014, pp. 182, 185). This is corresponding to previous findings that landing back weighted were an important risk factor to ACL injuries (Bere et al., 2011, p. 1423).

In another study by Schindelwig et al. (2015) they developed a simulation model to predict the landing impacts in downhill races with different slope inclinations in the landing area. They introduced the term ELH, which is a theoretical quantity, independent of skier mass, referring to the free fall height. By doing so, they calculated the amount of kinetic energy the jumper must absorb during the landing phase with different slope angles. As opposed to EFH, introduced to measure impacts on terrain park jumps, ELH also take changes to the landing inclination into account (Schindelwig et al., 2015, p. 800). Human muscles can only withstand a certain amount of energy without help from passive structures. Schindelwig et al. (2015) defined the maximum values of muscular absorbable fall height to be approximately 1.1m for women, and

1.5m for men, and used for maximum muscle absorbable equivalent landing height (mmaELH). They revealed that the predominant factors affecting ELH were take-off speed, take-off angle, and slope inclination of the landing area. The different landing inclinations revealed that the ELH values were lower than mmaELH in most situations but could be manipulated by lowering the centre of mass (CoM). Meaning that ELH values can exceed mmELH if the skier does not lower the CoM at certain speeds (Schindelwig et al., 2015, p. 804). Lower speeds can, however, cause higher ELH due to the skier not reaching the preferable landing area. Thus, increasing the approach speed and/or elevating the CoM to increase the flight distance to reach a steeper landing area would be preferably (Schindelwig et al., 2015, p. 804). When investigating landing surfaces with constant inclinations, ELH and EFH values were similar. When inclination angles increased over a short period of time the total impact were elevated. Thus, the injury risk is higher. Schindelwig et al. (2015) highlighted that the simulation model used was based on a skier landing upright on both legs simultaneously. And If the skier were landing back weighted or only on one ski, the outcome would likely be more severe, as previous findings have suggested (Bere et al., 2011, p. 1423; Heinrich et al., 2014, p. 185).

Another common cause of injury in alpine skiing, is related to excessive gain of angular momentum during airtime, which leads to the skier rotating backwards and ultimately making ground impact in critical body positions (Gilgien et al., 2014, p. 4). The duration of the air time play a crucial role for the injury outcome, since the a longer period of time in the air equals larger rotation angles (Gilgien et al., 2014, p. 4).

In contrast, Nordic ski jumping come with a lower risk of injury compared to other aerial snow sports (Flørenes et al., 2012, p. 61; Soligard et al., 2015, p. 3, 2019, p. 3). Despite the long jumps performed, the competition format in ski jumping is more strict and more controlled compared to other snow sports. To prevent injuries occurring by jumps longer than hill size, event officials alter the starting point to match the take-off speed of the athletes (Stenseth et al., 2020, p. 1).

3.3.2 Direction changes

Different types of turns are present in SX courses. The direction change category includes; banked turns, GS type turns, and negative turns (Fédération Internationale de Ski, n.d.-b, p. 6).

In alpine skiing, speed has previously been reported as the biggest injury risk factor (Flørenes et al., 2009, p. 975). However, more recent work has indicated that this might not be the only factor to account for. Gilgien et al. (2014). Investigated the mechanical characteristics and injury risk in alpine skiing. They reported that, despite the increasing speed from giant slalom to downhill, the number of injuries normalised to per hour skiing were similar between the sub-disciplines. Comparing giant slalom to super-G and downhill there was an increase in the amount of straight skiing, as well as an increase in turning speed and radius (Gilgien et al., 2014, p. 2). The GRF is also reported to be higher in giant slalom compared to downhill due to sharper and more frequent turns (Gilgien et al., 2014, p. 2). As a result of the smaller turn radii, skiers must aggressively lean backwards and inwards to make the ski turn fast. Thus, additional factors such as out of balance situations can be critical in these “maxed-out” body positions and could potentially lead to severe injury (Gilgien et al., 2014, p. 3). Furthermore, gate contact is reported to contribute to injury in giant slalom and super-G (Bere et al., 2014, p. 670). This occurred both directly by inappropriately skiing through the gate, or by hooking the inner ski in the gate, or indirectly by making contact with the gate after a previous fall (Bere et al., 2014, p. 670).

While injury situations in giant slalom are often related to turning mechanics, the speed component in super-G and downhill are considered a bigger risk factor (Gilgien et al., 2014, p. 3, 2020, p. 1, 2021, p. 1). The speed at impact in crash situations significantly increases the amount of energy that needs to be dissipated, and by increasing the speed more severe injuries are likely to occur (Gilgien et al., 2014, p. 3). With increased speed, the available time to adapt to the surroundings are low. Meaning that athletes are more prone to make mistakes, especially in critical sections, e.g., when jumping or turning (Gilgien et al., 2014, p. 3). To assess the safety of the athletes, reducing the speed by gate setting is reported to be an effective measure in both giant slalom (Gilgien et al., 2020, p. 3) and even more so in super-G (Gilgien et al., 2021, p. 4). This can be done eighter by increasing the horizontal gate offset, or by shortening the vertical gate distance. However, to avoid skier fatigue from higher GRF and impulse due to shorter turn radii, adjusting vertical gate distance is favoured over increasing horizontal gate offset (Gilgien et al., 2020, p. 3, 2021, p. 4).

3.3.3 Rollers – energy pumping and starting technique.

Rollers are an important element category and characteristics of SX. Rollers comes in different sizes and combinations depending on how the course is designed. This includes e.g., single rollers, double rollers, triple rollers, or rollers in combination with a turn (Fédération Internationale de Ski, n.d.-b, p. 5).

Little is known about rollers and injury risk. However, mastering rollers is crucial to gain speed in a time dependent racing discipline like SX. The use of kinetic energy, by moving the centre of mass with a pumping technique (energy pumping) can be used to increase the speed on rollers (Luginbühl et al., 2023, p. 1). The force that is working in the direction of the slope can be utilised to enhance skier speed by rising the normal force by increasing vertical acceleration of the centre of mass (Luginbühl et al., 2023, p. 1). Instead of skiing up and down the roller, the skier must perform a jumping-flying-landing-motion (Luginbühl et al., 2023, p. 9). This is done by the athlete performing a "jump" prior to the uphill, keeping the centre of mass relatively stable by mostly lifting the legs, and then maximally activate body force against the ground during the downhill phase to gain speed (Luginbühl et al., 2023, p. 9). Thus, the skiers aim to only ski down the roller to increase the downhill acceleration.

A good starting technique is very important in many racing disciplines, including SX. A good start is important to gain speed quickly in order to get in front of the opponents to choose the most appropriate trajectory down the course (Argüelles et al., 2011, p. 971). To do so, athletes must time the start well to push off quickly out of the gate. The first section in SX is generally a mix of rollers, and small jump features before the first direction change (Fédération Internationale de Ski, n.d.-b, p. 4). The combination of a good gate push-off and maximum leg work by energy pumping in the first section are therefore important, and will largely influence the outcome of the race (Argüelles et al., 2011, p. 971). The gate push-off phase in alpine skiing is also important. However, in alpine skiing the acceleration phase where the skier uses the skis and poles to gain speed after the push-off seem to be more important (Kröll et al., 2012, p. 11). Compared to

SX, where skiers compete simultaneously, gate push-off is likely more important to gain an advantage from the other opponents and to be in command early in the race (Argüelles et al., 2011, p. 971).

3.3.4 Injury risk in Ski Cross specific races

The knowledge from injury situations in other snow sports can be important to understand the risk factors involved in SX. However, since SX competitions include complex element combinations and simultaneous heat racing, additional risk factors are important to address to understand the causes and mechanisms leading to time-loss injuries in SX.

Randjelovic et al. (2014) is to date the only study to investigate the situations leading up to time-loss injuries in SX. By analysing video recordings of 33 injury situations, they revealed that injuries occurred while jumping (n=16), turning (n=8), a combination of turning and jumping (n=7), or on rollers (n=2). Most of the injuries occurred by opponent contact (n=6), followed by inappropriate strategy (n=5), technical error (n=3), out of balance due to previous obstacle (n=1), and injury caused by unknown causes (n=1). In all situations, the skiers became unbalanced prior to the point of injury, which resulted in a fall. Often the fall occurred after a jump or turn element (Randjelovic et al., 2014, p. 5).

The aerial features built in SX are designed with a focus on speed and minimising air time (Fédération Internationale de Ski, n.d.-b, p. 3). Compared to Big Air/Slopestyle, where athletes perform spectacular tricks while airborne, one might assume that jump-related injuries in SX are less common. However, according to Randjelovic et al. (2014) jumping related injuries in SX are frequent, both by skier error at take-off and by opponent contact when jumping or landing.

In turning situations, most of the contact related injuries occurred in banked turns. This occurred primarily due to skiers failing to maintain their intended line and collided with other competitors, causing falls (Randjelovic et al., 2014, p. 6) In regular turns, injury occurrence are often associated with technical errors, particularly by excessive inward lean causing a fall (Randjelovic et al., 2014, p. 6), which is a similar to mechanisms observed in giant slalom (Gilgien et al., 2014, p. 3).

The injury situations that occurred on rollers were largely associated with ski-to-ski contact (Randjelovic et al., 2014, p. 6). This stands in contrast to SBX where technical errors where the cause of injury (Bakken et al., 2011, p. 1319).

To date there is no existing standards regarding course building in SX, besides the distance from the start to the first turn (Fédération Internationale de Ski, 2023, p. 142). The Ski Cross Course Guidelines are merely a framework for designing the course. The guidelines do not provide specific instructions on how to build jumps or how to combine different obstacles with regard to their sizing or spacing, for instance. The findings of Randjelovic et al. (2014) propose that by increasing the space between obstacles as well as reducing the number of narrow sections down the course could be useful. With more space, skiers will have more time to adjust both their own body position and in relation to their opponents between the elements. This is likely to be beneficial to prevent situations associated with injury risk in SX (Randjelovic et al., 2014, p. 7).

It is recommended that attention is given to the jump profile in order to minimise the impact of landings (Randjelovic et al., 2014, p. 7). Engineered design principles can be applied not only to terrain park features, but also to SX. Safer jumps with more forgiving landing areas can be constructed based on the theory of EFH, to reduce the risk of severe injuries (Hubbard & Swedberg, 2012; Levy et al., 2015; McNeil et al., 2012). In addition, the use of appropriate safety nets is important. Randjelovic et al. (2014) reported that out of the 33 injury cases, nine involved contact with the safety net. Among these nine cases, the net was the wrong type or place incorrectly in three of them (Randjelovic et al., 2014, p. 5). In alpine skiing safety nets and barriers are strategically placed down the course to reduce crash-impacts (Bere et al., 2014, p. 673). Bere et al. (2014) observed that injuries caused by contact with the safety net only occurred in 9% of the situations, and that most of the injuries occurred in other areas of the course or before contact with the nets. Safety nets serve as crucial barriers to prevent skiers from colliding with objects outside the course (Bere et al., 2014, p. 673). However, if the applied safety measures are wrongfully executed, they can in some cases counteract their purpose (Randjelovic et al., 2014, p. 7).

3.4 Gender differences

The difference in injury incidence between male and female athletes is not well documented. However, reports from Winter Olympics in 2010 and 2014 suggested that female athletes were at higher risk of sustaining a injury compared to their male counterparts (Engebretsen et al., 2010, p. 774; Soligard et al., 2015, p. 4). Another study reported that the differences was non-significant (Flørenes et al., 2010, p. 807). Spörri et al. (2017) evaluated the knowledge on injury prevention in alpine skiing, and pointed out that male athletes tend to get injured more frequently compared to female athletes, and that female athletes in some cases are more prone to sustain knee injuries. Even though gender differences are often non-significant in these reports, injury type may influence such variations (Spörri et al., 2016, p. 606). Alpine skiing uses different courses for men and women, as opposed to SX where both genders use the same course (Fédération Internationale de Ski, 2020, p. 84, 2023, p. 142). Therefore, gender differences in SX are a topic of interest for future research.

3.5 Surrogate measures of injury risk

In the world of sports science, researchers often aim to prove an effect related to e.g., training or injury prevention. However, when applying these measures on relevant subgroups (e.g., gender, age, injury type/location) the risk of underpowering the study is likely (Kröll et al., 2017, p. 1644). Due to a small sample size, statistical testing may be impossible, leading to the risk of committing a type 2 error, where the null hypothesis is wrongfully accepted when in fact there is a difference. This can occur when the sample size is too small to accurately detect the effect being investigated (Kröll et al., 2017, p. 1644). Increasing the effect size or increasing the sample size can solve this problem. However, this is often costly and time-consuming, and may be limited by constraints within the study. A possible solution is to apply surrogate outcome measures to increase the statistical power (Kröll et al., 2017, p. 1645).

To investigate injuries in SX, surrogate measures of injury risk can be used to increase the sample size. These surrogate measures can be defined as certain events that represent injury risk, as long as they are frequently associated with injuries (Kröll et al., 2017, p. 1645). Randjelovic et al. (2014) identified out of balance and opponent contact as important events leading to time-loss injuries in SX. This is also corresponding well with findings in SBX (Bakken et al., 2011, p. 1321). Out of balance and contact can therefore potentially serve as surrogate measures of injury risk in SX.

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Article

Title: *Ski Cross World Cup: Which course obstacles lead to high risk of injury, and which allow for overtaking? Is it different for men and women? - A systematic video analysis of the 2021/22 World Cup season*

Abstract

Purpose: The purpose of this study was to assess the risk of injury and to investigate which obstacles (Direction Changes, Jumps, Rollers, Start Straight) lead to an increased risk of injury in World Cup Ski Cross. It also investigated which obstacles allow athletes to overtake other skiers and contribute to attractive competitions. ***Methods:*** The data was collected by video analysis of the 21/22 WC season for men and women. To measure injury risk, Surrogate measures of injury risk were assessed (Crash, Out of Balance, Contact, and Avoided Contact) and to measure overtaking, Rank Shifts were assessed. These Events were analysed using a standardised video rating process. Non-parametric tests were performed to assess differences between obstacles, venues, heats, and genders. ***Results:*** Male athletes generally showed a higher occurrence of Events compared to female athletes. Crashes occurred equally often between the genders. For males, the occurrence of Crash, Out of Balance and Contact was significantly lower in Idre Fjäll compared to other venues. For females, the occurrence of Contact was significantly higher in semi-final 2 compared to quarter-final 1 and semi-final 1. Most Crashes occurred on direction changes for males, likely due to increased opponent Contact. For females, the Crashes were equal between obstacle categories. Out of Balance occurred most on Jumps for both genders. A higher percentage of Out of Balance situations resulted in a Crash for women than for men. The frequency of obstacles was equal between genders and between venues. Lasty, the possibility to overtake were equal between obstacle categories, suggesting that the course layouts were not a limiting factor for Rank Shifts. ***Conclusion:*** Men generally exhibited more Events than women. For men, the occurrence of Crash was highest in Direction Changes, likely influenced by opponent Contact. For women, the occurrence of Crash was equal between obstacle categories, suggesting that women’s Crashes are due to the technicality of the course or the obstacles themselves. The possibility to overtake was

equal between obstacle categories but Rank Shifts may increase the risk of contact in narrow course sections. This is highlighting the importance of designing accommodating courses with less narrow sections that is suitable for both genders.

Introduction

Ski Cross (SX) is a recent addition to freestyle skiing, developed from alpine skiing with inspiration from both motocross and freestyle disciplines (Steenstrup et al., 2011, p. 1310). SX shares many similarities with Snowboard Cross (SBX), both in terms of its competition format and course characteristics (Fédération Internationale de Ski, 2023, p. 142). In cross sports, the athletes must navigate through challenging courses that feature a unique mix of turns, rollers, jumps, and other aerial features (Fédération Internationale de Ski, 2023, p. 141). SX was first added to the FIS World Cup (WC) in the 2002/03 season, and later included in the Olympic Winter Games (OWG) in 2010 (Fédération Internationale de Ski, n.d.-a). In WC competitions the athletes undergo an qualification race individually or in groups (Fédération Internationale de Ski, 2023, p. 158). Generally, a 64 and 32 bracket is used for men and women respectively. The 32 fastest men and the 16 fastest women advance to the final rounds, where heats are formed with (up to) four skiers (Fédération Internationale de Ski, 2023, pp. 158–163). Upon receiving a signal from the starter, the gate drops, and the skiers push off from the starting gate and begin their race (Fédération Internationale de Ski, 2023, p. 180). The two fastest in each heat advances on until the podium is decided in the big final (Fédération Internationale de Ski, 2023, pp. 163, 164, 180). To succeed in SX, a strong start is necessary to gain speed quickly in order to secure an advantageous trajectory line ahead of the opponents and ultimately cross the finish line first (Argüelles et al., 2011, p. 971).

SX is, however, reported to come with high injury risk and is considered among the most dangerous snow sports (Flørenes et al., 2010, p. 805; Soligard et al., 2015, p. 3, 2019, p. 3). Prior to the 2006/07 season, the International Ski Federation (FIS) developed the Injury Surveillance System (FIS ISS) to monitor the occurrence of injuries in FIS disciplines (Fédération Internationale de Ski, 2019). According to the FIS ISS, the time-loss (>1 day absence) injuries in SX are reported to be 33,8 per 100 athletes per season. Severe injuries (>28 days absence) are reported to be 14,9 per 100 athlete per season (Flørenes et al., 2010, p. 805). In general, female athletes in both SX and SBX are more likely to get injured than their male counterparts (Engebretsen et al., 2010, p. 4; Soligard et al., 2015, p. 4). Total injury incidences (per 1000 runs) has been reported to be 16,6 for males, and 21,8 for females (Flørenes et al., 2010, p. 807).

Although SX is relatively new to the OWG programme, injury rates are also reported to be high, increasing from 13% in Vancouver 2010 to around 25% in PyeongChang 2018 (Engebretsen et al., 2010, p. 775; Soligard et al., 2019, p. 3). Joint and ligament injuries, as well as bone stress and fractures are the most common type of injury, with the knee being the most frequently injured body part (Flørenes et al., 2010, p. 805). Contact with the ground, including impact on course features are the most common mechanism of injury in SX (Soligard et al., 2015, p. 3).

With knowledge from other snow sports, researchers have observed that injury situations often occur in turning and/or jumping situations (Bere et al., 2011, p. 1423; Gilgien et al., 2014a, p. 3; Heinrich et al., 2014, p. 185). In technical alpine disciplines, injuries often occur due to unexpected out of balance situations related to speed and small turn radii (Gilgien et al., 2014a, p. 3). In speed disciplines, speed itself is considered the most important injury risk factor. Thus, mistakes can result in high-force impacts with possible severe injury outcomes (Gilgien et al., 2014a, p. 3). In slopestyle and big air, jumping is key elements of the sports, and comes with high injury risk (Soligard et al., 2015, p. 3, 2019, p. 3; Steenstrup et al., 2014, p. 3). The athletes are competing on big jumps, while performing spectacular rotations, exposing the athletes to dangerous situations if not properly executed. In addition, skier error often occur in the final section of the course, indicating that skier fatigue could be an important injury risk factor as well (Bere et al., 2014, p. 673).

To assess the situations leading up to time-loss injuries in SX, Randjelovic et al. (2014) did a descriptive video analysis, investigating 33 injury cases over four seasons. They revealed that injuries occurred primarily in four different situations: jumping (n=16), turning (n=8), jumping and turning (n=7) and rollers (n=2). These injury situations occurred due to opponent contact (n=13), technical errors (n=8), or inappropriate strategy (n=8), causing the skier to crash (n=29). The combination of technical courses, high speed, and tight heat-racing are considered to be important injury risk factors in SX (Randjelovic et al., 2014, p. 1).

Course design has been suggested as an important measure for reducing injury risk in cross disciplines (Bakken et al., 2011, p. 1322; Randjelovic et al., 2014, p. 7). As of today, there is no standardisation regarding course and obstacle layout, only guidelines that ensure the framework for course design is maintained. This includes, for example, minimum course length, width, inclination, and obstacle recommendations. Beyond that, only the distance from the start to the first direction change is standardised (Fédération Internationale de Ski, n.d.-b). The course characteristics (e.g., jump height, number of obstacles, and distance between obstacles), is very much decided by the race director, and the course designers at the respective venues. This can be challenging because the lack of consistency between different courses and could possibly cause more injuries if designed poorly. The findings of Randjelovic et al. (2014) suggest that injuries in SX can be avoided by designing the course with more space between obstacles, so that the athletes have more time to adjust and tackle the obstacles. In addition, slowing down the athlete in relevant sections of the course (Gilgien et al., 2014a, p. 3), and implementation of engineered jump design principles to minimize the impact upon landing based on the theory of equivalent fall height (Hubbard & Swedberg, 2012, p. 3; Levy et al., 2015, p. 12; McNeil et al., 2012, p. 9), is suggested to be important for injury prevention as well.

To investigate injury situations in elite sports are challenging, and the risk of underpowering the study is likely due to small sample or effect size (Kröll et al., 2017, p. 1644). Increasing the sample size or effect size is, however, time-consuming and will often encounter limitations within the study. Nonetheless, knowledge about the risk factors involved is necessary to provide evidence-based preventive measures to reduce injury risk (Bahr & Krosshaug, 2005, p. 328). One solution is to use surrogate measures of injury risk. By doing so, analysing potential injury events are possible. As long as the surrogate measures are frequently associated with injury situations, these surrogate measures can serve as valid indicators for injury risk and contribute to increasing the statistical power in the absence of injury data (Kröll et al., 2017, p. 1645). Out of balance and opponent contact has been observed to be associated with injury in SX and SBX (Bakken et al., 2011, p. 1321; Randjelovic et al., 2014, p. 4). These variables can potentially serve as measures of injury risk. Previous master’s theses have used surrogate measures to investigate events associated with injury risk in SX/SBX based on definitions by Bruhin et al. (n.d.). The results suggest that most of the crash situations occurred during direction changes (Post, 2022, p. 19). This is contrary to the findings of Randjelovic et al. (2014) and Bakken et al. (2011) who observed that jumps accounted for the largest number of injuries. However, it was determined that contact between opponents were the most frequent during direction changes, which corresponds with the findings of Randjelovic et al. (2014). Another master's study reported that out of balance and crash situations were the strongest indicators for injury risk (Rieder, 2022, p. 35). This finding align with research indicating that most of the injuries result from athletes losing control and falling, thus sustaining an injury (Bakken et al., 2011, p. 1321; Randjelovic et al., 2014, p. 5).

This study is designed to analyse various Events based on definitions described by Bruhin et al. (n.d.), that occur during SX races. To differentiate between Events related to injury risk and Events related to preservation of the sport's entertainment value, the different Events are divided into two categories of interest; Surrogate Measures of Injury Risk, which includes, Contact, Avoiding Contact, Out of Balance, and Crash, and the other category which includes Rank Shifts. In the present study, *SMoIR* is used as an abbreviation for Surrogate Measures of Injury Risk. Figure 1 shows a schematic overview of the Event categories analysed in this study.

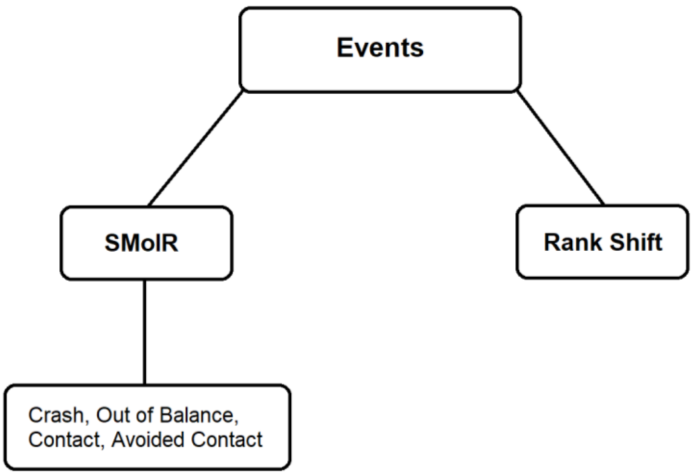


Figure 1. *Schematic overview of the Event categories analysed in this study. SMoIR = Surrogate Measures of Injury Risk.*

Furthermore, the analysis in this study was divided into two separated parts. The first part was to analyse the Events per hour raced (*phr*). Comparisons were made between genders, venues, and heat levels. Next, the *SMoIR* incidence was calculated for every obstacle within each venue. This provided three levels of detail for the analysis of *SMoIR.* In addition, the frequency between obstacles where calculated. Figure 2 shows a schematic overview of the analyses performed in this study.

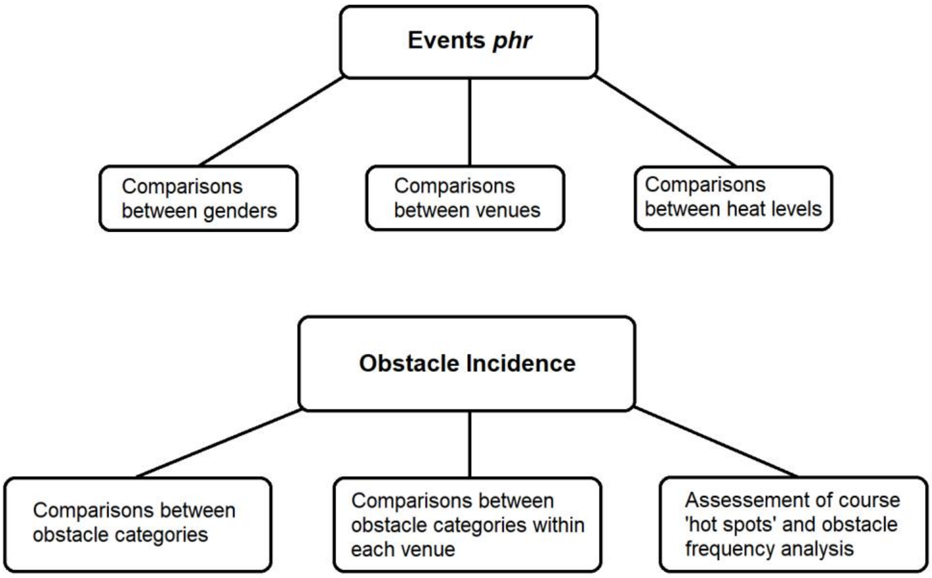


Figure 2. *Schematic overview of the levels of analysis performed in this study. Phr = per hour raced.*

Research questions

This master's thesis is part of a larger project initiated by FIS to reduce injury incidence in SX competitions. The objective of the present study is to expand the database and contribute knowledge regarding risk factors associated with injury risk. Moreover, an expansion of the database will provide a basis for further research and ultimately help designing safer yet exciting courses.

Based on video analysis of World Cup-level competitions, this study continued the work by Post (2022) and Rieder (2022) to quantify and characterise the occurrence of *SMoIR* and Rank Shifts in SX races. This study was based on the same methodology originally developed and described by Bruhin et al. (n.d.). The following research questions were addressed in this study:

Comparisons of Surrogate Measures of Injury Risk

- Is there a difference in number of *SMoIR* between *genders*?
- Is there a difference in number of *SMoIR* between *venues*?
- Is there a difference in number of *SMoIR* between *heat levels*? (Quarter-finals, Semi-finals, Small-finals, Big-finals)
- Is there a relation between the different types of *SMoIR*?

Element frequency

- Is there a difference in course obstacle frequency between *genders*?
- Is there a difference in course obstacle frequency between *venues*?

SMoIR comparisons between obstacles and obstacle categories

- Is there a difference in SMoIR incidence between *obstacle categories*? (Jumps, direction changes, rollers)
- Is there a difference in *SMoIR* incidence between *obstacle categories* within each *venue*?
- Is there a difference in *SMoIR* incidence between *individual* obstacles within each *venue*?

Rank Shift comparisons

- Is there a difference in number of Rank Shifts between *genders*?
- Is there a difference in number of Rank Shifts between *venues*?
- Is there a difference in number of Rank Shifts between *heat levels*? (Quarter-finals, Semi-finals, Small-finals, Big-finals)
- Is there a relation between Rank Shifts, and the different types of *SMoIR*?

Rank Shift comparisons between obstacles and obstacle categories

- Is there a difference in Rank Shift incidence between *obstacle categories*? (Jumps, direction changes, rollers)
- Is there a difference in Rank Shift incidence between *obstacle categories* within each *venue*?
- Is there a difference in Rank Shift incidence between *individual* obstacles within each *venue*?

Methods

Subjects

The subjects in this study were both male and female SX athletes who competed at the WC level. A total of 893 men and 460 female athletes were analysed. The same subject was analysed multiple times in different heats throughout the season. No written approval to participate from the athletes were required in this study.

Ethical considerations

The video recordings were provided by official FIS TV producers and analysis of the recordings did not require storage of sensitive or personal information. The project was ethically approved by NSD (Norwegian Centre for Research Data), and the Norwegian School of Sports Sciences Ethical Committee.

Video collection

Video recordings from the 2021/22 SX season included World Cup (*n* = 13) and Olympic Winter Games (*n* = 1) races in Secret Garden (CHN), Val Thorens (FRA), Arosa (SUI), Innichen (ITA), Nakiska (CAN), Idre Fjäll (SWE), Beijing OWG (CHN) Reiteralm (AUT), and Veysonnaz (SUI). Depending on the Event, video recordings included round of 64, eighth-finals, quarter-finals, semi-finals, small-finals, and big-finals.

The video recordings were performed by the official FIS TV broadcast right holders; Infront Productions (ITA). The online video analysis platform Dartfish.tv (Fribourg, 8.9.15.0, 2022) was used to upload the video recordings, and made available for analysis. The same platform was used to analyse races during the training and validation process because of its slow-motion feature and sharing options.

Validation process

To reach intra-rater reliability, to secure a high degree of agreement between raters, rating previous years data based on a standardised process (Bruhin et al., n.d.) was undergone by the rater prior to the video analysis of the 21/22 season. A set of pre-selected cropped videos was used to train and test the current rater to secure that the rater is qualified and in agreement with previous raters for the video analysis. The training and validation process was separated into three steps, where each step included selected videos to be rated. Each validation step was reviewed by experts comparing the results with previously rated protocols through a larger expert group, serving as the “gold standard” for how to rate the data. After each training step, high degree of agreement between the protocols was required before the new rater could continue to the next step. Situations with low consensus were discussed after each step to gain a common understanding. The third validation step consisted of selected videos from step one and two to be reanalysed. Intra-rater reliability was calculated using Fleiss’ kappa and Chronbach’s alpha. Values = 0 indicate no agreement and values close to 1 indicate strong agreement. Choen’s kappa was used to measure the inter-rater reliability.

Video analysis

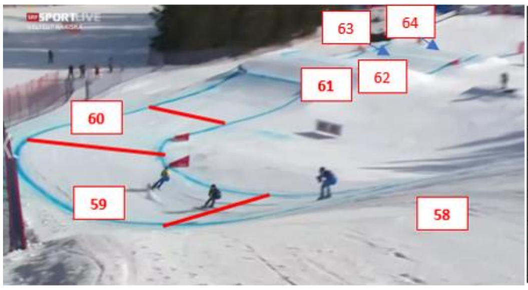
Video analyses were performed by one master’s student. A detailed Microsoft Excel (version 2303, 16.0.16227.20202) form was developed by experts to perform the video analysis. Each heat was separated by reporting start and finish. All Events that were observed was noted with its corresponding information in a new row. This included: general information (video title, gender, heat type), Event details (time, segment- and obstacle number, obstacle details), and type of Event (Crash, Time of no Return, Out of Balance, Contact, Avoiding Contact, ranking of the athletes, and gate order). An example of the excel form is visualised in Figure 3.

Event localisation

Course information for each venue was documented in Microsoft Word (version 2303, 16.0.16227.20202). This included detailed information of all the obstacles for each venue, with its respective obstacle number and course section (Figure 4). In addition, the obstacles had three levels of detail, describing where Events took place (Figure 5). This included going up the obstacle, going down the obstacle, and in between obstacles (after). The different obstacle categories in SX are visualised in Figure 6. In addition, the start straight obstacles were separated into a separate category for analysis purposes. Table 1 shows the number of obstacles per obstacle category and total number of obstacles for each venue.

Notitions	Video	Gender	Run	When	Where						Competitor [Rank]					Event [1 = yes; 0 = no]											
	Videoname [as on Dartfish TV]	[Gender]	[Type_#]	time [mm:ss.00]	Run-Event [Start - Finish]	Segment [#]	Obstacle [#]	going up obstacle	going down obstacle	in between obstacles (after)	Y	R	G	B	rs	contact	act	Athlet1	Athlet2	Athlet3	Athlet4	oob	Athlet1	tnr	Athlet1	crash	Athlet1
	211214 SX WC Arosa	f	BF	56:33.60	Start						1	1	1	1													
	211214 SX WC Arosa	f	BF	56:37.32		1	5			1	1	1	4	1	1												
	211214 SX WC Arosa	f	BF	56:37.64		1	5			1	3	1	3	1	1												
	211214 SX WC Arosa	f	BF	56:39.44		1	8			1	2	1	2	2	1												
	211214 SX WC Arosa	f	BF	56:40.36		1	9				4	1	2	2	1												
	211214 SX WC Arosa	f	BF	56:42.36		2	12		1		4	1	3	2	1												
	211214 SX WC Arosa	f	BF	56:55.96		3	23			1	4	1	2	1	1												
	211214 SX WC Arosa	f	BF	56:56.40		3	24				4	1	2	1		1		1	4								
	211214 SX WC Arosa	f	BF	56:56.76		3	24			1	4	1	2	1								1	1				
	211214 SX WC Arosa	f	BF	56:57.00		3	24			1	4	1	2	1								1	4				
	211214 SX WC Arosa	f	BF	56:57.68		3	25				4	1	2	1								1	1				
	211214 SX WC Arosa	f	BF	56:57.68		3	25				4	1	2	1								1	4				
	211214 SX WC Arosa	f	BF	56:58.56		3	25			1	4	2	3	1	1												
	211214 SX WC Arosa	f	BF	56:58.88		3	26	1			4	2	2	1	1												
	211214 SX WC Arosa	f	BF	56:59.00		3	26				4	2	2	1		1		1	3								
	211214 SX WC Arosa	f	BF	56:59.04		3	26				4	2	2	1										1	1		
	211214 SX WC Arosa	f	BF	56:59.04		3	26				4	3	2	1	1												
	211214 SX WC Arosa	f	BF	56:59.24		3	26		1		4	3	2	1												1	1
	211214 SX WC Arosa	f	BF	56:59.24		3	26		1		4	3	2	1								1	3				
	211214 SX WC Arosa	f	BF	56:59.48		3	26		1		3	3	2	1	1												
	211214 SX WC Arosa	f	BF	56:59.68		3	26		1		3	4	2	1	1												
	211214 SX WC Arosa	f	BF	57:00.76		3	27		1		3	4	2	1		1		3	4								
	211214 SX WC Arosa	f	BF	57:02.60		3	29				3	4	1	1	1												
	211214 SX WC Arosa	f	BF	57:04.16	Finish						3	4	1	1													

Figure 3. *Example of Excel rating sheet. Time stamps are the video-time of an Event occurring. Each Event was marked on a separate row with all the corresponding information.*



Obstacle Name	Obstacle Nr.	
Step Down Landing	58	Section 4
GS Turn Entry	59	
GS Turn Exit	60	
Jump Take Off	61	
Jump Landing	62	
Roller Double 1	63	
Roller Double 2	64	
Finish Line	65	

Figure 4. *Example of course information with obstacle name, number, and course section.*

Figure 5: *Example of an obstacle with obstacle number (21), going up obstacle (a), going down obstacle (b), and in-between (after) obstacles (c).*

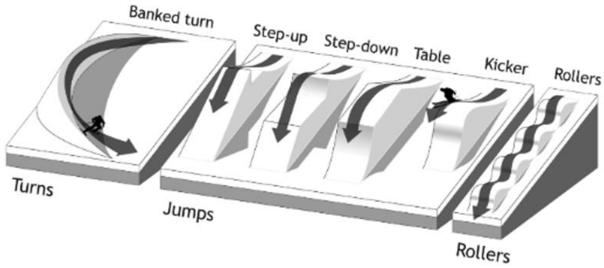


Figure 6. *Visualisation of different obstacles and obstacle categories in SX (Randjelovic et al., 2014).*

Table 1. *Number (n) of obstacles per obstacle category and total obstacles per venue.*

Venue	Direction Change	Jump	Roller	Start Straight	Total obstacles
	n	*n*	*n*	*n*	*n*
Secret Garden	20	8	26	13	67
Val Thorens	16	14	14	7	51
Arosa	3	6	11	9	29
Innichen	15	8	35	7	65
Nakiska	26	25	12	1	64
Idre Fjäll	9	23	36	5	73
Beijing	15	8	35	13	71
Reiteralm	10	16	28	6	60
Veysonnaz	14	8	26	6	54

Events

Five different Event types were observed in the video analysis. This included *SMoIR* Events (Contact, Avoided Contact, Out of Balance, and Crash), and Rank Shifts. In addition, Time of no Return were noted. See Event definitions below.

Crash (CR)

Crash situations was defined as the time point of full body Contact with the ground (Figure 7). If not injured, the athlete can get back up and finish the race if no gates were missed because of the fall. If gates were missed the athlete was out of the race.

Figure 7. *Example of Crash situation.*

Out of Balance (OOB)

Out of Balance was defined as the first spot where the athlete loses his/her balance (Figure 8). OOB occur in several ways depending on the obstacle. On jumps OOB situations was marked when the athlete was back weighted, unintentionally moving the arms, upright upper body, and if the skis are not parallel to the ground. OOB situations when turning where marked if the athlete was leaning inwards, outside arm in the air and/or outside ski in the air. General OOB situations related to unintentional change of direction of the skis, unintentional movements, and out of control situations was marked. In these situations, the athlete needed to quickly recover to regain control by e.g., fast arm movement or by opponent support.

Figure 8. *Example of Out of Balance situations.*

Contact (CT) and Avoided Contact (ACT)

Contact was defined as any Contact between opponents (Figure 9), including ski and poles. Pole to pole Contact which do not cause any harmful interference were excluded.

Avoided Contact was defined as when an athlete is actively Avoided Contact with another athlete by e.g., lifting the ski to make room for the opponent's ski or by braking.

CT and ACT: In case of Contact between opponents and then Avoided Contact right after, the first Contact was marked.

Figure 9. *Example of Contact and Avoiding Contact. Red circle marks Contact, and orange circle marks avoided Contact.*

Time of no Return (TNR)

Time of no return was defined as the spot when the athlete was not able to recover from an Out of Balance situation (Figure 10). The situation is equal to an Out of Balance in the early phase but resulted in a fall because of the athlete failed to recover and ended up Crashing. Note: Time of no Return always occurs prior to a Crash. Therefore, this Event was excluded from further statistical analysis in this study.

