



Ski Jump Launch Trainer

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Section 303

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Abstract

Ski jumping feedback is traditionally qualitative advice given by coaches who analyze jumps for general form and timing. However, due to the speed of the ski jumper and the natural human error of the coach, the feedback is neither reliable nor consistent. In order to make ski jumping feedback more robust, advice should be based on quantitative data metrics that show high correlation with jump quality. Many studies have already explored the feasibility and accuracy of these data collection methods including, differential Global Navigation Satellite System (dGNSS), inertial measurement units, markerless motion capture systems, and force sensors. Despite this, none of these approaches have looked into the results of each metric and their correlation with ski jumping performance to generate quantitative based feedback for the athletes. Following research and design matrix decision making, this project will utilize motion capture and force plates to attempt to identify this quantitative relationship for the takeoff and early flight phase of the jump. Data will be collected through multiple trips to a local ski jumping hill during training hours and on youth amateur ski jumpers. Once data is collected, regression analysis will be performed to establish key performance indicators that highly correlate with resultant jump scores. These performance indicators will allow for evidence backed feedback that coaches can give their athletes to improve their technique and form.

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Introduction

Motivation

Ski jumping first began in Norway in the 19th century and has increased in popularity around the world, becoming a fan favorite sport at the Winter Olympic Games [1]. Video analysis based coaching has also grown in popularity as, regardless of endeavor, it provides athletes with the opportunity to observe their physical performance from an outside perspective, providing insight into the form and approach being taken [2]. Furthermore, a focus on quantitative video analysis, emphasizing key Newtonian biomechanical metrics has emerged as a recent advancement which has been enabled by improvements in high-speed video cameras and artificial intelligence-based motion tracking [3]. Unfortunately, the use of video analysis based feedback has not been widely implemented in ski jumping compared to other sports such as track and field or baseball [4]. In a sport that is very dependent on form and approach, combined with its unique complex physics basis, the need for a quantitative-based visual learning system that tracks specific performance metrics and provides immediate feedback for areas of refinement is apparent. This system has the potential to not only provide coaches access to data driven feedback but also enhance athlete safety by identifying poor takeoff mechanics while establishing more training rigor to further develop a growing sport.

Current Methods

The current scope of ski jump training video analysis is based around a subjective and qualitative-based assessment. More specifically, formal quantitative assessments of ski jump performance have yet to be implemented as a traditional coaching tool [5]. Already in limited supply, most of the domain of published quantitative ski jump analysis relate to investigative explorations of sensor and data tracking in intense environments without regard to how the data collected from the sensors could be used for direct feedback. For example, the combined use of a differential Global Navigation Satellite System (dGNSS) and a markerless video-based pose estimation system in a Norwegian study allowed the collection of key body angle and force metrics. However, this data was used to prove equivalency between the two tracking methods themselves, rather than any specific investigation of a physics-based hypothesis that could be filtered into specific feedback for athletes [4].



Figure 1: Angle analysis from Markerless Video-Based Pose Estimation recording demonstrating the application of post processing angle determination from the sagittal plane [4].

For force plate or pressure data collection, modern pressure tracking insole systems which sectionalize the parts of the foot are mostly commercial products. Several of these products have been used in ski jumping related investigations including the aforementioned dGNSS study but are by no means limited to the specific application. These insoles provide insight into weight distribution and reaction force data created by the specific movements being performed by the athlete [6]. In a study focused on a full body inertial measurement unit (IMU) analysis of ski jumpers, these force insoles can be used in conjunction with other forms of data tracking to provide supporting data for certain observed results. Again, the purpose of the study being referenced was to evaluate the specific measurement system to be further applied to further dynamic analysis, not an improving ski jumping results specific inquiry [7].

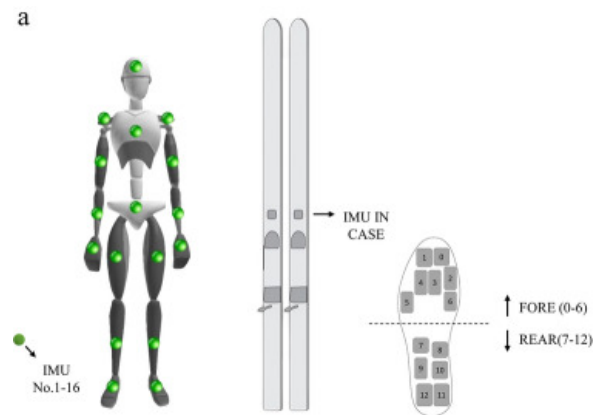


Figure 2: IMU and force insole sensor distribution on the body, skis, and boots of the athlete [7].

