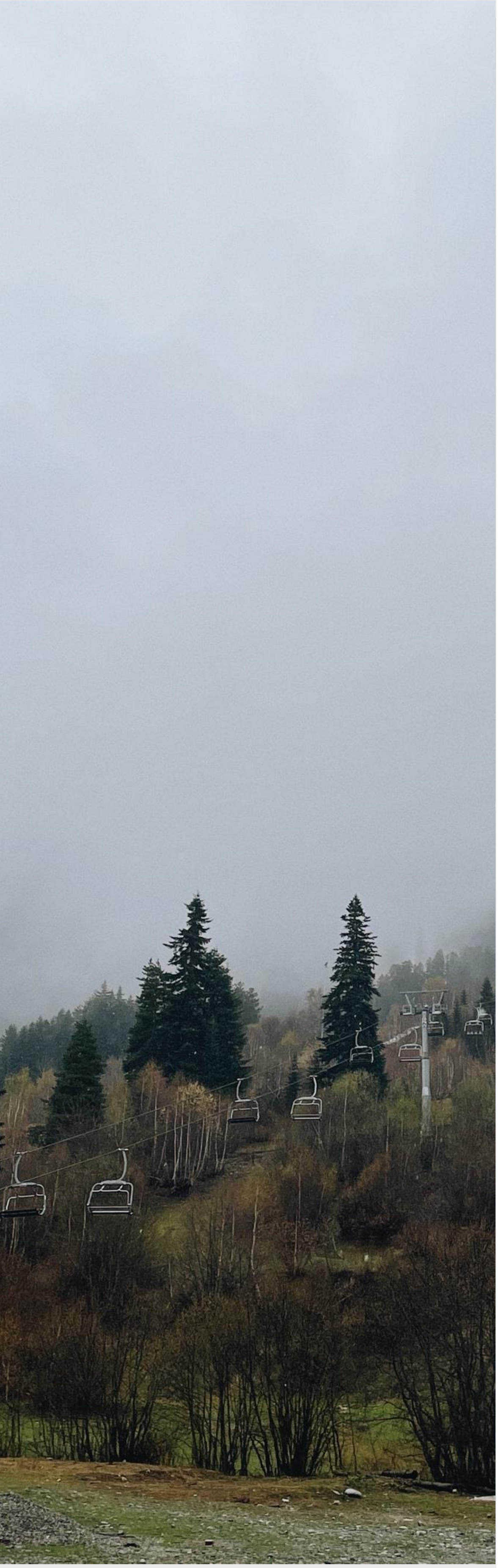
Freestyle Mogul Skiing

# *SPORT DEMANDS ANALYSIS*

2018-2022

JOSHUA B. BULLOCK

UNITED STATES OLYMPIC & PARALYMPIC COMMITTEE



# ABOUT THIS DOCUMENT

This document is the first of a two-part series on the athletic development process for the United States Freestyle Mogul Team between 2017 and 2022. This *Sport Demands Analysis* contains the why and what of the preparation process, in part two, the *Athletic Development Statement*, containing the how.

This document is the culmination of nearly five years of work, it contains ten independent research projects conducted around the world, and includes a complete literature review on the subject. As of its writing, it is considered the most comprehensive document ever written for the sport.

This document was not written in isolation. It is the work of countless professionals and many athletes willing to sacrifice a bit of themselves for the betterment of those who will walk in their metaphorical footsteps.

Edited By:
William A. Sands, Ph.D., FACSM
Josh Nelson, Ed.D.
Scott Fricke, MS, RSSCC*E

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# ABOUT AUTHOR

My name is Josh Bullock, and I have spent the last 17 years developing high-performing teams in both the collegiate and Olympic sports settings. My responsibilities have included but are not limited to 1) staff management and development, 2) facilities management, 3) budget oversight and capital projects, 4) applied sport science, data collection, analysis, and interpretation, 5) course development and instruction, 6) article publication and 7) athlete and coach development.

I have had the great fortune of working with some truly inspiring people on some challenging, enjoyable, and innovative projects. I have worked alongside and become friends with many influential and creative individuals along the way. I believe in the power of collaboration to create a whole that is greater than the sum of its parts.

## FIND ME


**Email :**
Josh.B.Bullock@gmail.com

**Website :**
www.joshbullock.org

**Instagram :**
Josh.B.Bullock

**LinkedIn :**
www.linkedin.com/in/josh-benjamin-bullock



Josh Bullock

Chapter 01

# OVERVIEW OF SPORT

Mogul skiing is a freestyle skiing competition consisting of one timed run of free skiing on a steep, heavily moguled course, stressing technical turns, aerial maneuvers, and speed (Federation International de Ski, 2013-2014). Internationally, the sport is contested at the Federation International De Ski (FIS) World Cup Tour, FIS Freestyle World Ski Championships, and the Winter Olympic Games.

The first competition involving mogul skiing occurred in 1971. The FIS created the Freestyle World Cup Circuit in 1980. The first World Championships were held in 1986 and are currently held in odd-numbered years. It has been a medal event in the Winter Olympics since 1992.

Dual mogul competition consists of elimination rounds where pairs of competitors compete against each other. Each winner advances to the next round, and each loser is eliminated until a final result is achieved. Dual mogul competition is not held in Olympic years.

## Duration

The duration of a typical mogul run varies by grade, length of the course, and overall course conditions. Below are the pace times for courses on the 2017-2018 World Cup Tour.

| VENUE | MEN | WOMEN |
|---|---|---|
| RUKA | 20.87 | 24.43 |
| THAIWOO | 22.71 | 26.59 |
| CALGARY | 20.87 | 24.43 |
| DEER VALLEY | 24.46 | 28.63 |
| TREMBLANT | 22.33 | 26.13 |
| PYEONGCHANG (OWG) | 24.27 | 28.40 |
| THAIWOO | 22.71 | 26.59 |
| MEGEVE | 25.33 | 29.65 |
| | | |
| AVERAGE | **22.94** | **26.86** |


# Scoring

## Single Moguls

Moguls competition scoring consists of three parts (Federation International de Ski, 2013-2014).

1) Aerial acrobatics constitute 20% of the score (0.0 – 20) and are broken down into two parts: a) form and b) difficulty.

2) Turns, which refers to the technical evaluation of how well a competitor turns through the moguls, constitute 60% of the score (0.0 – 60). Turn evaluation is scored using rhythmic changes in the direction of travel to either side of the fall line, utilizing an aggressive, controlled technique.

3) Speed constitutes 20% of the score (0.0 – 20). Speed is the distance (m) divided by the time (s) taken to complete the run. The pace for moguls is 8.8 m/s for women and 10.3 m/s for men.

## Scoring Procedures

Seven Judges evaluate the competitor's performance using a split scoring system as follows:

Five Turn Judges independently evaluate the competitor's performance. The high and low scores are discarded, and the remaining three scores are added together.

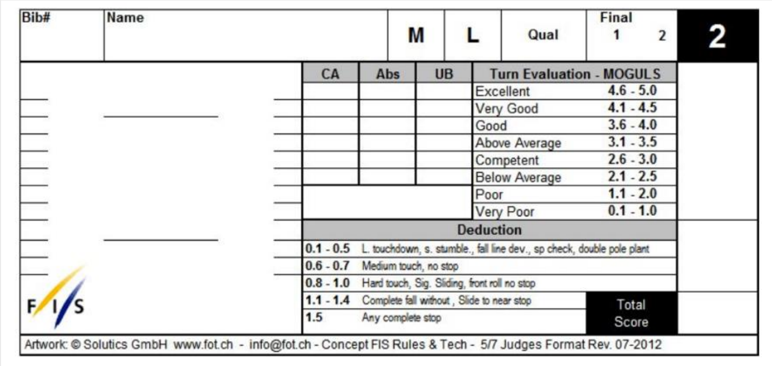
Two Air Judges independently evaluate the competitor's aerial manoeuvres. The scores are averaged for a total air score and truncated to two decimal places.

The average of the two air scores is added to the remaining three counting turn scores to get the competitor's evaluated score. The speed score is added to the total evaluated score to determine the competitor's complete score.