Figure 10: *Example of a time of no return situation.*

Rank Shift (RS)

Rank shift was defined as a change in position. At the start of the race the athletes were ranked as the same (1-1-1-1). The actual ranks were recorded, not the order of the athletes. To mark an RS, one athlete needed to fall one ski length behind its competitor, then the rank would be 1-1-1-4. If two athletes fall behind, and the two were within one ski length of each other, the rank would be 1-1-3-3. If an athlete catches up to another athlete, it would be marked as a RS if the tips of the skis were at the same level. No RS were noted after the finish line, except for *SMoIR*. Figure 11 shows a visual example of the ranking system. Note that the skis needed to be one ski-length apart to be noted as a rank shift, otherwise they would share the same rank as seen in the left picture (Figure 10).

Figure 11. *Example of rank shift situations.*

Heat timing

Heat timing data was provided for frequency analysis purposes. For males and females and for each competition day, the race time of the winner and the time from start to each obstacle were logged for the fastest skier at each obstacle from the official broadcasting TV footage. The take-off and point of landing on jumps, the top of rollers, and the beginning and end of direction changes were used to determine the frequency between obstacles. This also included obstacle category information as well as start and finish were noted. This was done using a premade Microsoft Excel (version 2303, 16.0.16227.20202) heat timing sheet. The formulas in the sheet calculated the time to the next obstacle and time to the previous obstacle. Heat timing sheet details are visible in Figure 12.

Venue	Sport	Date	BestTime	Gende	Bib n	Bib col	Segmen	Obstacl	Description	Time (hh:mm.00)	Time (sec)	Time to previous (sec)	Time to next (sec)	categories
Val Thorens	SX	12.12.2021	BF	m	3	R	1	Start	Start	77:45.84	4665,84		0,96	Start
Val Thorens	SX	12.12.2021	BF	m	3	R	1	1	Starttable	77:46.80	4666,80	0,96	0,60	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	2	Startdrop	77:47.40	4667,40	0,60	0,52	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	3	Step Down Take Off	77:47.92	4667,92	0,52	0,80	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	4	Step Down Landing	77:48.72	4668,72	0,80	1,60	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	5	Jump Take Off	77:50.32	4670,32	1,60	1,08	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	6	Jump Landing Table	77:51.40	4671,40	1,08	0,00	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	7	Jump Landing	77:51.40	4671,40	0,00	2,84	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	8	Jump Take Off	77:54.24	4674,24	2,84	0,88	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	1	9	Jump Landing	77:55.12	4675,12	0,88	1,80	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	2	10	Roller	77:56.92	4676,92	1,80	0,80	Roller
Val Thorens	SX	12.12.2021	BF	m	3	R	2	11	Roller	77:57.72	4677,72	0,80	2,04	Roller
Val Thorens	SX	12.12.2021	BF	m	3	R	2	12	Roller	77:59.76	4679,76	2,04	1,08	Roller
Val Thorens	SX	12.12.2021	BF	m	3	R	2	13	Step Up Take Off	78:00.84	4680,84	1,08	0,84	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	2	14	Step Up Landing	78:01.68	4681,68	0,84	2,40	Jump
Val Thorens	SX	12.12.2021	BF	m	3	R	2	15	Roller	78:04.08	4684,08	2,40	0,48	Roller
Val Thorens	SX	12.12.2021	BF	m	3	R	2	16	Roller	78:04.56	4684,56	0,48	0,40	Roller

Figure 12. *Example of a heat timing Excel sheet of the fastest man in Val Thorens.*

Data processing

Data combination

Prior to statistical analyses, the rated protocols were combined into one file. The individual rated heats were then merged into single rows using MATLAB (version R2023a). This resulted in 344 heat rows with the corresponding information; venue, gender, heat level, heat time, total heat time (heat time * number of athletes), number of athletes, sum Rank Shift, sum Contact, Sum Avoided Contact, sum Out of Balance, sum Crash.

Furthermore, obstacle category information was combined into one file, with the total number of Events that occurred on direction changes, jumps, and rollers for each venue.

Data filtering

To compare gender differences across heat categories, only quarterfinals (QF), semi-finals (SF), small-finals (SmF), and big-finals (BF) were included in the calculations. This selection was done to match the number of heats among male and female athletes.

To analyse obstacle frequency, the 'time to next (sec)' column in Figure 10 was used for each venue. To analyse important course sections for obstacle frequency and obstacle category comparisons, the start straight was separated with its own category. This was done because the start straight only consists of wu-tangs and other small obstacles which do not provoke many dangerous situations and could negatively affect the analysis if not separated. In addition, many of the start straight obstacles would go under the jump category, which would not be correct in the case of investigating jump related Events.

Data normalisation

Since different race venues has different course characteristics and number of runs, the number of Events were normalised to per hour raced (*phr*). The winner from each heat, using the observed video time, was multiplied by the number of athletes per heat, to sum up the total skiing time per heat using Microsoft Excel (version 2303, 16.0.16227.20202). This gave an exposure time for all the athletes`, which served as the base for the normalisation. To calculate the Events *phr*, the sum of each Event per heat was divided by the exposure time per heat. The following formula was used:

Equation 1: §

*Total skiing time per heat (h) = (fastest time per heat (sec) * number of athletes per heat (#))* : *3600 (sec)*

Events phr = sum of events per heat (#) : *total skiing time per heat (h)*

§ = the Events *phr* calculation was conducted for each Event separately; Crash *phr*, Out of Balance *phr*, Contact *phr*, Avoided Contact *phr*, and Rank Shift *phr*.

For Event comparisons between obstacle categories and individual obstacles, a second type of normalisation was done, using the following formula:

Equation 2: §

Incidence on obstacle (i) per final = number of events on the obstacle (i) in the final : number of skiers in the final

§ = obstacle incidences were calculated for each Event (Crash, Out of Balance, Contact, Avoiding Contact, and Rank Shift) per final (round of 64 (in case of 64 starters), eighth-finals, quarter-finals, semi-finals, small-finals, and big-finals), and divided by the number of skiers in each of the finals. This was done across all venues. Analyses could then be performed by grouping the data by the variables of interest. This included comparisons between obstacle categories (for example Rollers), comparisons between obstacle categories within each venue (for example Innichen), and comparisons between individual obstacles within each venue. Example of Crash incidence calculations are shown in Figure 13.

Venue	Segment	Obstacle	Description	Obstacle Category	CT	ACT	OOB	CR	CT incidens	ACT incidens	OOB incidens	CR incidens
Arosa	3	18	Negative Entry	Direction Change				1				0,333333333
Arosa	3	19	Negative Exit	Direction Change				2				0,666666667
Arosa	3	23	Roller	Direction Change								0
Arosa	2	14	Stepdown Turn Exit	Jump				1				0,166666667
Arosa	2	15	Stepdown	Jump								0
Arosa	2	16	Kicker Take Off	Jump								0
Arosa	2	17	Kicker Landing	Jump								0
Arosa	3	24	Jump Take Off	Jump								0
Arosa	3	25	Jump Landing	Jump								0
Arosa	2	10	Step Down	Roller								0
Arosa	2	11	Landing	Roller								0
Arosa	2	12	Roller Turn Entry	Roller								0
Arosa	2	13	Roller Turn Mid	Roller								0
Arosa	3	20	Roller	Roller								0
Arosa	3	21	Roller	Roller				2				0,181818182
Arosa	3	22	Roller	Roller								0
Arosa	4	26	Roller Turn	Roller				1				0,090909091
Arosa	4	27	Roller Turn	Roller								0
Arosa	4	28	Roller	Roller								0
Arosa	4	29	Roller	Roller								0
Beijing	2	28	Negative Entry	Direction Change								0
Beijing	2	29	Negative Exit	Direction Change								0
Beijing	3	32	GS Turn Entry	Direction Change								0
Beijing	3	33	GS Turn Exit	Direction Change								0
Beijing	3	35	GS Turn Entry	Direction Change								0
Beijing	3	36	GS Turn Mid Roller	Direction Change								0
Beijing	3	37	GS Turn Exit	Direction Change				1				0,066666667
Beijing	3	44	GS Turn Entry	Direction Change								0
Beijing	3	45	GS Turn Exit	Direction Change								0
Beijing	4	50	Bank Turn Entry	Direction Change								0
Beijing	4	51	Bank Turn Exit	Direction Change				2				0,133333333
Beijing	4	56	Bank Turn Entry	Direction Change				1				0,066666667
Beijing	4	57	Bank Turn Exit	Direction Change				1				0,066666667
Beijing	4	61	GS Turn Entry	Direction Change								0
Beijing	4	63	GS Turn Exit	Direction Change								0

Figure 13. *Example of Crash incidences for Direction Changes, Jumps, and Rollers in Arosa and Beijing.*

Statistical analysis

Descriptive data were performed using SPSS (version 28.0.0.0 (190)) and Microsoft Excel (version 2303, 16.0.16227.20202). Data that were not normally distributed was presented with eighter absolute values, or with median and interquartile range (IQR) with p values. Statistical calculations were performed in SPSS (version 28.0.0.0 (190)).

For analysing Events *phr* and Event occurrence between obstacle categories and individual obstacles, the following procedures were carried out in SPSS:

Comparisons between genders

Dependent variables: *SMoIR phr* and Rank Shift *phr*.

Grouping variable: Gender.

Comparisons between venues and between heat levels

Data was split by gender. (Venues and heat levels were analysed separately).

Dependent variables: *SMoIR phr* and Rank Shift *phr*.

Grouping variables: Venue and heat level.

Comparisons between obstacle categories

Data was split by gender.

Dependent variables: *SMoIR* incidence and Rank Shift incidence.

Grouping variable: Obstacle category.

Comparisons between obstacle categories within each venue

Data was split by gender and venue.

Dependent variables: *SMoIR* incidence and Rank Shift incidence.

Grouping variable: Obstacle category.

Comparisons between individual obstacles within each venue

Data was split by gender and venue. Comparisons were made within each venue (ex. comparing obstacle x against obstacle x in Arosa).

Dependent variables: *SMoIR* incidence and Rank Shift incidence.

Grouping variable: Obstacle number.

The statistical tests and data used for each research question is presented in Table 2. The level of significance was set at a two-tailed p-value of <0,05.

Table 2. *Research question variables with type of data, and statistical tests used in the analysis. RS = Rank shift, CT = Contact, ACT = Avoided Contact, CR = Crash. Phr = per hour raced. SMoIR = Surrogate Measures of Injury Risk.*

RQ - variables	Data	Statistics
Comparisons between Gender	CT phr, ACT phr, OOB phr, and CR phr. RS phr (analysed separately).	Mann Whitney U test. Presented with Median, Z score, p value, and effect size.
Comparisons between venues and heat levels	CT phr, ACT phr, OOB phr, and CR phr. RS phr (analysed separately).	Kruskal Wallis with Post-hoc Bonferroni. Presented with median, IQR, chi-square, degree of freedom, and p values.
Correlation between Events	CT phr, ACT phr, OOB phr, CR phr, RS phr.	Spearman`s rank correlation
Obstacle frequency	Time (sec) between obstacles, conducted from best heat-time per venue and gender.	Kruskal Wallis with Post-hoc Bonferroni. Presented with median, chi-square, degree of freedom, and p values.
Comparisons between obstacle categories and between individual obstacles	CR, OOB, CT, ACT incidences. RS (analysed separately).	Kruskal Wallis with Post-hoc Bonferroni. Presented with chi-square, degree of freedom, and p values.

Results

Events and venue characteristics

The present study analysed a total of 344 heats from the 2021/22 SX season, amounting to a total video time of 24,4 hours. A total of 893 males and 460 females were analysed across all heats. The analysis included nine venues, with a total of 224 heats for males and 120 for females, resulting in a total of 15,7 hours of racing for male athletes, and a total of 8,7 hours of racing for female athletes. See Appendix 1.1 and 1.2 for details. For full course description see Appendix 2.

The analysis of Ranks Shifts and *SMoIR* revealed a total of 3897 Events, respectively. Rank shifts were the most frequently observed Event, with 1761 for males, and 819 for females. Out of Balance situations were observed 690 times, with 89 of them resulting in a Crash. A descriptive distribution of the number of *SMoIR* is shown in Table 3.

Table 3. *Absolute number of SMoIR occurrences for male and female athletes with percentage distribution (%) of the total per gender. In addition, total SMoIR are presented accordingly.*

Event	Male		Female		Total	
	n	*%*	*n*	*%*	*n*	*%*
Contact	386	40,29	114	31,75	500	37,97
Avoiding Contact	30	3,13	5	1,39	35	2,66
Out of Balance	485	50,63	208	57,94	693	52,62
Crash	57	5,95	32	8,91	89	6,76
Sum	958	100	359	100	1317	100

Comparisons between genders

The Mann-Whitney U test comparing *SMoIR* between male athletes and female athletes showed no significant difference between the genders for Crash *phr*. Further, the test showed a significant difference in:

Out of Balance *phr* for male (Median = 26.8, n = 224) and female (Median = 19.4, n = 120), U = 10873, Z = 2.928, p = .003, r = 0.16.

Contact *phr* for male (Median = 14.14, n = 224) and female (Median = 0.0, n = 120), U = 9479.5, Z = 4.623, p = <.001, r = 0.25.

Avoided Contact *phr* for male (Median = 0.0, n = 224) and female (Median = 0.0, n = 120), U = 12324, Z = 2.594, p = .009, r = 0.14.

The effect size indicates that the difference between genders was largest for Contact *phr*, and similar between genders for Out of Balance and Avoiding Contact.

Comparisons between venues

The Kruskal Wallis test comparing *SMoIR* between venues revealed a significant difference in Contact *phr*, Out of Balance *phr*, and Crash *phr* between venues for male only. Avoided Contact *phr* was not significantly affected by venues. None of the Events were significantly different between venues for female athletes. Test results are presented in Table 4 and 5.

The Bonferroni Post-Hoc test assessing the pairwise comparisons between the venues for male athletes showed a significant difference for Idre Fjäll compared to other venues for all three Events. Arosa had the most Contacts *phr*, Val Thorens had the most Out of Balances *phr*, and Secret Garden had the most Crashes *phr*. Idre Fjäll had the lowest number of these Events.

Post-Hoc details with significant differences only are presented in table 6, 7, and 8. For complete Post-Hoc results, see Appendix 1.4.

Tabell 4. *Kruskal Wallis comparison of SMoIR per hour raced between venues for male athletes. Presented with median (Mdn), interquartile range (IQR), Chi-square (X^2), degree of freedom (df), and p values. Significant p values marked with bold font.*

Venue	Contact	Avoided Contact	Out of Balance	Crash
	Mdn (IQR)	*Mdn (IQR)*	*Mdn (IQR)*	*Mdn (IQR)*
Secret Garden	13,3 (49,2)	0,0 (0,0)	26,1 (32,7)	0,0 (13,2)
Val Thorens	19,3 (43,9)	0,0 (0,0)	39,3 (27,2)	0,0 (9,3)
Arosa	31,6 (94,0)	0,0 (0,0)	31,6 (54,4)	0,0 (0,0)
Innichen	12,6 (21,3)	0,0 (0,0)	24,6 (25,0)	0,0 (0,0)
Nakiska	19,5 (26,0)	0,0 (0,0)	26,0 (26,0)	0,0 (13,0)
Idre Fjäll	0,0 (12,2)	0,0 (0,0)	12,2 (35,8)	0,0 (0,0)
Beijing	24,9 (46,9)	0,0 (9,3)	25,0 (37,4)	0,0 (0,0)
Reiteralm	27,2 (29,5)	0,0 (0,0)	29,5 (29,4)	0,0 (0,0)
Veysonnaz	25,6 (33,8)	0,0 (0,0)	33,9 (17,4)	0,0 (0,0)
X^2	32,791	10,625	25,008	17,655
df	8	8	8	8
p value	**<0,001**	0,224	**0,002**	**0,024**

Tabell 5. *Kruskal Wallis comparison of SMoIR per hour raced between venues for female athletes. with significant differences for female athletes. Presented with median (Mdn), interquartile range (IQR), Chi-square (X^2), degree of freedom (df), and p values.*

Venue	Contact	Avoided Contact	Out of Balance	Crash
	Mdn (IQR)	*Mdn (IQR)*	*Mdn (IQR)*	*Mdn (IQR)*
Secret Garden	0,0 (34,2)	0,0 (0,0)	0,0 (18,7)	0,0 (0,0)
Val Thorens	12,7 (22,4)	0,0 (0,0)	14,6 (33,8)	0,0 (0,0)
Arosa	0,0 (29,8)	0,0 (0,0)	34,6 (73,0)	0,0 (0,0)
Innichen	0,0 (11,7)	0,0 (0,0)	13,6 (23,3)	0,0 (0,0)
Nakiska	12,4 (24,9)	0,0 (0,0)	18,6 (21,8)	0,0 (9,2)
Idre Fjäll	0,0 (8,3)	0,0 (0,0)	22,2 (32,7)	0,0 (8,4)
Beijing	13,3 (28,5)	0,0 (0,0)	26,3 (27,3)	0,0 (0,0)
Reiteralm	7,0 (17,4)	0,0 (0,0)	14,0 (38,4)	0,0 (10,4)
Veysonnaz	16,1 (12,2)	0,0 (0,0)	31,8 (27,9)	0,0 (12,0)
X^2	10,351	5,547	13,589	4,829
df	8	8	8	8
p value	0,241	0,698	0,093	0,776

Table 6. *Post-Hoc Bonferroni test results with significant differences for Contact per hour raced between venues for male athletes. Presented with Chi-square (X^2) and p values.*

Venue comparison	X^2	P value*
Idre Fjäll - Nakiska	59,766	0,007
Idre Fjäll - Val Thorens	64,891	0,002
Idre Fjäll - Reiteralm	-69,859	0,013
Idre Fjäll - Arosa	80,047	<0,001
Idre Fjäll - Veysonnaz	-76,797	<0,001

**=P value lower than 0,05 is significant.*

Table 7. *Post-Hoc Bonferroni test results with significant differences for Out of Balance per hour raced between venues for male athletes. Presented with Chi-square (X^2) and p values.*

Venue comparison	X^2	P value*
Idre Fjäll - Val Thorens	63,984	0,003
Idre Fjäll - Arosa	69,913	0,001

**P value lower than .05 is significant.*

Table 8. *Post-hoc Bonferroni test results with significant differences for Crash phr between venues for male athletes. Presented with Chi-square (X^2) and p value.*

Venue comparison	X^2	P value*
Idre Fjäll – Secret Garden	49,094	0,013

**P value lower than 0,05 is significant.*

Comparisons between heat levels

When comparing *SMoIR* between heat levels for males and females, the Kruskal Wallis test revealed a significant difference for Contact *phr* among females and Avoided Contact *phr* among both males and females (Table 9 and 10). Out of balance *phr* and Crash *phr* for both genders were not significantly affected by heat levels.

The Bonferroni test revealed that for female athletes, SF 2 had significantly more Contacts *phr* compared to QF 1. SF 2 had significantly more Contacts *phr* compared to SF 1. For male athletes, QF 3 had significantly more Avoided Contacts *phr* compared to both QF 4 and SF 2. Avoided Contact *phr* for females were not significantly different between heat levels when adjusted with Bonferroni. Post-Hoc Bonferroni analysis with significant results only is presented in Table 11 and 12. For Complete Post-hoc results see appendix 1.5.

Tabell 9. *Kruskal Wallis comparison of SMoIR per hour raced between heat levels for male athletes. Presented with median (Mdn), interquartile range (IQR), Chi-square (R^2), degree of freedom (df), and p values. Significant p values marked with bold font.*

Heat level	Contact	Avoided Contact	Out of Balance	Crash
	Mdn (IQR)	*Mdn (IQR)*	*Mdn (IQR)*	*Mdn (IQR)*
Quarter-final 1	12,2 (35,1)	0,0 (0,0)	14,9 (20,9)	0,0 (0,0)
Quarter-final 2	24,8 (41,2)	0,0 (0,0)	17,2 (50,7)	0,0 (6,2)
Quarter-final 3	25,9 (28,8)	0,0 (12,6)	33,9 (22,4)	0,0 (0,0)
Quarter-final 4	0,0 (20,0)	0,0 (0,0)	12,9 (30,4)	0,0 (12,2)
Semi-final 1	29,8 (59,0)	0,0 (0,0)	36,9 (40,0)	0,0 (6,5)
Semi-final 2	13,4 (37,6)	0,0 (0,0)	14,8 (31,6)	0,0 (0,0)
Small-final	12,3 (15,1)	0,0 (0,0)	36,2 (24,3)	0,0 (19,0)
Big-final	15,0 (39,2)	0,0 (0,0)	17,0 (37,5)	0,0 (0,0)
X^2	11,407	15,7	7,284	7,11
df	7	**7**	7	7
p value	0,122	**0,028**	0,400	0,417

Tabell 10. *Kruskal Wallis comparison of SMoIR per hour raced between heat levels for female athletes. Presented with median (Mdn), interquartile range (IQR), Chi-square (R^2), degree of freedom (df), and p values. Significant p values marked with bold font.*

Heat level	Contact	Avoided Contact	Out of Balance	Crash
	Mdn (IQR)	*Mdn (IQR)*	*Mdn (IQR)*	*Mdn (IQR)*
Quarter-final 1	0,0 (13,8)	0,0 (0,0)	12,2 (23,6)	0,0 (0,0)
Quarter-final 2	16,1 (24,7)	0,0 (0,0)	33,7 (36,8)	0,0 (14,4)
Quarter-final 3	11,5 (24,5)	0,0 (0,0)	24,8 (28,3)	0,0 (0,0)
Quarter-final 4	0,0 (13,4)	0,0 (0,0)	16,2 (23,5)	0,0 (5,5)
Semi-final 1	0,0 (13,2)	0,0 (0,0)	13,0 (34,9)	0,0 (0,0)
Semi-final 2	29,8 (27,4)	0,0 (5,5)	22,3 (52,3)	0,0 (12,2)
Small-final	11,2 (17,3)	0,0 (0,0)	11,5 (20,9)	0,0 (11,7)
Big-final	0,0 (29,7)	0,0 (0,0)	22,7 (20,9)	0,0 (11,6)
X^2	16,388	16,552	9,134	10,979
df	**7**	**7**	7	7
p value	**0,022**	**0,021**	0,243	0,140

Tabell 11. *Post-Hoc Bonferroni test results with significant differences for Contact phr between heat levels for female athletes. Presented with Chi-square (X^2) and p values. QF_1 = quarter-final 1, SF_1 = semi-final 1, SF_2 = semi-final 2.*

Heat level comparison	X^2	P value*
QF_1 - SF_2	-37,19	0,024
SF_1 - SF_2	-35,81	0,037

**P value lower than 0,05 is significant.*

Tabell 12. *Post-hoc Bonferroni test results with significant differences for Avoided Contact phr between heat categories for male athletes. Presented with Chi-square (X^2) and p values. QF_3 = quarter-final 3, QF_4 = quarter-final 4, SF_2 = semi-final 2.*

Heat level comparison	X^2	P value*
QF_4 - QF_3	23,38	0,024
SF_2 - QF_3	23,38	0,024

**P value lower than 0,05 is significant.*

Correlations between SMoIR and Rank Shifts

The Spearman`s rank correlation test assessing the relation between Events phr revealed a significant correlation for male athletes between Rank Shift phr and Contact phr, Rank Shift phr and Out of Balance phr, Contact phr and Out of Balance phr, and Out of Balance phr and Crash phr. For female athletes, the test revealed a significant correlation between Rank Shift phr and Contact phr, Rank Shift phr and Crash phr, Contact phr and Out of Balance phr, and for Out of Balance phr and Crash phr. Correlation details are presented in Table 13 and 14.

Table 13. *Spearman`s rank correlation matrix of all Events per hour raced for male athletes. Presented with correlation coefficients. Duplicated coefficients are excluded.*

	Rank Shift	Contact	Avoided Contact	Out of Balance	Crash
Rank Shift					
Contact	0,37**				
Avoided Contact	0,01	0,00			
Out of Balance	0,30**	0,40**	-0,00		
Crash	-0,02	0,16*	0,06	0,31**	

*Note. **p = < 0,01, *P = 0,05.*

Tabell 14. *Spearman`s rank correlation matrix of all Events per hour raced for female athletes. Presented with correlation coefficients. Duplicated coefficients are excluded.*

	Rank Shift	Contact	Avoided Contact	Out of Balance	Crash
Rank Shift					
Contact	0,30**				
Avoided Contact	0,09	0,01			
Out of Balance	0,10	0,27**	0,02		
Crash	0,24**	0,34**	-0,09	0,45**	

Note. ***p = < 0,01.*

Obstacle frequency differences

The Mann-Whitney U test investigating differences in frequency between obstacles for both genders showed no statistically significant differences between male (median = 0.92, n = 467) and females (median = 0.95, n = 467), p = 0.125.

Furthermore, the Kruskal Wallis test comparing the frequency of obstacles between venues was not significant for males (X^2 = 13.710, df = 8, p = 0.090), or females (X^2 = 11.632, df = 8, p = 0.168), meaning that the distribution of obstacles was the same between venues for both male and female athletes.

SMoIR comparisons between obstacle categories

To investigate *SMoIR* between obstacle categories, the Kruskal Wallis test showed a significant difference for all *SMoIR* between all obstacle categories for male athletes. For female athletes the test showed significant differences for Contact and Out of Balance across obstacle categories. Test results are presented in Table 15 and 16. The median of the *SMoIR* was 0 for all obstacle categories. To understand the size differences, see Appendix 1.7 for the size of the mean ranks used for comparisons in the Kruskal Wallis test.

The Post-Hoc Bonferroni test for pairwise comparisons for male athletes revealed a significant higher risk of Crash and Contact on Direction Changes compared to Jumps and Rollers. The risk of Out of Balance was significantly higher on Jumps compared to Direction Changes and Rollers. The risk of Avoiding Contact was significantly higher on Direction Changes compared to Rollers. Test results are presented in Table 17 and 18.

For female athletes, the risk of Contact was significantly higher on Direction Changes compared to Jumps and Rollers. The risk of Out of Balance was significantly higher on Jumps compared to Direction Changes and Rollers. Avoiding Contact and Crash were not significantly different across obstacle categories for female athletes.

For Start Straight obstacles, the risk of injury was generally lower compared to Direction Changes, Jumps, and Rollers for both males and females.

Tabell 15. *Kruskal Wallis test results, comparing the occurrence of SMoIR between obstacle categories for male athletes. Presented with Chi-square (R^2), degree of freedom (df) and p values.*

Event	X^2	df	p value*
Contact	91,567	3	<0,001
Avoided Contact	17,925	3	<0,001
Out of Balance	20,186	3	<0,001
Crash	27,322	3	<0,001

*****P = <0,05 is significant.

Tabell 16. *Kruskal Wallis test results, comparing SMoIR incidence between obstacle categories for female athletes. Presented with Chi-square (R^2), degree of freedom (df) and p values.*

Event	X^2	df	p value*
Contact	40,813	3	<0,001
Avoided Contact	3,711	3	0,294
Out of Balance	34,713	3	<0,001
Crash	4,900	3	0,179

*****P = <0,05 is significant.

Tabell 17. *Post-Hoc Bonferroni test results, comparing the occurrence of SMoIR between obstacle categories for male athletes. Presented with p values. Significant p values marked with bold font.*

Event	**Direction Change vs Jump**	**Direction Change vs Roller**	**Jump vs Roller**	**Start Straight vs Direction Change**	**Start Straight vs Jump**	**Start Straight vs Roller**
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Contact	**<0,001**	**<0,001**	1,000	**<0,001**	**<0,001**	**0,009**
Avoided Contact	0,177	**0,001**	0,929	**0,010**	0,852	1,000
Out of Balance	**0,035**	0,564	**<0,001**	1,000	0,189	1,000
Crash	**0,001**	**<0,001**	1,000	**0,019**	1,000	1,000

*P = <0,05 is significant.

Tabell 18. *Post-Hoc Bonferroni test results, comparing the occurrence of SMoIR between obstacle categories for female athletes. Presented with p values. Significant p values marked with bold font.*

Event	**Direction Change vs Jump**	**Direction Change vs Roller**	**Jump vs Roller**	**Start Straight vs Direction Change**	**Start Straight vs Jump**	**Start Straight vs Roller**
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Contact	**<0,001**	**<0,001**	1,000	**<0,001**	0,110	**0,049**
Out of Balance	**<0,001**	**0,008**	0,129	1,000	**<0,001**	**0,026**

***P** = <0,05 is significant.

SMoIR comparisons between obstacle categories within each venue

To investigate *SMoIR* between venues, the *SMoIR* for obstacle categories were compared. The Kruskal Wallis test revealed that for male athletes, Crash and Out of balance was significantly different between obstacle categories in Val Thorens. Contact was significantly different between obstacle categories in Secret Garden, Val Thorens, Arosa, Innichen, Idre Fjäll, and Beijing. Avoiding Contact was significantly different between obstacle categories in Arosa and Idre Fjäll.

For female athletes, Crash was not significantly influenced by obstacle category. Out of Balance was significantly different between obstacle categories in Arosa and Reiteralm. Contact was significantly different between obstacle categories in Secret Garden, Arosa, Innichen, Idre Fjäll and Beijing. Avoiding Contact was only significantly different between obstacle categories in Beijing. The test results for both genders are presented in Appendix 1.9.

For male athletes, the Post-Hoc Bonferroni test for pairwise comparisons showed that Crash and Out of Balance was not significantly different across obstacle categories when adjusted with Bonferroni. Furthermore, Contact occurred more on Direction Changes compared to the Start Straight in Secret Garden, Val Thorens, Arosa, Innichen, Idre Fjäll, and Beijing. Contact occurred more on Direction Changes compared to Jumps in Val Thorens and Idre Fjäll. Contact occurred more on Direction Changes compared to Rollers in Innichen, Idre Fjäll, and Beijing. Contacts occurred more on Rollers compared to the Start Straight in Arosa. Avoiding Contact occurred more on Direction Changes compared to Jumps and Rollers in Idre Fjäll.

For female athletes the Post-Hoc test showed that Out of Balance occurred more on Jumps compared to Direction Changes in Reiteralm. Out of Balance occurred more on Jumps compared to Start Straight in Arosa. Contact occurred more on Direction Changes compared to Jumps in Innichen and Idre Fjäll. Contact occurred more on Direction Changes compared to Rollers in Idre Fjäll and Beijing. Contact occurred more on Direction Changes compared to Start Straight in Innichen, Idre Fjäll, and Beijing. Contact occurred more on Rollers Compared to Start Straight in Arosa. Avoiding Contact occurred more on Jumps compared to Direction Changes, Rollers, and Start Straight in Beijing. Contact in Secret Garden was not significant when adjusted with Post-Hoc Bonferroni. Post-Hoc results are presented in Table 19 and 20.

To understand the size differences, see Appendix 1.8 for the size of the mean ranks used for comparisons in the Kruskal Wallis test.

Table 19. *Post-Hoc Bonferroni test results, comparing the occurrence of SMoIR between obstacle categories within each venue for male athletes. Presented with p values. Significant p values in bold font.*

	Direction Change vs Jump	**Direction change vs Roller**	**Jump vs Roller**	**Start Straight vs Direction Change**	**Start Straight vs Jump**	**Start Straight vs Roller**
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Secret Garden						
Contact	0,423	0,066	1,000	**0,003**	1,000	1,000
Val Thorens						
Contact	**0,012**	0,141	1,000	**0,012**	1,000	1,000
Out of Balance	1,000	0,144	0,117	0,444	0,367	1,000
Crash	0,185	0,091	1,000	0,302	1,000	1,000
Arosa						
Contact	0,201	1,000	0,409	**0,003**	0,688	**0,001**
Innichen						
Contact	0,214	**0,028**	1,000	**0,001**	0,865	1,000
Idre Fjäll						
Contact	**0,014**	**0,011**	1,000	1,000	1,000	1,000
Avoided Contact	**0,017**	**0,031**	1,000	1,000	1,000	1,000
Beijing						
Contact	1,000	**<0,001**	0,099	**0,001**	0,069	0,069

Table 20. *Post-Hoc Bonferroni test results, comparing the occurrence of SMoIR between obstacle categories within each venue for female athletes. Presented with p values. Significant p values in bold font.*

	Direction Change vs Jump	**Direction Change vs Roller**	**Jump vs Roller**	**Start Straight vs Direction Change**	**Start Straight vs Jump**	**Start Straight vs Roller**
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Secret Garden						
Contact	0,155	0,598	1,000	0,052	1,000	1,000
Arosa						
Contact	1,000	1,000	1,000	1,000	0,203	**0,005**
Out of Balance	1,000	1,000	1,000	1,000	**0,013**	0,117
Innichen						
Contact	**0,020**	0,683	1,000	**0,046**	1,000	1,000
Idre Fjäll						
Contact	**0,034**	**0,003**	1,000	**0,048**	1,000	1,000
Beijing						
Contact	0,775	**0,002**	1,000	**<0,001**	0,225	1,000
Avoided						
Contact	**0,014**	1,000	**0,003**	1,000	**0,016**	1,000
Reiteralm						
Out of Balance	**0,042**	0,778	0,728	1,000	0,124	1,000

Obstacle specific SMoIR analysis - Course "Hot-Spots"

To analyse potential course 'hot spots', *SMoIR* was compared between each individual obstacle within each course. The Kruskal Wallis test revealed that for male athletes, the risk of Crash was significantly different between the obstacles in Secret Garden, Val Thorens, and Nakiska. Out of Balance was significantly different between obstacles in Val Thorens, Innichen, and Nakiska. Contact was significantly different between obstacles in Secret Garden, Val Thorens, Arosa, and Idre Fjäll. Avoided Contact was significantly different between obstacles in Innichen. For female athletes, the risk of Crash was significantly different between obstacles in Arosa, Innichen, and Idre Fjäll.

Out of Balance was significantly different between obstacles in Beijing and Veysonnaz. Contact and Avoided Contact was not significantly different between obstacles for female athletes. For test results for both genders, see in Appendix 1.2.1.

The Post-Hoc Bonferroni test for pairwise comparisons showed the following results:

For male athletes, obstacle nr. 42 (Direction Change) in Val Thorens was more likely to cause a Crash compared to other obstacles in Val Thorens. Obstacle nr. 13 (jump) in Nakiska was more likely to cause a Crash compared to other obstacles in Nakiska. Furthermore, obstacle nr. 47 (Direction Change) in Innichen was more likely to cause an Avoided Contact compared to other obstacles in Innichen.

For female athletes, obstacle nr. 21 (Roller) in Arosa was more likely to cause a Crash compared to other obstacles in Arosa. Obstacle nr. 63 (Roller) in Idre Fjäll was more likely to cause a Crash compared to other obstacles in Idre Fjäll. Obstacle nr. 44 (Jump) and nr. 46 (Direction Change) in Innichen was more likely to cause a Crash compared to other obstacles in Innichen. For significant Post-Hoc results for both genders, See Appendix 1.2.2.

The Post-Hoc analysis also revealed that when adjusted with Bonferroni, Crash in Secret Garden was not significantly different for male athletes. Contact and Out of Balance did not differ significantly between obstacles at any of the venues for male athletes. For female athletes, Out of Balance was not significantly different between obstacles when adjusted with Post-Hoc Bonferroni.

For complete course descriptions with obstacle details, see Appendix 2.

Rank Shift comparisons

Rank Shift differences between genders

The Mann-Whitney U test comparing Rank Shift *phr* between genders showed a significant difference for male athletes (median = 110.3, n = 224) and female athletes (median = 87.9, n = 120), U = 10216, Z = 3.667, p = <.001. In addition, the effect size was calculated (r = 0.20), indicating a small effect size between the genders.

Rank Shift differences between venues

To investigate Rank Shift *phr* differences between venues, the Kruskal Wallis test showed a significant difference between venues for male athletes and female athletes (Table 21). Table 22 and 23 shows Post-Hoc details for significant results only. For complete Post-Hoc results see Appendix 1.6.

Looking at the median values for Ranks Shift *phr* (Table 21), Arosa exhibited the highest number of Rank Shift *phr* for both genders, followed by Reiteralm for males and Veysonnaz for females. The least Rank Shifts occurred in Beijing for males and Idre Fjäll for females.

Rank Shift *phr* were not significantly affected by heat levels for males (X^2 = 9.596, df = 7, p = 0,213), or females (X^2 = 13.105, df = 7, p = 0.070).

Table 21. *Kruskal Wallis comparison of Rank Shift per hour raced between males and females. Presented with median (Mdn), interquartile range (IQR), Chi-square (R^2), degree of freedom (df), and p values. Significant p values marked with bold font.*

Venue	**Male**	**Female**
	Mdn (IQR)	*Mdn (IQR)*
Secret Garden	112,0 (53,5)	93,8 (59,4)
Val Thorens	106,5 (41,4)	81,1 (34,6)
Arosa	157,5 (83,1)	154,0 (50,9)
Innichen	109,1 (61,1)	81,3 (42,6)
Nakiska	82,7 (39,6)	75,1 (29,6)
Idre Fjäll	108,8 (67,1)	65,9 (42,3)
Beijing	80,6 (46,9)	95,0 (71,4)
Reiteralm	147,4 (64,9)	88,6 (62,7)
Veysonnaz	115,7 (46,3)	121,4 (59,2)
X^2	63,086	32,416
df	8	8
*p value**	**<0,001**	**<0,001**

Table 22. *Post-Hoc Bonferroni test results with significant differences for Rank Shift phr between venues for male athletes. Presented with Chi-square (X^2) and p values.*

Venue comparison	X^2	P value*
Beijing - Reiteralm	-84,937	0,008
Beijing - Arosa	114,469	<0,001
Nakiska - Reiteralm	-79,625	0,002
Nakiska - Arosa	109,156	<0,001
Val Thorens - Arosa	-76,687	<0,001
Idre Fjäll - Arosa	73,938	<0,001
Innichen - Arosa	73,719	<0,001
Secret Garden - Arosa	-68,281	0,021
Veysonnaz - Arosa	67,906	0,022

**P value lower than 0,05 is statistically significant.*

Table 23. *Post-Hoc Bonferroni test results with significant differences for Rank Shift phr between venues for female athletes. Presented with Chi-square (X^2) and p values.*

Venue comparison	X^2	P value*
Beijing - Arosa	45,000	0,009
Nakiska - Arosa	48,688	0,003
Val Thorens - Arosa	-46,812	0,005
Idre Fjäll - Arosa	58,625	<0,001
Innichen - Arosa	46,563	0,006

**P value lower than 0,05 is significant.*

Rank Shift comparisons between individual obstacles and obstacle categories

To compere the occurrence of Rank Shift between obstacle categories and individual obstacles within each course, the Kruskal Wallis tests revealed as follows:

For Rank Shift differences between obstacle categories (Direction Change, Jump, Roller, and Start Straight), the test showed a significant result for males (X^2 = 19.856, df = 3, p = <0.001), and females (X^2 = 44.459, df = 3, p = <0.001). See Appendix 1.7 for the mean ranks used for comparisons in the Kruskal Wallis test.