Problem Statement

This project aims to develop and prototype a comprehensive training system that enables youth amateur ski jumpers to compare their technique to that of expert jumpers and receive data-driven feedback. The system will integrate 2D motion analysis and force plates to capture biomechanical data metrics, such as body joint angles and ground reaction forces, during the takeoff and initial flight phases. By analyzing relationships between these biomechanical variables and performance outcomes (distance

and qualitative scores), the study seeks to identify which metrics are most highly associated with a more successful jump. The system will then provide coaches with targeted, evidence based feedback that can guide ski jumper training to optimize performance and bridge the gap between amateur and professional performance.

Background

Biomechanics of Ski Jumping

Ski jumping is a highly technical sport that rewards points based on jump distance and style. There are 5 phases in ski jumping, in-run, take-off, early flight, stable flight, and landing. The first 3 phases are important for analyzing biomechanical metrics that will ultimately help the jumper improve technique as there is proven correlation between good form within these phases with higher velocity and farther jump distance [8]. During the early flight stages, judges focus on the symmetry of the ski-opening angle, torso orientation, knee and ankle flexion, and the positioning of the arms. Effective coordination between the ankle, knee, and hip joints ensure smoother transitions into flight and greater aerodynamic efficiency; maintaining optimal ski-opening angle and ankle angles enhance lift-to-drag ratio [9]. Additionally, analyzing body composition and angles during the in-run phase is important to maximize aerodynamics. Specifically, the torso and thigh attack angles as well as the ankle joint and hip joint abduction angles have the most influence on drag, but small adjustments in the torso angle produce larger changes in drag than equivalent changes at the lower body angles [10]. Since the scoring of a ski jump is based on distance and style, it's a very qualitative sport.

Scoring

Ski jumping incorporates two aspects to judge the success of a jump: K-score and style points. For distance, ski jumping incorporates a K-score metric that involves a K-point, the spot where the ski hill flattens out. Landing on this K-point gives a set amount of points with every extra meter past the K-point adding one point and every meter before subtracting one point [11]. In terms of style points, the three judges who are scoring the jump will look for a smooth transition between the in-run and the in-flight position as well as the telemark landing which involves a graceful and staggered ski landing [11].

Client

The client, Dr. Azam Ahmed, is a UW Health neurosurgeon and an associate professor in the Department of Neurological Surgery at the University of Wisconsin School of Medicine and Public Health. He has two daughters involved in youth amateur ski jumping interested in improvement of their technique that goes beyond coach suggestions. They both have been jumping at the Blackhawk Ski Club for five years on hills that use plastic in the offseason and snow during the winter months.

Design Specifications

Design specifications were determined by a combination of requests from the client, literature reviews, and formal standards (see Appendix A). The system should be designed with a focus on youth athletes, making relevant conversions between youth athletes and reference values of more experienced jumpers (coaches at the Blackhawk Ski Club and/or professional ski jumper data from papers). The

motion capture and force sensor should be used to analyze the two second interval transition from the in-run into take-off phases of the jump and then create clear points of improvement based on the acquired data. The system should be non-invasive and should have minimal impact on the athlete being tracked to ensure minimal changes in performance during data capture and normal jumps. In regards to fixed performance requirements, any force sensor recording ground reaction must be able to withstand a static load equal to 2.5 times greater than the maximum specific user weight, based on intrinsic loading requirements for general consumer recording equipment [12]. The sensors must also meet an accuracy class of at least 0.5 following standard recommendations of the International Vocabulary of Metrology (VIM) [13]. The system must also be able to withstand the operating environment, specifically the fluctuating and potentially harsh weather conditions in Wisconsin including 5th percentile temperatures of -23°C (-10°F) and 5th percentile wind speeds of 8 m/s (18 mph), per the Wisconsin Climatology Office [14]. Representation of human models within motion capture analysis should abide by ISO/IEC 19774-2:2019 to ensure compatibility and reproducibility of data outcomes across systems. This standard includes specifics on frame rate, the use of animation of articulated characters, and specific determination of camera position [15]. Any multi-axis force platforms used in the system must be verified and calibrated per standard ASTM F3109-22. These calibration efforts help quantify and reduce error in output signals, ensuring accurate data collection through these sensors [16]. Any human subject research must abide by OHRP and IRB protocol. This includes confirming consent of each subject with full transparency of the data being collected, the purpose of the research, and the risks of harm associated with participation. Additionally, for athletes under the age of 18, further consent from their legal guardian is required [17]. Any team members performing any level of human subject research must first be certified through human subject research training and therefore pass IRB approval and oversight [18].