# Dual Moguls

The dual mogul competition consists of elimination rounds where pairs of competitors compete against each other. Each loser is eliminated, and each winner advances to the next round until a final result is achieved. The competition again takes place on a steep, heavily moguled course, stressing technical turns, aerial maneuvers, and speed.

Beginning in the 2018-2019 season, dual mogul competition will be judged using the same format as the single mogul event. Simply stated, the two competitors will be judged independently using a single-run format. The higher score will advance to the next round until a winner is declared.



Bib# | Name | M | L | Qual | Final 1 2 | 2

| CA | Abs | UB | Turn Evaluation - MOGULS | |
|---|---|---|---|---|
| | | | Excellent | 4.6 - 5.0 |
| | | | Very Good | 4.1 - 4.5 |
| | | | Good | 3.6 - 4.0 |
| | | | Above Average | 3.1 - 3.5 |
| | | | Competent | 2.6 - 3.0 |
| | | | Below Average | 2.1 - 2.5 |
| | | | Poor | 1.1 - 2.0 |
| | | | Very Poor | 0.1 - 1.0 |

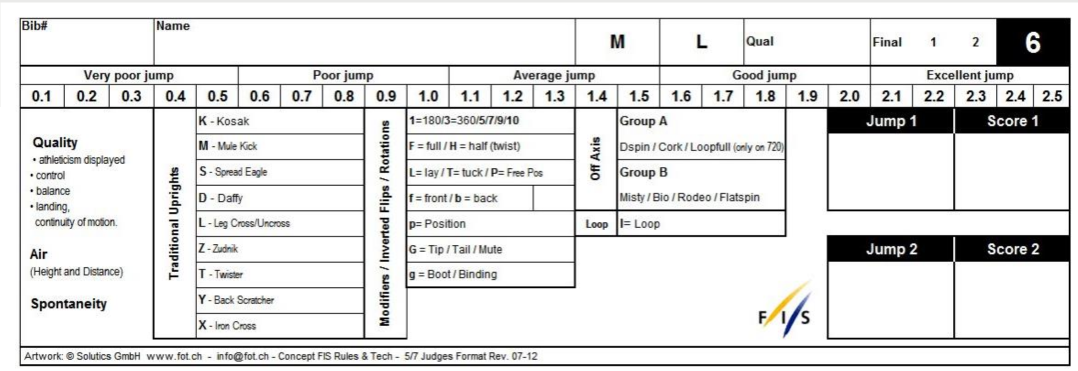
| Deduction | |
|---|---|
| 0.1 - 0.5 | L. touchdown, s. stumble., fall line dev., sp check, double pole plant |
| 0.6 - 0.7 | Medium touch, no stop |
| 0.8 - 1.0 | Hard touch, Sig. Sliding, front roll no stop |
| 1.1 - 1.4 | Complete fall without , Slide to near stop |
| 1.5 | Any complete stop |

Total Score

Artwork: © Solutics GmbH www.fot.ch - info@fot.ch - Concept FIS Rules & Tech - 5/7 Judges Format Rev. 07-2012

***Above:*** *Sample judge's scorecard for Turns.*

***Below:*** *Sample judge's scorecard for Airs.*



Bib# | Name | M | L | Qual | Final 1 2 | 6

| Very poor jump | | | | | Poor jump | | | | | Average jump | | | | | Good jump | | | | | Excellent jump | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 |

**Quality**
- athleticism displayed
- control
- balance
- landing, continuity of motion.

**Air**
(Height and Distance)

**Spontaneity**

Traditional Uprights:
K - Kosak
M - Mule Kick
S - Spread Eagle
D - Daffy
L - Leg Cross/Uncross
Z - Zudnik
T - Twister
Y - Back Scratcher
X - Iron Cross

Modifiers / Inverted Flips / Rotations:
1=180/3=360/5/7/9/10
F = full / H = half (twist)
L= lay / T= tuck / P= Free Pos
f = front / b = back
p= Position
G = Tip / Tail / Mute
g = Boot / Binding

Off Axis:
Group A
Dspin / Cork / Loopfull (only on 720)
Group B
Misty / Bio / Rodeo / Flatspin

Loop: l= Loop

| Jump 1 | Score 1 |
|---|---|
| | |

| Jump 2 | Score 2 |
|---|---|
| | |

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Chapter 02

# THE COURSES

## The Courses

Mogul courses differ from venue to venue, but all adhere to a specific minimum or maximum criteria. Course length ranges from 200-275 meters with an average slope grade of 26 degrees. Moguls are set approximately 3.5 meters apart, and the course contains two small jumps used for aerial acrobatics (Federation International de Ski, 2017).

The image at right displays World Cup course standards for freestyle mogul skiing as set by the FIS.

| Code | Mogul Course Criteria 4200 | Measurement |
|---|---|---|
| CW (m) | Course Width | 18m minimum |
| TW (m) | Track Width | 10m ± 2m |
| CL (m) | Course Length | 235m ± 35m |
| CF (m) | Control Gate to Fence | 2m minimum |
| SJ (m) | Start to Judges Stand | 300m maximum |
| VD (m) | Vertical Drop Start to Finish | 110m ± 30m |
| HD (m) | Horizontal Distance | 175m ± 35m |
| CA (°) | Course Angle | 28° ± 4° |
| A1 (m) | Start to 1st Air Bump | 15% of CL |
| A2 (m) | 2nd Air Bump to Finish Line | 20% of CL |
| FL (m) | Finish Area Length | 35m ± 5m |
| FA (°) | Finish Area Angle | 5° ± 5° |
| No section of the course longer than 20m, shall be less then 20° or greater than 37° | | |
| Minimum length of course for World Championships is 225 m and Winter Olympic Games is 250m | | |
| | **ICR 4202.1.4.6 Air Bump Criteria and Specification** | |
| JL (m) | Maximum Distance - last bump to the takeoff (m) | 4.0m - 5.0m |
| LZ (m) | Maximum Distance - takeoff to end of landing (m) | 15.0m |
| AH (cm) | Air Bump Height (cm) | 50cm - 60cm |
| LA (°) | Landing Zone Angle (LA) in degrees (°) | Greater than 26° |
| TA (°) | Takeoff Angle in degrees of jump (°) | 26° - 30° |
| AW (cm) | Air Bump Width (not less than in cm) | 120cm |

Chapter 03

# SPORT DETAILS

## Equipment

Freestyle ski equipment differs slightly from standard alpine skiing equipment.

### Skis

Mogul skis usually have no or a minimal side cut and are narrower since edge transition occurs very rapidly, approximately 3-4 times per second (Sands & Bullock, Accelerometry of Mogul Skiers, 2018). Mogul skis are stiff behind the binding and more flexible towards the tip, enabling the skier to keep a stable body position and absorb the forces induced by travel over bumps.

### Poles

The general rule in recreational skiers for choosing the correct pole length suggests a 90° angle between the upper arm and forearm when holding the pole. Ski poles are available in different widths and can be semi-flexible to stiff. Mogul poles are shorter than those of the average skier. They commonly measure between 95cm and 115cm in World Cup mogul skiers. Pole length is established as the skier stands in a valley between two bumps and places the pole atop the bump in front.

### Boots

Mogul ski boots have rigid soles and attach to the binding at the toe and heel. Boots are available in various degrees of stiffness or flex depending upon athlete anthropometry, skiing technique, and ability. Many athletes modify stock boots using custom footbeds, liners, and heating elements.


### Bindings

Bindings consist of a heel piece and a toe piece. Bindings have built-in safety features that allow them to release through the application of force that pulls up on the heel or torque that rotates the foot. The force required to release a binding can be adjusted based on athlete anthropometry, skiing technique, and ability. This setting is known as the Deutsches Institut or, more commonly as, the DIN. Finally, many mogul skiers opt to ski using a binding that has a pivoting heel piece.

# Technique

During a mogul run, the skis should stay together to act synchronously. The essential movements include bending the legs to absorb the mogul and the active extension of the legs immediately after crossing the mogul to push the ski tips into the subsequent void separating the bumps. Eccentric back extension also plays a pivotal role as the athlete impacts the bump and crosses over its crest (Sands & Bullock, EMG of Mogul Skiers, 2018). The poles are set alternately onto the backside of the mogul very quickly. They should remain in front of the body to avoid inefficient movements with the arms (Kurpiers, Dynamics of Freestyle Skiing, 1994, p. 30).