For Rank Shift differences between obstacle categories within each venue, the test showed for male athletes: ***Secret Garden*** (X^2 =3.982, df = 3, p = 0,263). ***Val Thorens*** (X^2 =10.039, df = 3, p = ,0,18). ***Arosa*** (X^2 = 8,368, df = 3, p = 0,039). ***Innichen*** (X^2 = 7.481, df = 3, p = 0,058). ***Nakiska*** (X^2 = 2.396, df = 3, p = 0,494). ***Idre Fjäll*** (X^2 = 2.835, df = 3, p = 0,418). ***Beijing*** (X^2 = 10.386, df = 3, p = 0,016). ***Reiteralm*** (X^2 = 3.894, df = 3, p = 0,273). ***Veysonnaz*** (X^2 = 4.702, df = 3, p = 0,195).

For female athletes: ***Secret Garden*** (X^2 = 2.325, df = 3, p = 0,508). ***Val Thorens*** (X^2 = 9.911, df = 3, p = 0.019). ***Arosa*** (X^2 = 16.600, df = 3, p = <0.001). ***Innichen*** (X^2 = 11.201, df = 3, p = 0.011). ***Nakiska*** (X^2 = 1.513, df = 3, p = 0.675). ***Idre Fjäll*** (X^2 =, df = 3, p = 0.140). ***Beijing*** (X^2 =, df = 3, p = 0.061). ***Reiteralm*** (X^2 = 6.817, df = 3, p = 0.078). ***Veysonnaz*** (X^2 = 1.852, df = 3, p = 0.604). See Appendix 1.8 for the mean ranks for both genders used for comparisons in the Kruskal Wallis test.

The Post-Hoc Bonferroni tests for overall comparisons between obstacle showed that the Start Straight had significantly more Rank Shifts compared to Direction Changes, Jumps, and Rollers for both males and females. For Post-Hoc details, see Appendix 1.2.3.

The Post-Hoc comparisons between obstacle categories within each venue showed that for male athletes, the Start Straight in Val Thorens and Beijing had significantly more Ranks Shifts compared to Direction Change. The Start Straight in Arosa had significantly more Ranks Shifts compared to Jumps.

For female athletes, the Post-Hoc results showed that the Start Straight in Val Thorens and Innichen had significantly more Rank Shifts compared to Rollers. The Start Straight in Arosa had significantly more Rank Shifts compared to Jumps and Rollers. For Post-Hoc details for both genders see Appendix 1.2.4.

For Rank Shift comparisons between individual obstacles within each venue, the test showed for male athletes: ***Secret Garden*** (X^2 =59.458, df = 54, p = 0,284). ***Val Thorens*** (X^2 = 72.543, df = 47, p = 0.01). ***Arosa*** (X^2 = 43.785, df = 24, p = 0.008). ***Innichen*** (X^2 = 90.862, df = 58, p = 0.004). ***Nakiska*** (X^2 = 75.849, df = 52, p = 0.017). ***Idre Fjäll*** (X^2

= 77.224, df = 64, p = 0.681). ***Beijing*** (X^2 = 48.626, df = 54, p = 0.681). ***Reiteralm*** (X^2 = 48.219, df = 43, p = 0.270). ***Veysonnaz*** (X^2 = 41.794, df = 32, p = 0.115).

For female athletes: ***Secret Garden*** (X^2 = 35.330, df = 32, p = 0.314). ***Val Thorens*** (X^2 = 43.578, df = 39, p = 0.283). ***Arosa*** (X^2 = 37.070, df = 23, p = 0.032). ***Innichen*** (X^2 = 63.718, df = 47, p = 0.053). ***Nakiska*** (X^2 = 48.581, df = 36, p = 0.079). ***Idre Fjäll*** (X^2 = 61.384, df = 46, p = 0.064). ***Beijing*** (X^2 = 72.623, df = 55, p = 0.056). ***Reiteralm*** (X^2 = 39.327, df = 36, p = 0.323). ***Veysonnaz*** (X^2 = 36.369, df = 28, p = 0.133).

The Post-Hoc test revealed that significantly more Rank Shifts occurred on obstacle nr. 9 compared to obstacle nr. 62 in Nakiska (X^2 = 91.500, p = 0.044).

Discussion

This study assessed the risk of injury and investigated which obstacles lead to an increased risk of injury in World Cup Ski Cross, by analysing Surrogate Measures of Injury Risk at different levels of detail. In addition, this study focused on Rank Shift situations, and identified courses that allow for the most Rank Shifts, which is important to preserve the distinctiveness and entertainment value of the sport.

The main findings in this study were that male athletes generally experienced more Events *phr* compared to female athletes. For males, the occurrence of Crash and Contact were largest on Direction Changes, while the occurrence of Out of Balance was greater on Jumps. For females, the occurrence of Crash was evenly distributed between the obstacle categories, while the occurrence of Out of Balance was largest on Jumps. A higher percentage of the Out of Balance situations lead to a Crash for females than males. The occurrence of Contact was largest on Direction Changes for both genders.

Gender and heat level comparisons

When comparing the absolute number of Events observed in this study, male athletes experienced more Events compared to female athletes. The most obvious reason for this is due to the exposure times. Male skiers tend to ski up to twice as much as female athletes during a competition day because of number of participants and number of heats. Therefore, it is important to emphasise the normalised data to accurately compare

SMoIR and Rank Shifts across groups. By looking at the normalised data for *SMoIR*, this study revealed that male athletes had significantly ($p<0{,}05$) more Out of Balance *phr*, Contact *phr*, Avoided Contact *phr*, and Rank Shifts *phr* compared to female athletes. Interestingly, the occurrence of Crash *phr*, the most important *SMoIR* in this study, was equal between the genders. By analysing SX races, male athletes generally race closer and fight for their position longer than female athletes. Hence, more *SMoIR* will likely occur. Even though no significant difference in Crash *phr* between genders could be calculated, it is interesting that male athletes appear to encounter more Contacts *phr* and Out of Balance *phr*, despite experiencing similar amounts of Crash *phr* compared to female athletes. Previous Master`s work by Rieder (2022) also found similar tendencies, indicating that male athletes tend to better re-gain control in Out of Balance situations. Thus, more Crashes are being avoided compared to female athletes. This could also explain the stronger correlation observed between Contact phr and Crash phr, and between Out of Balance phr and Crash phr for female athletes. However, this is in contrast to findings in alpine skiing, where male athletes are more likely to get injured (Flørenes et al., 2009, p. 974; Spörri et al., 2016, p. 606). On the other side, WC alpine skiing utilises different courses for male and female athletes (Fédération Internationale de Ski, 2020, p. 84). This is in contrast to SX, where the same course is generally used (Fédération Internationale de Ski, 2023, p. 142). This could result in performance differences, favouring male athletes, unlike alpine skiing where separate courses are used.

Previous assessment of injury situations in SX and SBX has reported that opponent Contact and Out of Balance situations occur prior to the onset of injury (Bakken et al., 2011, p. 1319; Randjelovic et al., 2014, p. 5), meaning that athletes often fall due to mechanisms associated with heat racing. Interestingly, when looking at *SMoIR* differences between heat levels, female athletes had significantly ($p<0{,}05$) less Contacts *phr* in quarter-final 1 and semi-final 1 compared to their heat level counterparts. When analysing videos of SX races, there seem to be a greater disparity in skill level for female athletes compered to male athletes. This often results in consistent top performance by the same athletes in various competitions. The natural latter to climb for the top performer is by quarter-final 1, semi-final 1 and then eventually entering the big final. Considering these factors, these heats might stretch out more resulting in less Rank Shifts and eventually less Contacts. However, although not significant, there seems to be more *SMoIR* occurring in the big-final compared to the small-final for female athletes. However, considering that the athletes competing in the small-final are not fighting for the podium as opposed to the once competing in the big-final, less fighting for positions will likely occur in the small-final. Thus, the lower occurrence of Contacts in quarter-final 1 and semi-final 1 may not be relevant in the big-final.

Further elaboration on *SMoIR* and heat levels, it is important to consider that in the present study, eighth finals were excluded from the analysis. Generally, male athletes start with eight-finals, and female athletes with quarter-finals due to the number of participants. Considering that males compete more than females, male athletes may be more tired due to a greater exposure time. However, one additional heat per athlete might not be of great importance for these top trained athletes. Previous literature on alpine skiing has reported that injuries often occur towards the end of races (Bere et al., 2014, p. 673). One reason for this could be skier error caused by e.g., miscalculation or decreased concentration due to muscular fatigue (Bere et al., 2014, p. 673). On the other hand, no elevated *SMoIR* occurrence was observed throughout the heat levels, indicating that the fatigue component is not as prominent in SX. With relatively short heat durations, and sufficient recovery times between the heats are likely sufficient for the athletes to be able to repeat their performance at a high level throughout the competition in SX. Although no fatigue indications were observed in these analyses, it is important to consider that some venues host two consecutive race days. This may provoke more *SMoIR* since skiers may experience more fatigue during the second race day. Post (2022) compared all race days during the 20/21 SX season, unlike this study which only compared venues. The findings of Post (2022) suggested that multiple race days may partially provoke more Crash *phr*, but as different races have different numbers of heats, it is not easy to compare, as the exposure times will vary and therefore the level of fatigue may be different. However, none of the two-day competition venues analysed in this study showed significantly more *SMoIR* compared to single race-day venues.

Venue comparisons

Looking at *SMoIR* between venues this study found a significant lower occurrence of Contact *phr*, Out of Balance *phr*, and Crash *phr* for male athletes in Idre Fjäll compared to other venues. Despite being the venue with the highest total exposure time, there were generally fewer *SMoIR* observed in Idre Fjäll compared to other venues. Notable is that no Crashes were observed during the two consecutive race days for male athletes in Idre Fjäll. There was no significant difference between the other venues, suggesting that the course layout in Idre Fjäll may be favourable in terms of injury prevention. On the other hand, Idre Fjäll had the most jumps and second most rollers, and the highest total number of obstacles of all the venues. In addition, the course seems to have most of the obstacles aligned in a straight line, which means that less Direction Changes are affecting the course. This means that the speed can also increase because the skier is working less against gravity due to the direction of the slope. Although speed was not analysed in this study, it is known from alpine speed disciplines that high speed can dramatically increase the risk of injury if mistakes are made in critical sections of the course (Gilgien et al., 2014a, p. 3). In a Crash situation, the severity of the injury outcome can vary greatly depending on the forces involved. Speed is therefore an important factor to consider, as the greater the speed, the more energy is absorbed by the falling skier, increasing the risk of severe injury (Gilgien et al., 2014a, p. 3). On the other hand, in downhill alpine skiing, the speed component is much greater compared to SX. Given this, and the fact that multiple athletes are racing at the same time, speed itself may not be the most important injury risk factor in SX.

Furthermore, the occurrence of Crash *phr* was significantly higher in Secret Garden Compared to Idre Fjäll. When comparing the course characteristics of these two courses, they have one distinct difference, namely Direction Changes. Secret Garden is characterised by a lot of Direction Changes as opposed to Idre Fjäll which has quite few Direction Changes. In a previous master's thesis by Post (2022) which investigated hazardous Events in SX, the Idre Fjäll competition consisted of four races, one of which included a short course. Interestingly, the short course in Idre Fjäll had no direction changes, and no Crashes were observed. This is similar to the present study, which observed that male athletes had zero Crashes in Idre Fjäll, and the second to last number of direction changes of all the venues.

In addition, although not significant, Val Thorens and Nakiska had among the highest number of Crash *phr* after Secret Garden. All three venues featured a lot of Direction Changes. Interestingly, Val Thorens showed a higher occurrence of Out of Balance, and both Val Thorens and Nakiska showed a higher occurrence of Contact compared to

Secret Garden. Suggesting that the Crash mechanisms in Secret Garden differ compared to other venues with high Crash occurrence. One could speculate that the overall technicality of the course in Secret Garden may result in a higher percentage of the Out of Balance situations are resulting in a Crash. As opposed to Val Thorens and Nakiska where factors such as opponent Contact may influence the Crash situations to a greater extent. In contrast, Arosa showed the highest number of Contact *phr* among all venues but showed a lower occurrence of Crash *phr* compared to Val Thorens and Nakiska. However, the course characteristics in Arosa differs to the others by being very short and intense. This means that the skiers must fight for positions over a short race duration, which likely provoke most of the Contact situations observed. One can speculate that the consequences of sustaining a Contact or Out of Balance on a course like Arosa may not be as severe as the course allows for this level of aggression to some extent. Compared to courses like Val Thorens and Nakiska which has larger obstacles and a lot of direction changes that may increase the risk of Crashing if unforeseen Events such as Out of Balance or Contact occurs.

SMoIR comparisons between obstacle categories

By looking at *SMoIR* comparisons between obstacle categories, male athletes tended to exhibit a higher occurrence of Crash, Contact and Avoiding Contact on Direction Changes. Out of Balance occurred more on Jumps. For female athletes, Crash and Avoiding Contact were not significantly different between obstacle categories. Out of Balance occurred more on Jumps and Contact occurred more on Direction changes.

Direction Changes

In the literature on SX and SBX, most injuries are observed to be associated with jumping (Bakken et al., 2011, p. 1317; Randjelovic et al., 2014, p. 2). However, comparisons of *SMoIR* between obstacle categories analysed in this study revealed that male athletes showed significantly more Crashes on Direction Changes compared to Jumps and Rollers, which is similar to the findings of Post (2022). A possible explanation could be related to the differences in impacts involved in a Crash situation compared to actual injuries. This is suggesting that the impacts may be higher on Jumps, leading to more injuries, compared to Crash situations which likely is less severe.

SX courses often include several types of direction changes. One of them is giant slalom turns. It is known that the risk of injury in giant slalom is often linked to the aggressive leaning inwards and backwards of the skiers to make turns, which puts the athlete`s body in an unfavourable position in the case of additional factors such as Out of Balance situations (Gilgien et al., 2014b, p. 3). In SX, there has been observed that injuries also occur in similar turns, however, more often due to technical mistakes carried over from the previous obstacle (Randjelovic et al., 2014, p. 6). Another type of turn frequently used in Cross competitions are banked turns. These turns are observed to provoke more contact related injuries compared to traditional turns in both SX and SBX (Bakken et al., 2011, p. 1319; Randjelovic et al., 2014, p. 3).

One might initially think that Direction Changes would be the ‘hot spot’ for Out of Balance as well, as this is where most of the Crashes occurred. Although Out of Balance was significantly correlated with Crash, the cause of Crash for male athletes appears to be influenced more by the Direction Change or Direction Change layout than by the Out of Balance situation itself, suggesting that other factors may play an important role in the early stages of Crash situations. In this study, the occurrence of Contact between opponents was identified to be significantly higher on Direction Changes compared to Jumps and Rollers for both male and female athletes. As highlighted by previous literature, Contact is known to be frequently associated with injury situations in SX and SBX (Bakken et al., 2011, p. 1319; Randjelovic et al., 2014, p. 5). This suggests that the reason for the increased occurrence of Crash on Direction Changes observed in this study may be due to excessive ski-to-ski racing and fighting for positions. In these situations, a change of direction could lead to Contact between the athletes, which could result in an Out of Balance situation. In the case of an Out of Balance, the athlete can either counteract the rotations to regain balance, or it can develop into a Crash if the athlete fails to recover, resulting in body Contact with the ground. Taking this into account, every Crash involves an Out of Balance Event leading up to the fall, suggesting that Contact may be the more important predictor for Direction Change related Crashes in SX.

Furthermore, Direction Changes are generally marked with gates, in which the skiers must pass on the correct side. This is an important aspect to consider regarding Contact and Crash situations in Direction Changes. When skiers navigate down the course in a straight line, the width of the course are often sufficient for the athletes to manoeuvre side by side. However, as soon as the turn initiates, the gate that the skiers must pass make for a substantial narrowing of the racing line. As a result, Contact with opponents can occur when skiers are forced to follow a narrower line to maintain speed, and/or by trying to avoid being pushed off the course and passing the gate on the wrong side, resulting in a DNF. Contact with the gate has also been observed to cause injuries in Alpine skiing (Bere et al., 2014, p. 670), and influenced the injury outcome in SBX (Bakken et al., 2011, p. 1319). This means that there can also be several reasons for Crashes in Direction Changes. However, in this study, the Crash mechanisms was not investigated apart from noting the Events with corresponding obstacle number and details as described in the methods. Hence, such factors can only be speculated upon.

Furthermore, Avoiding Contact was also observed to occur more on Direction Changes compared to Rollers. It is natural that if there is an increased occurrence of Contact, as observed with Direction Changes, some will be avoided.

Jumps

Significantly more Out of Balance occurred on Jumps compared to Direction Change for males and compared to both Direction Changes and Rollers for females. As suggested by multiple researchers investigating injury risk factors in alpine skiing, improper technique or strategy in approaching the jump are key factors for injury risk (Bere et al., 2011, p. 1423; Gilgien et al., 2014b, p. 4; Heinrich et al., 2014, p. 185). However, in this study, most Out of Balance situations were saved, usually by counteracting movements with the arms and the upper body. Thus, Crashes were for the most part avoided. By doing video analysis, it is clear that the duration of the flight is a major factor determining the outcome of an Out of Balance. If athletes are landing back weighted, they usually regain balance due to Contact with the ground, and therefore stopping the backward rotation using muscular counterwork. However, in alpine skiing, factors such as increased angular momentum resulting in unwanted backward rotations during airtime has been suggested to be important injury risk factors (Gilgien et al., 2014b, p. 4). The injury outcome of excessive backward rotation is very much determined by the duration of the flight, meaning that a longer jump would cause more rotation, resulting in a critical body position on impact with the ground (Gilgien et al., 2014b, p. 4). Injuries in SBX have also been observed to occur due to overshooting of the landing, making the landing impacts too high for the athletes to absorb, thus sustaining an injury (Bakken et al., 2011, p. 1317). This means that both high speed and/or technical errors during the take-off can result in Crashes and potential severe injury. On the other hand, the threshold for an Out of Balance to be noted in this study, were quite low. This means that many of the Out of Balance situations are likely to be natural counteracting movements, given the differences between the forces acting on the ground and in the air. Therefore, in actual injury situation in SX the injury mechanisms may be different leaning towards those described by Randjelovic et al. (2014) and Bakken et al. (2011).

Rollers

The occurrence of *SMoIR* on Rollers were only significant for Out of Balance compared to Direction Changes for female athletes. Considering the characteristic of a roller compared to a sharp turn or a technical jump, the construction of a roller is generally more orientated in a straight line. This means that in most cases a Roller can be manoeuvred more freely and side by side. Without the influence of a change of direction, a potential Contact on Rollers is unlikely to be as critical, as the orientation of the slope allows for this Contact to take place without the risk of critical Out of Balance situations as indicated by similar situations on Direction Changes. However, females appear to be more challenged to maintain balance going over Rollers. An important aspect of Rollers is that they are often constructed in series. Going over one Roller may be easy. However, going over multiple Rollers can be challenging due to different possible strategies. This means that in some Roller combinations the skier can choose to jump from one Roller and land down the second Roller. In multiple Roller combinations some choose to jump over in some cases, and ‘pump’ others. The outcome of different strategies will be determined by the skiers’ speed and technical execution of the manoeuvres. Energy pumping is known to be important, by doing a jumping-flying-landing-motion, the kinetic energy from the moving of the centre of mass can be utilised to gain speed in the direction of the slope (Luginbühl et al., 2023, p. 1). In technical Roller combinations, the athletes may choose a different strategy than others trying to gain an advantage. If this is miscalculated, skiers may land incorrectly, on top of or between rollers, which can lead to Out of Balance situations, as these results suggest for female athletes.

Start Straights

Generally, less *SMoIR* occurred on the Start Straight compared to other obstacle categories. This is natural due to the characteristics of the Start Straight. The Start Straight usually contains typical ‘low-speed’ obstacles like Wu-Tangs and other small obstacles. In addition, the Start Straight does not include any Direction Changes. Although the analyses in this study showed that there are generally fewer *SMoIR* occurring on the Start Straight, some still occur. In the initial stage of a race, the athletes are trying to gain speed and fight for positions before the first Direction Change. This means that some Out of Balance and Contact situations will likely occur. However, given the type of obstacles used and the lower speed, the risk of critical Events is likely to be lower on the Start Straight, as implied by the results of this study.

To summarise the overall distribution of *SMoIR* across obstacle categories, the mechanisms appear to be slightly different between male and female athletes. The reason for male athletes Crashing is likely due to tight heat racing with high speed, and in the presence of a Direction Change and gates to be passed correctly, the likelihood of Contact and Crash are increased. In contrast to female athletes, there appears to be more room to manoeuvre for the athletes. Thus, less critical Contact situations will likely occur. On the other hand, females may encounter more Crashes due to a lower technical skill level and overall higher course technicality compared to their male counterparts, meaning that Crashes will likely be more spread across different obstacle categories. Interestingly, the correlation between Out of Balance *phr* and Crash phr, and between Contact *phr* and Crash *phr* appears to be stronger for females, highlighting the likelihood of these suggestions.

Comparisons of obstacle categories within each venue

By looking at obstacle categories at each venue, the occurrence of Crash was not significantly different between obstacle categories. The reason for this may be that the number of Crashes observed in this study may not be sufficient to analyse these differences at the venue level. However, significant differences in Contact were frequently observed on Direction Changes within multiple venues for both genders. Interestingly, when comparing the course characteristics of Val Thorens and Idre Fjäll, Val Thorens had almost twice as many Direction Changes as Idre Fjäll, and Idre Fjäll had many more Jumps and Rollers than Val Thorens. Still the occurrence of Contact was significantly higher on Direction Changes compared to Jumps in Val Thorens for male athletes, and compared to Rollers and Jumps in Idre Fjäll for both male and female athletes. This highlights the suggestion that Contacts are more likely to occur in combination with Direction Changes than other obstacle categories. In contrast, Secret Garden did not show any significantly more Contacts between the obstacle categories, despite having the most Crashes *phr* and among the venues with the most Direction Changes. It can be speculated that Secret Garden is an overall technical course with high speed, but with less ‘hot spots’ in which the number *SMoIR* would likely be more evenly distributed between the obstacle categories.

Assessment of course ‘hot spots’ and frequency analysis

The cause of SMoIR can be influenced by the time between each obstacle. This means that both distance between obstacles and speed influence the obstacle frequency or time between obstacles. This can explain some of the gender differences observed in this study, considering that male athletes tend to use shorter time on the same course than females. However, the result of the frequency analyses performed in this study, revealed that the frequency of obstacles as a function of time were equal between genders and between venues. The reason for this may be that the sport uses the gravity to ski down a course, meaning that the race time will not vary greatly between genders or venues, compared to other sports like Cross Country skiing which uses courses with completely different topography and longer race durations. Furthermore, these findings suggests that the cause of *SMoIR* is likely associated with the obstacle itself or the combination of obstacles rather than the frequency between them. The final analysing step in this study was a detailed comparison of each individual obstacle within each course, to investigate potential ‘hot spots’ that frequently cause *SMoIR* and to assess their characteristics.

Val Thorens

Obstacle nr. 42 (Direction Change) in Val Thorens was observed to provoke significantly more Crashes compared to other obstacles for male athletes. Looking at this obstacle in more detail revealed some interesting aspects. Obstacle nr. 42 is characterised by being a sharp right hand turn combination that starts with obstacle nr. 41 (turn entry), then nr. 42 (turn mid), and lastly nr. 43 (turn exit). The point between turn entry and turn mid is marked with a gate in which the athletes must pass correctly and is likely to cause many of these Crashes. However, to understand why, it is important to consider the obstacles before this turn combination. Starting with obstacle 37, which is a Roller before going into a highly technical left hand negative turn combination (38, 39, and 40). At obstacle 37 the athletes enter with great speed which makes the skiers lift of making the initiation of the negative turn challenging. This can in some cases result in the skiers to be pulled down deep into the negative turn combination, requiring a very sharp entry angle to successfully pass the gate that marks the point between turn nr. 41 and nr. 42. In these situations other opponents behind might take advantage of this opportunity and try to overtake by holding a higher line, which allow for a more correct turn entry on obstacle nr. 41. However, this could lead to Contact between the athletes due to a clash at the point of gate passage with the skier that are trying to get back on the course line. The Contact that occurs can, in some cases, lead to unrecoverable Out of Balance situations and thus Crashes, as suggested by these results.

Nakiska

Obstacle nr. 13 (Jump landing) in Nakiska was observed to provoke significantly more Crashes compared to other obstacles for male athletes. To understand the reason why the landing in obstacle nr. 13 is observed to cause more Crashes than others, it is necessary to investigate the obstacle both prior and after obstacle nr. 13. Obstacle nr. 12 and nr. 13 is a corner jump-landing combination. This is characterised by a jump in combination with a turn. In addition, obstacle 13 is also the beginning of the next turn (obstacle 14). This means that the flight trajectory of the skier is very much influenced by aiming for the turn after the landing. If multiple athletes are aiming for the same line at the same time, Contacts, Out of Balance, and Crashes are more likely to occur. Also, the size of the corner jump is quite small, meaning that the flight needs to be controlled to avoid overshooting the landing. Furthermore, by watching videos of these situations, Contacts often occurred prior to or at the take-off, thus influenced some of the Crash situations by pushing the athletes out of their chosen trajectory causing skier to be Out of Balance in critical moments. This is similar to the situations observed by Randjelovic et al. (2014) who reported that an inappropriate trajectory at take-off often caused by opponent Contact were one of the reasons for athletes sustaining a jump related injury in SX.

Arosa

For female athletes, obstacle nr. 21 (Roller) in Arosa was observed to provoke significantly more Crashes compared to other obstacles. Prior to this Roller there is a technically challenging negative turn (nr. 18 and nr. 19) followed by a roller (nr. 20) and then a second roller (nr. 21). The turn exit (nr. 19) requires a lot of counteracting muscle force to hold the line, and in some cases results in the athletes are pulled down deep, making the entry of Roller nr. 20 highly angled from the side. Furthermore, every Roller is marked with a gate at each side, between which the skiers must pass accordingly. However, due to the characteristics of turn 19, passing of the gate at Roller nr. 20 can be challenging. This could lead to Out of Balance situations often due to the skier fails to 'pump' the roller, thus making the skier airborne. Therefore, unwanted rotations of the skier may occur due to the aggressive entry angle trying to avoid hitting the gate or passing the gate on the wrong side. This Out of Balance situation is then carried over to the next Roller (nr. 21). In addition, Contact between athletes can also occur resulting in an even more uncontrolled Out of Balance situation making a Crash highly likely at the next obstacle.

Innichen

For female athletes, obstacle nr 44 (Jump) and obstacle nr. 46 (Direction Change) in Innichen was observed to provoke significantly more Crashes compared to other obstacles. Crashes at obstacle nr. 44 occurred for the most part at the take-off. This suggests that the skier lost balance before or in the transition of the take-off. Before jump nr. 44, there is a compression turn (nr. 42 and nr. 43). The compression from this turn combination is gradually transformed into the take-off of obstacle nr. 44. If an athlete chooses the wrong course line or miscalculates the turn, the forces that are acting on the skier can cause the skier to be back weighted, resulting in a Crash when going up the take-off.

Obstacle nr. 46 is a turn after the landing of jump nr. 44. The reason for these Crashes is again probably a combination of the previous obstacles. If a potential Crash is saved at the take-off of jump nr. 44, the Out of Balance is carried over to the next obstacle, often resulting in an uncontrolled flight and Contact with the ground at the start of turn nr. 46 due to the flight length of Jump nr. 44.

In addition, Avoiding Contact was observed to occur more frequently on turn nr. 47 for male athletes, which is the turn exit of the same section as the females where Crashing. Interestingly, these observations suggests that male athletes manage to manoeuvre tightly together through this technical section without critical sustaining critical Events compared to their female counterparts.

Idre Fjäll

Interestingly, Idre Fjäll had significantly more Crashes at obstacle nr. 63 for female athletes, as opposed to male athletes which had zero Crashes overall at Idre Fjäll. This section of the course is characterised by being in a straight line, and not influenced by Direction Changes. Obstacle nr. 63 is the last Roller in a combination of a total of seven Rollers forming a 'Dragon'. The reason for the Crashes on this particular Roller is likely due to the combination of rollers causing a series of Out of Balance situations. Since the skiers barely touch each roller due to the speed they are carrying, an Out of Balance is challenging to recover due to lack of ground contact, resulting in the accumulation of Out of Balance on each roller, which are resulting in a Crash on the last Roller.

Cause of Crash and gender differences

The 'hot spots' localised in this study suggests that male athletes did Crash primarily in Direction Changes and on jumps. However, the jump situations were likely influenced by the design of the jump, considering that the jump was constructed as part of a turn. Contact between opponents were likely to be involved in most of these Crash situations. For female athletes, the Crashes seem to be more influenced by the technicality of the course section, meaning that skier errors, causing Out of Balance, are carried over from the previous obstacles, which ultimately results in Crashing. The combination of obstacles seems to have a greater effect on female Crashes than on male's Crashes. These results therefore support the speculation that male athletes are better to regain balance in critical situations compared to female athletes, and that male Crashes are strongly influenced by Contact between opponents. In addition, it is important to emphasise that the obstacles that were identified as the location where most Crashes occurred, are not always the obstacle that caused the Crash, rather it is the location where the skier makes ground contact during Crashing. This means that the cause of the Crash is typically a consequence of an Event or series of Events prior to the Crash obstacle.

Rank Shift comparisons

Gender and venue comparisons

This study analysed Ranks Shifts *phr*, which was the most frequently observed Event during the video analysis. The results showed that the occurrence was higher among male athletes compared to female athletes. This is underlining the observations that males tend to race closer to each other, and as a result, more Rank Shift will occur. By looking at Rank Shift *phr* between venues, Arosa and Reiteralm showed the most for male athletes, and Arosa showed the most for female athletes. With more Rank Shifts, races will be more action-packed. However, with more Rank Shifts, more potential injury situations will also likely occur. Interestingly, Rank Shift *phr* was significantly correlated ($p< 0,01$) with Contact *phr* and Out of Balance *phr* for male athletes, and with Contact *phr* and Crash *phr* for female athletes. However, neither of these venues showed any significantly increased occurrence of Crash *phr* despite high numbers of Contact *phr* for male athletes. This is emphasising that rank shift itself is not an injury risk factor, but it may influence Crash situations in combination of opponent Contact and direction changes, as previously discussed.

Furthermore, the lowest number of Rank Shifts *phr* occurred in Idre Fjäll for female athletes. Interestingly, Idre Fjäll were among the venues with most Crashes *phr* for females. Although Crash was not significantly different between venues for females, these findings are interesting considering that male athletes had zero Crashes in Idre Fjäll. One can speculate that male Crash situations are associated with tight heat racing in combination with direction changes, while female Crash situations are more associated with the obstacles itself.

Rank Shift comparisons between obstacle categories

When analysing Rank Shift differences between obstacle categories, the Start Straight was significantly different to the other obstacle categories. Given that all athletes start at the same position at the starting gate, multiple Rank Shift will occur during the first section of the course. The athletes can benefit from a fast first section if they manage to time their start technique well in combination with a good pumping technique going over the first few obstacles. This could create a gap to the opponents. It is known that a good starting technique is important in order to be able to accelerate quickly during the first section of the course to be the skier in command and to choose the most appropriate racing line (Argüelles et al., 2011, p. 971). Furthermore, the distribution of Rank Shift was equal between Direction Changes, Jumps, and Rollers. These findings are important to be able to map the occurrence and location of Rank Shifts. Furthermore, by providing information suggesting that none of the obstacle categories are limiting the possibility to overtake is important for future course building.

Rank Shift comparisons between individual obstacles

When analysing the occurrence of Rank Shifts between each individual obstacle, only one obstacle was pointed out among all venues for male athletes. Obstacle nr. 9 (Jump) in Nakiska exhibited a significantly higher occurrence of Rank Shifts compared to obstacle nr. 62 (Roller) in Nakiska. Obstacle nr. 9 is a landing of a jump. This jump is the last obstacle before the first direction change and marks the end of the first section. The first section is characterised by wu-tang inspired obstacles which requires a good technical execution to gain speed. After the start straight obstacles, there is a quite long stretch of gliding before the jump take-off. As a result of the technical execution of the previous obstacles, the speed differences get noticeable during the take-off of the jump, resulting in Rank Shifts during the later part of the flight or at the end of the landing just before turn entry of the direction change coming after. In addition, the direction change after the landing may also force the athletes to adjust to avoid unwanted Contact between athletes going into the turn.

Interestingly, obstacle nr. 12 and nr. 13 after the direction change were reported to cause significantly more Crashes compared to other obstacles in Nakiska, as previously discussed. This is indicating that this section of the course is highly technical, and if the space is too narrow for the skiers to manoeuvre properly, Contact-induced Crash situations may occur. The strategy of a skier can also influence the Rank Shift in this section. If a skier places himself behind the opponent to avoid Contact during the turn, the possibility to choose a different trajectory towards the next obstacle is possible. Instead of risking a collision between opponents at the first opportunity, the skier could try to overtake at the next opportunity. However, to avoid losing speed, skiers often take advantage of overtaking opportunities that are risky, which may lead to dangerous situations, as these results suggest.

Future implications

Overall, this study revealed that most Crashes occurred on direction changes, which was highly associated with opponent Contact for male athletes. Most Out of Balance situations occurred on Jumps for both male and female athletes. However, a detailed course 'hot spot' analysis showed that Crashes occurred both by turning and by jumping-turning situations for male athletes. Common to both was that Contact was likely to have been involved in most of the Crash situations. For female athletes, Crashes occurred on both jumps and rollers, in which one occurred due to Out of Balance at the jump take-off, resulting in Crash in the beginning of the next turn.

Since there is no existing standardisation regarding course design in SX, except the distance from the start to the first direction change (Fédération Internationale de Ski, 2023, p. 142), different courses may provoke different amounts of Events as a result of its characteristics. SX and SBX courses are costly to build, suggesting that the aim for the future would be to build safer courses that is suitable for both male and female athletes, while still be exiting for the athletes and for the spectators to watch. The result of this study suggests that adherence to both obstacle design, obstacle combination, and manoeuvrability between obstacles are important to build courses that are safer, yet suitable for both male and female athletes. For male athletes, it is important to emphasise that the ability to manoeuvre between obstacles seems to be important to reduce the risk of Contact-induced Crash situations, which has been suggested in previous literature as well (Randjelovic et al., 2014, p. 7). It was frequently observed in this study that a sudden narrowing of the optimal trajectory going into direction changes or during take-off, caused Contact between opponents, resulting in Crashes. For female athletes, the technical difficulty of the obstacle itself, or the combination of obstacles were likely to cause Crashes, likely due to personal errors. This means that course designers in the future should focus on designing course layouts that can accommodate several outcomes of an athlete's strategy or miscalculation. Whether it is their different trajectory or the speed they are carrying.

Although Crash situations are closely related to injury situations, most of the Crashes does not likely lead to severe injury, suggesting that the mechanisms leading to actual injuries may lean more towards those described by Bakken et al. (2011) and Randjelovic et al. (2014) which reported that most injuries were associated with jumping. It is known from terrain park jumps that overshooting of the landing or landing on the "knuckle" is associated with high injury risk, due to the large impacts (Levy et al., 2015, p. 2; McNeil et al., 2012, p. 10). This may also be true in SX, suggesting that the potential impacts on related to jumping is larger than turn-related Crashes observed in this study.

Future research should therefore analyse these situations in more detail to get a better understanding of the mechanisms involved. Although few overshooting situations were observed during the WC 21/22 SX season, injuries in SBX have been observed to occur due to technical errors when jumping, resulting in overshooting of the landing, making the landing impacts too high for the athletes to absorb without sustaining an injury (Bakken et al., 2011, p. 1317). Therefore, adherence to Equivalent Fall Height (EFH) has been proposed to be important when analysing landing impacts (Hubbard & Swedberg, 2012, p. 3; Levy et al., 2015, p. 12; McNeil et al., 2012, p. 9). Jumps are therefore suggested to be designed with a constant EFH landing surface, that can handle multiple take-off velocities to reduce landing impacts (Levy et al., 2015, p. 12). By implementing these engineering principles, the severity of injuries associated with jumping can be dramatically reduced.

In addition, SX and SBX is foremost sports where highly trained athletes compete to be the fastest through challenging courses. Also, it is a spectator's sport that offers intense heat racing, high speed, and spectacular courses. To maintain the entertainment value of the sport, race directors and course builders must continue to preserve these important aspects in the future. This means that if dangerous 'hot sports' are being avoided less severe injury will likely occur. Furthermore, the ability to overtake opponents is important in SX and SBX. This study showed that the possibility for rank shifts were equal between obstacle categories, and overtaking is possible in all the venues. However, rank shifts can influence Crash situations if athletes are trying to overtake in situations where Contacts are likely to cause Out of Balance situations.

Methodological considerations

This study is part of a bigger ongoing project aimed at mapping the occurrence of potential injury situations in Ski Cross. By analysing videos from the 21/22 World Cup season, this study utilised surrogate measures as indicators for injury risk based on an existing method developed by Bruhin et al. (n. d). By using appropriate surrogate measures of injury risk, it is possible to analyse potential injury situations, without actual injury data (Kröll et al., 2017, p. 1645).

The video rating process in this study is based on standardised definitions. However, some subjective elements cannot be ruled out. This means that some situations may have been overlooked or incorrectly noted. However, inter-rater reliability was secured by undergoing a standardised process to reach a high level of agreement between the present rater and previous raters prior to the video analysis in this study. This suggests that even if some incorrect Events were noted, the overall impact would be limited. However, another source of error could be related to the quality of the available videos. First, the videos came from official broadcasters, meaning that the camera angles and the timing of switching between camera angles are not optimal for analysing delicate Events such as Contacts or Avoided Contacts. Furthermore, the replay after each heat does not always show all the important situation, which means that some Events could be challenging to determine. Second, the weather conditions could also influence the quality of the videos, making the Events hard to identify in some situations.

The sample size obtained in this study is limited for some Events. Crash and Avoiding Contact were only noted 89 and 35 times across the whole dataset, meaning that when analysing these variables between groups, the sample size is quite small. In addition, the data was not normally distributed, meaning that the Mean and Standard Deviation could not be used when presenting the data. The use of the median resulted in many variables being zero due to several heats had missing values, because no Event had occurred. Therefore, the medians presented in this study do not always describe the data well. To understand the size differences, the mean ranks utilised by the Kruskal Wallis test was presented in the Appendix as supportive descriptive data for some of the results. With a bigger sample size, it may have been easier to analyse differences in some of the groups. However, even if more data had been added, the distribution of the data is still likely to be skewed, leading to the use of non-parametric tests.