Preliminary Designs

Accelerometers (IMUs)

The accelerometer (IMUs) design is based around the use of various Inertial Measurement Units that would look to provide high-frequency motion data, with a specific focus on acceleration, angular velocity, and spatial relation. Several small IMU devices would be placed on the user in several specific locations dictated by an associating machine learning software. These locations would be easy to reach, practical, and relevant locations on the body such as the left foot, right shoulder, and waist. The IMU's would be a part of a larger circuit that would involve a central microcontroller functioning both as a voltage distributor and as a processing hub for the raw data being recorded by the IMUs, as well as a battery for voltage supply. These two components would be placed on the waist, along with one of the IMU's.

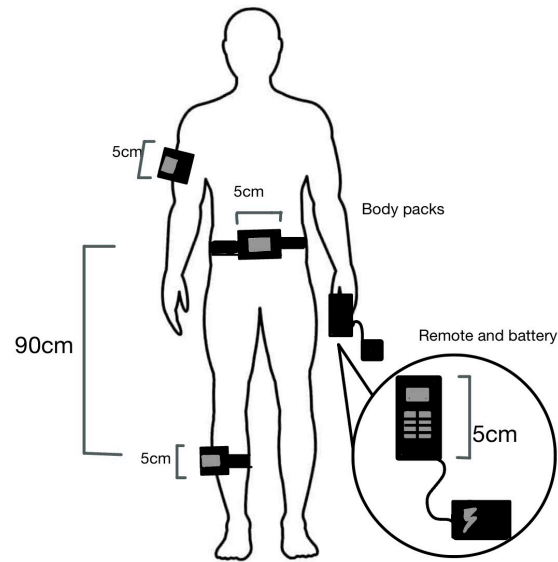


Figure 3: Accelerometers (IMUs) design diagram with dimensions. Remote and battery shown as well as individual unit locations [19].

Force Plate + Motion Capture

The design of the force plate and motion capture is centered around having force plate insoles in the skier's shoes. These force plates are portable devices that we would manually place in the soles of the ski boots and would record reaction force and force distribution measurements. The motion capture aspect of the design would record 2-dimensional body images and segments of movement during the jump from multiple perspectives. This would include the angles of the body, the velocity of the jump, and the kinematics of the takeoff. The motion capture device would be a compact camera or mobile device suitable for outdoor usage, and would be placed directed towards the side view of the jump/jumper.

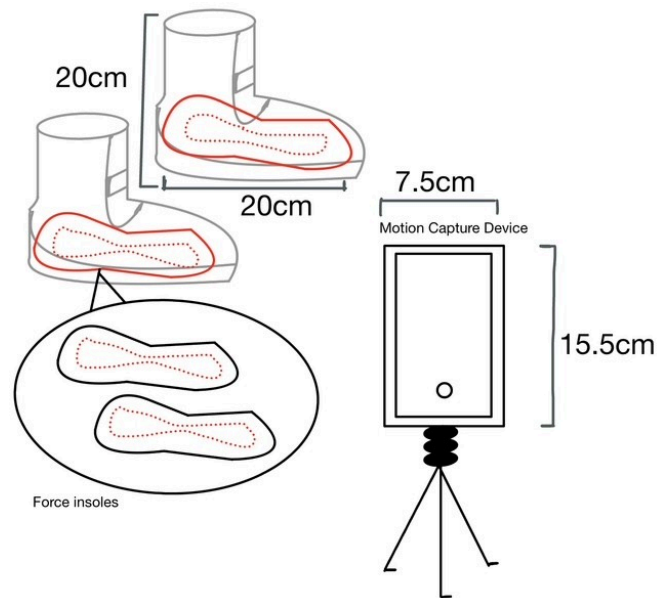


Figure 4: Force Plate + Motion Capture diagram with dimensions. Force insoles and motion capture device shown with tripod [20].

EMG Sensors

The EMG sensor system is aimed to capture electrical signals of the ski jumper's muscles. The system includes a central hub that is wrapped around the user's waist or leg via a belt system and houses the microcontroller, filters, signal converters, and more. The electrodes are textile based and are strategically placed around the athletes body to capture signals from the most important muscles. The goal of this design is to provide insight into muscle activation patterns during the takeoff portion of the jump and may help athletes figure out optimal timing and coordination.