# Uniforms

Currently, there is a general belief in the mogul skiing community that a white uniform will camouflage mistakes made by the skier and therefore improve the final score for the competitor. Additionally, in observations made by the author, it is not uncommon to see athletes modify the knee patch using tape, marker, or paint to improve judging perception. Given the anecdotal nature of the author's observations, some further investigation was warranted. Using data collected throughout the 2018-2019 season, Sands and Bullock (Moguls Uniform Study, 2019) categorized skiers into four categories and aggregated the turn scores from the top 24 skiers from each gender in the World Cup. The analyses were collapsed across gender (N=48).

The four categories include light or dark uniform, light or dark patches, patches worn high (above the midline of the tibia) or low (below the midline of the tibia), and large (those that cover more than one half the tibial length) or small patches (those that cover less than one half the tibial length). When categorizing athletes, video review was used while the athlete was at approximately 90 degrees of knee flexion with a front-facing view, just as the judges stand at the World Cup is positioned.

All data was analyzed chi-square using SPSS “Cross Tabs” procedure. The results of the analysis are in the graphs on the following pages.

# Pant Color: Light vs. Dark

**Crosstab**

| | | | PantsL1D2 1 | PantsL1D2 2 | Total |
|---|---|---|---|---|---|
| All Median Groups | 1 | Count | 10a | 2a | 12 |
| | | % within PantsL1D2 | 27.8% | 16.7% | 25.0% |
| | 2 | Count | 7a | 5a | 12 |
| | | % within PantsL1D2 | 19.4% | 41.7% | 25.0% |
| | 3 | Count | 11a | 1a | 12 |
| | | % within PantsL1D2 | 30.6% | 8.3% | 25.0% |
| | 4 | Count | 8a | 4a | 12 |
| | | % within PantsL1D2 | 22.2% | 33.3% | 25.0% |
| Total | | Count | 36 | 12 | 48 |
| | | % within PantsL1D2 | 100.0% | 100.0% | 100.0% |

Each subscript letter denotes a subset of PantsL1D2 categories whose column proportions do not differ significantly from each other at the .05 level.

**Chi-Square Tests**

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 4.444[a] | 3 | .217 |
| Likelihood Ratio | 4.710 | 3 | .194 |
| Linear-by-Linear Association | .087 | 1 | .768 |
| N of Valid Cases | 48 | | |

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

The images above display the statistical analysis for pant color (light or dark) category. Pant color fails to differentiate between median scores or groups (Sands & Bullock, Moguls Uniform Study, 2019).

# Patch Color: Light vs. Dark

**Crosstab**

| | | | PatchShadeD1L2 1 | PatchShadeD1L2 2 | Total |
|---|---|---|---|---|---|
| All Median Groups | 1 | Count | 10a | 2a | 12 |
| | | % within PatchShadeD1L2 | 27.8% | 16.7% | 25.0% |
| | 2 | Count | 7a | 5a | 12 |
| | | % within PatchShadeD1L2 | 19.4% | 41.7% | 25.0% |
| | 3 | Count | 11a | 1a | 12 |
| | | % within PatchShadeD1L2 | 30.6% | 8.3% | 25.0% |
| | 4 | Count | 8a | 4a | 12 |
| | | % within PatchShadeD1L2 | 22.2% | 33.3% | 25.0% |
| Total | | Count | 36 | 12 | 48 |
| | | % within PatchShadeD1L2 | 100.0% | 100.0% | 100.0% |

Each subscript letter denotes a subset of PatchShadeD1L2 categories whose column proportions do not differ significantly from each other at the .05 level.

**Chi-Square Tests**

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 4.444[a] | 3 | .217 |
| Likelihood Ratio | 4.710 | 3 | .194 |
| Linear-by-Linear Association | .087 | 1 | .768 |
| N of Valid Cases | 48 | | |

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 3.00.

The images above display the statistical analysis for the patch color (light or dark) category. Patch color fails to differentiate between median scores or groups (Sands & Bullock, Moguls Uniform Study, 2019).

# Patch Size: Small vs. Large

**Crosstab**

| | | | PatchSizeS1L2 1 | PatchSizeS1L2 2 | Total |
|---|---|---|---|---|---|
| All Median Groups | 1 | Count | 8a | 4a | 12 |
| | | % within PatchSizeS1L2 | 27.6% | 21.1% | 25.0% |
| | 2 | Count | 6a | 6a | 12 |
| | | % within PatchSizeS1L2 | 20.7% | 31.6% | 25.0% |
| | 3 | Count | 10a | 2a | 12 |
| | | % within PatchSizeS1L2 | 34.5% | 10.5% | 25.0% |
| | 4 | Count | 5a | 7a | 12 |
| | | % within PatchSizeS1L2 | 17.2% | 36.8% | 25.0% |
| Total | | Count | 29 | 19 | 48 |
| | | % within PatchSizeS1L2 | 100.0% | 100.0% | 100.0% |

Each subscript letter denotes a subset of PatchSizeS1L2 categories whose column proportions do not differ significantly from each other at the .05 level.

**Chi-Square Tests**

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 5.140[a] | 3 | .162 |
| Likelihood Ratio | 5.417 | 3 | .144 |
| Linear-by-Linear Association | .426 | 1 | .514 |
| N of Valid Cases | 48 | | |

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 4.75.

The images above display the statistical analysis for the patch size (small or large) category. Patch size fails to differentiate between median scores or groups (Sands & Bullock, Moguls Uniform Study, 2019).

# Patch Position: High vs. Low

**Crosstab**

| | | | PatchPosH1L2 1 | PatchPosH1L2 2 | Total |
|---|---|---|---|---|---|
| All Median Groups | 1 | Count | 7a | 5a | 12 |
| | | % within PatchPosH1L2 | 23.3% | 27.8% | 25.0% |
| | 2 | Count | 6a | 6a | 12 |
| | | % within PatchPosH1L2 | 20.0% | 33.3% | 25.0% |
| | 3 | Count | 9a | 3a | 12 |
| | | % within PatchPosH1L2 | 30.0% | 16.7% | 25.0% |
| | 4 | Count | 8a | 4a | 12 |
| | | % within PatchPosH1L2 | 26.7% | 22.2% | 25.0% |
| Total | | Count | 30 | 18 | 48 |
| | | % within PatchPosH1L2 | 100.0% | 100.0% | 100.0% |

Each subscript letter denotes a subset of PatchPosH1L2 categories whose column proportions do not differ significantly from each other at the .05 level.

**Chi-Square Tests**

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 1.778[a] | 3 | .620 |
| Likelihood Ratio | 1.802 | 3 | .615 |
| Linear-by-Linear Association | .627 | 1 | .429 |
| N of Valid Cases | 48 | | |

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 4.50.

The images above display the statistical analysis for the patch position (high or low) category. Patch size fails to differentiate between median scores or groups (Sands & Bullock, Moguls Uniform Study, 2019).

In short, uniform selection has a negligible effect on turn scores in the sport of freestyle moguls skiing (Sands & Bullock, Moguls Uniform Study, 2019). Athletes should be advised to focus on other areas of performance while ensuring comfort and confidence are not compromised through uniform selection and modification.

# Qualification

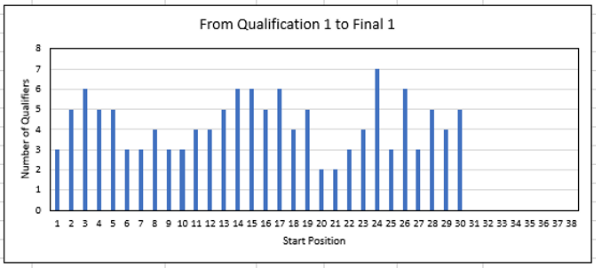
The current single mogul competition is comprised of three rounds of competition. The rounds are entitled Qualification 1 (Q1), Final 1 (F1), and Final 2 (F2). In Q1, all athletes compete. The start list order is randomized for those whose current FIS World Cup rank is between 1 and 30. Those athletes occupy the first 30 start positions in random order. Those outside the top 30 are randomized, beginning with start position number 31 through the remainder of the field.