This study did not analyse training runs. This could have resulted in some important data to be missed. As highlighted by Post (2022), the injury occurrence between training runs and final runs in SX seems to be diverse, suggesting that more research on this topic is required. However, it can be argued that more is at stake during the final heats, and this will lead to greater commitment and fighting spirit among the athletes, which may alter the risk of injury during final heats.

The timing data used for different calculations, like total timed skied and frequency between obstacles, were obtained by actual video time and not by official timekeepers, which could affect the calculations. However, the timing was obtained equally between genders and venues, which means that the impact on the analysis is likely to be small.

Lastly, this study did not consider if athletes did not finish their heat. When obstacle incidences were calculated, the number of athletes starting each heat was used for the calculations. This, however, did not consider if an athlete did not finish their race, or skipped some obstacles due to e.g., missing of a gate or due to a Crash. This could influence the obstacle incidences in some cases. In most cases, however, the skiers did finish their race, suggesting that the impacts on the calculations are limited.

Conclusion

To conclude, male athletes seem to encounter more Events associated with injury risk compared to female athletes. However, the occurrence of Crash *phr* was equal between genders. Only male athletes showed a significant difference in Crash *phr*, Contact *phr*, and Out of Balance *phr* between venues. Across heat levels, females showed a higher occurrence of Contact *phr* in SF 2 compared to QF 1 and SF 1, indicating that there may be some heats that is more stretched out due to a disparity in skill levels among female athletes. For Males, the occurrence of Crash was observed to be higher on direction changes, while for females the occurrence was equal between obstacle categories. The Crash situation for males is characterised by close ski-to-ski heat racing, resulting in opponent Contact often due to a sudden narrowing of the course going into or out of direction changes. For females the cause of Crash seems to be more associated with the technical difficulty of the course layout, likely due to a lower technical and/or physical skill level. In addition, a higher percentage of Out of Balance *phr* are resulting in a Crash for females, suggesting that males have a better ability to regain balance in critical situations. Furthermore, the possibility to overtake was equal between obstacle categories, suggesting that the courses did not limit the skiers to manoeuvre between their opponents. However, narrow sections of the course can lead to Contact situations if skiers try to overtake. This study therefore suggests that narrow course sections should be limited and should be avoided in combination with other technical obstacles or sections to reduce the risk of Contact and unrecoverable Out of Balance situations. Furthermore, the combination and layout of obstacles should be designed to accommodate both male and female athletes, with more space for the athletes to recover Out of Balance situations. Finally, race directors and course builders should strive to design safer courses that are still exciting for both the athletes and the spectators, which allow for tight heat racing and overtaking possibilities. For the sport to remain popular in the future, the very nature of Ski Cross requires that these aspects be emphasised.

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Appendix 1

1.1 Venue characteristics

Total number of runs (n), total number of skiers (n), and total time skied (sec) for each venue. In addition, numbers are split by gender.

Venue	Total runs	Total number of skiers	Total time skied	Gender	Total runs	Total number of skiers	Total time skied
	n	*n*	*sec*		*n*	*n*	*sec*
Secret Garden	24	96	6681	M	16	64	4377
				F	8	32	2305
Val Thorens	48	190	13266	M	32	128	8804
				F	16	62	4462
Arosa	48	187	5495	M	32	127	3658
				F	16	60	1837
Innichen	48	190	14228	M	32	128	9422
				F	16	62	4805
Nakiska	48	190	13356	M	32	126	8723
				F	16	64	4633
Idre Fjäll	48	189	14417	M	32	128	9524
				F	16	61	4892
Beijing	32	121	9167	M	16	64	4608
				F	16	57	4559
Reiteralm	24	94	5865	M	16	64	3934
				F	8	30	1931
Veysonnaz	24	96	5211	M	16	64	3424
				F	8	32	1787

1.2 Absolute number of Events per venue

Shows the absolute number (n) of SMoIR and Rank Shifts per obstacle category for each venue.

Male athletes

Venue	Rank Shift	Contact	Avoiding contact	Out of Balance	Crash
	n	*n*	*n*	*n*	*n*
Secret Garden	139	32	1	34	9
Val Thorens	266	67	7	96	12
Arosa	179	57	1	55	5
Innichen	295	58	6	71	7
Nakiska	212	58	5	72	14
Idre Fjäll	299	19	3	52	0
Beijing	107	35	5	38	3
Reiteralm	157	28	0	36	3
Veysonnaz	107	32	2	31	4

Female athletes

Venue	Rank Shift	Contact	Avoiding contact	Out of Balance	Crash
	n	*n*	*n*	*n*	
Secret Garden	63	9	0	4	0
Val Thorens	105	16	0	30	3
Arosa	84	15	0	25	3
Innichen	120	12	0	29	4
Nakiska	109	19	1	26	8
Idre Fjäll	105	6	1	33	6
Beijing	115	25	2	35	4
Reiteralm	58	6	0	11	2
Veysonnaz	60	6	1	15	2

1.3 Absolute number of Events per obstacle category

Shows the absolute number (n) of SMoIR per obstacle category.

Event	Direction Change		Jump		Roller	
	n	*%*	*n*	*%*	*n*	*%*
Contact	249	51,7	112	27,4	130	37,7
Avoiding Contact	19	3,9	12	2,9	4	1,2
Out of Balance	169	35,1	265	64,8	194	56,2
Crash	45	9,3	20	4,9	17	4,9
Total	482	100	409	100	345	100

1.4 Venue Post-Hoc analysis

Contact for Male athletes.

Kruskal Wallis with Bonferroni Post-hoc analysis of Contact *phr* across venues for male athletes. Significant p values are marked with bold font.

Venue comparison	R^2	P value*
Idre Fjäll - Innichen	46.313	.137
Idre Fjäll - Beijing	-56.984	.131
Idre Fjäll - Secret Garden	57.109	.129
Idre Fjäll - Nakiska	**59.766**	**.007**
Idre Fjäll - Val Thorens	**64.891**	**.002**
Idre Fjäll - Reiteralm	**-69.859**	**.013**
Idre Fjäll - Veysonnaz	**-76.797**	**.003**
Idre Fjäll - Arosa	**80.047**	**<.001**
Innichen - Beijing	-10.672	1.000
Innichen - Secret Garden	10.797	1.000
Innichen - Nakiska	-13.453	1.000
Innichen - Val Thorens	18.578	1.000
Innichen - Reiteralm	-23.547	1.000
Innichen - Veysonnaz	-30.484	1.000
Innichen - Arosa	33.734	1.000
Beijing - Secret Garden	0.125	1.000
Beijing - Nakiska	2.781	1.000
Beijing - Val Thorens	7.906	1.000
Beijing - Reiteralm	-12.875	1.000
Beijing - Veysonnaz	-19.812	1.000
Beijing - Arosa	23.063	1.000
Secret Garden - Nakiska	-2.656	1.000
Secret Garden - Val Thorens	-7.781	1.000
Secret Garden - Reiteralm	-12.75	1.000

Secret Garden - Veysonnaz	-19.687	1.000
Secret Garden - Arosa	-22.937	1.000
Nakiska - Val Thorens	5.125	1.000
Nakiska - Reiteralm	-10.094	1.000
Nakiska - Veysonnaz	-17.031	1.000
Nakiska - Arosa	20.281	1.000
Val Thorens - Reiteralm	-4.969	1.000
Val Thorens - Veysonnaz	-11.906	1.000
Val Thorens - Arosa	-15.156	1.000
Reiteralm - Veysonnaz	-6.937	1.000
Reiteralm - Arosa	10.188	1.000
Veysonnaz - Arosa	3.25	1.000

*P value <.05 is significant

Out of Balance for female athletes.

Kruskal Wallis with Bonferroni Post-hoc analysis for Out of Balance *phr* comparisons between venues for male athletes. Significant p values are marked with bold font.

Venue comparison	X^2	P value*
Idre Fjäll - Innichen	29.375	1.000
Idre Fjäll - Secret Garden	30.906	1.000
Idre Fjäll - Beijing	-37.062	1.000
Idre Fjäll - Nakiska	38.781	.595
Idre Fjäll - Veysonnaz	-39.594	1.000
Idre Fjäll - Reiteralm	-52.594	.286
Idre Fjäll - Val Thorens	**63.984**	**.003**
Idre Fjäll - Arosa	**69.313**	**.001**
Innichen - Secret Garden	1.531	1.000
Innichen - Beijing	-7.687	1.000
Innichen - Nakiska	-9.406	1.000
Innichen - Veysonnaz	-10.219	1.000
Innichen - Reiteralm	-23.219	1.000
Innichen - Val Thorens	34.609	1.000
Innichen - Arosa	39.938	.489
Secret Garden - Beijing	-6.156	1.000
Secret Garden - Nakiska	-7.875	1.000
Secret Garden - Veysonnaz	-8.687	1.000
Secret Garden - Reiteralm	-21.687	1.000
Secret Garden - Val Thorens	-33.078	1.000
Secret Garden - Arosa	-38.406	1.000
Beijing - Nakiska	1.719	1.000
Beijing - Veysonnaz	-2.531	1.000
Beijing - Reiteralm	-15.531	1.000
Beijing - Val Thorens	26.922	1.000

Beijing - Arosa	32.250	1.000
Nakiska - Veysonnaz	-.812	1.000
Nakiska - Reiteralm	-13.812	1.000
Nakiska - Val Thorens	25.203	1.000
Nakiska - Arosa	30.531	1.000
Veysonnaz - Reiteralm	13.000	1.000
Veysonnaz - Val Thorens	24.391	1.000
Veysonnaz - Arosa	29.719	1.000
Reiteralm - Val Thorens	11.391	1.000
Reiteralm - Arosa	16.719	1.000
Val Thorens - Arosa	-5.328	1.000

*P value <.05 is significant

Crash for male athletes.

Kruskal Wallis with Bonferroni Post-hoc analysis of Crash *phr* comparisons between venues for male athletes. Significant p values are marked with bold font.

Venue comparison	X^2	P value*
Idre Fjäll - Arosa	16.406	1.000
Idre Fjäll - Innichen	18.188	1.000
Idre Fjäll - Beijing	-18.219	1.000
Idre Fjäll - Reiteralm	-21.656	1.000
Idre Fjäll - Veysonnaz	-22.781	1.000
Idre Fjäll - Val Thorens	28.625	.391
Idre Fjäll - Nakiska	34.906	.068
Idre Fjäll - Secret Garden	**49.094**	**.013**
Arosa - Innichen	-1.781	1.000
Arosa - Beijing	-1.812	1.000
Arosa - Reiteralm	-5.250	1.000
Arosa - Veysonnaz	-6.375	1.000
Arosa - Val Thorens	12.219	1.000
Arosa - Nakiska	-18.500	1.000
Arosa - Secret Garden	32.688	.632
Innichen - Beijing	-0.031	1.000
Innichen - Reiteralm	-3.469	1.000
Innichen - Veysonnaz	-4.594	1.000
Innichen - Val Thorens	10.438	1.000
Innichen - Nakiska	-16.719	1.000
Innichen - Secret Garden	30.906	.891
Beijing - Reiteralm	-3.437	1.000
Beijing - Veysonnaz	-4.562	1.000
Beijing - Val Thorens	10.406	1.000
Beijing - Nakiska	16.688	1.000
Beijing - Secret Garden	30.875	1.000
Reiteralm - Veysonnaz	-1.125	1.000
Reiteralm - Val Thorens	6.969	1.000

Reiteralm - Nakiska	13.250	1.000
Reiteralm - Secret Garden	27.438	1.000
Veysonnaz - Val Thorens	5.844	1.000
Veysonnaz - Nakiska	12.125	1.000
Veysonnaz - Secret Garden	26.313	1.000
Val Thorens - Nakiska	-6.281	1.000
Val Thorens - Secret Garden	20.469	1.000
Nakiska-Secret Garden	14.188	1.000

*P value <.05 is significant

1.5 Heat level Post-Hoc analysis

Contact for female athletes.

Kruskal Wallis with Bonferroni Post-hoc analysis of Contact *phr* comparisons between heat levels for female athletes. Significant p values are marked with bold font.

Heat comparison	X^2	P value*
QF_1 - SF_1	-1.385	1.000
QF_1 - QF_4	-5.115	1.000
QF_1 - SmF	-12.923	1.000
QF_1 - BF	-13.462	1.000
QF_1 - QF_3	-14.654	1.000
QF_1 - QF_2	-21.115	1.000
QF_1 - SF_2	**-37.192**	**.024**
SF_1 - QF_4	3.731	1.000
SF_1 - SmF	-11.538	1.000
SF_1 - BF	-12.077	1.000
SF_1 - QF_3	13.269	1.000
SF_1 - QF_2	19.731	1.000
SF_1 - SF_2	**-35.808**	**.037**
QF_4 - SmF	-7.808	1.000
QF_4 - BF	-8.346	1.000
QF_4 - QF_3	9.538	1.000
QF_4 - QF_2	16.000	1.000
QF_4 - SF_2	-32.077	.113
SmF - BF	-0.538	1.000
SmF - QF_3	1.731	1.000
SmF - QF_2	8.192	1.000
SmF - SF_2	24.269	.829
BF - QF_3	1.192	1.000
BF - QF_2	7.654	1.000
BF - SF_2	23.731	.935
QF_3 - QF_2	6.462	1.000
QF_3 - SF_2	-22.538	1.000
QF_2 - SF_2	-16.077	1.000

*P value <.05 is significant

Avoiding Contact for male athletes.

Kruskal Wallis with Bonferroni Post-hoc analysis of Avoided Contact *phr* comparisons between heat levels for male athletes. Significant p values are marked with bold font.

Heat comparison	X^2	P value
QF_4 - QF_1	4.500	1.000
SF_2 - QF_1	4.500	1.000
QF_4 - QF_2	8.308	1.000
SF_2 - QF_2	8.308	1.000
QF_4 - QF_3	**23.385**	**.024**
SF_2 - QF_3	**23.385**	**.024**
QF_4 - SF_2	0.000	1.000
QF_4 - BF	-3.808	1.000
QF_4 - SF_1	-7.692	1.000
QF_4 - SmF	-8.308	1.000
SF_2 - BF	-3.808	1.000
SF_2 - SF_1	7.692	1.000
SF_2 - SmF	-8.308	1.000
BF - QF_1	0.692	1.000
BF - SF_1	3.885	1.000
BF - QF_2	4.500	1.000
BF - SmF	4.500	1.000
BF - QF_3	19.577	.148
QF_1 - SF_1	-3.192	1.000
QF_1 - QF_2	-3.808	1.000
QF_1 - SmF	-3.808	1.000
QF_1 - QF_3	-18.885	.200
SF_1 - QF_2	0.615	1.000
SF_1 - SmF	-0.615	1.000
SF_1 - QF_3	15.692	.711
QF_2 - SmF	0.000	1.000
QF_2 - QF_3	-15.077	.888
SmF - QF_3	15.077	.888

1.6 Rank Shift Post-Hoc analysis

Male across venues

Kruskal Wallis Post-hoc Bonferroni test for RS *phr* across venues for male athletes. Significant p values are marked with bold font.

Venue comparison	X^2	P value*
Beijing - Nakiska	5.313	1.000
Beijing - Val Thorens	37.781	1.000
Beijing - Idre Fjäll	40.531	1.000
Beijing - Innichen	40.750	1.000

Beijing - Secret Garden	46.188	1.000
Beijing - Veysonnaz	-46.562	1.000
Beijing - Reiteralm	**-84.937**	**.008**
Beijing - Arosa	**114.469**	**<.001**
Nakiska - Val Thorens	32.469	1.000
Nakiska - Idre Fjäll	-35.219	1.000
Nakiska - Innichen	35.438	1.000
Nakiska - Secret Garden	40.875	1.000
Nakiska - Veysonnaz	-41.250	1.000
Nakiska - Reiteralm	**-79.625**	**.002**
Nakiska - Arosa	**109.156**	**<.001**
Val Thorens - Idre Fjäll	-2.750	1.000
Val Thorens - Innichen	-2.969	1.000
Val Thorens - Secret Garden	8.406	1.000
Val Thorens - Veysonnaz	-8.781	1.000
Val Thorens - Reiteralm	-47.156	.629
Val Thorens - Arosa	**-76.687**	**<.001**
Idre Fjäll - Innichen	0.219	1.000
Idre Fjäll - Secret Garden	5.656	1.000
Idre Fjäll - Veysonnaz	-6.031	1.000
Idre Fjäll - Reiteralm	-44.406	.908
Idre Fjäll - Arosa	**73.938**	**<.001**
Innichen - Secret Garden	5.438	1.000
Innichen - Veysonnaz	-5.812	1.000
Innichen - Reiteralm	-44.187	.934
Innichen - Arosa	**73.719**	**<.001**
Secret Garden - Veysonnaz	-0.375	1.000
Secret Garden - Reiteralm	-38.750	1.000
Secret Garden - Arosa	**-68.281**	**.021**
Veysonnaz - Reiteralm	38.375	1.000
Veysonnaz - Arosa	**67.906**	**.022**
Reiteralm - Arosa	29.531	1.000

Female across venues

Kruskal Wallis Post-hoc Bonferroni test for RS *phr* comparisons between venues for female athletes. Significant p values are marked with bold font.

Venue comparison	X^2	P value*
Beijing - Secret Garden	12.063	1.000
Beijing - Veysonnaz	-25.937	1.000
Beijing - Reiteralm	-19.312	1.000
Beijing - Arosa	**45.000**	**.009**
Nakiska - Val Thorens	1.875	1.000
Nakiska - Innichen	2.125	1.000
Nakiska - Secret Garden	15.750	1.000

Nakiska - Veysonnaz	-29.625	1.000
Nakiska - Reiteralm	-23.000	1.000
Nakiska - Arosa	**48.688**	**.003**
Val Thorens - Innichen	-0.250	1.000
Val Thorens - Secret Garden	13.875	1.000
Val Thorens - Veysonnaz	-27.750	1.000
Val Thorens - Reiteralm	-21.125	1.000
Val Thorens - Arosa	**-46.812**	**.005**
Idre Fjäll - Innichen	12.063	1.000
Idre Fjäll - Secret Garden	25.688	1.000
Idre Fjäll - Veysonnaz	-39.562	.310
Idre Fjäll - Reiteralm	-32.937	1.000
Idre Fjäll - Arosa	**58.625**	**<.001**
Innichen - Secret Garden	13.625	1.000
Innichen - Veysonnaz	-27.500	1.000
Innichen - Reiteralm	-20.875	1.000
Innichen - Arosa	**46.563**	**.006**
Secret Garden - Veysonnaz	-13.875	1.000
Secret Garden - Reiteralm	-7.250	1.000
Secret Garden - Arosa	-32.937	1.000
Veysonnaz - Arosa	19.063	1.000
Reiteralm - Arosa	25.688	1.000
Idre Fjäll - Nakiska	9.938	1.000
Idre Fjäll - Val Thorens	11.813	1.000
Idre Fjäll - Beijing	-13.625	1.000
Nakiska - Beijing	-3.687	1.000
Val Thorens - Beijing	-1.812	1.000
Innichen - Beijing	-1.562	1.000
Reiteralm - Veysonnaz	-6.625	1.000

1.7 Mean ranks between obstacle categories

The mean ranks used for Kruskal Wallis comparisons between obstacle categories. These ranks are used to tell the magnitude of the obstacle category injury risks. A higher rank equals higher risk of injury (*SMoIR*). In addition, Rank Shift is included in the table and indicate the size difference in Rank Shift occurrence on each obstacle category. Note! Rank Shifts are analysed and presented separately in the result chapter.

Male athletes:

	Direction Change	Jump	Roller	Start Straight
	Mean rank	*Mean rank*	*Mean rank*	*Mean rank*
Contact	593,5	483,7	460,3	380,8
Avoided Contact	512,4	497,3	487,8	483,5
Out of Balance	493,9	549,4	462,6	490,6
Crash	523,6	489,5	482,7	488,3
Rank Shift	489,8	493,2	471,4	611,2

Female athletes:

	Direction Change	Jump	Roller	Start Straight
	Mean rank	*Mean rank*	*Mean rank*	*Mean rank*
Contact	355,5	300,3	302,4	264,7
Avoided Contact	309,0	313,1	308,5	307,0
Out of Balance	273,7	354,7	320,7	271,6
Crash	311,8	314,1	309,7	298,0
Rank Shift	297,1	308,2	272,2	414,7

1.8 Mean ranks per venue between obstacle categories

The mean ranks used for Kruskal Wallis comparisons between obstacle categories. These ranks are used to tell the size difference of obstacle category injury risks. Example: the test subtracts the mean rank of Crash on Jump with mean rank of crash on Roller. This gives a difference indicating more/less of a given Event. In addition, Rank Shift is included in the table and indicate the size difference in Rank Shift occurrence on each obstacle category. Note! Rank Shifts are analysed and presented separately in the result chapter.

Male athletes:

	Direction Change	Jump	Roller	Start Straight
	Mean rank	*Mean rank*	*Mean rank*	*Mean rank*
Secret Garden				
Contact	63,2	47,9	49,1	40,4
Avoided Contact	53,0	51,5	51,5	51,5
Out of Balance	55,8	46,3	53,0	46,7
Crash	54,8	47,5	51,7	50,1
Rank Shift	51,5	55,2	46,0	61,8
Val Thorens				
Contact	82,1	60,2	64,6	52,4
Avoided Contact	70,6	66,7	67,2	65,0
Out of Balance	73,9	75,2	55,4	55,7
Crash	73,0	66,1	64,5	64,5
Rank Shift	60,3	74,3	59,4	91
Arosa				
Contact	50,2	34,4	44,8	24,5
Avoided Contact	41,3	37,5	37,5	37,5
Out of Balance	38,1	41,2	35,4	39,1
Crash	43,6	38,2	36,0	37,9
Rank Shift	32	28,6	38,8	48,3
Innichen				
Contact	82,3	65,6	62,2	51,0
Avoided Contact	73,6	68,5	68,5	68,5
Out of Balance	66,8	81,9	67,4	79,0
Crash	73,1	68,0	70,4	68,0
Rank Shift	76,8	65,1	55,5	80,8
Nakiska				
Contact	58,3	59,7	51,0	38,0
Avoided Contact	56,7	59,0	55,5	55,5
Out of Balance	49,7	65,1	57,3	37,5
Crash	60,2	56,0	55,3	52,5
Rank Shift	62,5	56,2	49,5	47,5
Idre Fjäll				
Contact	97,9	77,4	78,0	71,5
Avoided Contact	87,3	78,5	79,4	78,5
Out of Balance	82,5	85,2	76,4	62,0
Crash	80,0	80,0	80,0	80,0
Rank Shift	69,8	87,2	77,9	52
Beijing				
Contact	66,6	59,1	43,5	40,1
Avoided Contact	54,9	51,9	50,3	49,0
Out of Balance	52,6	54,6	47,6	55,2
Crash	53,9	50,0	50,0	52,7

Rank Shift	36,5	57	53,9	61,9
Reiteralm				
Contact	56,1	47,9	45,0	37,0
Avoided Contact	47,5	47,5	47,5	47,5
Out of Balance	47,3	55,6	43,7	34,0
Crash	46,0	49,2	47,1	46,0
Rank Shift	50,7	40,4	49,4	61,7
Veysonnaz				
Contact	41,1	35,3	32,1	24,0
Avoided Contact	34,5	39,2	34,5	34,5
Out of Balance	31,9	40,5	36,3	27,5
Crash	38,1	35,8	33,5	33,5
Rank Shift	40,6	39,7	29,8	31

Female athletes:

	Direction Change	**Jump**	**Roller**	**Start Straight**
	Mean rank	*Mean rank*	*Mean rank*	*Mean rank*
Secret Garden				
Contact	31,8	23,0	26,4	23,0
Avoided Contact	26,5	26,5	26,5	26,5
Out of Balance	26,7	25,0	26,8	26,8
Crash	26,5	26,5	26,5	26,5
Rank Shift	25	29,8	22,9	30,1
Val Thorens				
Contact	34,5	33,6	33,6	34,5
Avoided Contact	34,0	34,0	34,0	34,0
Out of Balance	27,7	40,7	32,2	36,9
Crash	33,5	35,2	33,5	33,5
Rank Shift	31,7	35,7	25,3	49,2
Arosa				
Contact	30,3	33,7	36,9	23,5
Avoided Contact	31,0	31,0	31,0	31,0
Out of Balance	28,8	39,8	33,8	23,7
Crash	30,0	30,0	32,7	30,0
Rank Shift	37,1	19,1	25,8	41,9
Innichen				
Contact	47,0	35,5	39,4	35,5
Avoided Contact	41,0	41,0	41,0	41,0
Out of Balance	38,6	50,0	41,8	34,1
Crash	40,6	43,6	39,5	39,5
Rank Shift	38,8	39,8	27,8	57,3
Nakiska				
Contact	35,0	31,7	32,9	25,0

Avoided Contact	32,5	33,6	32,5	32,5
Out of Balance	31,7	35,8	29,0	23,0
Crash	32,9	34,3	30,0	30,0
Rank Shift	35,2	32,8	28	44,5
Idre Fjäll				
Contact	53,3	41,3	39,0	38,0
Avoided Contact	40,5	40,5	41,4	40,5
Out of Balance	28,5	45,3	41,8	34,7
Crash	39,0	40,6	41,9	39,0
Rank Shift	36,4	40,9	39,0	61,8
Beijing				
Contact	70,3	58,9	50,3	43,0
Avoided Contact	53,0	60,6	53,0	53,0
Out of Balance	47,4	50,4	58,7	51,4
Crash	57,6	52,5	53,5	52,5
Rank Shift	51,1	64,9	47,6	66,1
Reiteralm				
Contact	30,8	26,2	26,3	24,0
Avoided Contact	27,0	27,0	27,0	27,0
Out of Balance	22,0	33,6	27,7	22,0
Crash	28,3	26,0	27,2	26,0
Rank Shift	21,7	25,1	26,8	40
Veysonnaz				
Contact	30,2	23,0	24,2	23,0
Avoided Contact	26,9	25,5	25,5	25,5
Out of Balance	22,8	31,0	26,1	20,0
Crash	26,4	25,0	26,3	25,0
Rank Shift	24,7	30,6	24,9	17

1.9 Post-Hoc test results comparing obstacle categories within each venue.

Kruskal Wallis comparison of obstacle category within each venue. Presented with Chi-square (R^2), degree of freedom (df), and p values. Significant p values in bold font.

Male athletes:

	Event	X^2	df	p value
Secret Garden	**Contact**	13,832	3	**0,003**
	Avoided Contact	1,943	3	0,584
	Out of Balance	2,495	3	0,476
	Crash	2,569	3	0,463
Val Thorens	**Contact**	14,746	3	**0,002**
	Avoided Contact	2,917	3	0,405
	Out of Balance	8,823	3	**0,032**
	Crash	8,451	3	**0,038**
Arosa	**Contact**	18,602	3	**<0,001**
	Avoided Contact	6,500	3	**0,09**
	Out of Balance	1,055	3	0,788
	Crash	5,983	3	0,112
Innichen	**Contact**	18,793	3	**<0,001**
	Avoided Contact	5,369	3	0,147
	Out of Balance	5,071	3	0,167
	Crash	3,405	3	0,333
Nakiska	**Contact**	1,88	3	0,598
	Avoided Contact	1,979	3	0,577
	Out of Balance	7,526	3	0,057
	Crash	2,14	3	0,544
Idre Fjäll	**Contact**	10,705	3	**0,013**
	Avoided Contact	9,447	3	**0,024**
	Out of Balance	2,653	3	0,448
	Crash	0	3	1,000
Beijing	**Contact**	22,733	3	**<0,001**
	Avoided Contact	3,894	3	0,273
	Out of Balance	2,032	3	0,556
	Crash	4,117	3	0,249
Reiteralm	**Contact**	5,272	3	0,153
	Avoided Contact	0	3	1,000
	Out of Balance	7,224	3	0,065
	Crash	2,064	3	0,559
Veysonnaz	**Contact**	4,685	3	0,196

	Avoided Contact	7,441	3	0,059
	Out of Balance	3,653	3	0,301
	Crash	4,197	3	0,241

Female athletes:

	Event	X^2	df	P value
Secret Garden	**Contact**	8,505	3	**0,037**
	Avoided Contact	0,000	3	1,000
	Out of Balance	0,571	3	0,903
	Crash	0,000	3	1,000
Val Thorens	**Contact**	0,071	3	0,995
	Avoided Contact	0,000	3	1,000
	Out of Balance	7,261	3	0,064
	Crash	2,350	3	0,503
Arosa	**Contact**	11,836	3	**0,008**
	Avoided Contact	0,000	3	1,000
	Out of Balance	10,861	3	**0,013**
	Crash	3,359	3	0,503
Innichen	**Contact**	12,017	3	**0,007**
	Avoided Contact	0,000	3	1,000
	Out of Balance	7,100	3	0,069
	Crash	3,301	3	0,348
Nakiska	**Contact**	1,022	3	0,796
	Avoided Contact	1,167	3	0,761
	Out of Balance	2,301	3	0,512
	Crash	1,749	3	0,626
Idre Fjäll	**Contact**	12,641	3	**0,005**
	Avoided Contact	0,884	3	0,829
	Out of Balance	5,304	3	0,151
	Crash	1,169	3	0,760
Beijing	**Contact**	18,879	3	**<0,001**
	Avoided Contact	13,412	3	**0,004**
	Out of Balance	3,683	3	0,298
	Crash	4,669	3	0,198
			3	
Reiteralm	**Contact**	3,575	3	0,311
	Avoided Contact	0,000	3	1,000
	Out of Balance	9,077	3	**0,028**
	Crash	1,480	3	0,687
			3	
Veysonnaz	**Contact**	7,148	3	0,067

	Avoided Contact	1,833	3	0,608
	Out of Balance	4,279	3	0,233
	Crash	0,712	3	0,870

1.2.1 Kruskal Wallis test results – Individual obstacle comparisons

Kruskal Wallis test results, comparing SMoIR between obstacles withing each venue. Presented with Chi-square (R^2), degree of freedom (df), and p values. Significant p values in bold font.

Male athletes:

	Event	X^2	df	p value
Secret Garden				
	Contact	72,477	54	**0,047**
	Avoided Contact	33,333	54	0,988
	Out of Balance	67,219	54	0,107
	Crash	76,318	54	**0,024**
Val Thorens				
	Contact	67,609	47	**0,026**
	Avoided Contact	43,297	47	0,627
	Out of Balance	76,513	47	**0,004**
	Crash	78,754	47	**0,003**
Arosa				
	Contact	36,581	24	**0,048**
	Avoided Contact	24,000	24	0,462
	Out of Balance	35,584	24	0,060
	Crash	15,546	24	0,904
Innichen				
	Contact	66,926	58	0,197
	Avoided Contact	95,712	58	**0,001**
	Out of Balance	82,471	58	**0,019**
	Crash	62,453	58	0,321
Nakiska				
	Contact	51,544	52	0,492
	Avoided Contact	32,822	52	0,983
	Out of Balance	71,182	52	**0,040**
	Crash	85,088	52	**0,003**
Idre Fjäll				
	Contact	87,529	64	**0,027**
	Avoided Contact	68,422	64	0,330
	Out of Balance	76,759	64	0,132
	Crash	0,000	64	1,000
Beijing				

	Contact	58,936	54	0,300
	Avoided Contact	40,677	54	0,910
	Out of Balance	60,505	54	0,253
	Crash	54,296	54	0,463
Reiteralm				
	Contact	54,988	43	0,104
	Avoided Contact	0,000	43	1,000
	Out of Balance	53,017	43	0,141
	Crash	34,068	43	0,833
Veysonnaz				
	Contact	33,918	32	0,375
	Avoided Contact	16,912	32	0,987
	Out of Balance	38,799	32	0,190
	Crash	33,019	32	0,417

Female athletes:

	Event	**X2**	**df**	**P value**
Secret Garden				
	Contact	41,838	32	0,114
	Avoided Contact	0,000	32	1,000
	Out of Balance	33,660	32	0,387
	Crash	0,000	32	1,000
Val Thorens				
	Contact	31,702	39	0,790
	Avoided Contact	0,000	39	1,000
	Out of Balance	41,118	39	0,378
	Crash	52,171	39	0,077
Arosa				
	Contact	24,579	23	0,372
	Avoided Contact	0,000	23	1,000
	Out of Balance	29,394	23	0,168
	Crash	38,644	23	**0,022**
Innichen				
	Contact	56,666	47	0,158
	Avoided Contact	0,000	47	1,000
	Out of Balance	58,967	47	0,113
	Crash	65,466	47	**0,039**
Nakiska				
	Contact	37,604	36	0,396
	Avoided Contact	15,250	36	0,999
	Out of Balance	41,706	36	0,237
	Crash	40,531	36	0,277
Idre Fjäll				
	Contact	60,981	46	0,069
	Avoided Contact	26,000	46	0,992
	Out of Balance	52,452	46	0,238

	Crash	66,979	46	**0,023**
Beijing				
	Contact	63,416	55	0,204
	Avoided Contact	38,488	55	0,956
	Out of Balance	73,954	55	**0,045**
	Crash	57,525	55	0,382
Reiteralm				
	Contact	32,859	36	0,619
	Avoided Contact	0,000	36	1,000
	Out of Balance	44,316	36	0,161
	Crash	37,981	36	0,379
Veysonnaz				
	Contact	36,186	28	0,138
	Avoided Contact	24,500	28	0,655
	Out of Balance	41,810	28	**0,045**
	Crash	36,480	28	0,131

1.2.2 Post-Hoc test results – Individual obstacle comparisons

Pairwise comparisons of individual obstacles. Only significant comparisons are included. Presented with Chi-square (R^2) and p values.