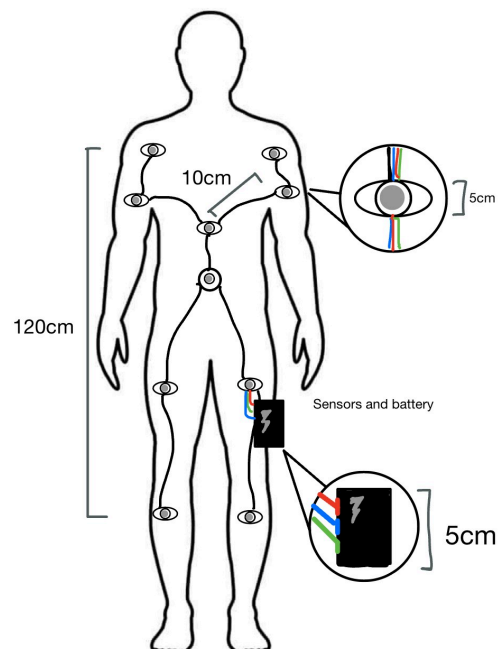
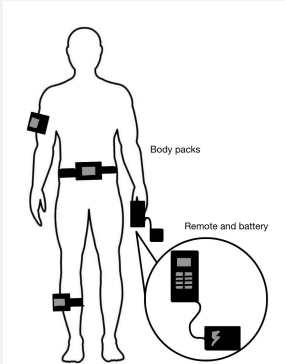
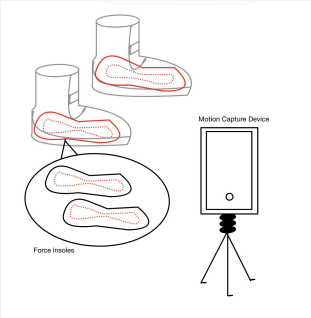
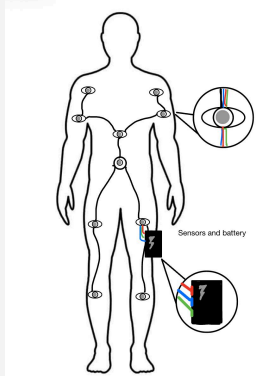


Figure 5: EMG Sensor diagram with dimensions. Suggested electrode placement and sensor/battery main unit shown [21].

Preliminary Design Evaluation

Design Matrix

The most critical design specifications were considered when creating the design matrix. Criteria are weighted and ordered based on importance. The winning design was the Force Plate Pressure Sensor combined with Motion Capture.

		Design 1: Accelerometers (IMUS)		Design 2: Force Plate + Motion Capture		Design 3: EMG Sensors	
							
Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Repeatability	25	3/5	15	5/5	25	2/5	10
Accuracy	25	3/5	15	4/5	20	4/5	20
Athlete Comfort/Interference	15	3/5	9	4/5	12	2/5	6
Ease of Use (Setup and Takedown)	10	4/5	8	4/5	8	2/5	4
Data Feasibility/Processing Burden	10	1/5	2	4/5	8	3/5	6
Durability	5	4/5	4	4/5	4	2/5	2

Safety	5	5/5	5	5/5	5	5/5	5
Cost	5	5/5	5	3/5	3	5/5	5
Total (Out of 100):	63			85			58

Table 1: Ski jump design matrix evaluating form of data collection.

Design Matrix Summary

The design matrix was used as an objective and quantitative method of determination of the best design for the specific form of data collection for the ski jump analysis system. The criteria chosen for this evaluation included: repeatability, accuracy, athlete comfort / interference, ease of use (setup and takedown), data feasibility / processing burden, durability, safety, and cost. Repeatability and accuracy were jointly ranked highest and were defined as the degree to which the same measurement system could produce the same results under the same conditions when repeated multiple times, and the proximity of a measured value to the actual, true and accepted reference value, respectively. Because of the intensely dynamic nature of ski jumping, a system that could provide consistent, reliable results over the course of time was deemed paramount. The Force Plate + Motion Capture design was ranked highest in these categories because of its manual post-processing requirements and inherent lack of data disturbance caused through noise or circuit breakage. Because of the direct interaction between the system and the athletes themselves, athlete comfort / interference was deemed highly important. Again, the Force Plate + Motion Capture design was ranked highest because of the lack of system components that would need to be placed on the athlete directly. The lower ranked designs contain more invasive component distributions, and therefore have a higher chance of irritation, disturbance and influence on athlete performance. Ease of Setup and Takedown and Data Feasibility were also considered. Defined as the ease to which the system can be setup and taken down each time the ski hill is visited, with relative consistency, and the practical possibility of data collection in the actual environment, outside of theoretical design, respectively, both categories again tended towards the Force Plate + Motion Sensor design because of inherent sensor characteristics of both the Accelerometers (IMUs) and EMG Sensors design. In an external environment, accelerometers utilize a global reference frame which introduces high probability of data error. EMG sensors require the consistent placement of electrodes on specific muscles across users, which introduces difficulty in the system setup. The last three categories, durability, safety, and cost, were important to consider but did not provide much disparity between the designs. This lack of disparity in conjunction with their low weights means they did not make significant impacts on the final conclusion of the matrix.