Competition begins with Q1, and each athlete in the field has the opportunity to complete one run that is judged using the criteria stated above. Upon completion of Q1, the top 16 qualification scores are seeded in reverse order, from the lowest to the highest score for F1. The remainder of the field is done competing in the event. After elimination, competition continues with F1, in which the remaining 16 athletes have the opportunity to complete one run to be judged using the same criteria. Upon completion of F1, the field is narrowed for F2. In F2, the top 6 qualification scores from F1 are seeded in reverse order one final time, from lowest to highest score. The six remaining athletes ski one last time before the judges until a winner is declared. This process applies to both male and female single mogul competition.

Given the current mogul format, coaches and athletes should consider the odds of advancement and make tactical decisions whereby the competitor has the best opportunity to advance to the next round. In an attempt to classify qualifiers from non-qualifiers, an analysis of the 2018-2019 data was undertaken by Bullock and Sands (Analysis of Single Mogul Start List Order, 2019) in which non-parametric tests were divided into two categories: 1) Nominal (group) and 2) Ordinal (start list). Two hypotheses were then developed: H0) both groups have the same start orders, and H1) groups differ in their start orders.

From Qualification 1 to Final 1

| | Ruka | Thaiwoo | Calgary | Lake Placid | Tremblant | Tazawako | Shymbulak | Deer Valley | |
|---|---|---|---|---|---|---|---|---|---|
| | Start List | Start List | Start List | Start List | Start List | Start List | Start List | Start List | Total List |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 |
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 6 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 |
| 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 3 |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 |
| 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 3 |
| 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 3 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 4 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 4 |
| 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 5 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 6 |
| 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 6 |
| 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 5 |
| 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 6 |
| 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 4 |
| 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 5 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 2 |
| 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 2 |
| 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 3 |
| 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 4 |
| 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 7 |
| 25 | 25 | 25 | 25 | 25 | 25 | 25 | | 25 | 3 |
| 26 | 26 | 26 | 26 | 26 | 26 | 26 | | 26 | 6 |
| 27 | 27 | 27 | 27 | 27 | 27 | | | 27 | 3 |
| 28 | 28 | 28 | 28 | 28 | 28 | | | 28 | 5 |
| 29 | 29 | 29 | 29 | 29 | 29 | | | 29 | 4 |
| 30 | 30 | 30 | 30 | 30 | 30 | | | 30 | 5 |
| 31 | 31 | 31 | 31 | 31 | 31 | | | 31 | 0 |
| 32 | 32 | | 32 | 32 | 32 | | | 32 | 0 |
| 33 | 33 | | 33 | 33 | 33 | | | 33 | 0 |
| 34 | 34 | | 34 | 34 | 34 | | | 34 | 0 |
| 35 | | | 35 | 35 | 35 | | | | 0 |
| 36 | | | 36 | 36 | 36 | | | | 0 |
| 37 | | | 37 | 37 | | | | | 0 |
| 38 | | | 38 | | | | | | 0 |




Total List Women

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 | 8 | 21.1 | 21.1 | 21.1 |
| | 2 | 2 | 5.3 | 5.3 | 26.3 |
| | 3 | 8 | 21.1 | 21.1 | 47.4 |
| | 4 | 6 | 15.8 | 15.8 | 63.2 |
| | 5 | 8 | 21.1 | 21.1 | 84.2 |
| | 6 | 5 | 13.2 | 13.2 | 97.4 |
| | 7 | 1 | 2.6 | 2.6 | 100 |
| | Total | 38 | 100 | 100 | |

Ranks

| | Group | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| Qual 1 to Final 1 | Qualfied | 130 | 119.38 | 15519 |
| | Not Qualitifed | 130 | 141.62 | 18411 |
| | Total | 260 | | |

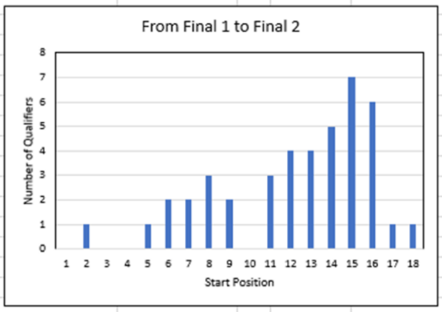
Earlier in Line Up is Better

Test Statistics

| | Qual 1 to Final 1 | |
|---|---|---|
| Mann-Whitney U | 7004 | |
| Wilcoxon W | 15519 | |
| Z | -2.386 | |
| Asymp. Sig. (2-tailed) | 0.017 | Statistically Different |

*Above: Graphical display of FIS World Cup Women's Q1 to F1 qualification rate. Note that earlier in the line-up is better. Zero athletes outside of the top 30 FIS World Cup rank were able to advance from Q1 to F1.*

| | From Final 1 to Final 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ruka | Thaiwoo | Calgary | Lake Placid | Tremblant | Shymbulak | Deer Valley | |
| | Start List | Start List | Start List | Start List | Start List | Start List | Start List | Total List |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 |
| 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 2 |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 3 |
| 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 2 |
| 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 0 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 3 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 4 |
| 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 4 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 5 |
| 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 7 |
| 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 6 |
| | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 1 |
| | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 1 |




Total List

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 | 4 | 10.5 | 22.2 | 22.2 |
| | 1 | 4 | 10.5 | 22.2 | 44.4 |
| | 2 | 3 | 7.9 | 16.7 | 61.1 |
| | 3 | 2 | 5.3 | 11.1 | 72.2 |
| | 4 | 2 | 5.3 | 11.1 | 83.3 |
| | 5 | 1 | 2.6 | 5.6 | 88.9 |
| | 6 | 1 | 2.6 | 5.6 | 94.4 |
| | 7 | 1 | 2.6 | 5.6 | 100 |
| | Total | 18 | 47.4 | 100 | |
| Missing | System | 20 | 52.6 | | |
| Total | | 38 | 100 | | |

Ranks

| | Group | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| Final 1 to Final 2 | Qualfied | 42 | 82.6 | 3469 |
| | Not Qualified | 72 | 42.86 | 3086 |
| | Total | 114 | | |

Later in Line Up is Better

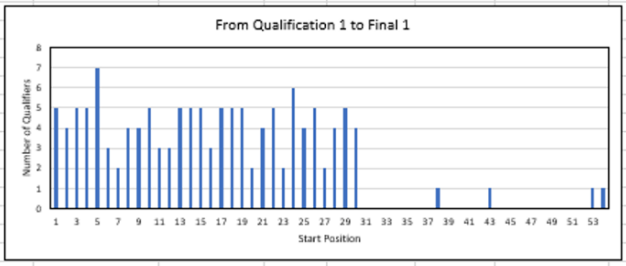
Test Statisticsa

| | Final 1 to Final 2 | |
|---|---|---|
| Mann-Whitney U | 458 | |
| Wilcoxon W | 3086 | |
| Z | -6.203 | |
| Asymp. Sig. (2-tailed) | 0 | Statistically Different |

| | Ranks | Percent | |
|---|---|---|---|
| Line Up 11-16 | 29 | 74.359 | Chance to qualify Final 1 to Final 2 |
| Line up 5-10 | 10 | 25.641 | Chance to qualify Final 1 to Final 2 |
| Total Ranks | 39 | | |