Male athletes:

Avoiding Contact – Innichen

Obstacle Comparison	X^2	p value
7 – 47	-53,000	0,000
9 – 47	-53,000	0,000
12 – 47	-53,000	0,000
5 – 47	-53,000	0,000
8 – 47	-53,000	0,000
10 – 47	-53,000	0,000
11 – 47	-53,000	0,000
22 – 47	-53,000	0,000
46 – 47	-53,000	0,000
51 – 47	53,000	0,000
53 – 47	53,000	0,000
1 – 47	-53,000	0,000
6 – 47	-53,000	0,000
13 – 47	-53,000	0,000
25 – 47	-53,000	0,000
26 – 47	-53,000	0,000
29 – 47	-53,000	0,000

48 – 47	53,000	0,000
49 – 47	53,000	0,000
50 – 47	53,000	0,000
52 – 47	53,000	0,000
58 – 47	53,000	0,000
7 – 38	-69,000	0,003
9 – 38	-69,000	0,003
12 – 38	-69,000	0,003
5 – 38	-69,000	0,004
8 – 38	-69,000	0,004
10 – 38	-69,000	0,004
11 – 38	-69,000	0,004
22 – 38	-69,000	0,004
46 – 38	69,000	0,004
51 – 38	69,000	0,004
53 – 38	69,000	0,004
2 – 47	-53,000	0,005
3 – 47	-53,000	0,005
15 – 47	-53,000	0,005
16 – 47	-53,000	0,005
17 – 47	-53,000	0,005
18 – 47	-53,000	0,005
19 – 47	-53,000	0,005
27 – 47	-53,000	0,005
28 – 47	-53,000	0,005
30 – 47	-53,000	0,005
31 – 47	-53,000	0,005
34 – 47	-53,000	0,005
36 – 47	-53,000	0,005
45 – 47	-53,000	0,005
55 – 47	53,000	0,005
56 – 47	53,000	0,005
60 – 47	53,000	0,005
62 – 47	53,000	0,005
1 – 38	-69,000	0,009
6 – 38	-69,000	0,009
13 – 38	-69,000	0,009
25 – 38	-69,000	0,009
26 – 38	-69,000	0,009
29 – 38	-69,000	0,009
48 – 38	69,000	0,009
49 – 38	69,000	0,009
50 – 38	69,000	0,009
52 – 38	69,000	0,009
58 – 38	69,000	0,009
2 – 38	-69,000	0,029

3 – 38	-69,000	0,029
15 – 38	-69,000	0,029
16 – 38	-69,000	0,029
17 – 38	-69,000	0,029
18 – 38	-69,000	0,029
19 – 38	-69,000	0,029
27 – 38	-69,000	0,029
28 – 38	-69,000	0,029
30 – 38	-69,000	0,029
31 – 38	-69,000	0,029
34 – 38	-69,000	0,029
36 – 38	-69,000	0,029
45 – 38	69,000	0,029
55 – 38	69,000	0,029
56 – 38	69,000	0,029
60 – 38	69,000	0,029
62 – 38	69,000	0,029

Crash – Val Thorens

Obstacle Comparison	X^2	p value
7 – 42	-51,500	0,002
17 – 42	-51,500	0,002
32 – 42	-51,500	0,002
4 – 42	-51,500	0,002
9 – 42	-51,500	0,007
11 – 42	-51,500	0,007
12 – 42	-51,500	0,007
14 – 42	-51,500	0,007
18 – 42	-51,500	0,007
23 – 42	-51,500	0,007
24 – 42	-51,500	0,007
34 – 42	-51,500	0,007
5 – 42	-51,500	0,031
8 – 42	-51,500	0,031
13 – 42	-51,500	0,031
16 – 42	-51,500	0,031
19 – 42	-51,500	0,031
26 – 42	-51,500	0,031
27 – 42	-51,500	0,031
29 – 42	-51,500	0,031
37 – 42	-51,500	0,031
39 – 42	-51,500	0,031
36 – 42	-51,500	0,031

41 – 42	-51,500	0,031

Crash – Nakiska

Obstacle Comparison	X^2	p value
7 – 13	-57,333	0,005
9 – 13	-57,333	0,005
8 – 13	-57,333	0,014
11 – 13	-57,333	0,014
16 – 13	57,333	0,014
30 – 13	57,333	0,014
62 – 13	57,333	0,014

Female athletes:

***Crash* – Arosa**

Obstacle Comparison	X^2	p value
9 – 21	- 30,000	0,000
5 – 21	- 30,000	0,000
8 – 21	- 30,000	0,000
13 – 21	- 30,000	0,000
27 – 21	30,000	0,000
11 – 21	- 30,000	0,001
12 – 21	- 30,000	0,001
16 – 21	- 30,000	0,001
4 – 21	- 30,000	0,001
24 – 21	30,000	0,001
3 – 21	- 30,000	0,002
7 – 21	- 30,000	0,002
10 – 21	- 30,000	0,002
14 – 21	- 30,000	0,002
17 – 21	- 30,000	0,002
19 – 21	- 30,000	0,002
6 – 21	- 30,000	0,002
25 – 21	30,000	0,002
29 – 21	30,000	0,002
18 – 21	- 30,000	0,030
20 – 21	- 30,000	0,030
23 – 21	30,000	0,030

Crash – Idre Fjäll

Obstacle Comparison	X^2	p value
5 – 63	-41,000	0,000
62 – 63	-41,000	0,000
8 – 63	-41,000	0,000
9 – 63	-41,000	0,000
11 – 63	-41,000	0,000
13 – 63	-41,000	0,000
16 – 63	-41,000	0,000
30 – 63	-41,000	0,000
61 – 63	-41,000	0,000
67 – 63	41,000	0,000
7 – 63	-41,000	0,000
10 – 63	-41,000	0,000
15 – 63	-41,000	0,000
19 – 63	-41,000	0,000
6 – 63	-41,000	0,000
53 – 63	-41,000	0,000
40 – 63	-41,000	0,000
66 – 63	41,000	0,000

Crash – Innichen

Obstacle Comparison	X^2	p value
5 – 44	-40,000	0,004
5 – 46	-40,000	0,004
7 – 44	-40,000	0,004
7 – 46	-40,000	0,004
9 – 44	-40,000	0,004
9 – 46	-40,000	0,004
22 – 44	-40,000	0,004
22 – 46	-40,000	0,004
10 – 44	-40,000	0,008
10 – 46	-40,000	0,008
11 – 44	-40,000	0,008
11 – 46	-40,000	0,008
13 – 44	-40,000	0,008
13 – 46	-40,000	0,008
36 – 44	-40,000	0,008
36 – 46	-40,000	0,008
58 – 44	40,000	0,008
58 – 46	40,000	0,008

3 – 44	-40,000	0,025
3 – 46	-40,000	0,025
12 – 44	-40,000	0,025
12 – 46	-40,000	0,025
17 – 44	-40,000	0,025
17 – 46	-40,000	0,025
23 – 44	-40,000	0,025
23 – 46	-40,000	0,025
26 – 44	-40,000	0,025
26 – 46	-40,000	0,025
6 – 44	-40,000	0,025
6 – 46	-40,000	0,025
47 – 46	40,000	0,025
51 – 46	40,000	0,025
40 – 46	-40,000	0,025
40 – 44	-40,000	0,025
47 – 44	40,000	0,025
51 – 44	40,000	0,025
55 – 44	40,000	0,025
55 – 46	40,000	0,025

1.2.3 Post-Hoc test results – Rank Shift between obstacle categories

Male Athletes

Obstacle category comparison	X^2	p value
Roller – Direction Change	18,447	1,000
Roller – Jump	21,822	1,000
Roller – Start Straight	-139,801	<0,001
Direction Change – Jump	-3,375	1,000
Direction Change – Start Straight	-121,354	0,001
Jump – Start Straight	-117,978	0,002

Female Athletes

Obstacle category comparison	X^2	p value
Roller – Direction Change	24,995	1,000
Roller – Jump	36,013	0,327
Roller – Start Straight	-142,555	<0,001
Direction Change – Jump	-11,018	1,000
Direction Change – Start Straight	-117,56	<0,001
Jump – Start Straight	-106,542	<0,001

1.2.4 Post-Hoc test results – Rank Shift between obstacle categories within each venue

Male Athletes

	Direction Change vs Jump	Direction change vs Roller	Jump vs Roller	Start Straight vs Direction Change	Start Straight vs Jump	Start Straight vs Roller
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Val Thorens						
Rank Shift	0,544	1,000	1,000	0,037	0,865	0,052
Arosa						
Rank Shift	1,000	1,000	0,725	0,320	0,037	0,821
Beijing						
Rank Shift	0,124	0,105	1,00	0,022	1,000	1,000

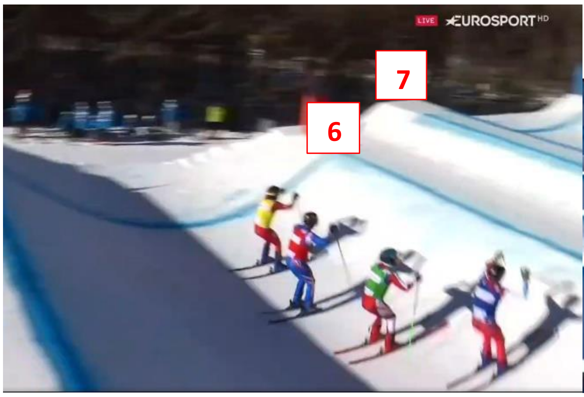
Female Athletes

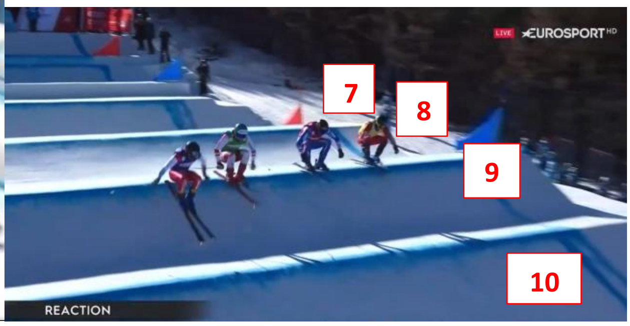
	Direction Change vs Jump	Direction change vs Roller	Jump vs Roller	Start Straight vs Direction Change	Start Straight vs Jump	Start Straight vs Roller
	*p value**	*p value**	*p value**	*p value**	*p value**	*p value**
Val Thorens						
Rank Shift	1,000	1,000	0,644	0,110	0,428	0,013
Arosa						
Rank Shift	0,445	1,000	1,000	1,000	0,002	0,012
Innichen						
Rank Shift	1,000	1,000	1,000	0,062	0,169	0,009

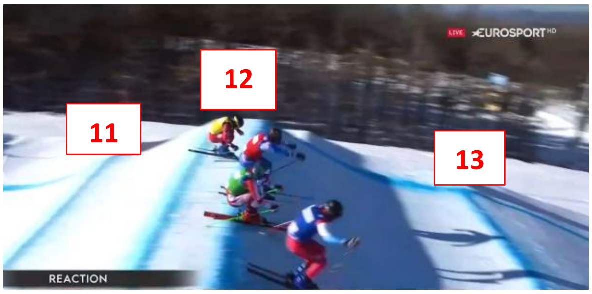
Appendix 2

Course descriptions for all venues.

Track Information WC Secret Garden

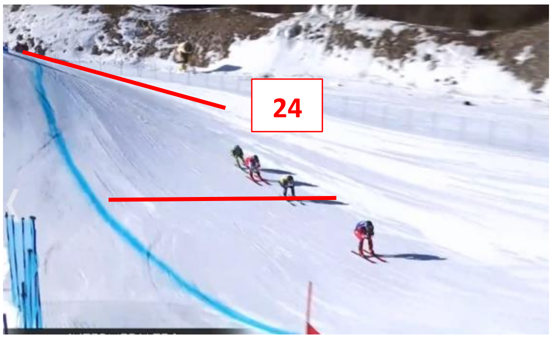




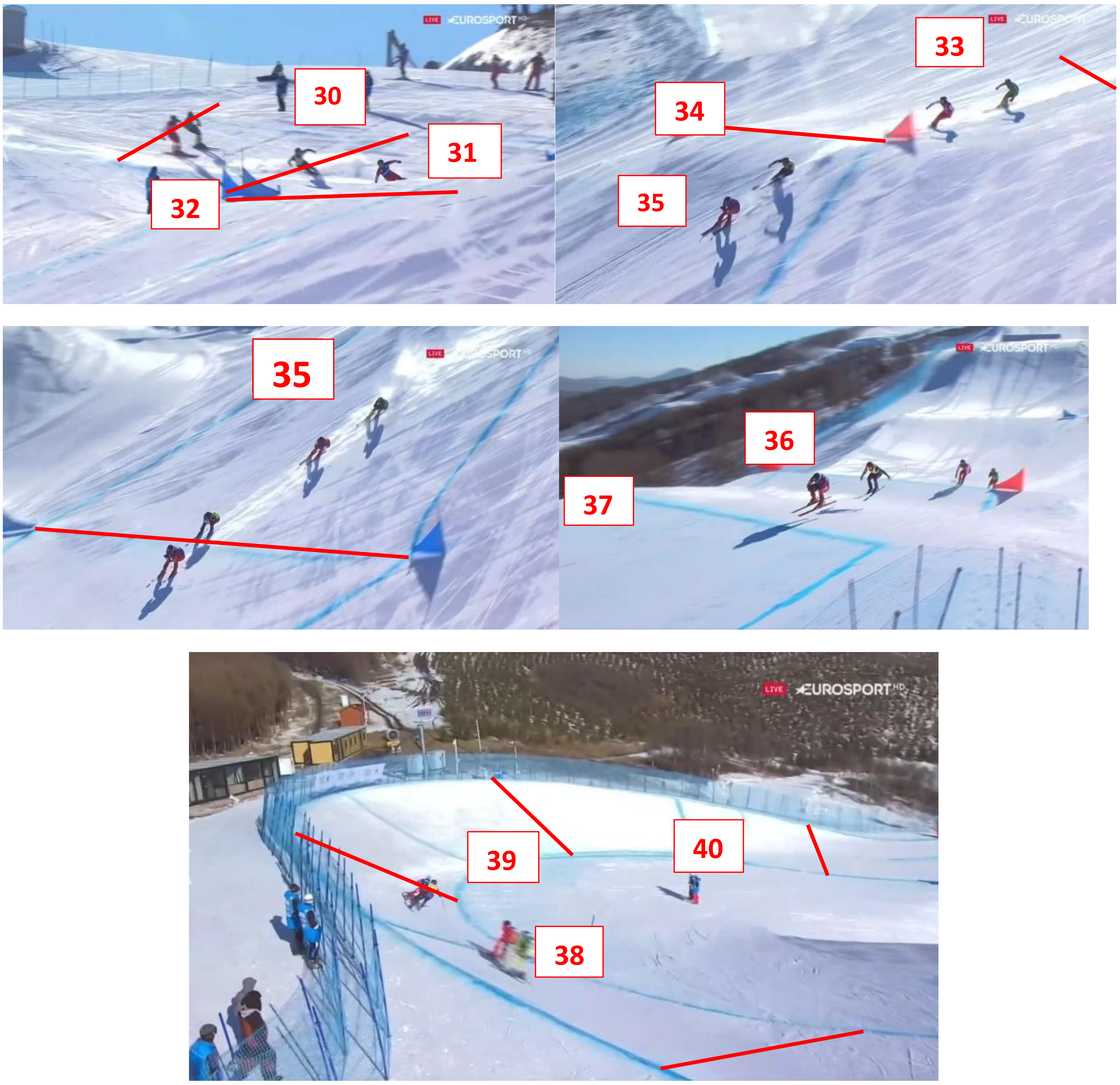


Obstacle Name	Obstacle Nr.	
Startdrop	1	Sektion 1
Step Down Take Off	2	
Step Down Landing	3	
Kicker Take Off	4	
Kicker Landing	5	
Wutang Up	6	
Wutang Peak	7	
Bathtube	8	
Wutang Peak	9	
Wutang Landing	10	
Wutang Take Off	11	
Wutang Peak	12	
Wutang Landing	13	

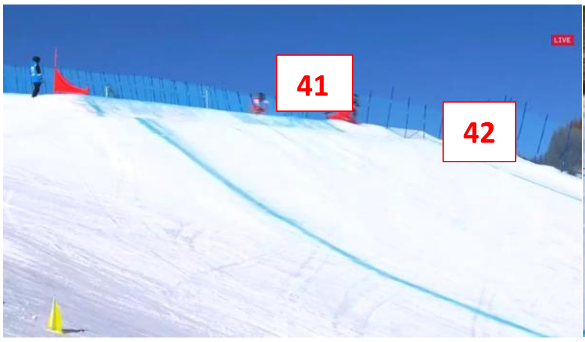
Obstacle Name	Obstacle Nr.	
Roller	14	Section 1
Roller	15	
Roller	16	
Roller	17	
Jump Take Off	18	
Jump Landing	19	
Roller	20	
Double Roller 1	21	
Double Roller 2	22	

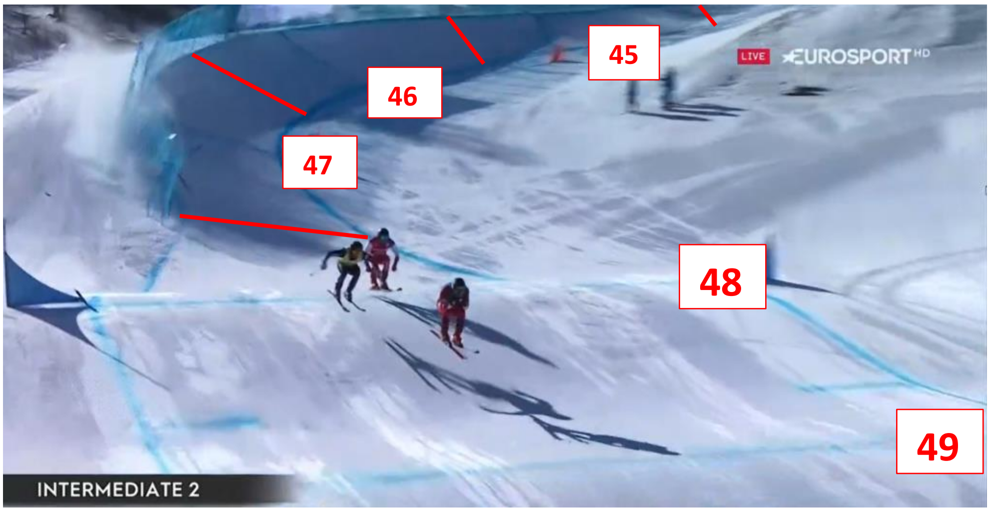


Obstacle Name	Obstacle Nr.	
Negative Entry	23	Section 2
Negative Exit	24	
Roller Double 1	25	
Roller Double 2	26	
Negative Entry	27	
Negative Exit	28	
Jump Take Off	29	
Jump Landing	30	

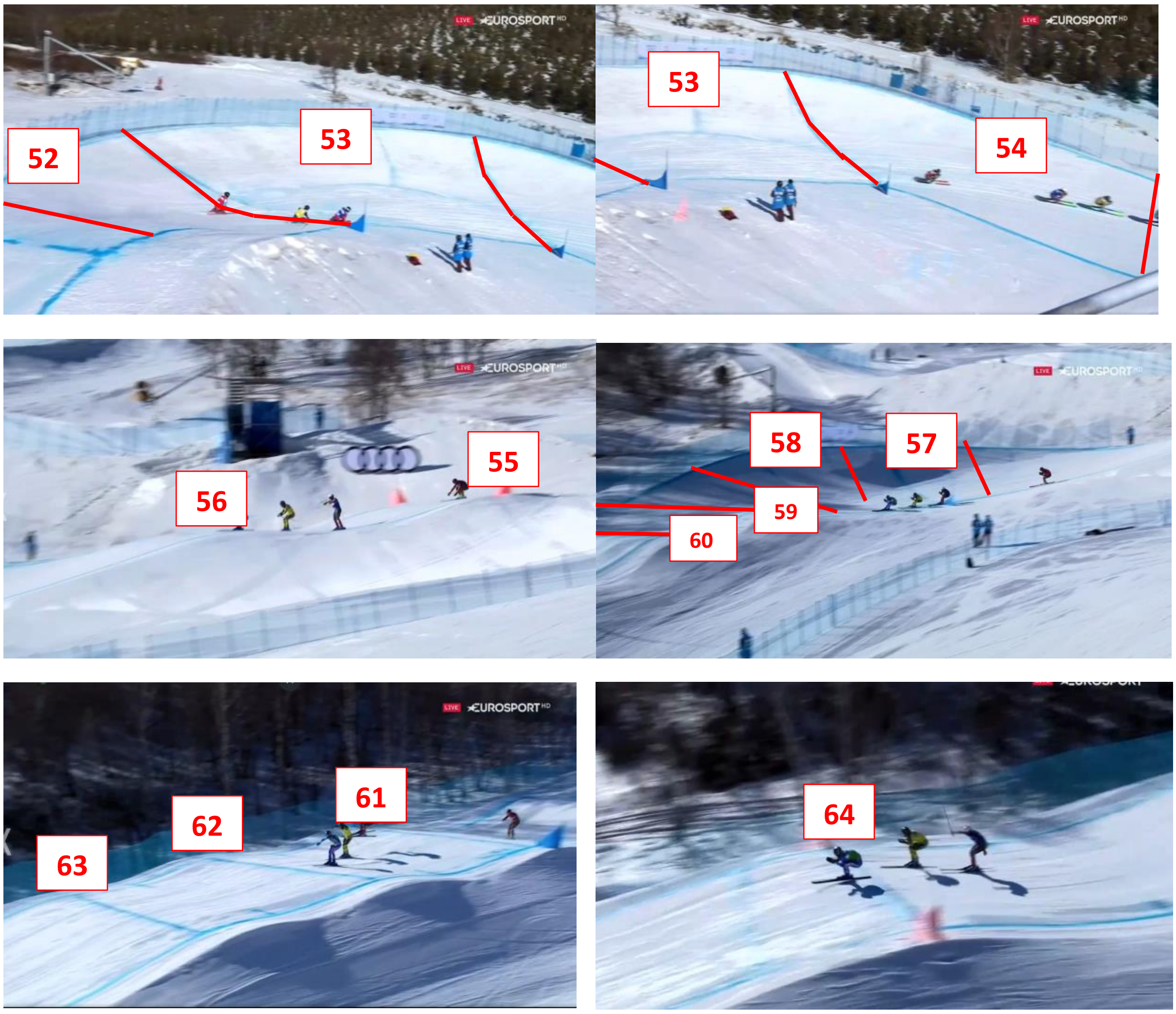


Obstacle Name	Obstacle Nr.	
Turn Entry	30	Section 3
Turn Exit	31	
Roller	32	
Turn Entry	33	
Turn Mid Roller	34	
Turn Exit	35	
Kicker Take Off	36	
Kicker Landing	37	
Bank Turn Entry	38	
Bank Turn Mid	39	
Bank Turn Exit	40	





Obstacle Name	Obstacle Nr.	Section 4
Double Roller 1	41	
Double Roller 2	42	
Roller Double 1	43	
Roller Double 2	44	
Turn Entry	45	
Turn Mid	46	
Turn Exit	47	
Roller Double 1	48	
Roller Double 2	49	
Roller Double 1	50	
Roller Double 2	51	

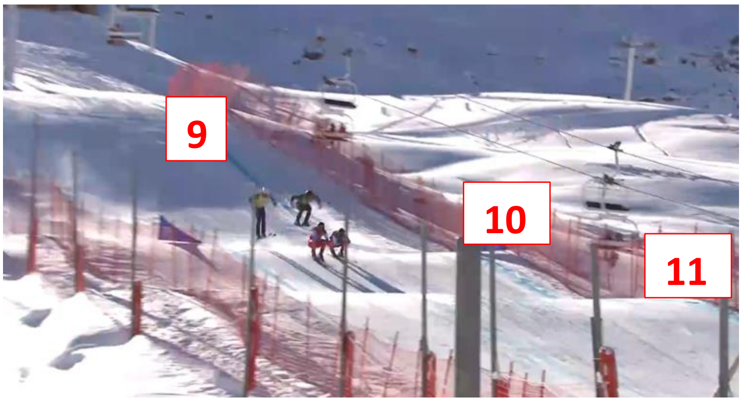


Obstacle Name	Obstacle Nr.	
Turn Entry	52	Section 4
Turn Mid	53	
Turn Exit	54	
Roller	55	
Roller	56	
Turn Entry	57	
Turn Mid	58	
Turn Exit Roller Double 1	59	
Turn Exit Roller Double 2	60	
Roller	61	Section 5
Roller	62	
Roller	63	
Roller	64	

Obstacle Name	Obstacle Nr.	Section 5
Kicker Take Off	65	
Kicker Landing	66	
Finish Line	67	

Track Information WC Val Thorens

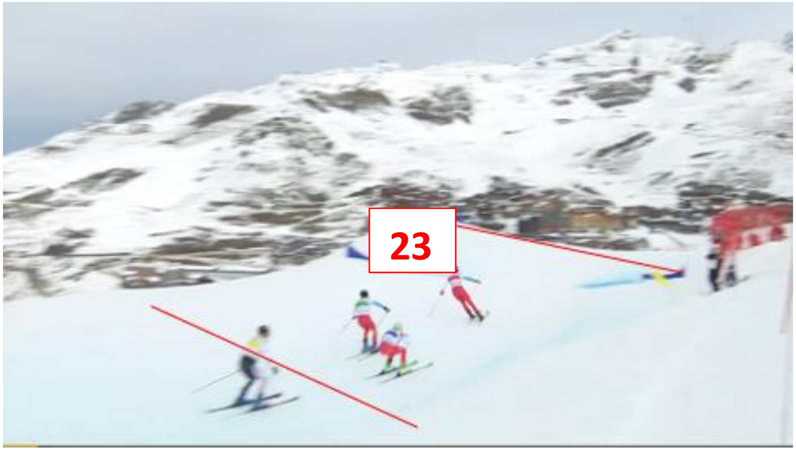
Obstacle Name	Obstacle Nr.	
Starttable	1	Sektion 1
Startdrop	2	
Step Down Take Off	3	
Step Down Landing	4	
Jump Take Off	5	
Jump Landing Table	6	
Jump Landing	7	
Jump Take Off	8	
Jump Landing	9	



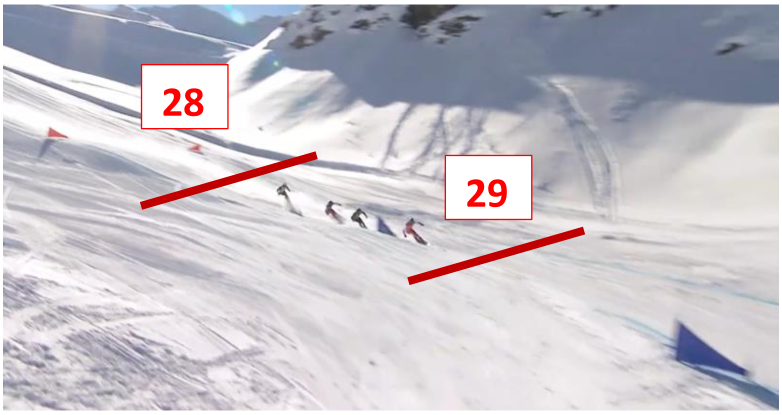
Obstacle Name	Obstacle Nr.	
Roller	10	Sektion 2
Roller	11	
Roller	12	
Step Up Take Off	13	
Step Up Landing	14	

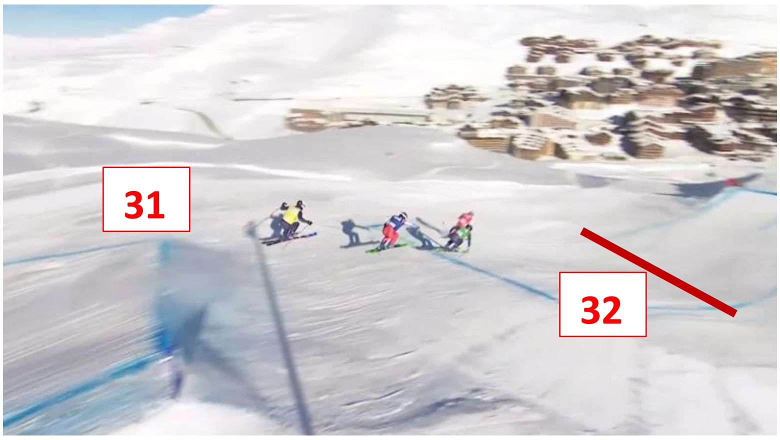
Obstacle Name	Obstacle Nr.	Sektion 2
Roller	15	
Roller	16	
Roller	17	
GS gate	18	

Obstacle Name	Obstacle Nr.	Sektion 3
Jump Take Off	19	
Jump Landing	20	
Double Roller 1	21	
Double Roller 2	22	



Obstacle Name	Obstacle Nr.	
Negative Entry	23	Sektion 3
Negative Mid	24	
Negative Exit	25	

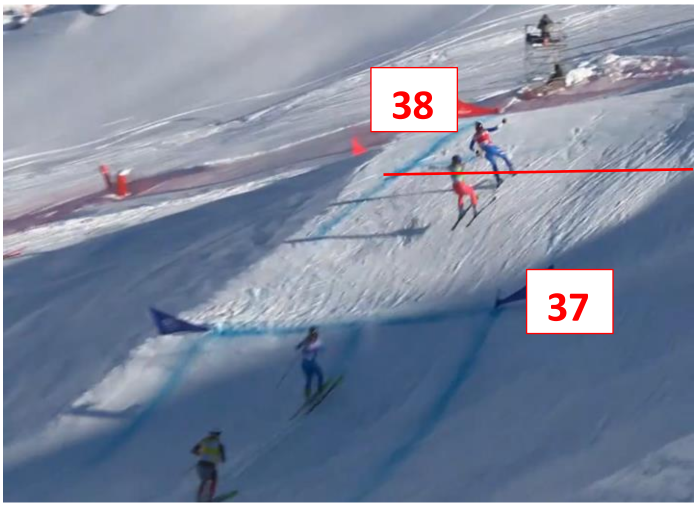




Obstacle Name	Obstacle Nr.	Sektion 4
Kicker Take Off	26	
Kicker Landing	27	
Roller	28	
Turn Entry	29	
Turn Mid	30	
Turn Exit Step Down Take Off	31	
Turn Exit Step Down Landing	32	


34
35
INTERMEDIATE 2


36
TERMEDIATE 2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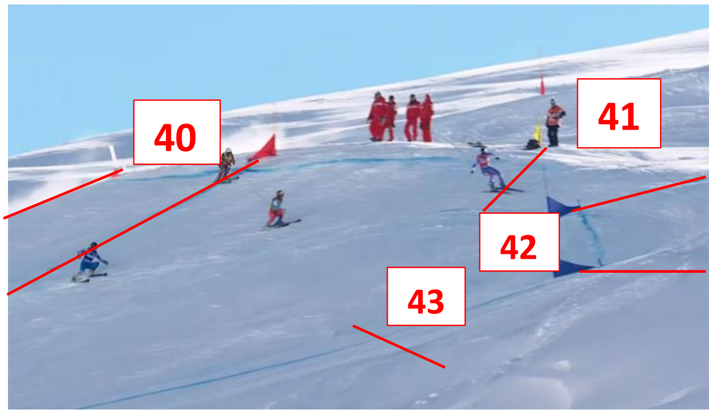
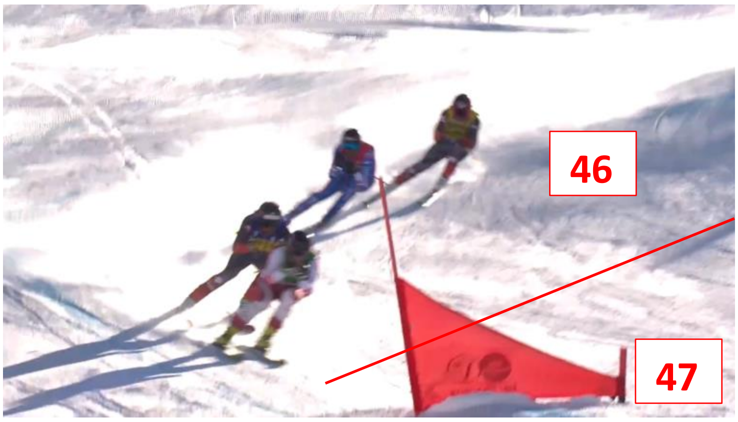
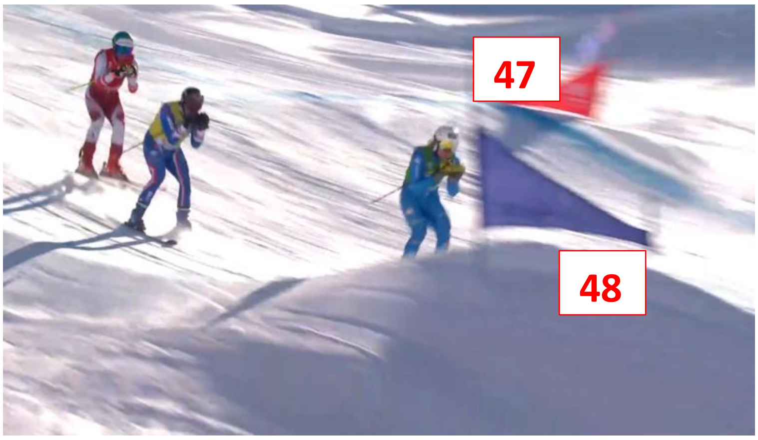
37

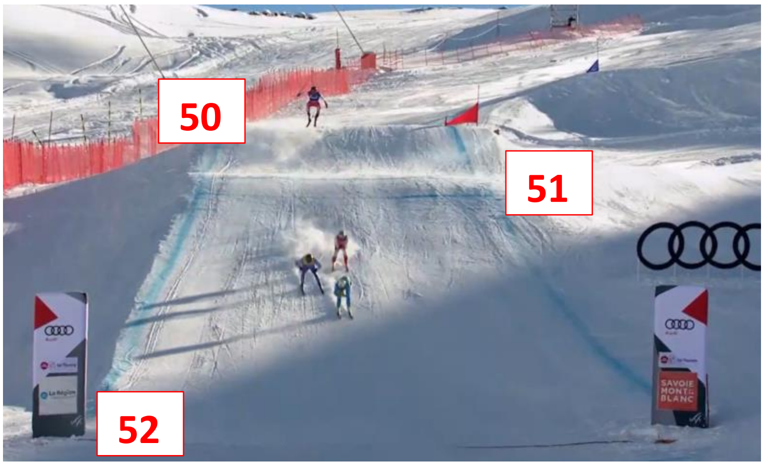

39



Obstacle Name	Obstacle Nr.	
Jump Take Off	33	Sektion 5
Jump Landing	34	
Jump Take Off	35	
Jump Landing	36	
Roller	37	
Negative Entry	38	
Negative Mid	39	
Negative Exit	40	
Turn Entry	41	
Turn Mid	42	
Turn Exit	43	

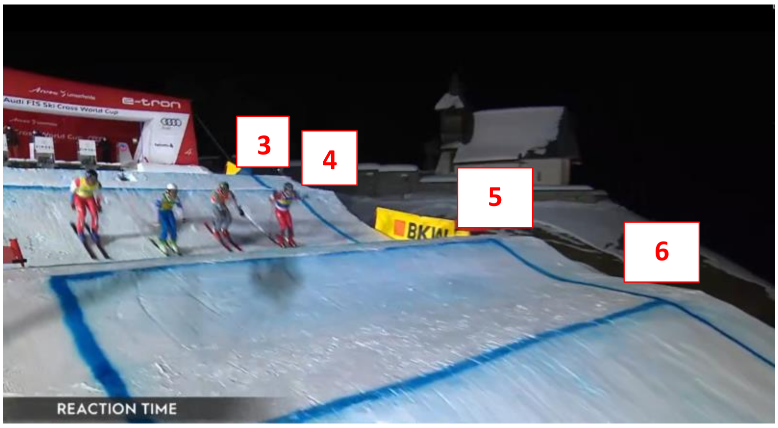




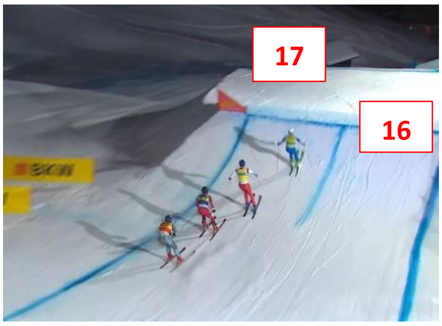


Obstacle Name	Obstacle Nr.	
Roller	44	Sektion 5
Negative Entry	45	
Negative Exit	46	
Roller	47	
Double Roller 1	48	
Double Roller 2	49	
Step Down Take Off	50	
Step Down Landing	51	
Finish Line	52	

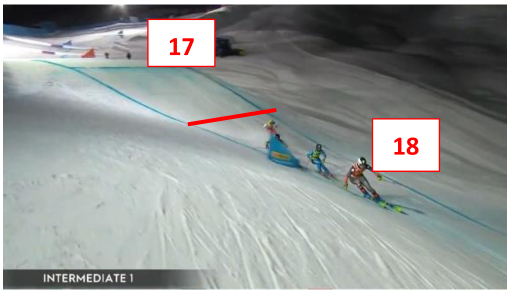
Track Information WC Arosa

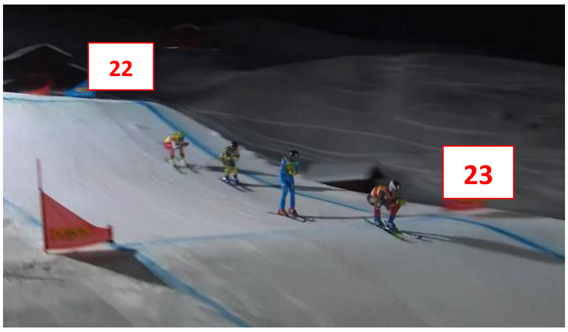


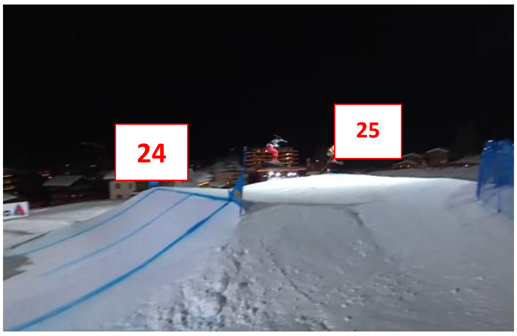
Obstacle Name	Obstacle Nr.	
Startdrop	1	Sektion 1
Wutang Up	2	
Wutang Peak	3	
Wutang Down	4	
Kicker Take Off	5	
Kicker Landing	6	
Step Up	7	
Wutang Peak	8	
Wutang Landing	9	



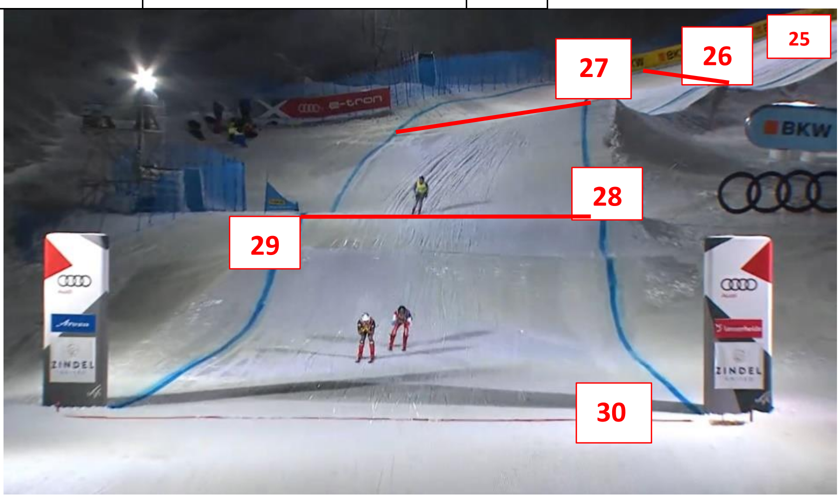
Obstacle Name	Obstacle Nr.	
Step Down	10	Sektion 2
Landing	11	
Roller Turn Entry	12	
Roller Turn Mid	13	
Stepdown Turn Exit	14	
Stepdown	15	
Kicker Take Off	16	
Kicker Landing	17	





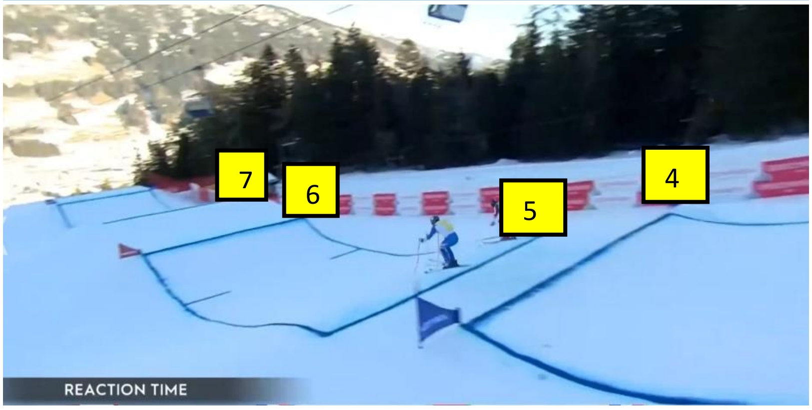


Obstacle Name	Obstacle Nr.	
Negative Entry	18	Sektion 3
Negative Exit	19	
Roller	20	
Roller	21	
Roller	22	
Roller	23	
Jump Take Off	24	
Jump Landing	25	

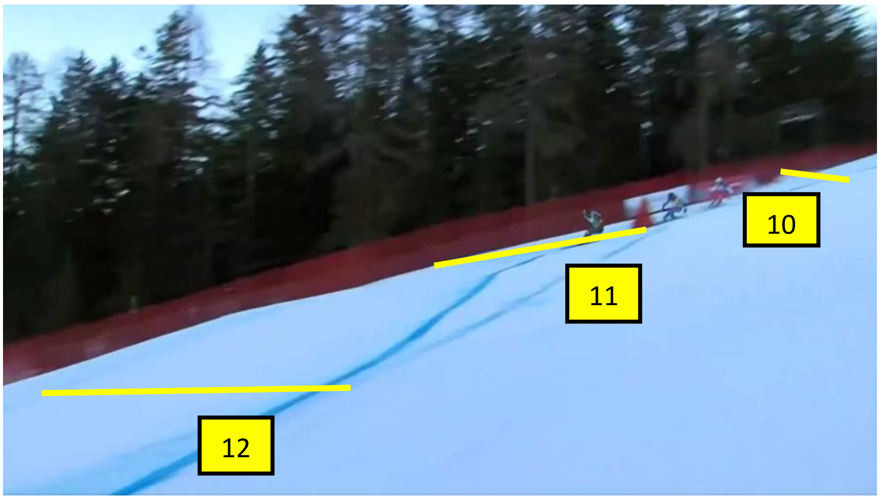


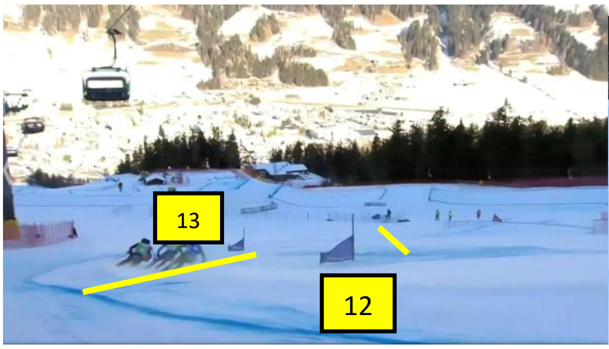
Obstacle Name	Obstacle Nr.	
Roller Turn Entry	26	Sektion 4
Roller Turn Mid	27	
Roller Turn Exit	28	
Roller	29	
Finish Line	30	