Proposed Final Design

The design that will be focused on moving forward is the Force Plate + Motion Capture design. This design scored highest, or joint highest, in all categories besides cost. The Force Plate + Motion Capture design utilizes contemporary methods of ski jump analysis and applies quantitative analysis to allow for a comprehensive review of performance. The design is reliable, consistent, and minimizes athlete interference through use of noise-resistant and non-invasive methods. The system consists of force plate insoles to track the generation of reaction forces and weight distribution of the athlete and a

2-dimensional motion capture software to track vital angle development through the progression of the jump. The metric values derived from these components will be translated into concrete pieces of advice that will be given to the athlete, allowing for the direct improvement of jump score.

Fabrication

Materials

The materials required for the project are broken down into the two data collection methods: motion capture and force sensor. For the force sensor, there are commercially available options that could be purchased, however, with each participant in the study getting individually sized insoles, their cost could get expensive. Custom fabrication of force insoles would be more cost effective and would require force sensors, conductive wiring to transmit outputs, and a central microcontroller to convert analog forces into readable digital devices. Additional components could include connectors, compact power supply, and protective encapsulation material. In parallel, a motion capture video analysis system will be implemented to collect kinematic data of the jumper's body position and angles during takeoff and flight. Because the system will be deployed at two separate testing locations, it will require two software-compatible recording devices and two adjustable tripods to maintain consistent camera positioning and synchronization with the force data. Together, these components will provide complementary kinetic and kinematic data necessary to evaluate ski jumping performance and technique.

Fabrication Plan

Force Plate Insoles

The insole will be fabricated through the use of Velostat, an electrically conductive material whose resistance changes due to flexion or compression [22]. Small portions of the Velostat will be placed on various parts of the ski boot liner and connected to thin strips of copper tape which will be soldered to electrical wiring at the back end of the insole. The insole will be wrapped in electrical tape to stabilize the sensors and tape in place, and to avoid both circuit and athlete harm. The wires at the back of the insoles will further be connected to a microcontroller which will keep track of all data being recorded. The microcontroller will be kept within a 3D-printed housing unit with a battery that will be attached to the exterior of the athlete's boot.

Motion Capture System

The fabrication of the Motion Capture system is rather a general set up of the components. Two distinct cameras will be set down on opposite sides of the jump via tripods. The first camera will be aimed directly orthogonal to the jump path, approximately 15 feet away, acquiring a 2-dimensional side image of the takeoff phase. The second camera will be from the judges perch, which will capture an isometric perspective of the initial flight phase of the jump. Once data collection has begun, specific tripod locations and height settings will be recorded and replicated in order to keep consistent video characteristics across days.

Testing and Results

Testing Plan

In order to use the specific quantitative variables being observed within the system as grounds for jump improvement, statistical backing needs to be provided to prove variable correlation. Because neither a 3-dimensional physics model for ski jumping nor a consistent and large body of ski jump data exists, extensive data would be required to prove a causational relationship. More specifically, an isolated independent variable needs to be tested against a set of conditions which is not feasible in ski jumping due to the immense amount of variability that is present during any jump. Therefore, the project will focus more on finding correlational relationships between chosen metrics and jump results and use the key metric to explain potential points of improvement for athletes.

At Blackhawk ski club, there are 3 to 5 consistent year round youth ski jumpers who are planned subjects for the project. Beyond this, there are several other members of the club who could be added on to this subject list. Based off of the coaches training plan, each youth athlete does approximately 8 to 10 jumps, twice a week. The current plan is to track data for two practices and record data for 16 to 20 jumps for each individual athlete.

Once data is collected, regression analysis will be performed to determine which specific metrics correlate strongest with the best jump results.

Conclusions

The project is a biomechanical research study on ski jumping that utilizes a data collection system allowing youth ski jumpers to compare their technique to experts and receive data driven feedback. The data collection system will integrate motion capture and force sensing insoles to collect body angles and ground reaction forces during the take-off and early flight phases of the jump.