*Above: Graphical display of FIS World Cup Women's F1 to F2 qualification rate. Note in this case that later in the line-up is better. Athletes who failed to qualify 11-16 (top-6 in Q1) in the line-up saw their chances of advancement for F1 to F2 decrease from 74.3% to 25.6%. Only one athlete throughout the 2018-2019 season qualified who qualified in a position less than 11 was able to reach F2.*

| | From Qualification 1 to Final 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ruka | Thaiwoo | Calgary | Lake Pla | Tremblar | Tazawak | Shymbul | Deer Valley | |
| | Start List | Start List | Start List | Start List | Start List | Start List | Start List | Start List | Total List |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 7 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 |
| 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 2 |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 |
| 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 4 |
| 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 5 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 3 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 3 |
| 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 5 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 5 |
| 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 5 |
| 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 3 |
| 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 5 |
| 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 5 |
| 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 5 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 2 |
| 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 4 |
| 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 5 |
| 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 2 |
| 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 6 |
| 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 4 |
| 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 5 |
| 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 2 |
| 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 4 |
| 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 5 |
| 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 4 |
| 31 | 31 | 31 | 31 | 31 | 31 | 31 | 31 | 31 | 0 |
| 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 0 |
| 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 0 |
| 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 0 |
| 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 0 |
| 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 0 |
| 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 0 |
| 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 1 |
| 39 | 39 | 39 | 39 | 39 | 39 | 39 | 39 | 39 | 0 |
| 40 | 40 | 40 | 40 | 40 | 40 | 40 | | 40 | 0 |
| 41 | 41 | 41 | 41 | 41 | 41 | 41 | | 41 | 0 |
| 42 | 42 | 42 | 42 | 42 | 42 | 42 | | 42 | 0 |
| 43 | 43 | 43 | 43 | 43 | 43 | 43 | | 43 | 1 |
| 44 | 44 | 44 | 44 | 44 | 44 | 44 | | 44 | 0 |
| 45 | 45 | 45 | 45 | 45 | 45 | | | | 0 |
| 46 | 46 | 46 | 46 | 46 | 46 | | | | 0 |
| 47 | 47 | 47 | 47 | 47 | 47 | | | | 0 |
| 48 | 48 | 48 | 48 | 48 | 48 | | | | 0 |
| 49 | 49 | 49 | 49 | 49 | 49 | | | | 0 |
| 50 | 50 | | 50 | 50 | 50 | | | | 0 |
| 51 | 51 | | 51 | 51 | 51 | | | | 0 |
| 52 | 52 | | 52 | 52 | 52 | | | | 0 |
| 53 | 53 | | 53 | 53 | 53 | | | | 1 |
| 54 | 54 | | 54 | 54 | 54 | | | | 1 |
| 55 | 55 | | 55 | 55 | 55 | | | | |




Total List Men

| | | Frequen | Percent | Valid Perce | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 | 20 | 37.7 | 37.7 | 37.7 |
| | 1 | 4 | 7.5 | 7.5 | 45.3 |
| | 2 | 4 | 7.5 | 7.5 | 52.8 |
| | 3 | 4 | 7.5 | 7.5 | 60.4 |
| | 4 | 7 | 13.2 | 13.2 | 73.6 |
| | 5 | 12 | 22.6 | 22.6 | 96.2 |
| | 6 | 1 | 1.9 | 1.9 | 98.1 |
| | 7 | 1 | 1.9 | 1.9 | 100 |
| | Total | 53 | 100 | 100 | |

Ranks

| | Group | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| Qual 1 to Final 1 | Qualified | 112 | 110.3 | 12353.5 |
| | Not Qualified | 243 | 209.2 | 50836.5 |
| | Total | 355 | | |

**Earlier in Line Up is Better**

Test Statistics

| | Qual 1 to Final 1 | |
|---|---|---|
| Mann-Whitney U | 6025.5 | |
| Wilcoxon W | 12353.5 | |
| Z | -8.44 | |
| Asymp. Sig. (2-tail | 0 | Statistically Different |

Ranks Top 30 Only

| | Group | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| Qual to Final 1 | Qualified | 126 | 118.09 | 14879 |
| | Not Qualified | 114 | 123.17 | 14041 |
| | Total | 240 | | |

No effect from Line Up Position

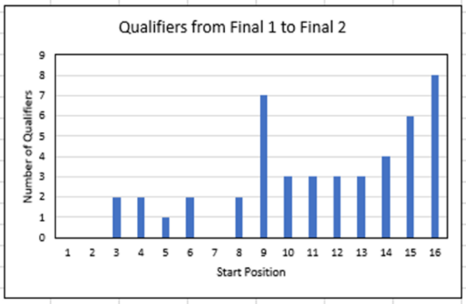
Test Statisticsa

| | Group | |
|---|---|---|
| Mann-Whitney U | 6878 | |
| Wilcoxon W | 14879 | |
| Z | -0.566 | |
| Asymp. Sig. (2-tail | 0.571 | Not Statisically Different |

*Above: Graphical display of FIS World Cup Men's Q1 to F1 qualification rate. Note that earlier in the line-up is better. Four athletes outside of the top 30 FIS World Cup rank were able to advance from Q1 to F1.*

From Final 1 to Final 2

| Ruka Start List | Thaiwoo Start List | Calgary Start List | Lake Placid Start List | Tremblant Start List | Tazawako Start List | Shymbula Start List | Deer Valley Start List | Total List |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 |
| 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 0 |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 2 |
| 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 7 |
| 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 3 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 3 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 3 |
| 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 3 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 4 |
| 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 6 |
| 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 8 |
| | | | | | | | 17 | |
| | | | | | | | 18 | |




| Start Positions | 13-16 | 9-12 | 5-8 |
|---|---|---|---|
| Sum of Positions | 46 | | |

| | 13-16 | 9-12 | 4-8 |
|---|---|---|---|
| Qualifier vs Non | 21 | 16 | 5 |
| Percentage | 45.6522 | 34.7826 | 10.8696 |

Ranks

| | Group | N | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| Final 1 to Final 2 | Qualified | 42 | 75.17 | 3157 |
| | Not Qualified | 70 | 45.3 | 3171 |
| | Total | 112 | | |

Later in Line Up is Better

| Test Statisticsa | Final 1 to Final 2 | |
|---|---|---|
| | Final 1 to | |
| Mann-Whitney U | 686 | |
| Wilcoxon W | 3171 | |
| Z | -4.721 | |
| Asymp. Sig. (2-tailed) | 0 | Statistically Different |

*Above: Graphical display of FIS World Cup Men's F1 to F2 qualification rate. Note in this case that later in the line-up is better. Athletes who failed to qualify 9-16 (top-8 in Q1) in the line-up saw their chances of advancement for F1 to F2 decrease from 88.2% to 10.8%. Only five athletes throughout the 2018-2019 season qualified who qualified in a position less than 9 was able to reach F2.*

# Chapter 04

# INJURIES

## Incidence

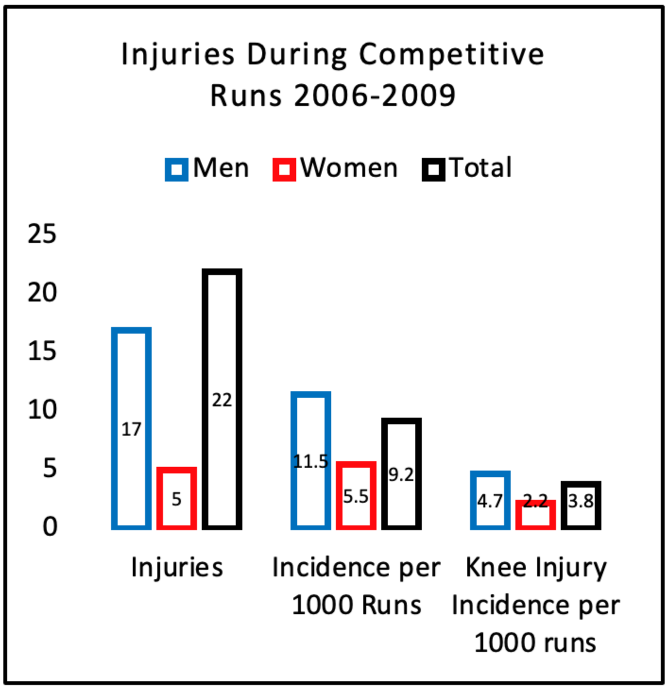
In data taken from the 2006 to 2009 seasons, among all freestyle skiing events, moguls/dual moguls have a comparatively high injury rate (Florenes, Heir, Nordsletten, & Bahr, 2010). From 2006 to 2009, Florenes et al. (2010) recorded 76 acute injuries in moguls/dual moguls that resulted in at least a one-day cessation in training or competition (2010). It is essential to note that these data only include runs completed during World Cup/World Ski Championship competitions and do not include training.

In the same study, 57 of the reported 76 injuries resulted in greater than an eight-day cessation from training or competition, while the average loss of time was 24.5 days (Florenes, Heir, Nordsletten, & Bahr, 2010). 28 (37%) of those injuries were categorized as severe with a greater than 28 days' cessation in training (Florenes, Heir, Nordsletten, & Bahr, 2010).

The relative injury rate, expressed as the number of injuries per 100 athletes per season, was 32.5 (Florenes, Heir, Nordsletten, & Bahr, 2010).