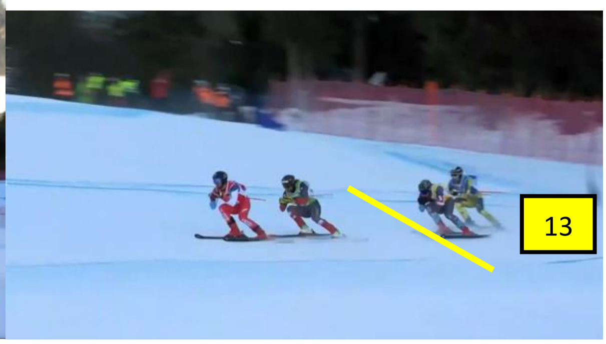
Track Information Innichen

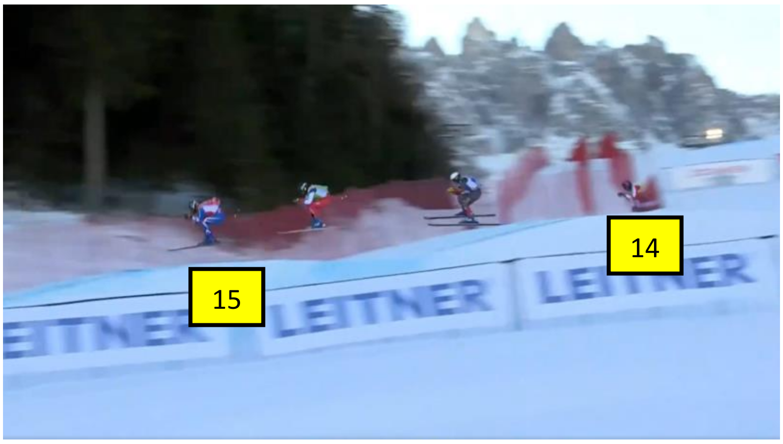


Obstacle Name	Obstacle Nr.	
Start Drop	1	Section 1
Kicker Take Off	2	
Kicker Landing	3	
Step Down Take Off	4	
Step Down landing	5	
Step Up Take Off	6	
Step Up Landing	7	
Jump Take Off	8	
Jump Landing	9	

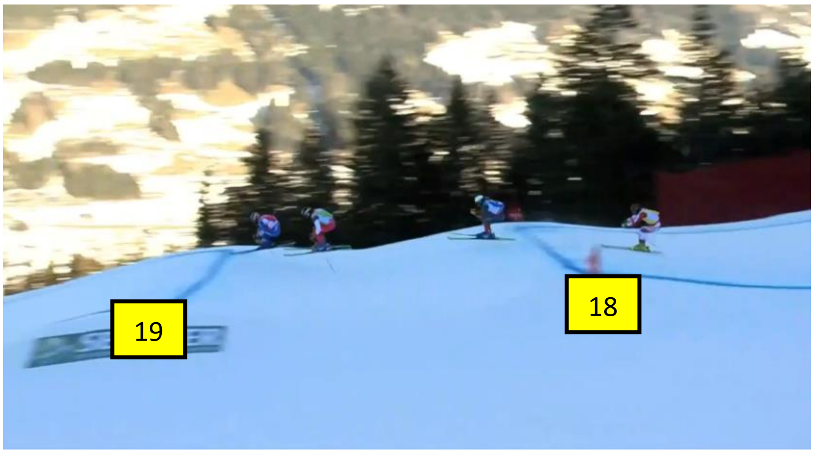


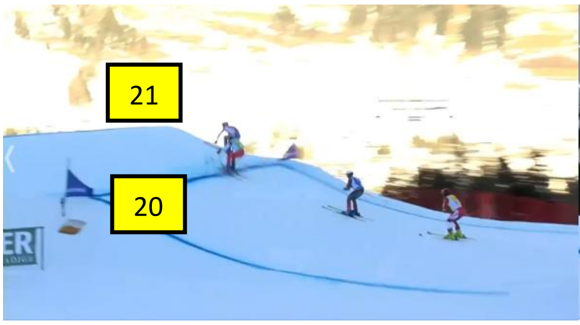




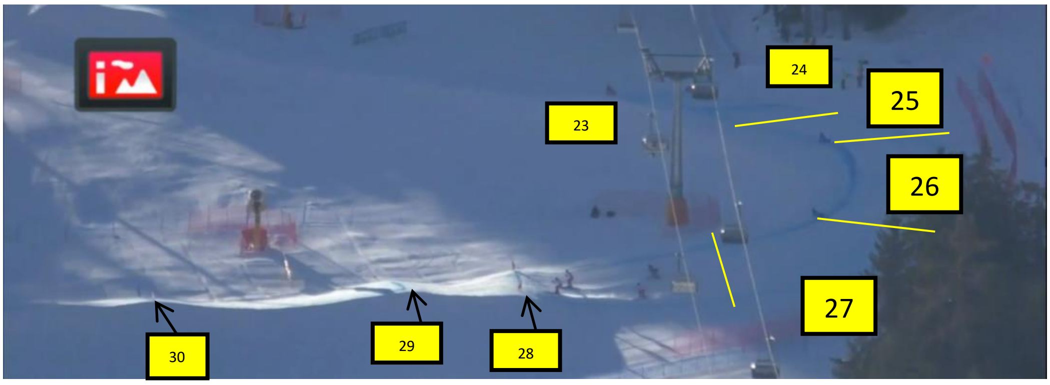


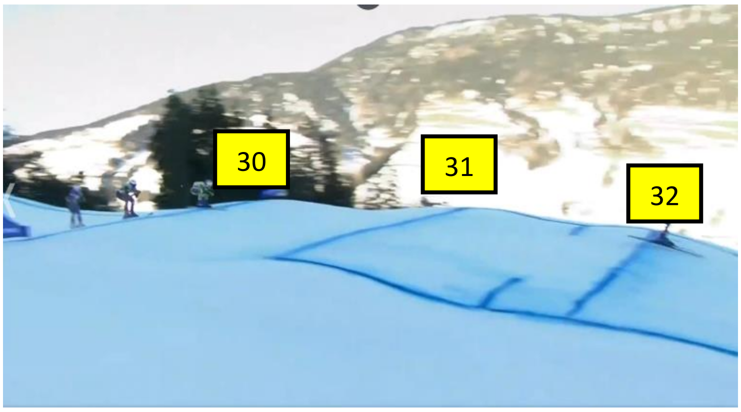
Obstacle Name	Obstacle Nr.	
GS Turn Entry	10	Section 2
GS Turn Exit	11	
GS Turn Entry	12	
GS Turn Exit	13	
Roller Double 1	14	
Roller Double 2	15	



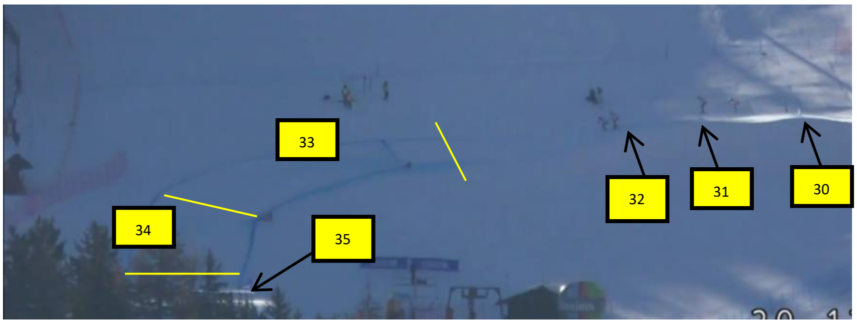


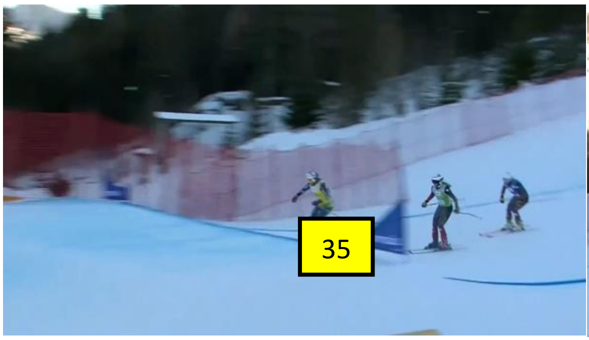
Obstacle Name	Obstacle Nr.	
Bank Turn Entry	16	Section 2
Bank Turn Exit	17	
Roller Double 1	18	
Roller Double 2	19	
Dragon Up	20	
Dragon Peak	21	
Dragon Down	22	

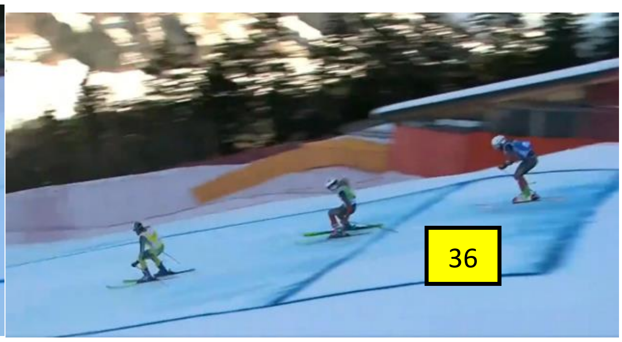


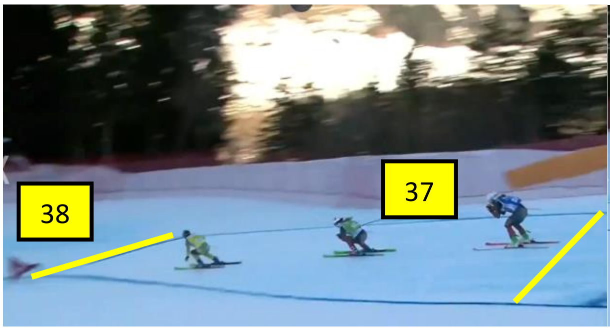


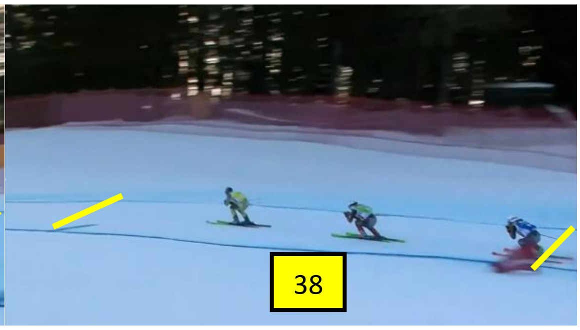
Obstacle Name	Obstacle Nr.	
Roller	23	Section 2
Roller	24	
GS Turn Entry	25	
GS Turn Mid	26	
GS Turn Exit	27	
Roller Double 1	28	
Roller Double 2	29	
Roller	30	
Roller Double 1	31	
Roller Double 2	32	



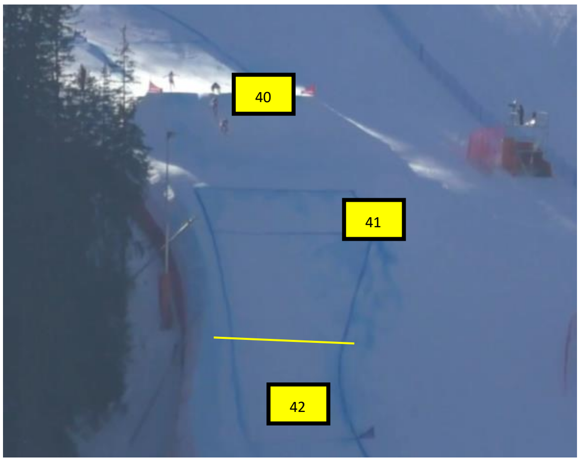


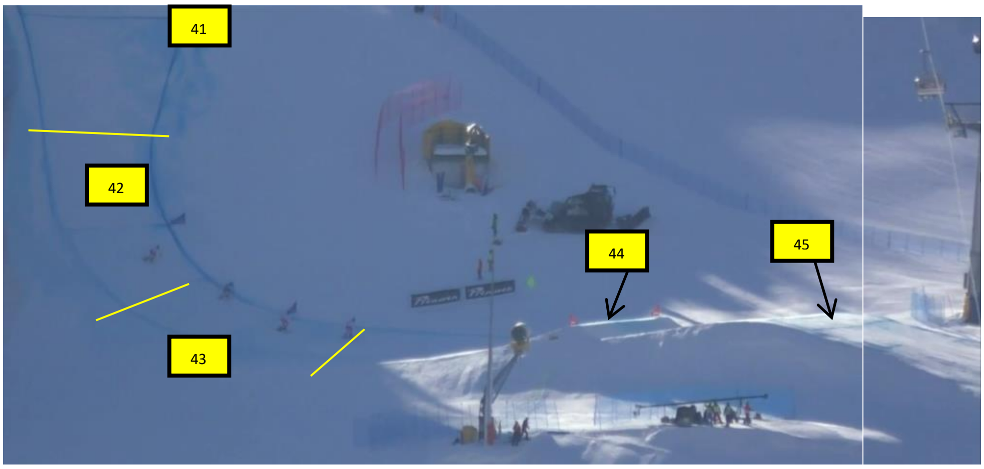




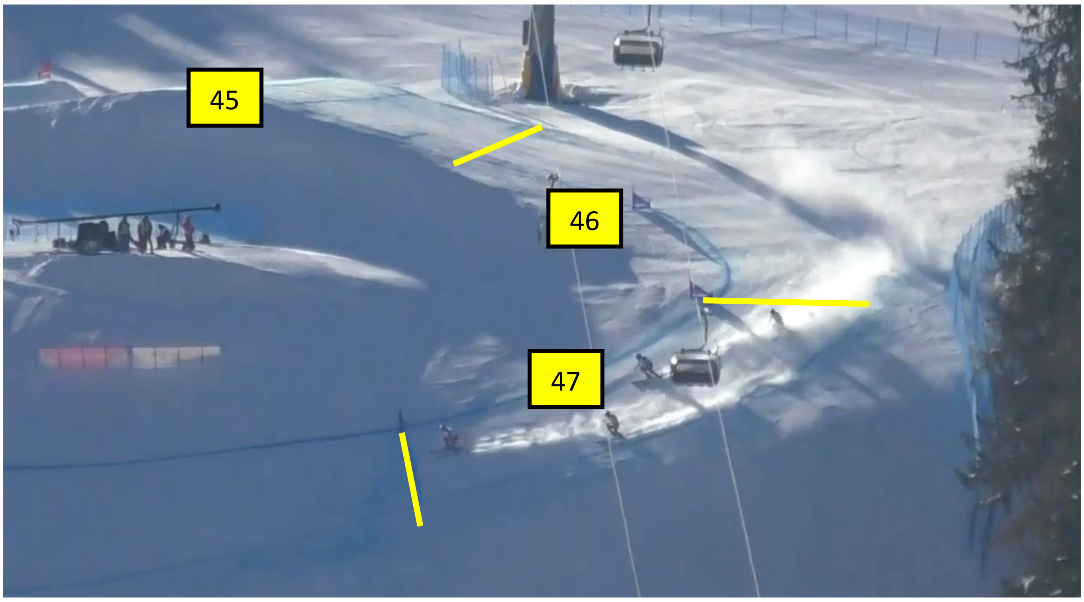


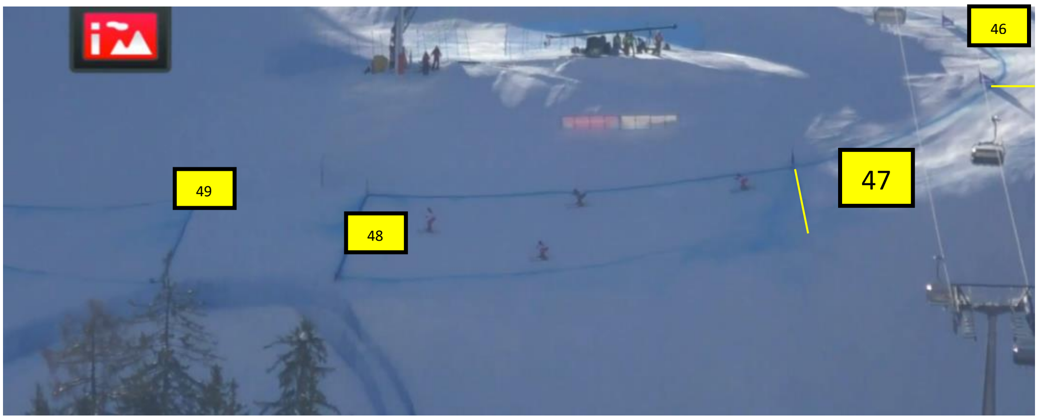
Obstacle Name	Obstacle Nr.	
GS Turn Entry	33	Section 3
GS Turn Exit	34	
Kicker Take Off	35	Section 4
Kicker Landing	36	
GS Turn Entry	37	
GS Turn Exit	38	
GS Gate	39	
Jump Take Off	40	

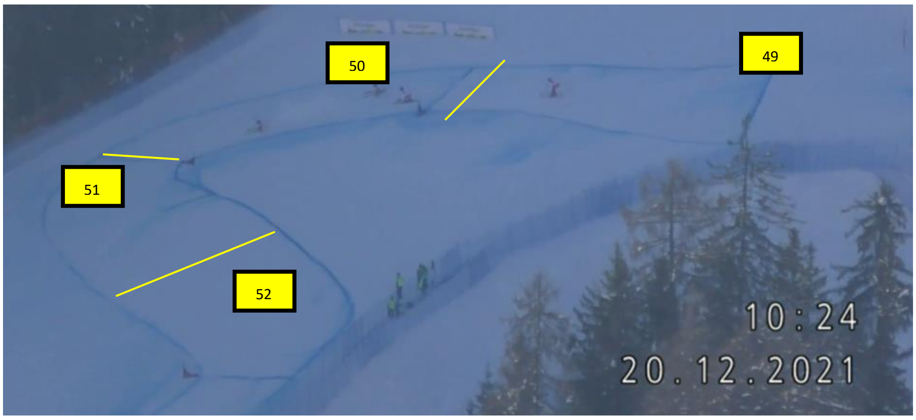




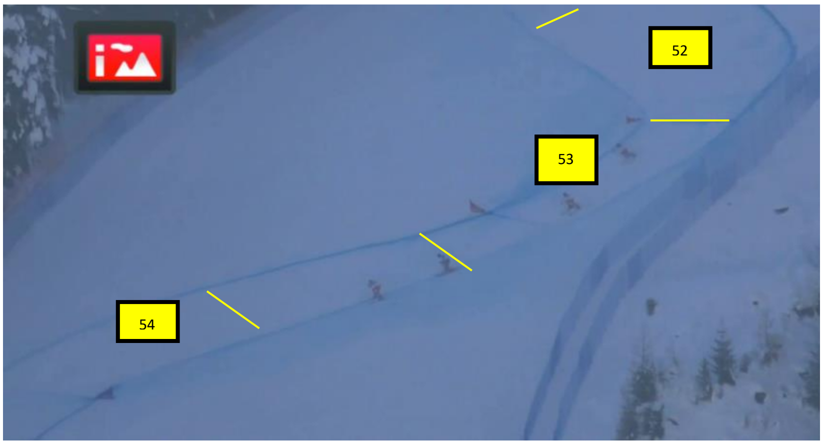
Obstacle Name	Obstacle Nr.	
Jump Landing	41	Section 4
Compression Turn Entry	42	
Compression Turn Exit	43	
Jump Take Off	44	
Jump Landing	45	

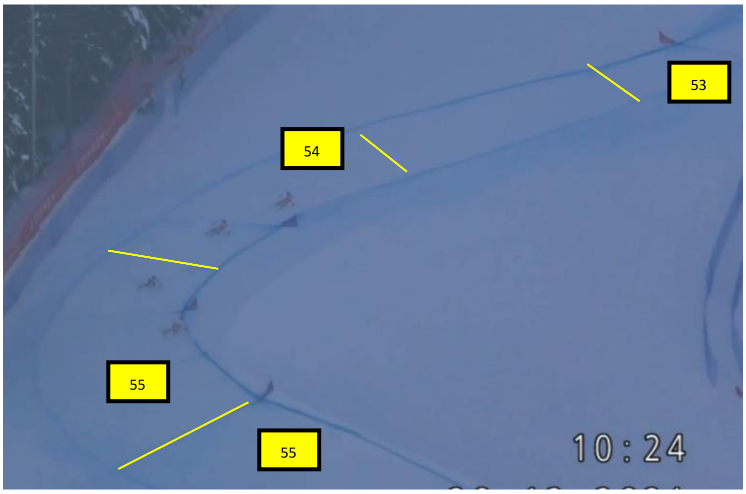


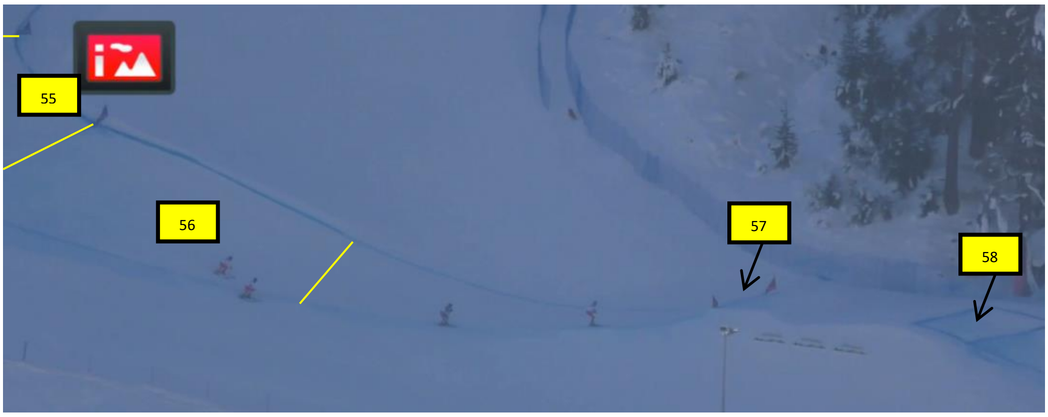




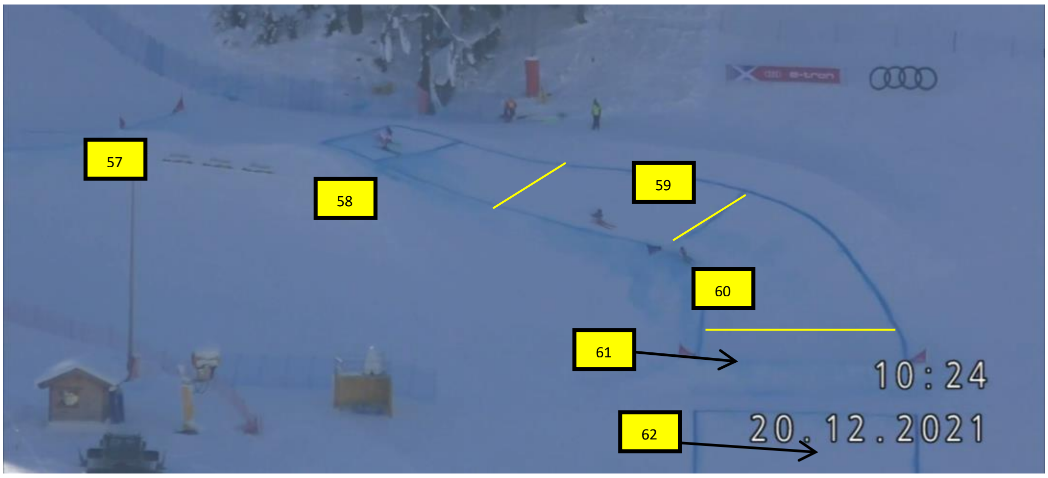
Obstacle Name	Obstacle Nr.	
GS Turn Entry	46	Section 4
GS Turn Exit	47	
Roller	48	
Roller	49	
GS Turn Entry	50	Section 5
GS Turn Exit	51	
GS Turn Entry	52	

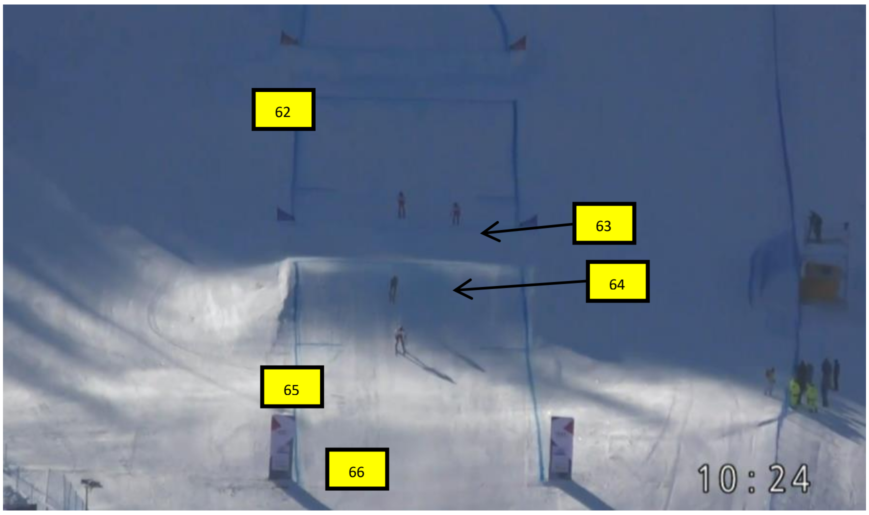


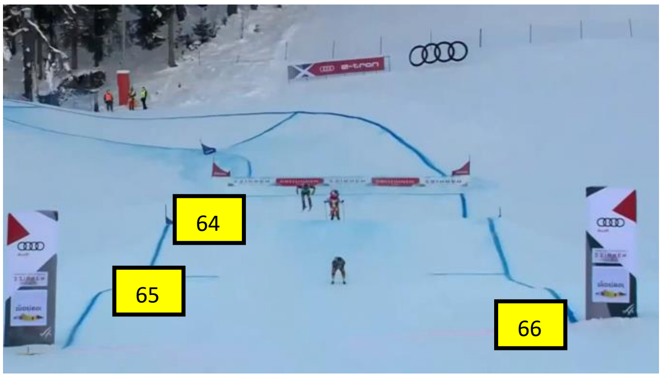




Obstacle Name	Obstacle Nr.	
GS Turn Entry	53	Section 5
GS Turn Exit	54	
GS Turn Entry	55	
GS Turn Exit	56	
Jump Take Off	57	
Jump Landing	58	



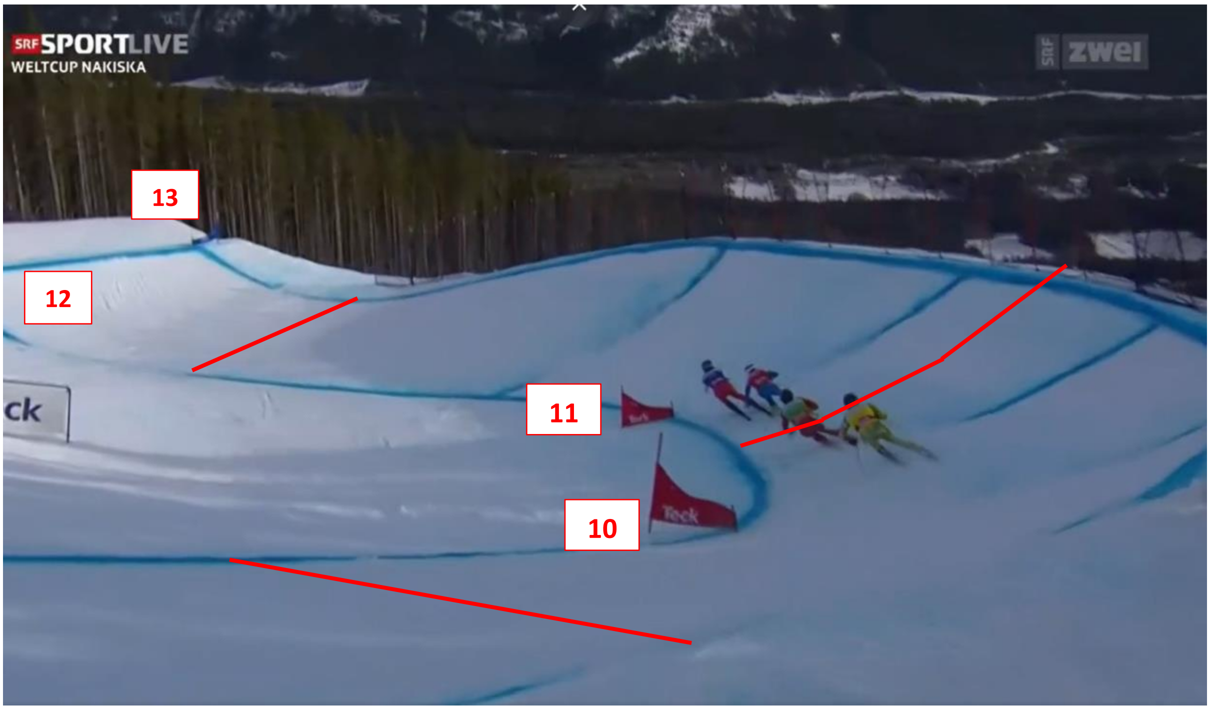


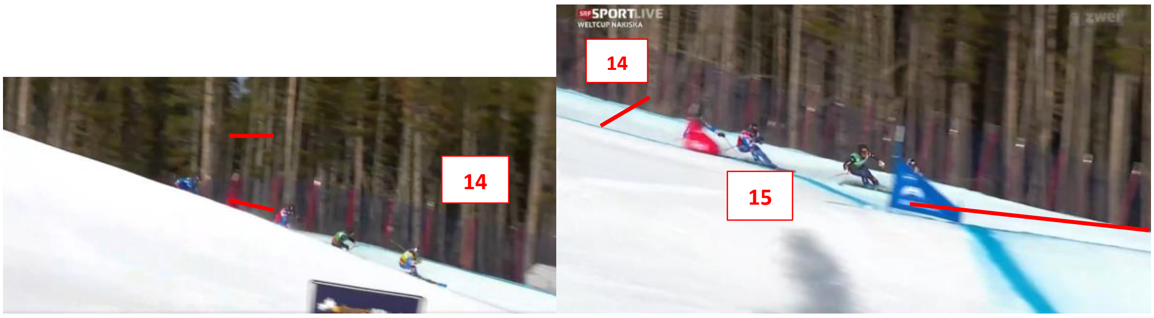


Obstacle Name	Obstacle Nr.	
GS Turn Entry	59	Section 6
GS Turn Exit	60	
Jump Take Off	61	
Jump Landing	62	
Jump Take Off	63	
Jump Landing	64	
Roller	65	
Finish Line	66	

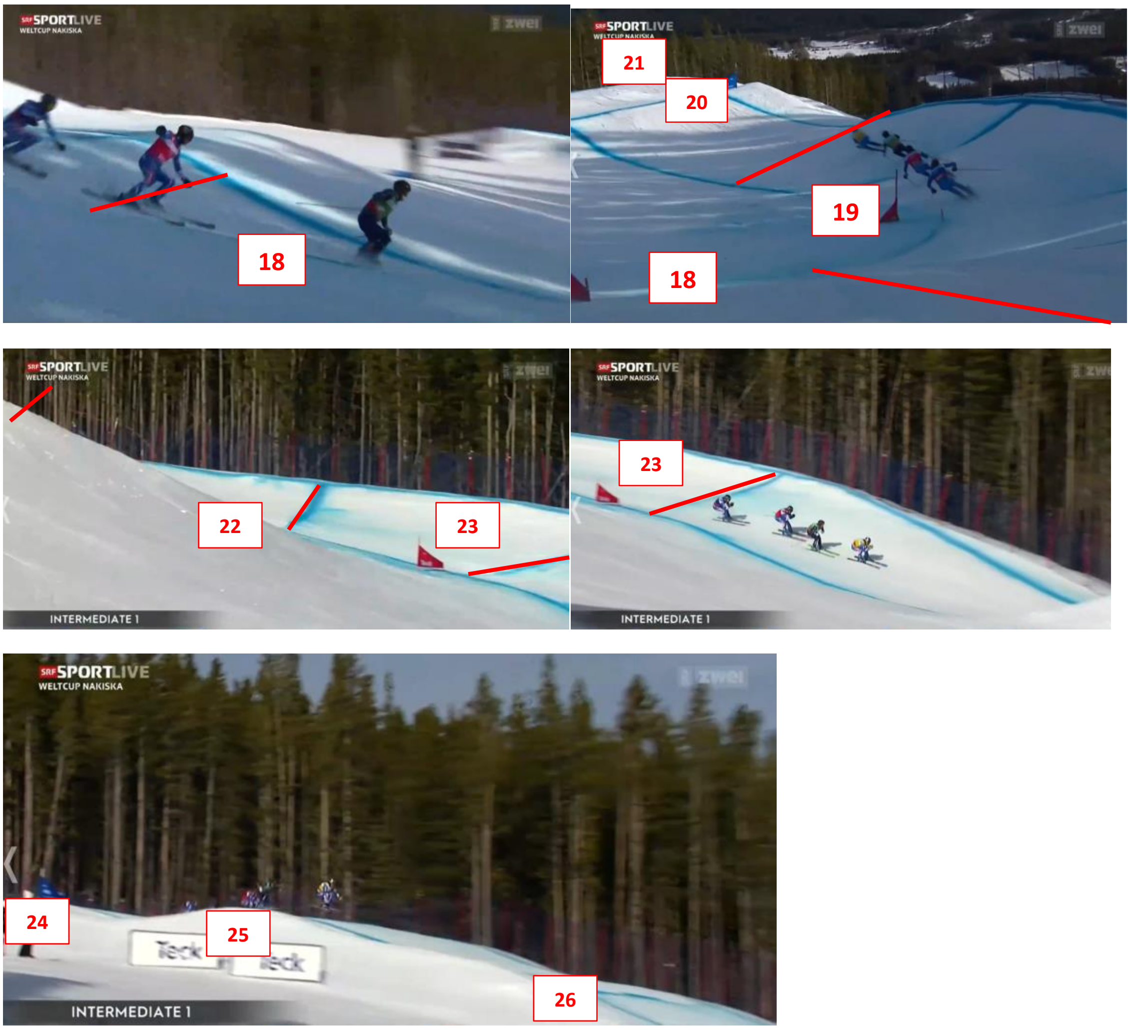
Track Information WC Nakiska

Obstacle Name	Obstacle Nr.	Section 1
Startdrop	1	
Roller	2	
Roller	3	
Roller	4	
Roller	5	
Step Down Take Off	6	
Step Down Landing	7	
Jump Take Off	8	
Jump Landing	9	

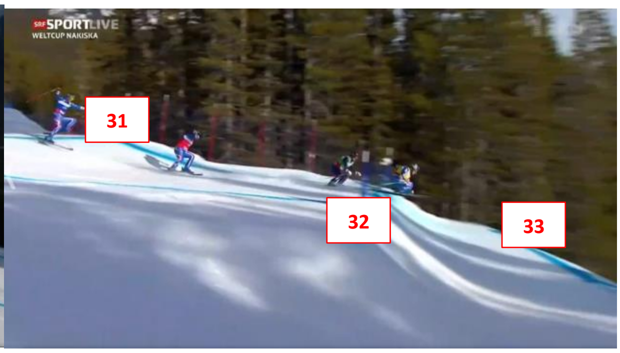




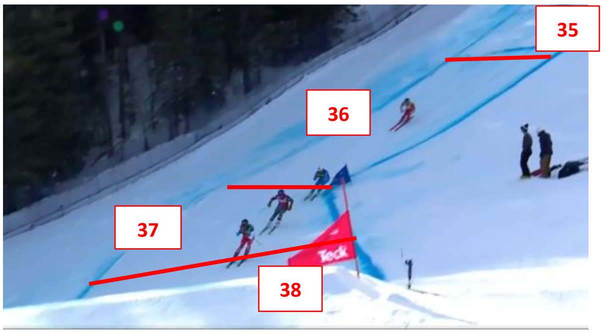
Obstacle Name	Obstacle Nr.	Section 2
Bank Turn Entry	10	
Bank Turn Exit	11	
Corner Jump Take Off	12	
Corner Jump Landing	13	
Turn Entry (red gate)	14	
Turn Exit	15	
Roller	16	
Roller	17	

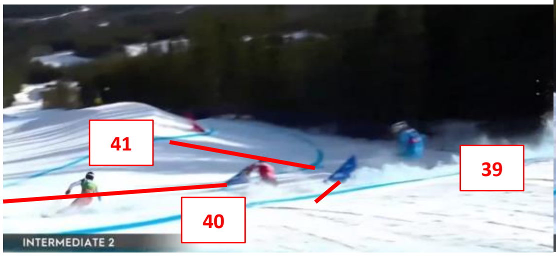


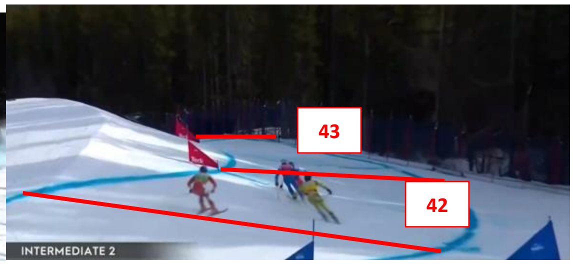
Obstacle Name	Obstacle Nr.	
Turn Entry	18	Section 2
Turn Exit	19	
Kicker Take Off	20	
Kicker Landing	21	
Turn Entry	22	
Turn Exit	23	
Triple Roller 1	24	
Triple Roller 2	25	
Triple Roller 3	26	



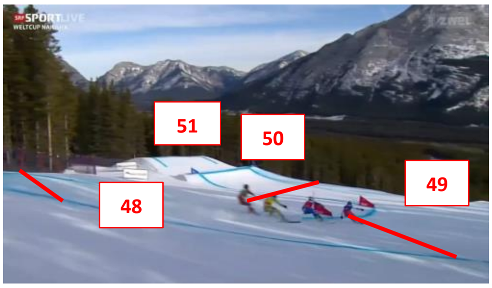
Obstacle Name	Obstacle Nr.	
Turn Entry	27	Section 3
Turn Exit	28	
Kicker Take Off	29	
Kicker Landing	30	
Corner Jump	31	
Step Down Take Off	32	
Step Down Landing	33	
Jump Take Off	34	
Jump Landing	35	