The development of the system introduces a new quantitative approach to coach feedback in ski jumping, contrary to the traditional method of watching each jump and giving advice based on qualitative cues. To further develop the project, trips will be made to Blackhawk ski club to troubleshoot data collection methods until reliable data is able to be collected. Then, a more comprehensive data collection process will be implemented, as outlined in *Testing Plans*, which will give the information required for the regression analysis of all metrics.

Identifying these correlational relationships will allow partnership with coaches to figure out direct feedback for the youth athletes in terms of form and technique.

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Appendix

Appendix A: Preliminary Design Report

Function

Ski jumping is a highly technical and competitive sport that demands precise angular body positioning and timing to achieve optimal performance. To assist youth athletes in improving their skills, a ski jumping training system will collect biomechanical data during the in-run and take-off portions of the jump and compare it with reference data captured from more experienced jumpers. The system must capture key biomechanical data metrics, including lower-body joint angles, torso stability, torso orientation, and vertical ground reaction forces. Data analysis must be performed on these measurements to identify differences between youth and experienced athletes. This analysis will provide youth ski jumpers and their coaches with quantifiable feedback to improve technique, optimize take-off timing, and ultimately enhance jump performance.

Client Requirements

Dr. Azam Ahmed and Dr. Walter Block outlined the following specifications for the ski jumping training system:

- The ski jump training system should be designed for youth athletes.
- The system must enable comparison between youth athletes and expert reference data.
- The ski jump training system must be usable at ski hills to capture realistic training conditions.
- A motion capture system that is capable of recording the 1-2 second in-phase to take-off transition of the jumping phase.
- Video and data analysis software that provide athletes and coaches with clear points of improvement based on input data.
- The project budget is up to \$5,000, contingent on demonstrated progress, to acquire various sensors, IMU, force insoles, and other necessary materials.
- Resources provided by the University of Wisconsin-Madison and recommended for use by the client include CAE software, BME teaching labs, ECB built-in force plates, and ECB motion capture system.
- Human subject testing must follow consent procedures, especially for minors.

Design Requirements:

1. Physical and Operational Characteristics:

a. Performance Requirements:

- i. The device must be capable of accurately calculating vertical ground reaction forces while withstanding a static load equal to 2.5 times the greater of 136 kg or the maximum specified user weight. The loading factor of 2.5 is based on intrinsic loading requirements for general consumer fitness recording equipment standards [1].
- ii. To optimize motion capture performance outdoors on ski hills, the system must

utilize a minimum of three non-collinear markers per rigid body segment to track its six degrees of freedom (6-DOF) [2].

- iii. The data analysis and motion capture software GUI must be operated on devices with a minimum 800 MHz processor, 2 GB RAM, and 1 GB available hard disk space [3].

b. Safety:

- i. All accessible areas of the training system must be free of burrs and sharp edges [1].
- ii. All corners of the training system must be radiused or chamfered [1].
- iii. Prior to testing the training system on youth athletes, parental permission and child assent must be obtained and comply with federal regulations (45 CFR 46 Subpart D) [4].
- iv. IRB approval and oversight are required prior to human subject data collection from various ski jumping athletes: all investigators must complete certified human-subjects training [4].
- v. Safety and injury prevention of participants must be prioritized by placing low risk simulated practice tasks before outdoor ski hill testing [4].

c. Accuracy and Reliability:

- i. The sensors in the training system must meet an accuracy class of at least 0.5 following the International Vocabulary of Metrology (VIM) standard. This ensures that the combined effects of measurement uncertainty, linearity deviation, and temperature-related drift remain within plus or minus 0.5% of full scale per 10 °C under specified operating conditions [5].
- ii. The motion capture of our training system must measure lower-limb and torso joint angles in the sagittal plane with a precision (repeatability) better than $\pm 3^\circ$ under ski hill conditions [6].