Injury rates among males and females are noteworthy. Between 2006 and 2009, males were injured at nearly twice the rate, with males reporting 154 injuries and women reporting 79 (Florenes, Heir, Nordsletten, & Bahr, 2010). This is likely due to the higher volume of participation by males. Florenes et al. (2010) also state that the relative injury rate per 1000 runs in males during the period was 11.5 and 5.5 in females. The relative rate of knee injuries per 1000 runs in males was 4.7 and 2.2 in females.

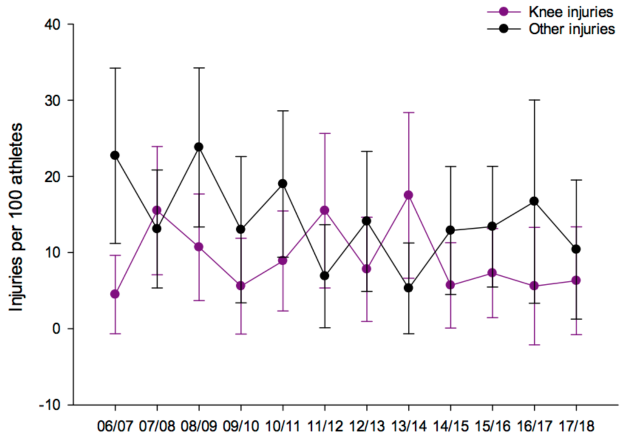
In an earlier study, Heir et al. investigated the incidence and trends of ACL injuries in FIS World Cup freestyle mogul skiing over a ten-year period from the 1992/93 season through the 2001/02 season. In that period, 65 ACL injuries occurred within 60.048 skier days, giving an overall rate of 1.23 ACL injuries per 1000 skier days (2003). Furthermore, the risk of ACL injury was 3.8 (women) to 8.0 (men) times higher in competition as compared to training (Heir, Krosshauk, & Ekeland, 2003).



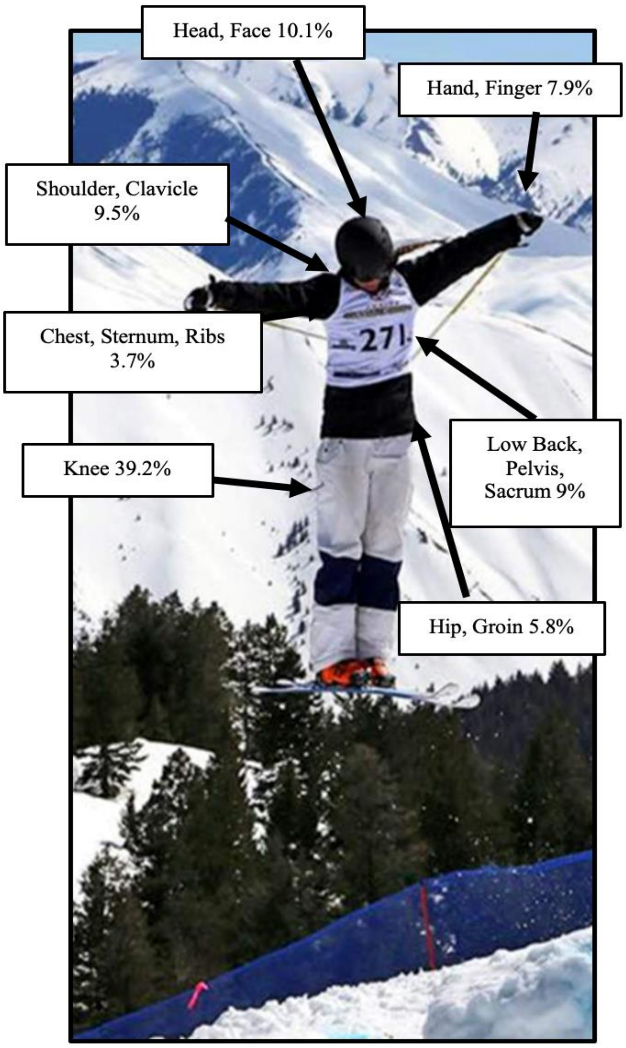
Again, mogul skiing had a significantly higher injury rate than the other freestyle disciplines (Heir, Krosshauk, & Ekeland, 2003). This is important to note for the practitioner as physical preparation has the potential to reduce these incidences.

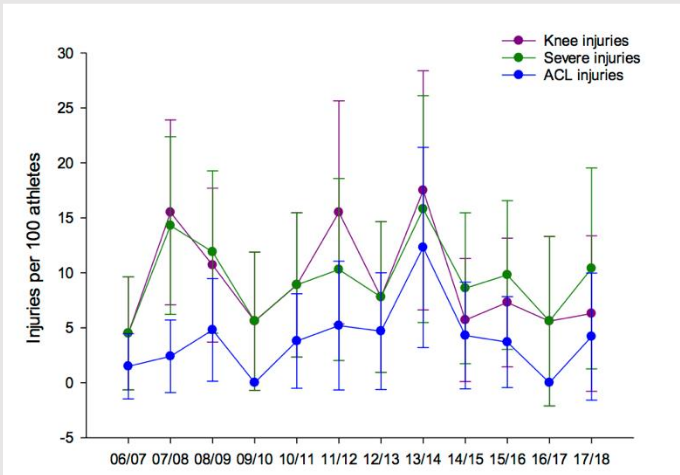
## FIS Data

Data from the FIS (2008) dating back to the 2006-2007 season display injury rates for those skiers on the World Cup Tour. In that period, athletes most commonly experienced injuries to the knee (39.2%), the low back, pelvis, and sacrum (9%), and the head and face (10.1%). For more detailed information from this literature, refer to the graphic representations at right and the image below.




*Above: Injury rate, expressed as injuries per 100 athletes for injuries to the knee vs other injuries, reported in the mogul discipline for each of the 12 seasons (2006-18).*




*Above: Injury rate, expressed as injuries per 100 athletes for knee injuries, severe injuries, and ACL injuries (all), reported in the mogul discipline for each of the 12 seasons (2006-18).*

# The Spine

Given the data from the FIS and that collected over a 4-year period by U.S. Ski & Snowboard, there is a significant interest in the mogul skier's phenomenon known as "Mogul Back." Data from Bullock and Sands (2018) shows a high erector spinae activation as the skier contacts the face of the bump and potentially a second activation if the athlete is in a poor position (the knees are under the hips with the legs extended, and the torso pitched forward) as the athlete reaches the peak of the bump. The high velocity and high loads associated with this eccentric muscle action are believed to be related to the Mogul Back phenomenon.

In 2017, Thoreson et al. conducted a study to investigate the presence of spinal MRI abnormalities and the lifetime prevalence of low back pain (LBP) in 16 young elite mogul skiers compared to 28 non-athletes in the corresponding age in a cross-sectional design. Low back pain was assessed by a questionnaire consisting of a section pertaining to previous or present back pain, the Oswestry disability index, and the EuroQol questionnaire. MRI examinations from T5 to the sacrum were conducted to evaluate spinal pathologies.

According to the study by Thoreson et al. (2008), Mogul skiers had significantly more MRI abnormalities (e.g., disc degeneration) in the mean (7.25 vs. 3.78, $P < 0.023$) compared to the controls. No significant difference was seen regarding the lifetime LBP prevalence between the groups (50% vs. 42%, $P = 0.555$), and no correlation could be found between disc degeneration and back pain in this study.

| |
|---|
| **Loss of Control** |
| Poor Physical Condition |
| Inexperience or Poor Technique |
| Fatigue |
| Excessive Speed |
| **Dangerous Course Conditions** |
| Ruts |
| Obstacles (barriers, markers, etc.) |
| **Variable Quality of Snow** |
| Powdered/Fresh Snow |
| Ice |
| Change from Sun to Shade |
| Temperature Changes |
| Soft/Slushy Snow |
| **Weather Conditions** |
| Extreme Cold / Heat |
| Poor Visibility |
| Sun Exposure |
| **Equipment Malfunction or Failure** |
| Hard Gear Malfunction/Failure |
| Soft Gear Malfunction/Failure |
| Lack of Preventative Maintenance |
| Lack of Equipment Preparation |

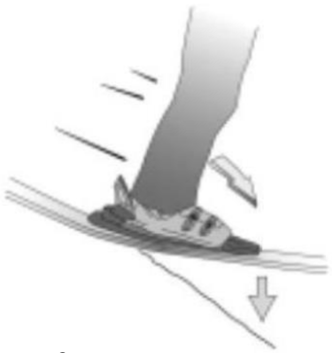
# Mechanism

Injuries in freestyle mogul skiing occur due to several different causal factors (McIntyre, 1963). The chart at left is a summary of those factors.