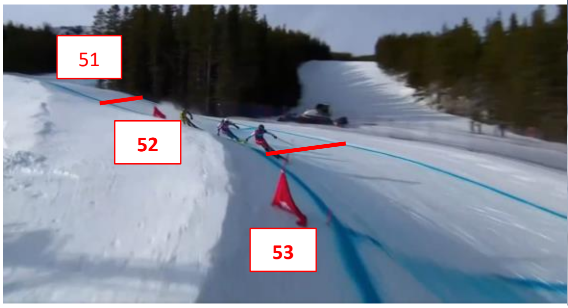


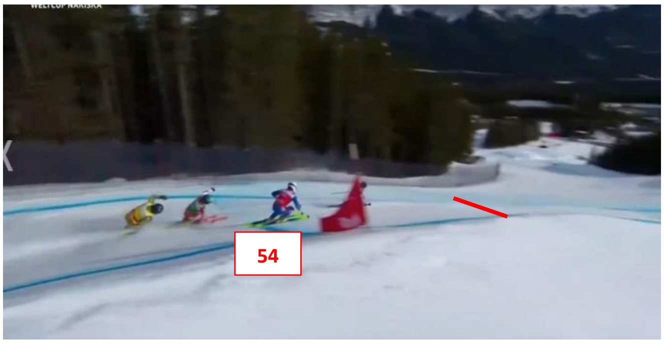


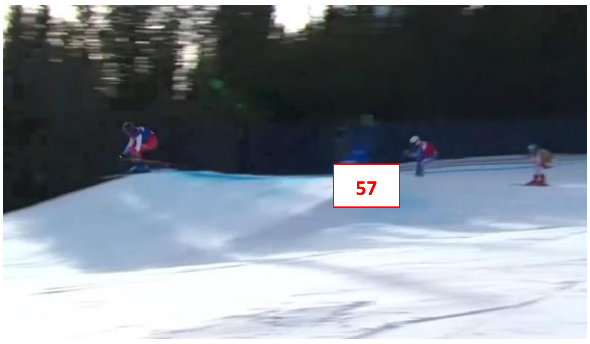


Obstacle Name	Obstacle Nr.	
GS Turn Entry	36	Section 3
GS Turn Exit	37	
Corner Jump Take Off	38	
Corner Jump Landing	39	
GS Turn Entry (blue gate)	40	
GS Turn Exit	41	
Negative Turn Entry	42	
Negative Mid	43	
Negative Exit	44	
GS Turn Entry	45	
GS Turn Exit	46	
Roller	47	
GS Turn Entry	48	
GS Turn Exit	49	
Jump Take Off	50	
Jump Landing	51	

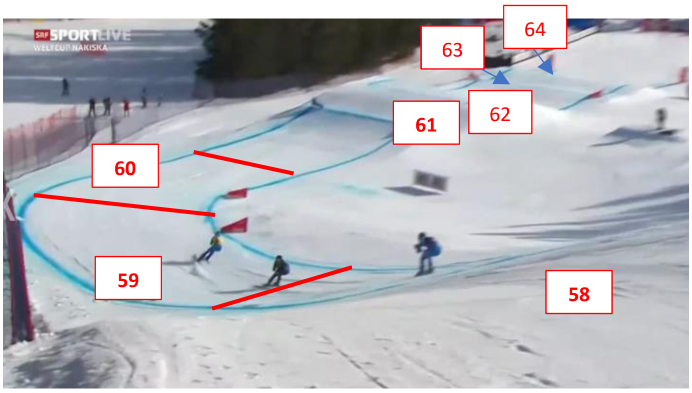


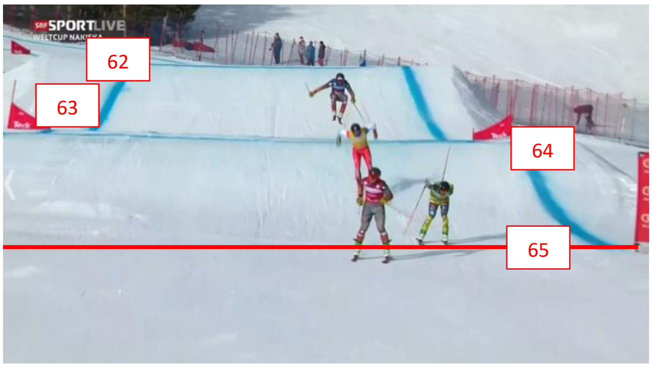






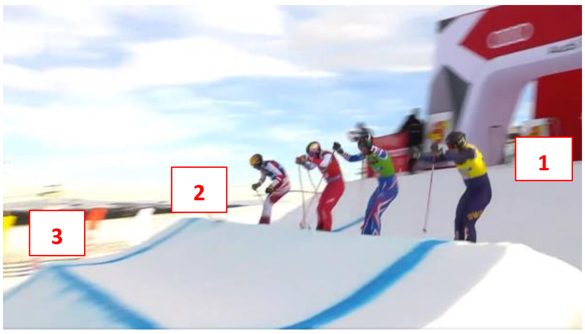
Obstacle Name	Obstacle Nr.	
Turn Entry	52	Section 4
Turn Mid	53	
Turn Exit	54	
Corner Jump Take Off	55	
Corner Jump Landing	56	
Step Down Take Off	57	



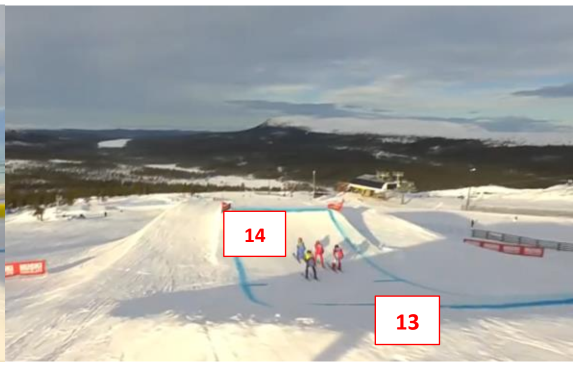


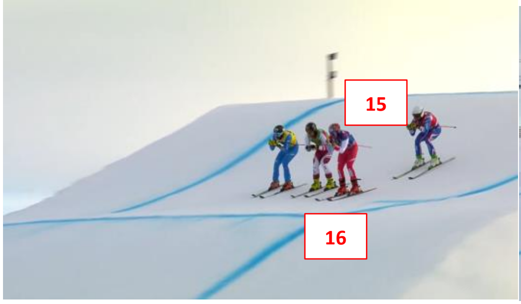
Obstacle Name	Obstacle Nr.	Section 4
Step Down Landing	58	
GS Turn Entry	59	
GS Turn Exit	60	
Jump Take Off	61	
Jump Landing	62	
Roller Double 1	63	
Roller Double 2	64	
Finish Line	65	

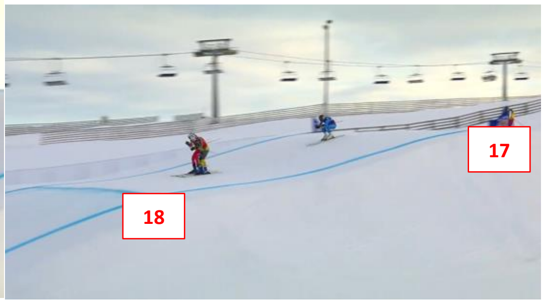
Track information WC Idre Fjäll



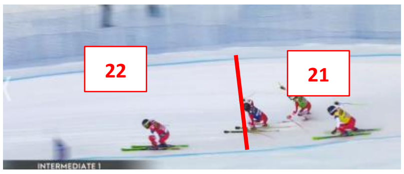
Obstacle Name	Obstacle Nr.	
Start Drop	1	Section 1
Step Down Take Off	2	
Step Down Landing	3	
Step Up Take Off	4	
Step Up Landing	5	
Roller	6	
Roller	7	
Roller	8	
Roller	9	
Roller	10	
Roller	11	

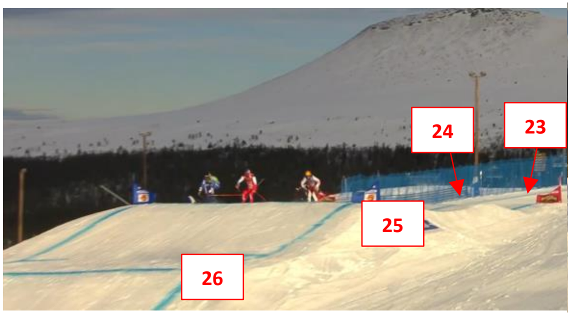


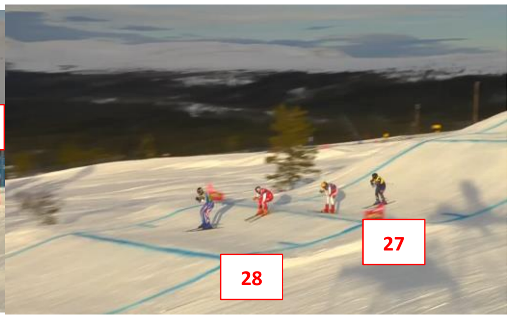




Obstacle Name	Obstacle Nr.	
Kicker Take Off	12	Section 1
Kicker Landing	13	
Jump Take Off	14	
Jump Landing	15	
Roller	16	
Roller	17	
Roller	18	
Jump Take Off	19	
Jump Landing	20	







Obstacle Name	Obstacle Nr.	
Bank Turn Entry	21	Section 2
Bank Turn Exit	22	
Roller	23	
Roller	24	
Roller	25	
Roller	26	
Double Roller 1	27	
Double Roller 2	28	
Jump Take Off	29	
Jump Landing	30	
Bank Turn Entry	31	
Bank Turn Exit	32	

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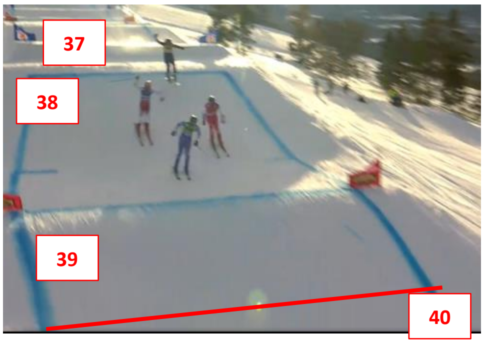
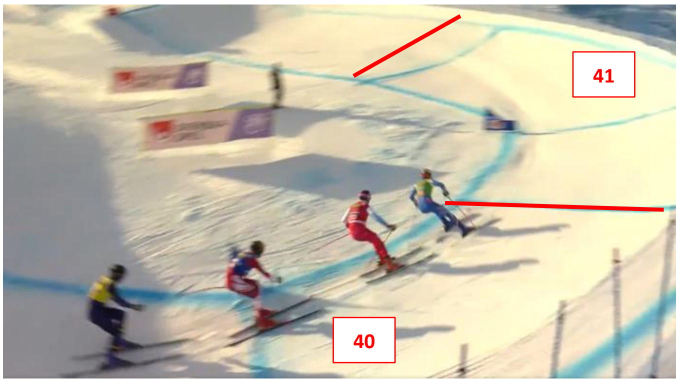
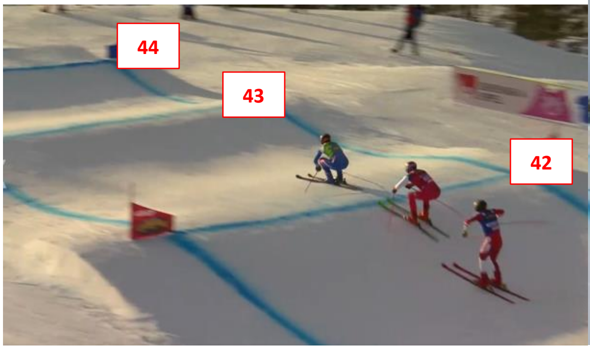
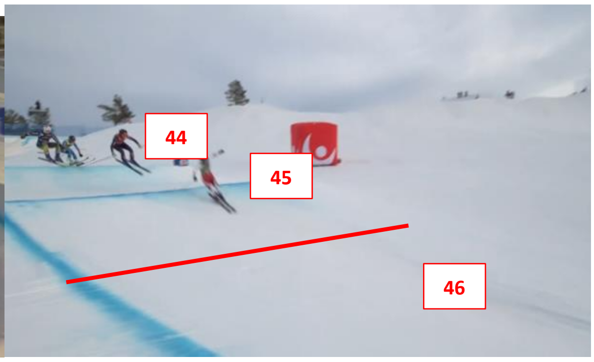
Obstacle Name	Obstacle Nr.	
Roller	33	Section 3
Roller	34	
Roller	35	
Roller	36	
Kicker Takeoff	37	
Kicker Landing	38	
Roller	39	
Bank Turn Entry	40	

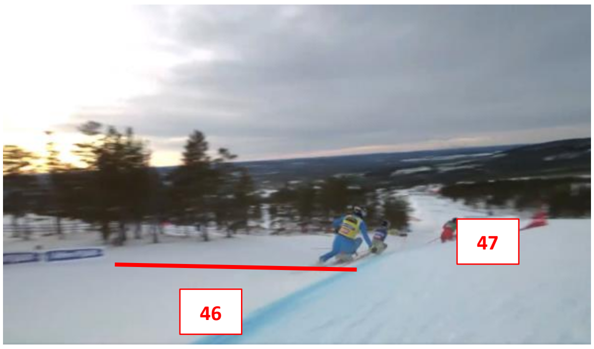


Bank Turn Exit	41	
Roller	42	
Roller	43	
Corner Jump Take Off	44	
Corner Jump Landing	45	
Negative Entry	46	

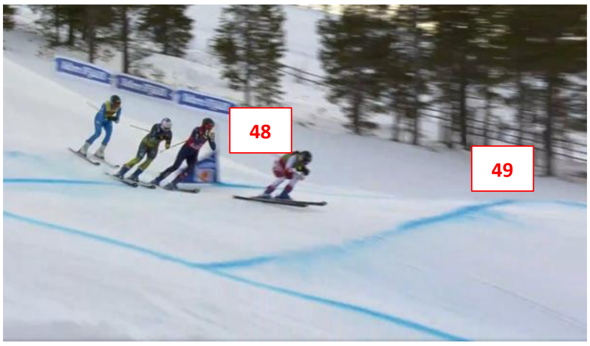




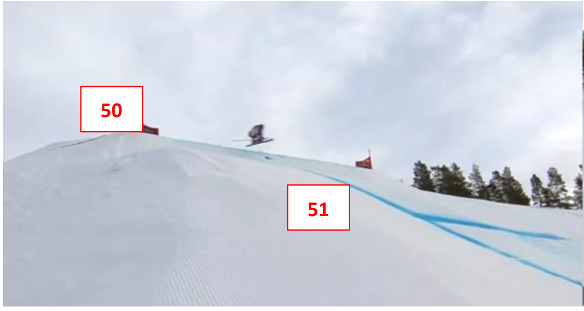


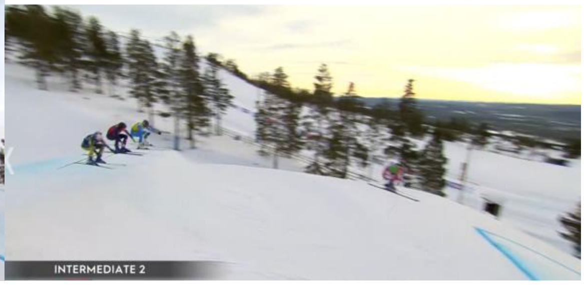


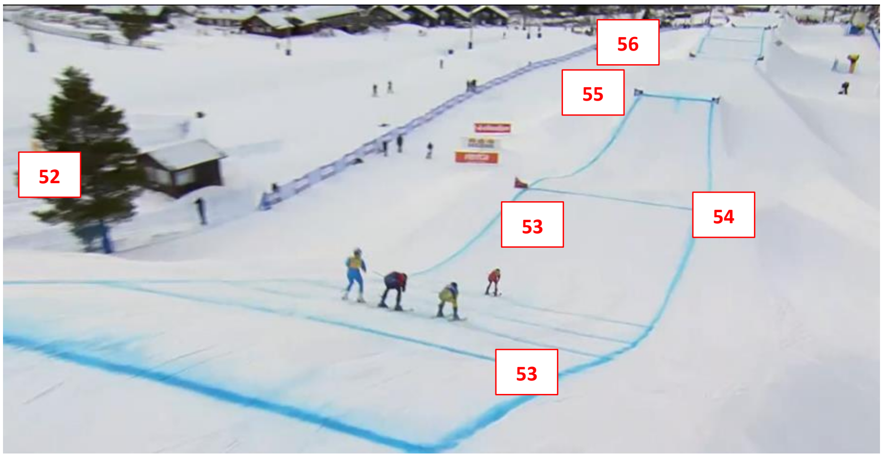
Obstacle Name	Obstacle Nr.	Section 4
Negative Entry	46	
Negative Exit	47	
GS Gate	48	
Roller	49	

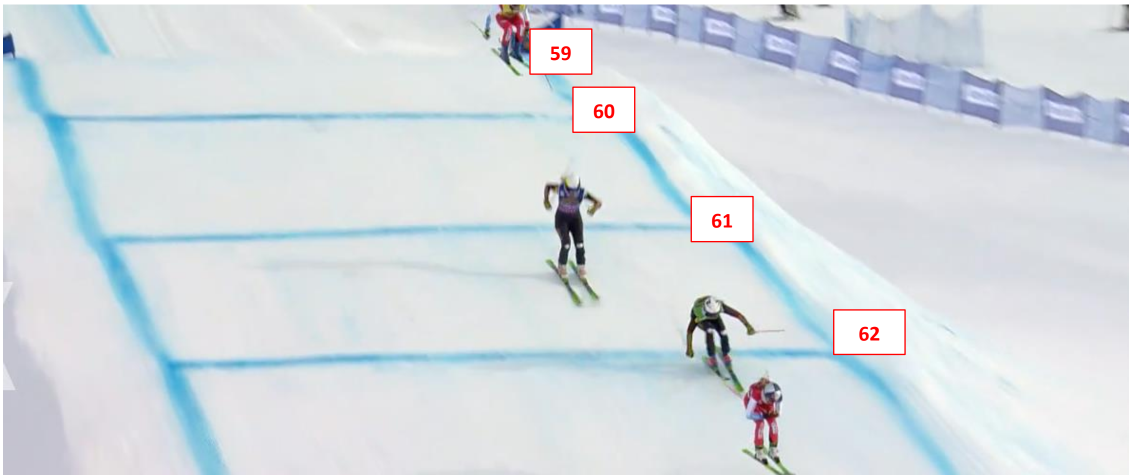


Step Down Take Off	50	
Step Down Landing	51	
Jump Takeoff	52	
Jump Landing	53	
Roller	54	
Jump Takeoff	55	
Jump Landing	56	

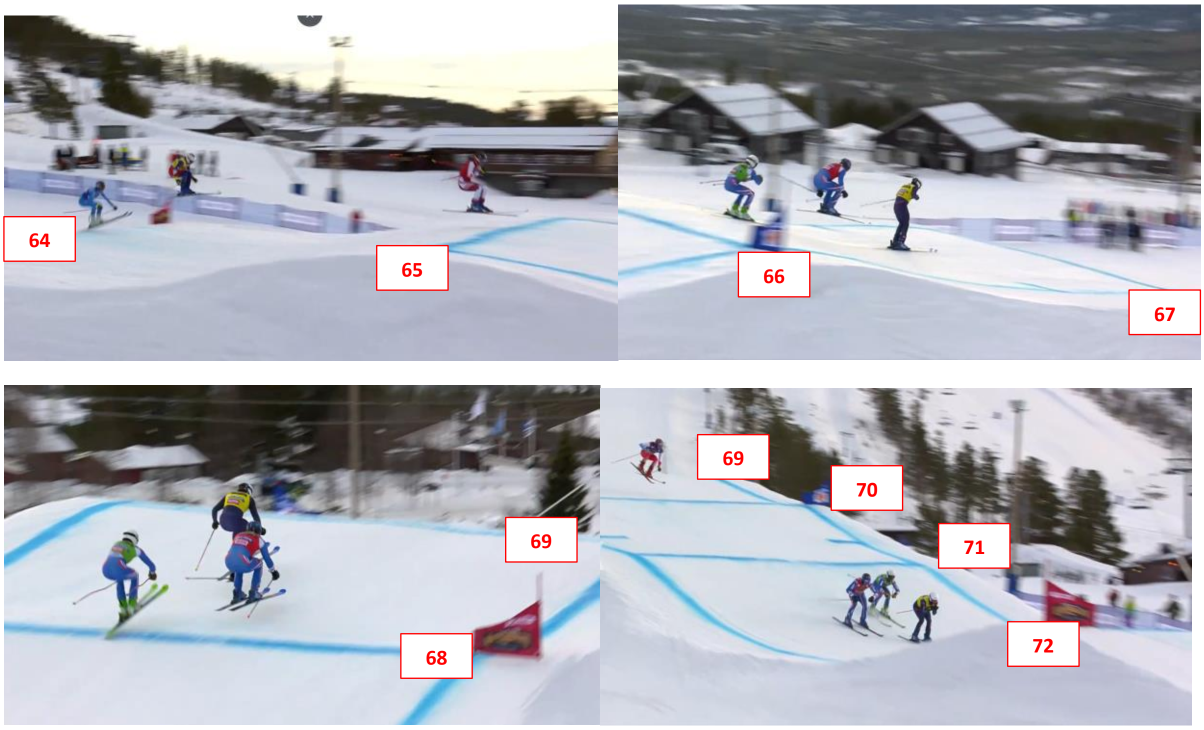


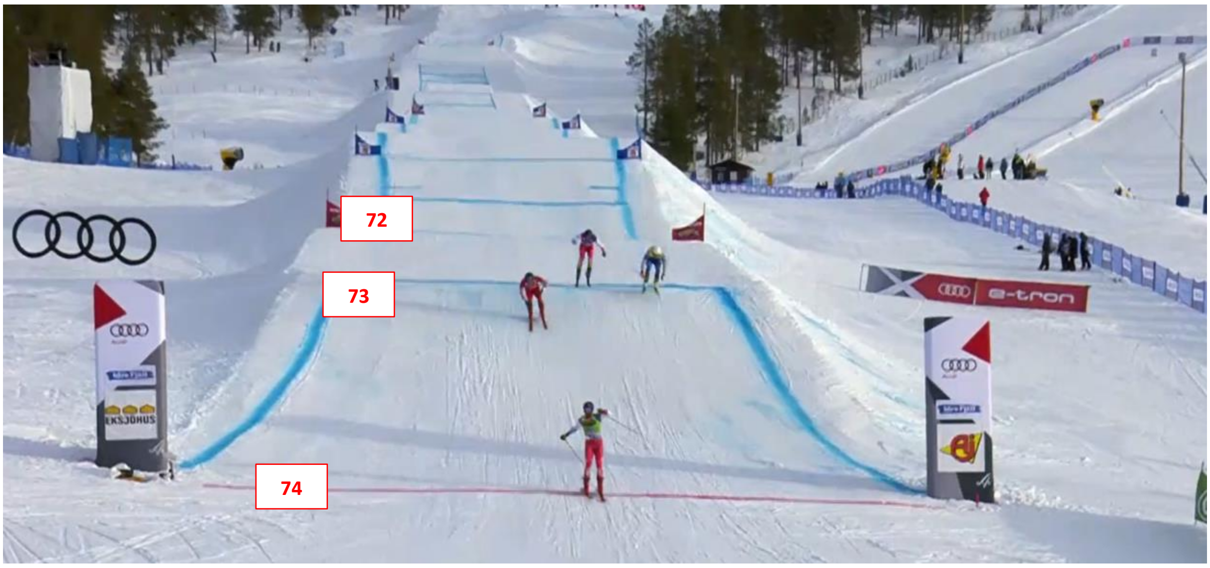






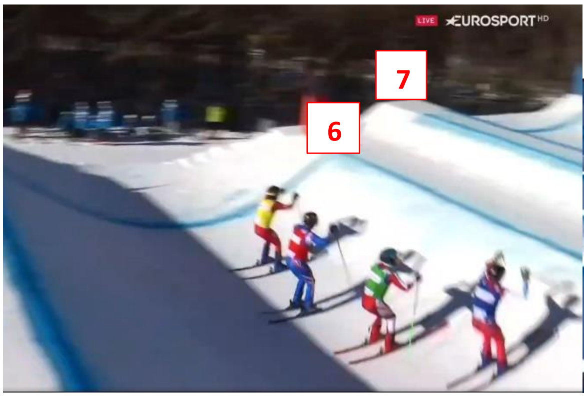
Obstacle Name	Obstacle Nr.	Section 5
Dragon Up 1	57	
Dragon Up 2	58	
Dragon Peak	59	
Dragon Down 1	60	
Dragon Down 2	61	
Dragon Down 3	62	
Dragon Down 4	63	

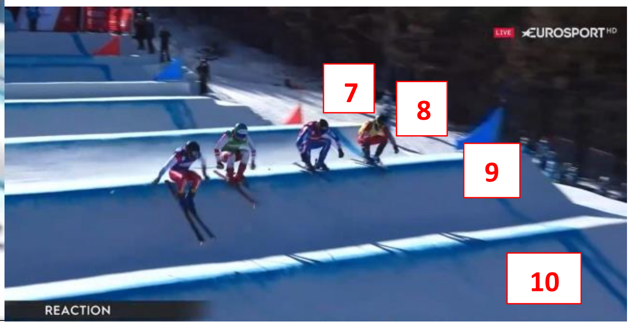


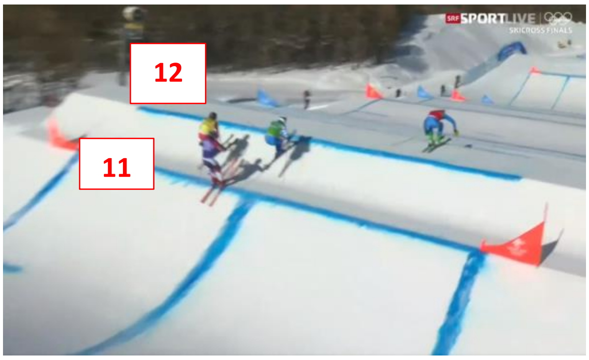


Obstacle Name	Obstacle Nr.	Section 5
Kicker Takeoff	64	
Kicker Landing	65	
Roller	66	
Roller	67	
Dragon Up	68	
Dragon Peak	69	
Dragon Down 1	70	
Dragon Down 2	71	
Jump Take Off	72	
Jump Landing	73	
Finish Line	74	

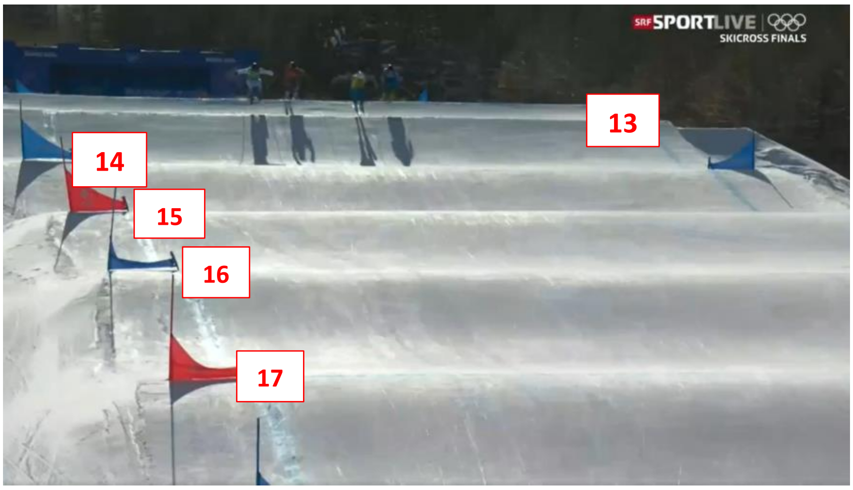
Track Information WOG Beijing 2022

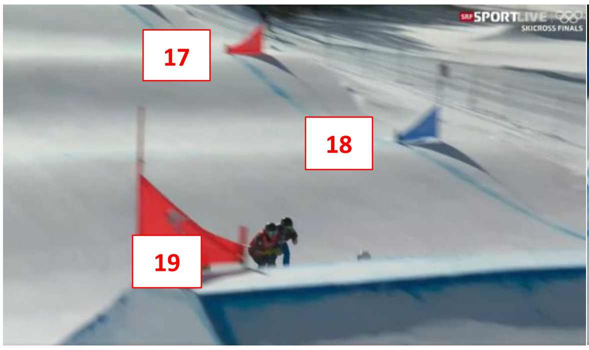




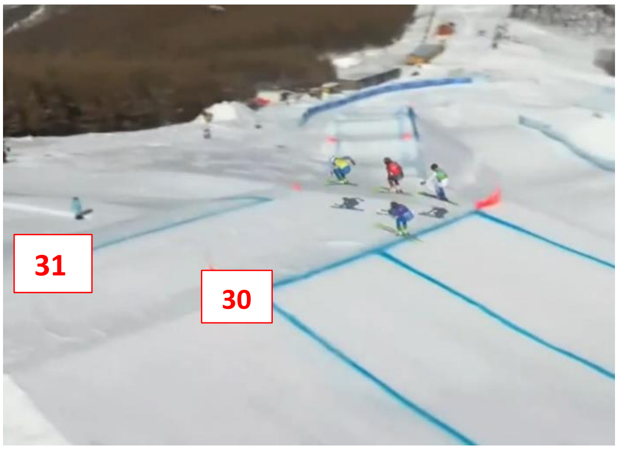


Obstacle Name	Obstacle Nr.	
Startdrop	1	Section 1
Step Down Take Off	2	
Step Down Landing	3	
Kicker Take Off	4	
Kicker Landing	5	
Wutang Up	6	
Wutang Peak	7	
Bathtube	8	
Wutang Peak	9	
Wutang Landing	10	
Wutang Up	11	
Wutang Peak	12	
Wutang Down	13	

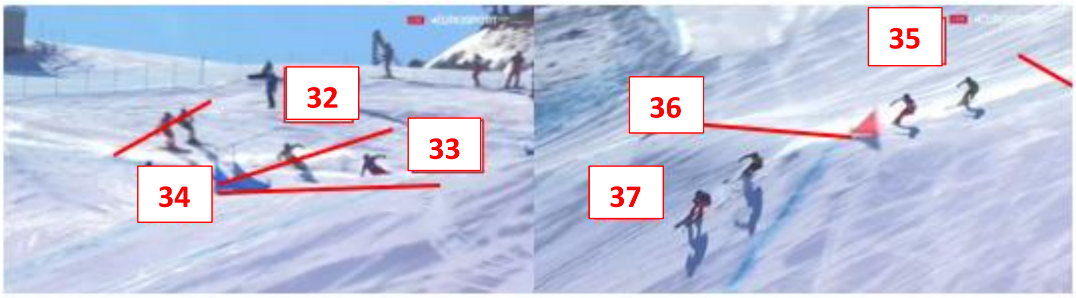




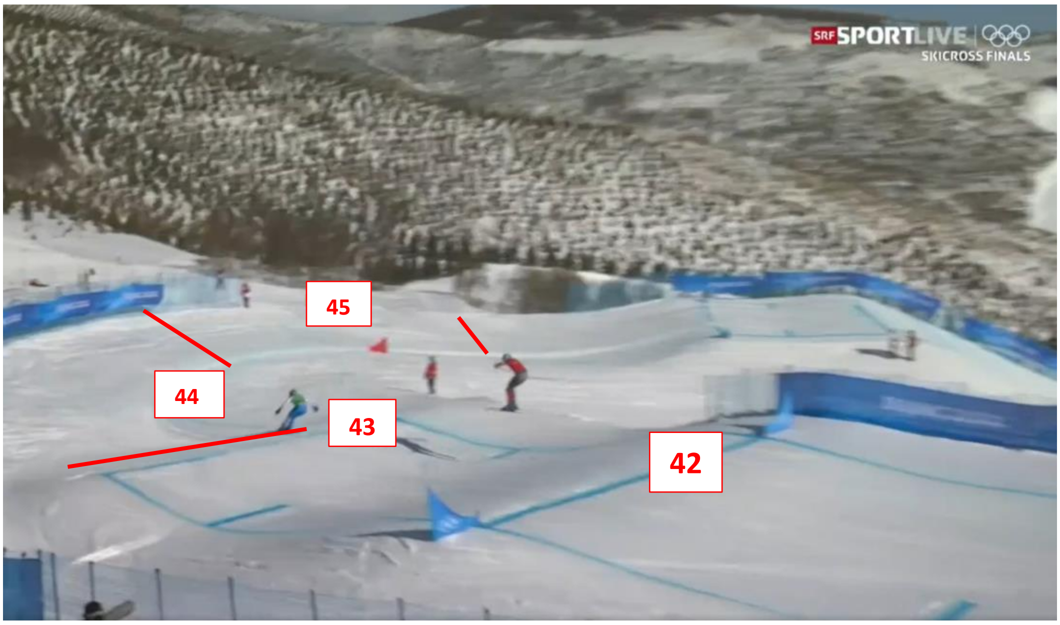
Obstacle Name	Obstacle Nr.	
Roller	14	Section 1
Roller	15	
Roller	16	
Roller	17	
Roller	18	
Jump Take Off	19	
Jump Landing	20	
Roller	21	
Roller	22	
Roller	23	



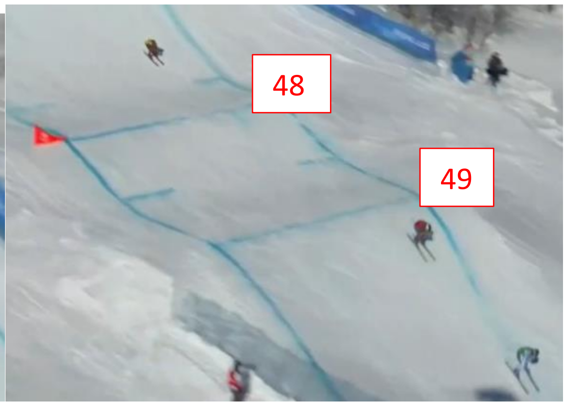
Obstacle Name	Obstacle Nr.	
Corner Jump Take Off	24	Section 2
Corner Jump Landing	25	
Roller Double 1	26	
Roller Double 2	27	
Negative Entry	28	
Negative Exit	29	
Jump Take Off	30	
Jump Landing	31	

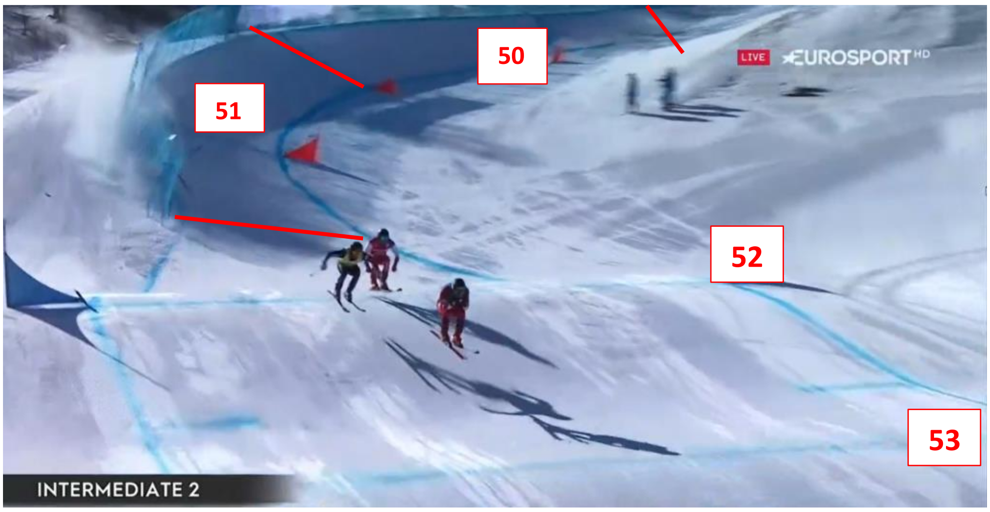


Obstacle Name	Obstacle Nr.	
GS Turn Entry	32	Section 3
GS Turn Exit	33	
Roller	34	
GS Turn Entry	35	
GS Turn Mid Roller	36	
GS Turn Exit	37	
Roller	38	
Roller Double 1	39	
Roller Double 2	40	

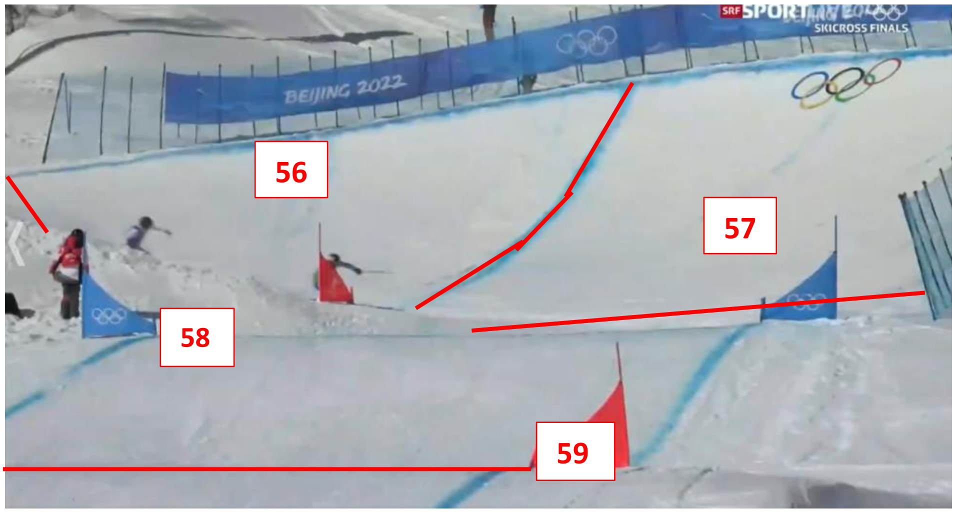


Obstacle Name	Obstacle Nr.	
Roller	41	Section 3
Roller Double 1	42	
Roller Double 2	43	
GS Turn Entry	44	
GS Turn Exit	45	