- iii. Under ECB teaching lab conditions, the markerless motion capture system should demonstrate relative error $\leq 0.51\%$ and absolute error $\leq 0.22^\circ$ [6].

d. Life in Service

- i. Based on ski jumping training system development guidelines, youth athletes aged 10–13 typically perform 1–2 dryland training sessions per week. The training system must be designed to withstand this frequency of use over its service life [7].
- ii. In terms of annual usage of the training system U12 athletes on average perform 300 to 400 jumps which the system should be able to withstand at least half if the athlete wants to track their data over time [7].

e. Shelf Life:

- i. The piezoelectric sensors integrated into the force plate system must demonstrate a shelf life of 15–20 years under normal storage conditions (15–25 °C), non-corrosive environment, no excessive shock or vibration. [8].
- ii. Motion capture cameras involved in our training system are IR cameras with an average shelf life of 5.7 to 11.4 years [9].

f. Operating Environment:

- i. The training system must operate reliably in laboratory conditions with average temperatures ranging from 20-25 °C and a relative humidity of 30-50% [10]. The lab environment should be free of corrosive gases, particulates, and other harmful substances that may damage the system [10].
- ii. The training system must also operate reliably in outdoor conditions, which can vary significantly due to the year-round nature of ski jumping. Operation must remain stable across typical seasonal changes, with details of extreme weather tolerances provided in Section J.

g. Ergonomics:

- i. Any software element of the system that users will be interacting with should be user-friendly and should not require any prior knowledge or training.
- ii. The comparison of relevant mechanics and metrics done by the system should be a streamlined process, and suggested improvements should be easy to understand.
- iii. The recording system should be low in component number and should follow an easy set up procedure for ease of use on the ski hill.

h. Size:

- i. Components of the system must be transported up and down the ski hill as well as between the ski hill and campus and therefore should assume a relatively small size for easy transportation. Packed together, the overall system should not exceed a 0.56 m x 0.36 m x 0.23 m (22 in x 14 in x 9 in) volume in any dimension [11]. The components should be small enough to fit within these dimensions per traditional backpack size recommendations given by the DHS as this will allow easy transportation of the system.

i. Weight:

- i. The weight of the system should be safe to lift and light enough to carry an extended distance by any individual regardless of strength. Components of the system will need to be transported up and down the ski jump hill and should therefore be easily transportable. The system should preferably weigh less than 20% of the transporter's personal body weight in order to avoid intense strain [12]. Further, the system should not exceed a weight of 23.1 kg if it were to be carried in a backpack per NIOSH and OSHA recommendations in order to prevent extensive damage to the bones and ligaments of the back [13].

j. Materials:

- i. Durable and climate-resistant materials are a necessity for the intense setting of

ski jumping. The training system should consist of materials that can survive in the harsh winter conditions of Wisconsin. These conditions include 5th percentile temperatures of -23°C (-10 °F) [14] and 5th percentile wind speeds of 8 m/s (18 mph) [15], per the Wisconsin Climatology Office. Further, the system should be able to endure adequate levels of moisture and precipitation, including direct external contact with both rain and snow.

- ii. Components of the design in direct contact with both human subjects and users must be made of non-irritative materials and must be absent from common allergens in order to prevent complications [16]. General biocompatibility in context with usage is required for any component utilized during human subject involvement and should therefore follow ISO standard 10993 for biological evaluation of medical devices [17].
- iii. The fast-paced, dynamic nature of skiing also requires materials to be able to withstand intense force. Any component of the system worn or attached to the user must be able to withstand repeated extreme inertial, drag, and compressive forces [18].

k. Aesthetics, Appearance, and Finish:

- i. The finish of the analysis system should be clean and smooth. The system should be absent of sharp or harsh edges and all electrical wiring should be covered and separated from the outside environment [19]. The entire system should be as simple and organized as possible for ease of use, without sacrificing functionality. The system should also present a darker color to make identification of components easier in a potential white landscape of snow on the hill. The entire system should look cohesive and should carry a professional aesthetic.

2. Product Characteristics:

a. Quantity:

- i. Only one ski jump launch trainer will be designed and fabricated. The entire system will be reusable and shared amongst the users. Prototyping will be a consistent iteration of the same system and testing of the system will be done to ensure the final product has consistent output and performance.

b. Target Product Cost:

- i. With consideration of the various components required for the system already available at the university, and an evaluation of prices for motion capture based training systems, a target cost for the project is approximately \$500 [20]. This figure is a summation that includes the \$50 stipend given for the project by the department as well as further monetary support that will be provided by the client if and when required.

3. Miscellaneous:

a. Standards and Specifications

- i. The ASTM F3109-22 standard states how to verify, test, or calibrate multi-axis force platforms like force plates used in balance. It has methods to quantify error in output signals across the working surface and force ranges, and includes parameters like the Center of Pressure. The ski jump simulator falls under this standard, as we will have to run multiple tests of the force plates to determine the data of the amateur skier and compare it to the data of the expert [21].
- ii. The ISO/IEC 19774-2:2019 standard covers motion capture and motion data animation for humanoid models. It specifies how to represent motion capture data in a structured way, particularly for the use of animation of articulated characters. It ensures compatibility and reproducibility of motion data between systems. The ski jump simulator falls under this standard because it will use the

motion capture of humanoid models to obtain data related to the biomechanics of ski jumping. For example, data is sampled per frame and this standard defines the frame count, frame time (time per frame) and how the total duration is computed [22].

b. Customer:

- i. The users of this device will be youth amateur ski jumpers with the average age from 8 to 12 years old. They will want the data collected to be reliable and accurately compared to an expert's data so they know what aspects of their jump they must change to improve it and more closely mimic the expert.