All mechanisms fall into one of three categories: 1) intrinsic risk factors such as strength, power, fitness level, prior injury history, and anatomy; 2) extrinsic risk factors such as ruts, obstacles, snow conditions, visibility, weather, equipment factors, and other skiers; and finally, 3) inciting events such as a crash, loss of balance, catastrophic equipment failure, or inefficient body position (Kurpiers, Dynamics of Freestyle Skiing, 1994).

Three positions appear to compromise the knee joint specifically as it relates to ligamentous structures (Kurpiers, Dynamics of Freestyle Skiing, 1994).

1



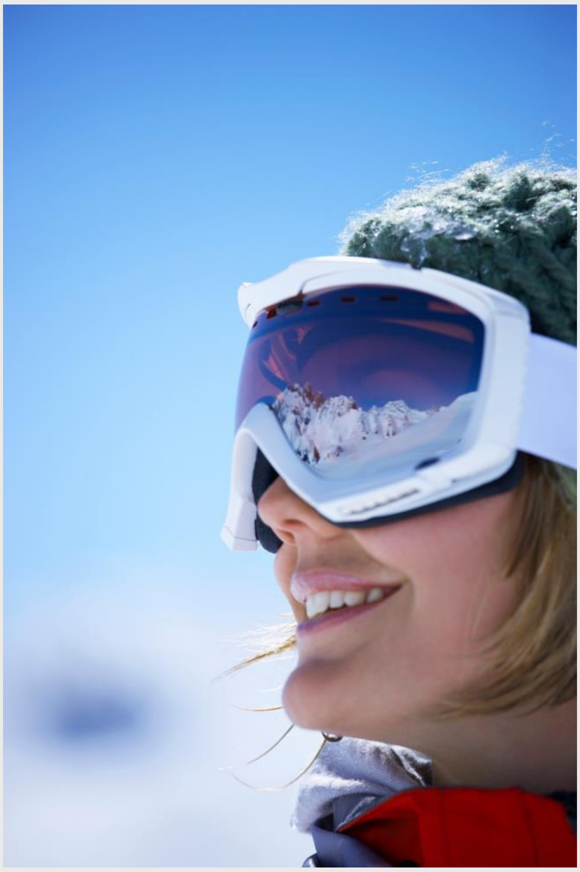
2

The first is a combined valgus and external rotation which occurs when the skier falls forward between the skis after catching an inside edge (Kurpiers, Dynamics of Freestyle Skiing, 1994).

The second mechanism is the boot-induced anterior drawer, which occurs when the boot forces the tibia anteriorly when contacting the back of the ski with an almost extended knee. It has been proposed that this is the most frequently encountered injury mechanism to the knee in mogul skiing (Heir, Krosshauk, & Ekeland, 2003).

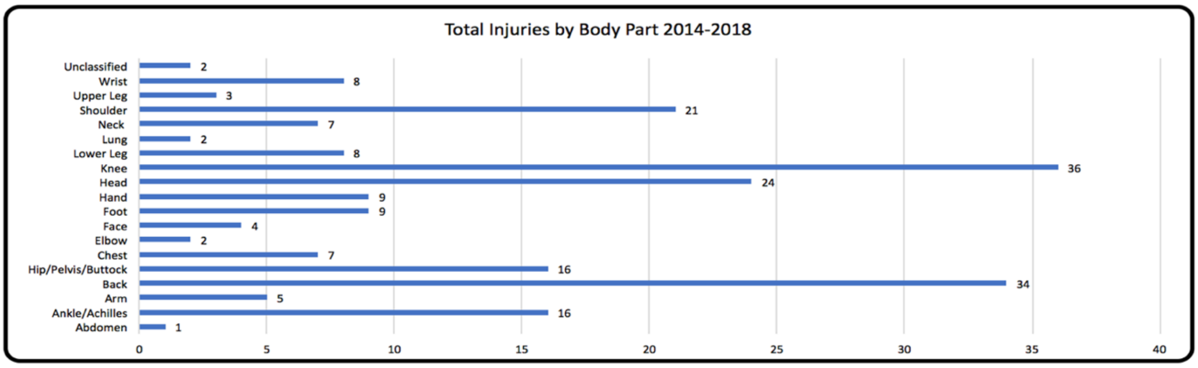
3

The third mechanism is known as the phantom-foot phenomenon. This position describes a fall backward between the skis, catching the inside or outside edge of the downhill ski and leading to a forced rotation of the knee (Kurpiers, Dynamics of Freestyle Skiing, 1994). Common movements that lead to this position include attempting to get up while moving after a fall, recovering from an off-balance position, and sitting down after losing control (Johnson, Ettlinger, & Shealy, 2005).



## Types

The most common injuries in mogul skiing are to the knee (Heir, Krosshauk, & Ekeland, 2003). In a study from 2001, Heir et al. surveyed 95 FIS Freestyle World Championship skiers. Of those surveyed, 47% had previously sustained one or more major knee injuries and still returned to a high level of athletic performance. One-fourth of the skiers had sustained one or more ACL ruptures (Heir, Krosshauk, & Ekeland, 2003). Below is a graph that displays internal data on the number of injuries, and type of injury, in U.S. Ski & Snowboard team members from 2014 to 2018.