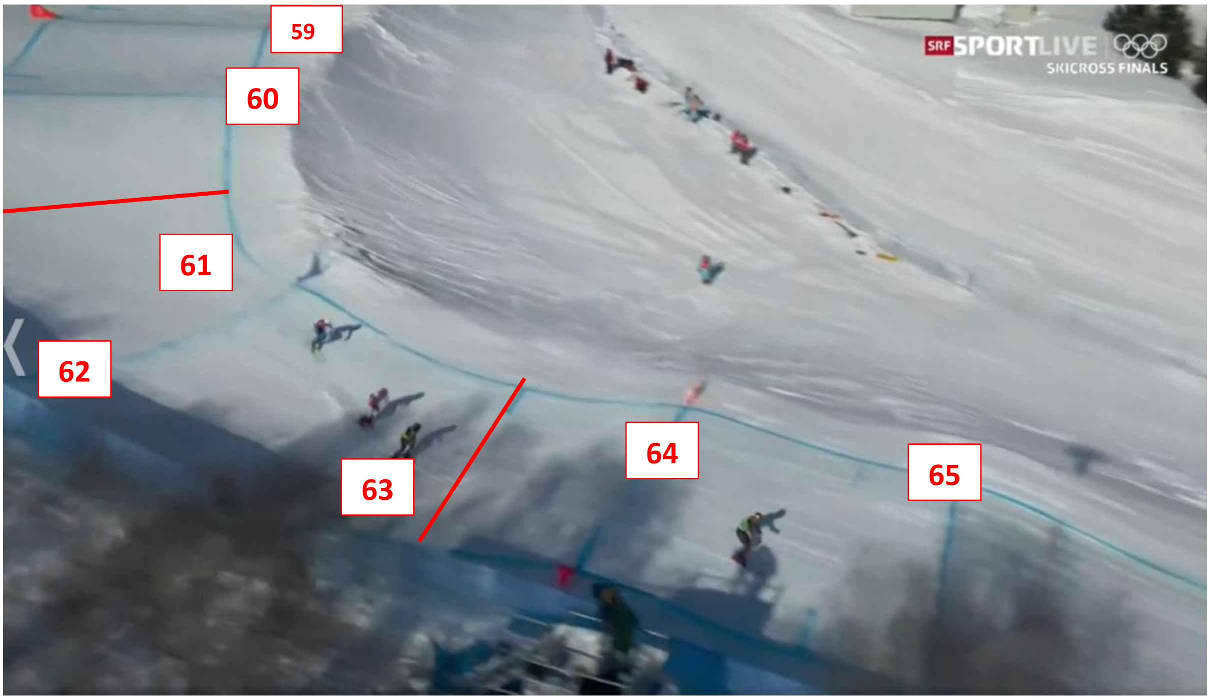




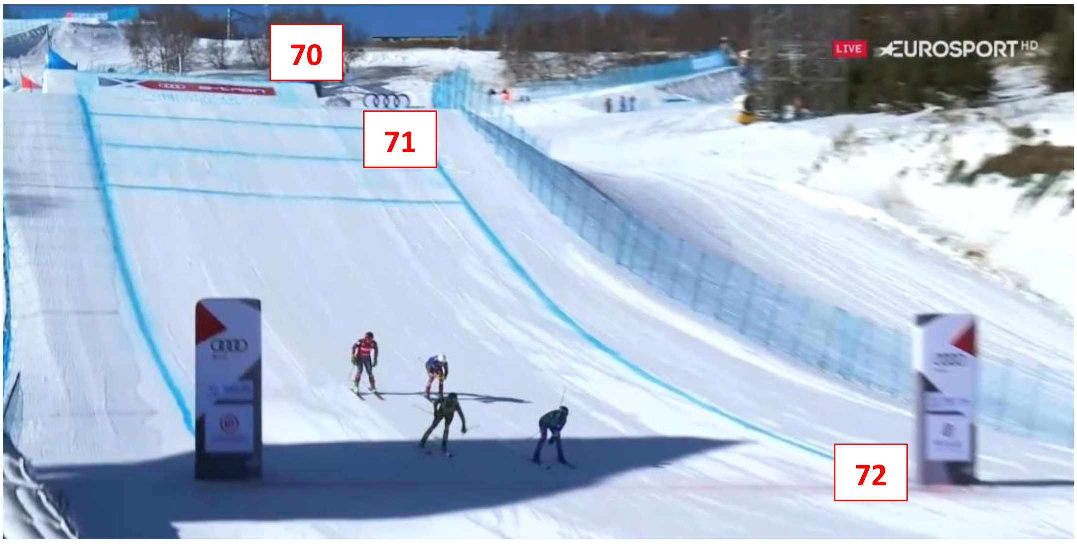
Obstacle Name	Obstacle Nr	Section 4
Double Roller 1	46	
Double Roller 2	47	
Roller Double 1	48	
Roller Double 2	49	
Bank Turn Entry	50	
Bank Turn Exit	51	
Roller Double 1	52	
Roller Double 2	53	



Obstacle Name	Obstacle Nr.	
Roller Double 1	54	Section 4
Roller Double 2	55	
Bank Turn Entry	56	
Bank Turn Exit	57	
Roller	58	
Roller Double 1	59	

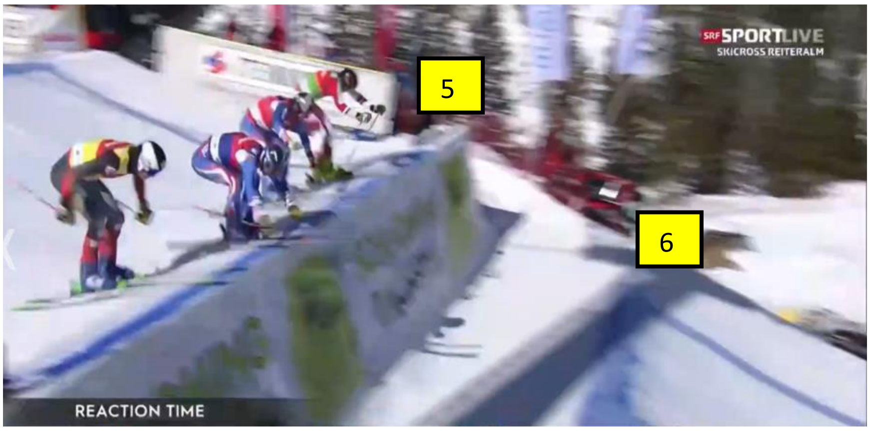


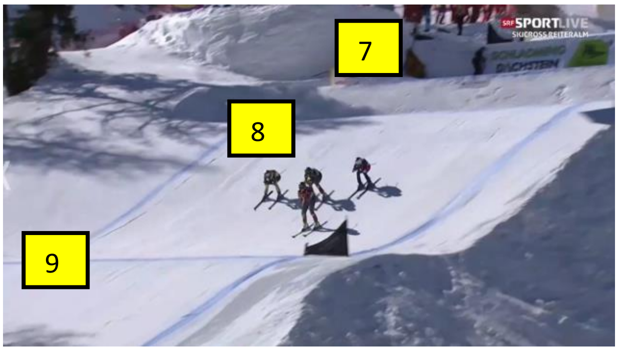
Obstacle Name	Obstacle Nr.	
Roller Double 2	60	Section 4
GS Turn Entry	61	
GS Turn Mid Roller	62	
GS Turn Exit	63	
Roller	64	Section 5
Roller	65	
Dragon Up 1	66	
Dragon Peak	67	
Dragon Down 1	68	
Dragon Down 2	69	



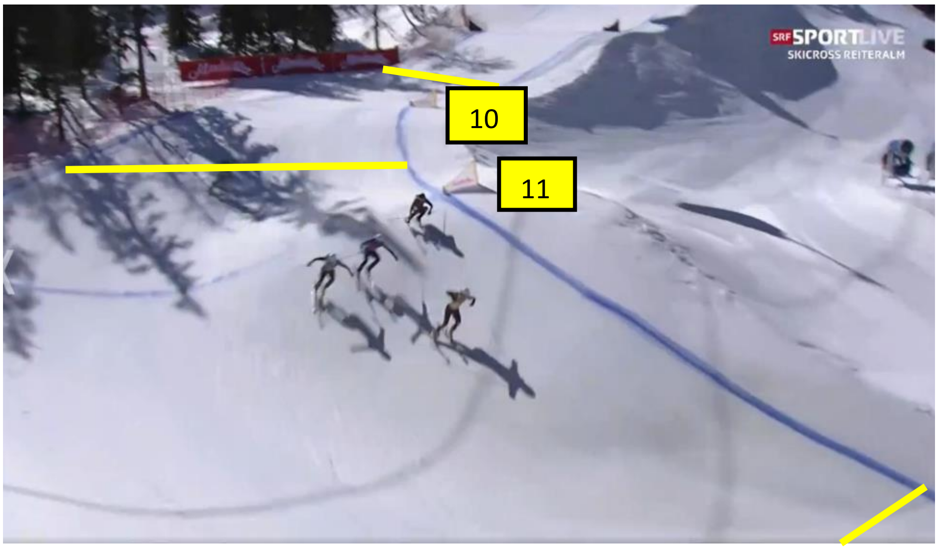
Obstacle Name	Obstacle Nr.	
Jump Take Off	70	Section 5
Jump Landing	71	
Finish Line	72	

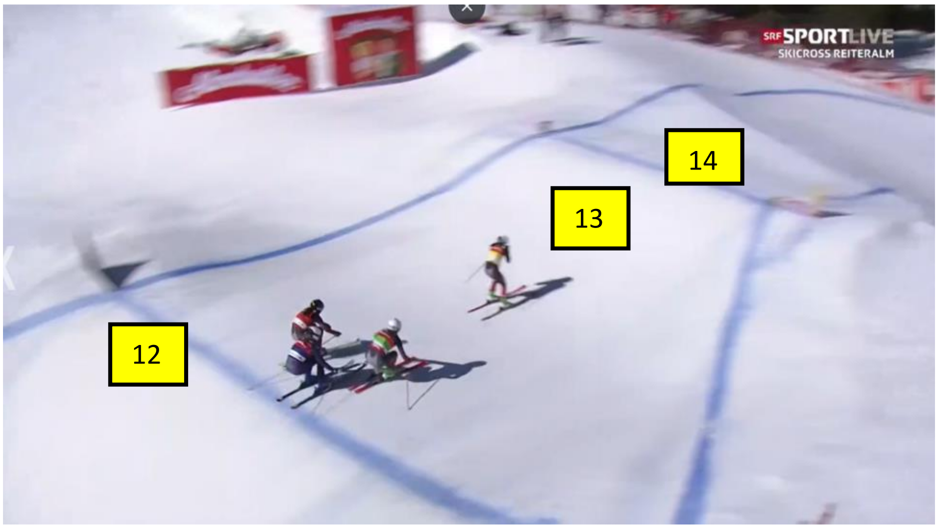
Track Information WC Reiteralm

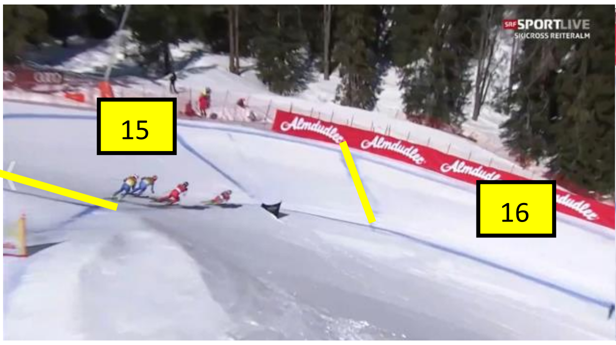




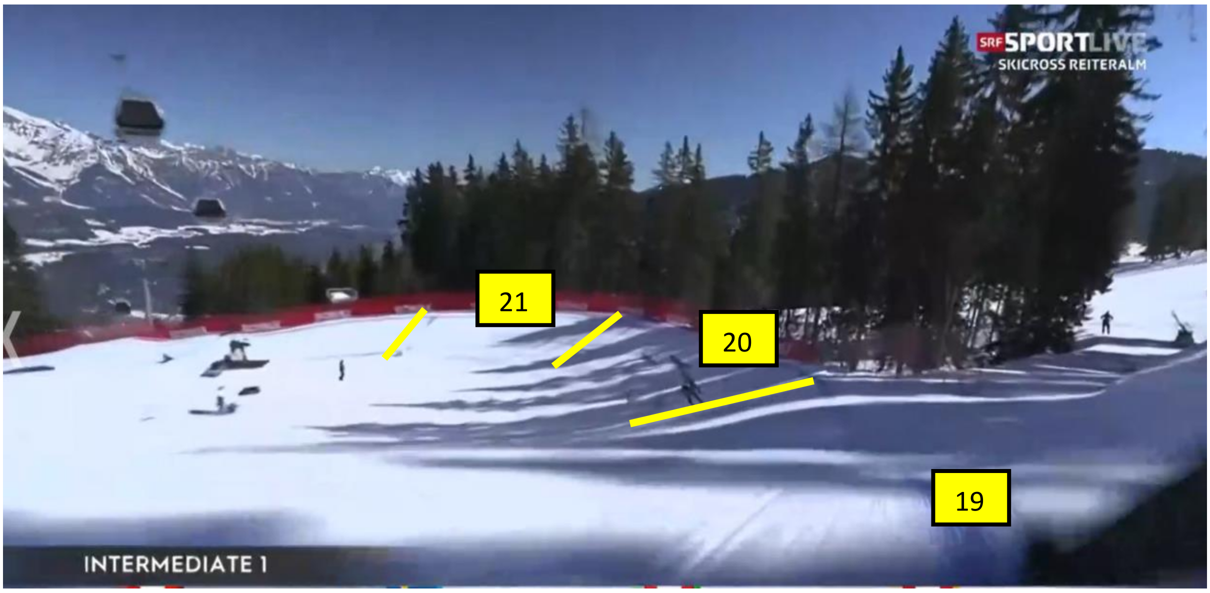
Obstacle Name	Obstacle Nr.	
Start Drop	1	Section 1
Wutang	2	
Step Up Take Off	3	
Step Up Landing	4	
Step Down Take Off	5	
Step Down Landing	6	
Jump Take Off	7	
Jump Landing	8	
Roller	9	



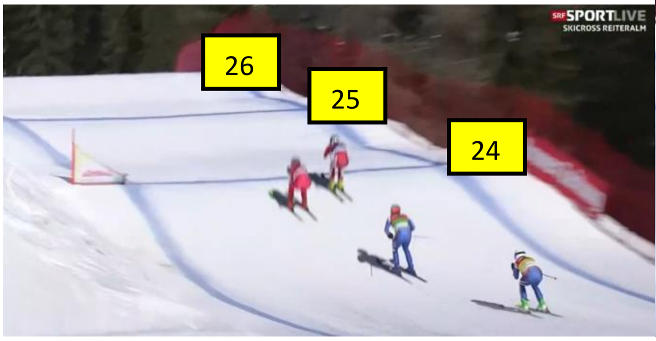


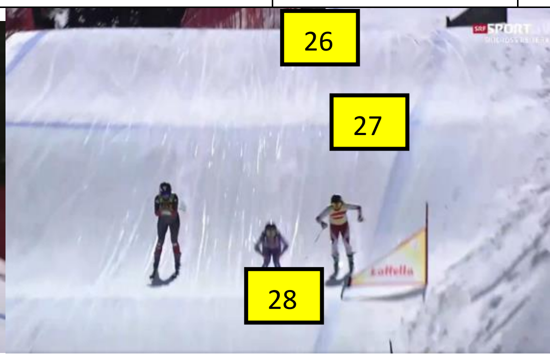


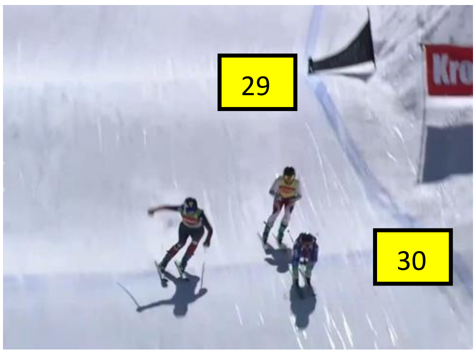
Obstacle Name	Obstacle Nr.	Section 2
Roller Turn Entry	10	
Roller Turn Exit	11	
Roller	12	
Roller Double 1	13	
Roller Double 2	14	
Bank Turn Entry	15	
Bank Turn Exit	16	

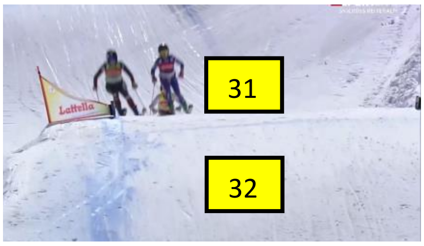


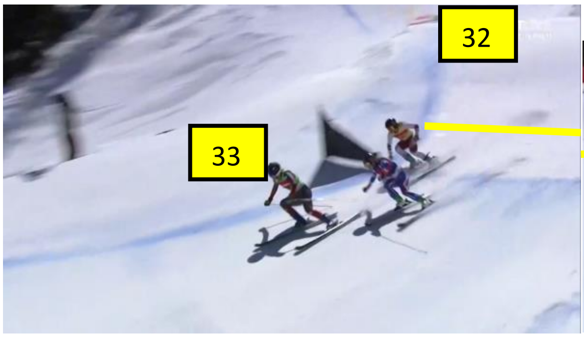
Obstacle Name	Obstacle Nr.	
Step Down Take Off	17	Section 2
Step Down Landing	18	
Roller	19	Section 3
Bank Turn Entry	20	
Bank Turn Exit	21	
Double Roller 1	22	
Double Roller 2	23	
Dragon Up 1	24	
Dragon Up 2	25	
Dragon Peak	26	
Dragon Down	27	
Roller	28	

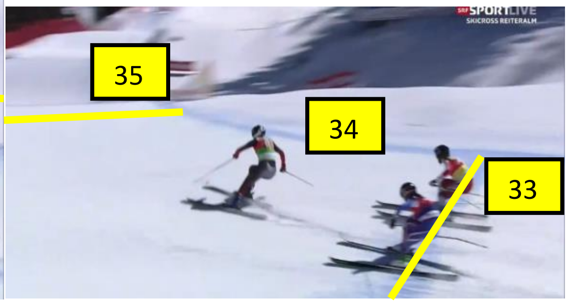


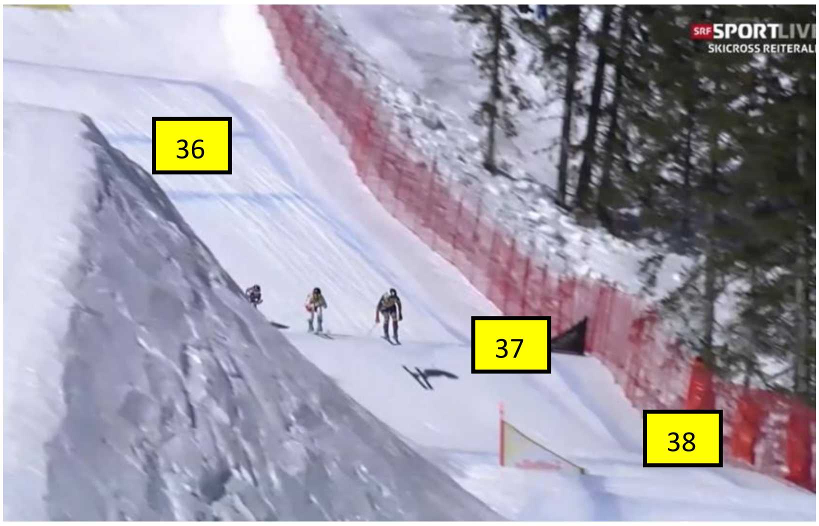




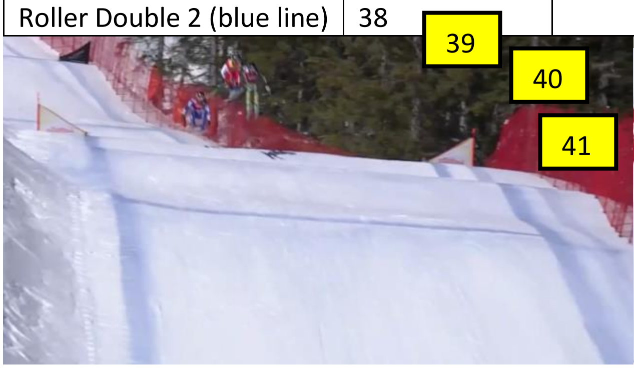


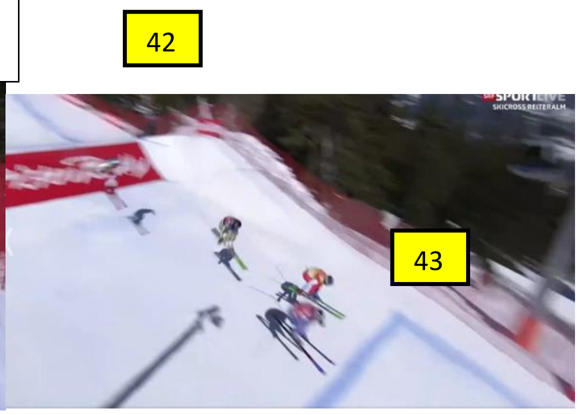


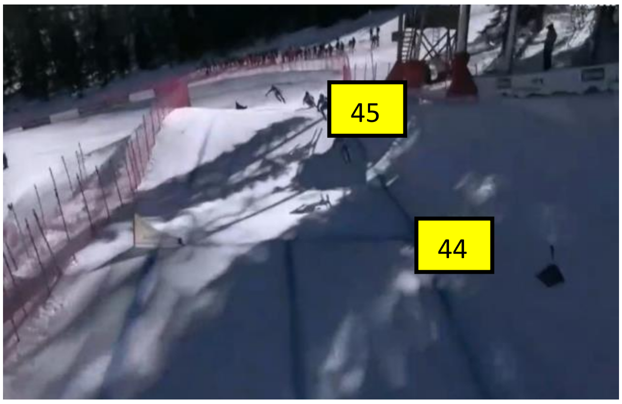




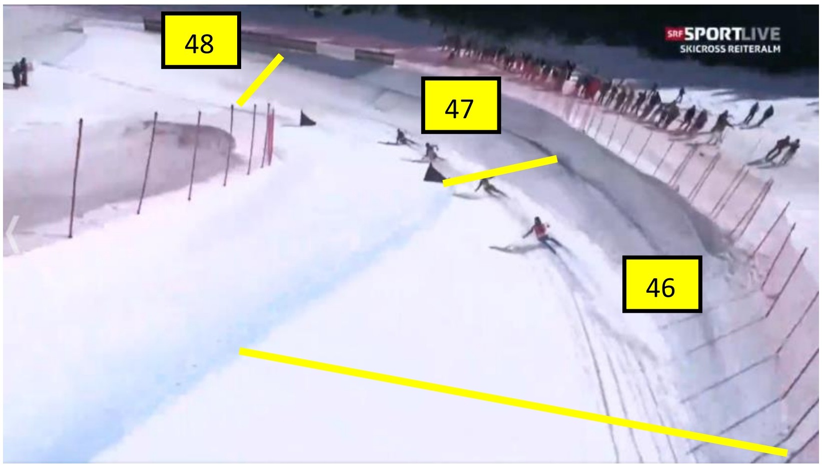
Obstacle Name	Obstacle Nr.	
Roller	29	Section 3
Roller	30	
Corner Jump Take Off	31	
Corner Jump Landing	32	
Turn Entry	33	Section 4
Turn Exit	34	
Step Down Take Off	35	
Step Down Landing	36	
Roller Double 1	37	
Roller Double 2 (blue line)	38	

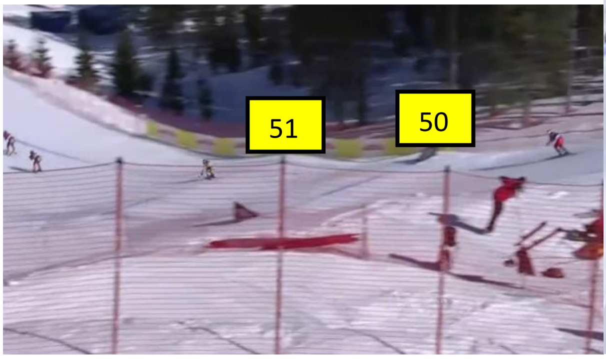


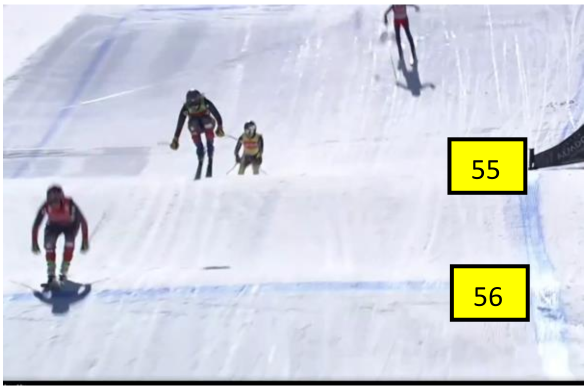


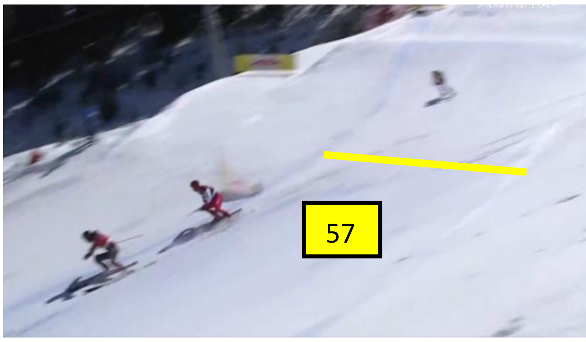


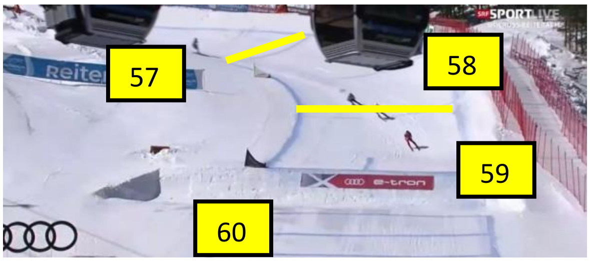
Obstacle Name	Obstacle Nr.	
Triple Roller 1	39	Section 4
Triple Roller 2	40	
Triple Roller 3	41	
Jump Take Off	42	
Jump Landing	43	
Roller Double 1	44	
Roller Double 2	45	
Bank Turn Entry	46	
Bank Turn Exit	47	
Jump Take Off	48	
Jump Landing	49	

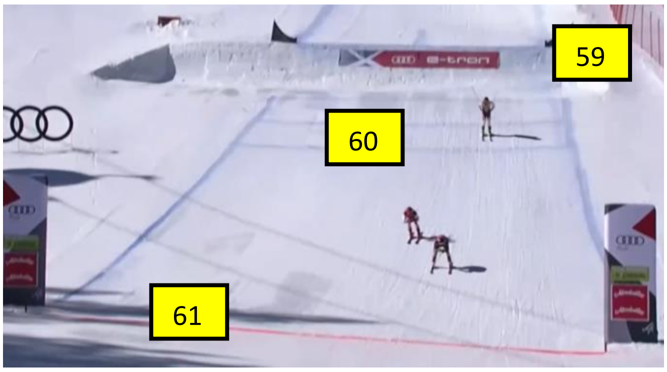






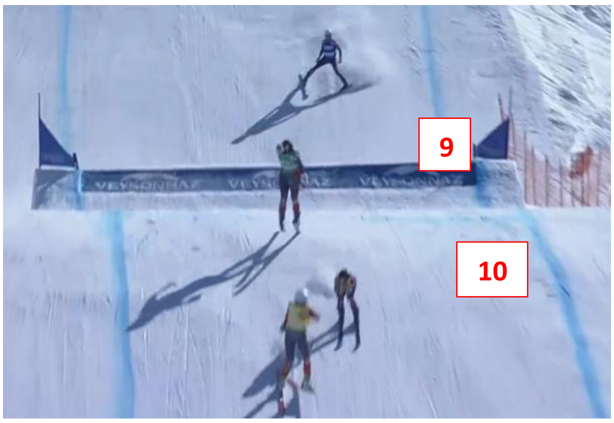




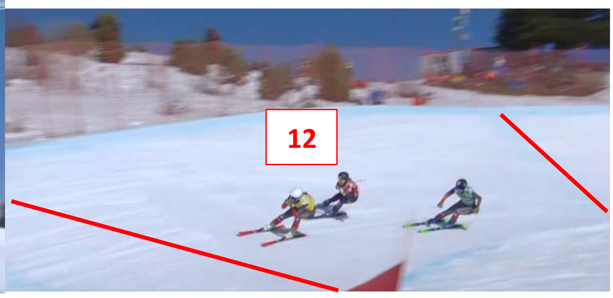


Obstacle Name	Obstacle Nr.	Section 5
Roller Double 1	50	
Roller Double 2	51	
Jump Take Off	52	
Jump Landing	53	
Roller	54	
Roller Double 1	55	
Roller Double 2	56	
GS Turn Entry	57	
GS Turn Exit	58	
Step Down Take Off	59	
Step Down Landing	60	
Finish Line	61	

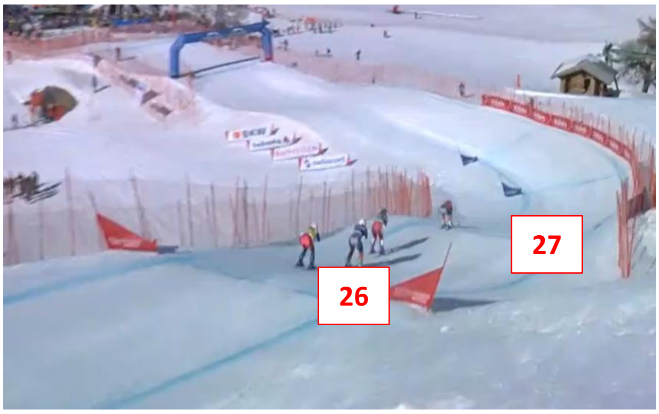
Track Information Veysonnaz



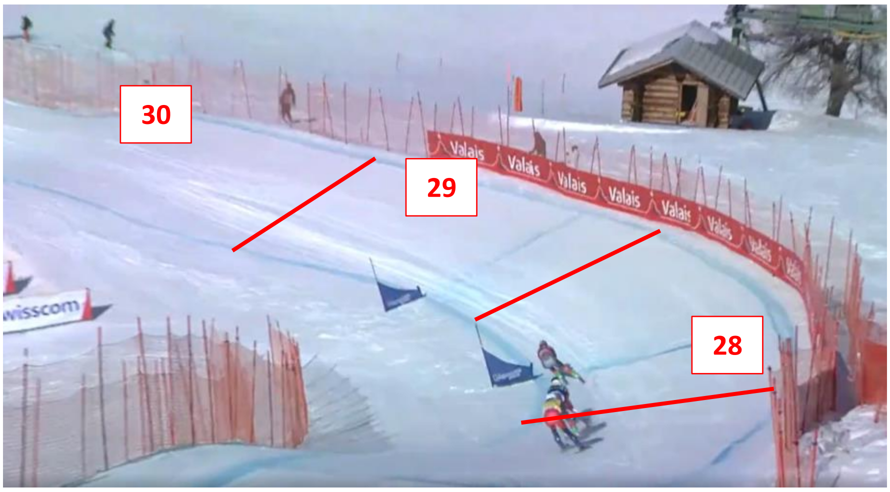
Obstacle Name	Obstacle Nr.	
Start Drop	1	Section 1
Roller	2	
Step Up Take Off	3	
Step Up Landing	4	
Roller	5	
Wutang	6	
Roller	7	
Roller	8	
Jump Take Off	9	
Jump Landing	10	

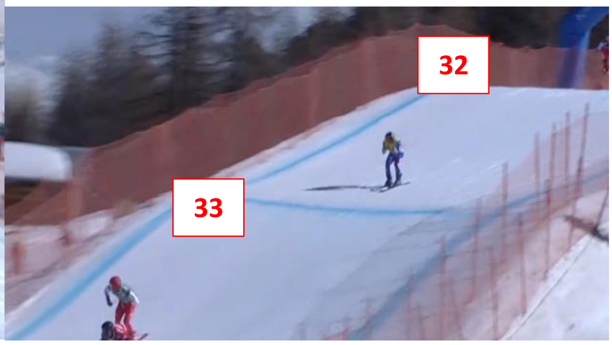


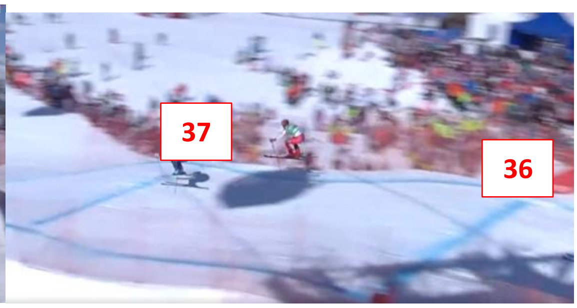
Obstacle Name	Obstacle Nr.	Section 2
Bank Turn Entry	11	
Bank Turn Exit	12	
Bank Turn Entry	13	
Bank Turn Mid	14	
Bank Turn Exit	15	
Dragon Roller Up	16	
Dragon Roller Peak	17	
Dragon Roller Down	18	



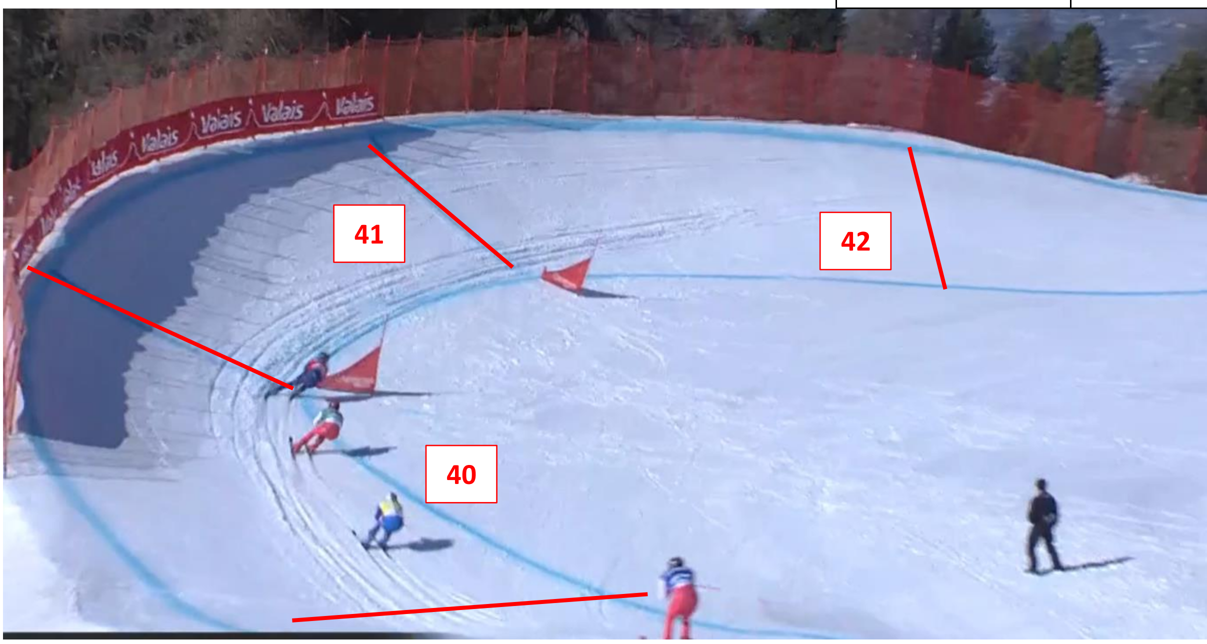
Obstacle Name	Obstacle Nr.	
Kicker Take Off	19	Section 2
Kicker Landing	20	Section 2
Kicker Take Off	21	Section 2
Kicker Landing	22	Section 2
Roller	23	Section 2
Roller	24	Section 2
Roller	25	Section 2
Roller	26	Section 2
Roller	27	Section 2
Bank Turn Entry	28	Section 3
Bank Turn Exit	29	Section 3
Roller	30	Section 3

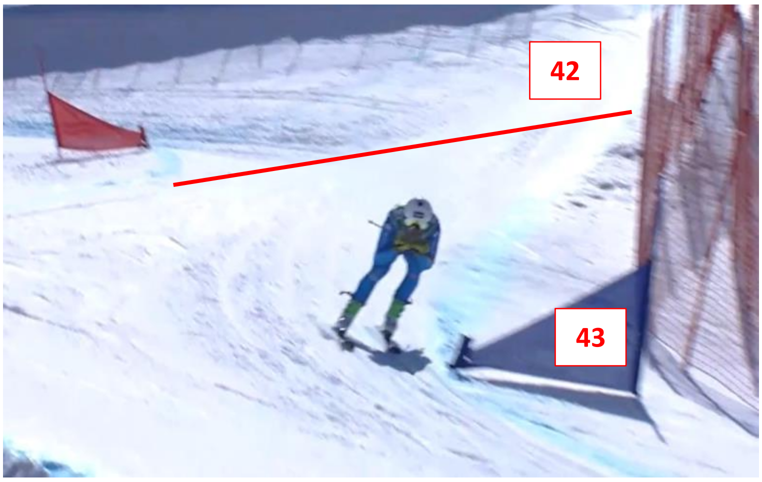


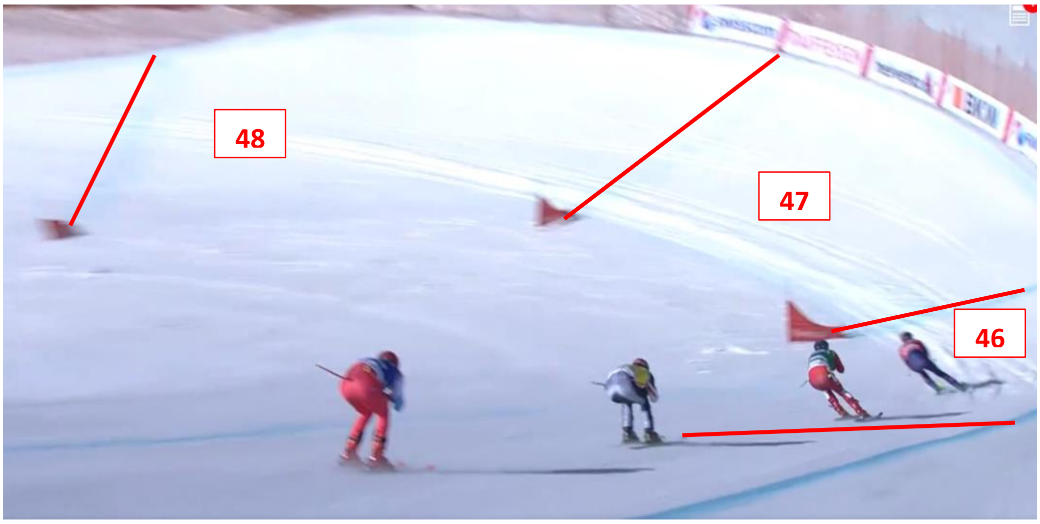




Obstacle Name	Obstacle Nr.	
Roller Double 1	31	Section 3
Roller Double 2	32	
Roller	33	
Roller Double 1	34	
Roller Double 2	35	
Roller Double 1	36	
Roller Double 2	37	
Roller Double 1	38	
Roller Double 2	39	
Bank Turn Entry	40	
Bank Turn Mid	41	
Bank Turn Exit	42	







Obstacle Name	Obstacle Nr.	
GS Gate	43	Section 4
Step Down Take Off	44	
Step Down Landing	45	
Bank Turn Entry	46	
Bank Turn Mid	47	
Bank Turn Exit	48	

Obstacle Name	Obstacle Nr.	
Roller	49	Section 4
Roller Double 1	50	
Roller Double 2	51	
Dragon Roller Up	52	
Dragon Roller Peak	53	
Dragon Roller Down	54	
Finish Line	55