Patient-Related Concerns:

- a. For human subject research, the participants must fully understand what data is being collected from their ski jump, what the motion capture set up involves, and how the data will be used, stored, or shared. Since we will be working with young amateur athletes, getting the parents informed consent is also needed [23].
- b. Participants may also be concerned about the risk of harm depending on the use of the motion capture. If it gets in the way of the ski jump, it could cause injuries. We must ensure the motion capture equipment does not get in the way of safety gear or impact the jumper's mobility in any way [23].
- c. Privacy and confidentiality are crucial for the motion capture data because it could potentially personally identify the jumper by video footage or biometric signatures. To ensure privacy, we should first clearly inform the participants how long the data will be kept and who can access it as well as try to de-identify the motion capture data related to each jumper who participates [23].
- d. Since there is a trainer involved who may have the Blackhawk ski club use our motion capture system for their ski jump, it is important to make sure all participants know their participation is voluntary and that just because their club may be using our system, they

aren't required to have their jump data measured and collected [23].

Competition:

Automated Motion Evaluation System from Wearable Sensor Devices for Ski Jumping

- i. Researchers developed a machine learning-based system using inertial sensors to automatically evaluate ski jumping performance, capturing full-body motion data from junior athletes and comparing it to style scores from expert judges to train and test the model [24].
- ii. The system segments jumps into key phases, analyzes kinematic features, and detects style faults in accordance with official scoring rules, showing strong alignment with human judging and offering potential for more objective, mobile performance evaluation in jury-based sports [24].
- iii. A multi-step data processing pipeline was developed to extract accurate kinematic motion data from inertial sensors, including sensor-bone alignment, orientation estimation, magnetic disturbance compensation, and joint position calculation, enabling reliable segmentation of ski jumps into key phases like flight and landing [24].
- iv. Key motion features—both technical (e.g., ski angles, joint positions) and aesthetic (e.g., stability, leg extension)—were extracted and used in a machine learning pipeline with Dynamic Time Warping to compare jumps against reference patterns, achieving high precision and recall (70–85%) in detecting style errors relative to human judge scores [24].

Theia Markerless Motion Capture Device

- v. Uses 10 SONY RX02 cameras to collect data sets of ski jumping movements in a ski jumping stadium [25].
- vi. Uses data collected from cameras to offer insight into performances, technique,

and aerodynamics [25].

- vii. Analyzes the joint angles of the hip, knee and trunk movement across the take-off phase, aerodynamic profiles in airflow and lift/drag during flight phase, and real-world technique to give performance insights [25].
- viii. User-friendly “ANALYZE” function after calibration to accelerate data processing [25].

Foot Pressure Sensors

- ix. Insoles composed of 16 pressure sensors, 3 accelerometers, and 3 angular rate sensors per side [26].
- x. Great for tracking volume and distribution of force during a specific action [26].
- xi. Uses many internal sensors that are hooked up to a chip that communicates to its online interface through Bluetooth [26].

Appendix B: Materials Table

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Motion Capture System										
Tripod with Bag	60 inch lightweight tripod with adjustable-height legs and rubber feet, compatible with smartphone adapters.	Amazon Basics	WT3540	Amazon	B005KP473Q	10/1/25	2	\$25.99	\$51.98	https://www.amazon.com/AmazonBasics-Lightweight-Camera-Mount-Tripod/dp/B005KP473Q/ref=sr_1_3?crd=3QVMAL6ADM9UU&keywords=amazon%2Btripod&qid=1641324171&srefix=amazon%2Btripod%2Caps%2C150&sr=8-3&th=1
Tripod Mount Adapter	Vertical and horizontal mount adapters for smartphones.	Sharing Moment Co.	H-200112	Amazon	B07S8TTH34	10/1/25	1	\$6.99	\$6.99	https://www.amazon.com/dp/B07S8TTH34?ref=ppx_vo2ov_dt_b_fed_asin_title

	Pack of 2								
							TOTAL:	\$58.97	

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