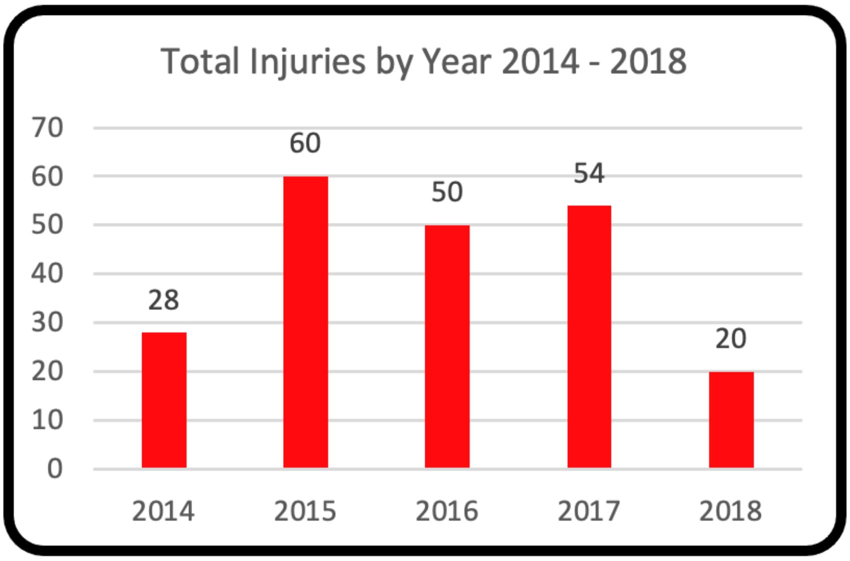


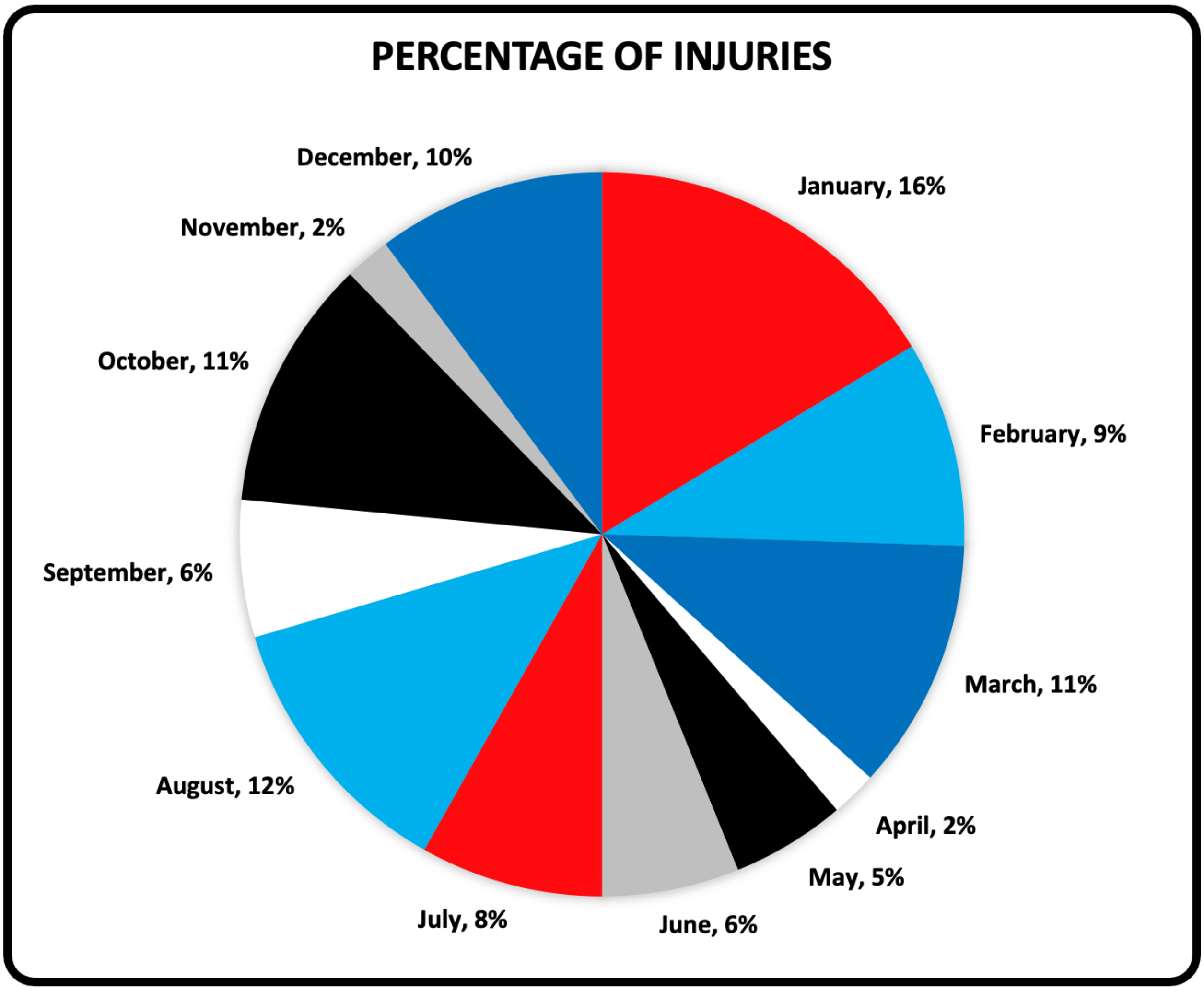

## U.S. Ski & Snowboard Data

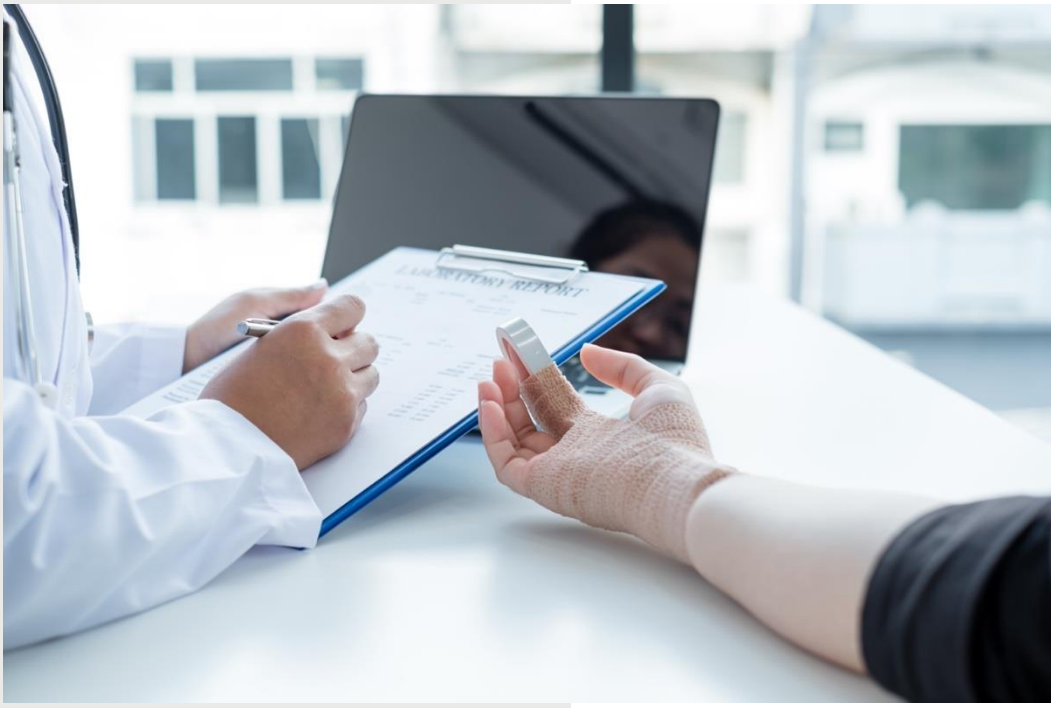
*Disclaimer: When reviewing these data, please note that records were poor from January 2014 to August 2014.*

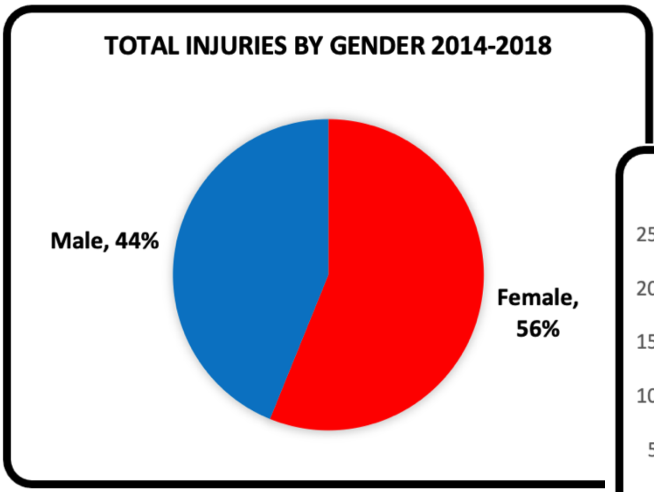
## Injuries Per Year

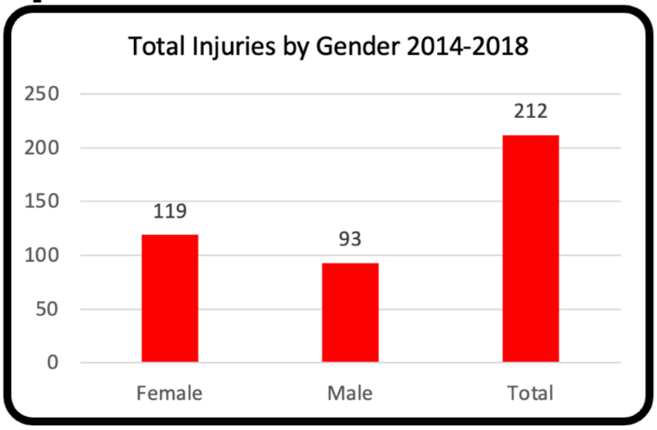
The total number of injuries by year ranges from 50-60; January has the highest incidence of injury (16%). This is possibly due to the high density of competitions that occur in January (4) and the cessation of training in late December due to the Christmas holiday. The lowest density of injuries occurs in April (2%). This is likely due to extremely low exposure to competition and training. During April, there is only one training opportunity and zero competitions (Bullock, Incidence of Injury in United States World Cup Mogul Skiers from 2014-2018, 2018).




PERCENTAGE OF INJURIES
December, 10%
January, 16%
November, 2%
October, 11%
February, 9%
September, 6%
March, 11%
August, 12%
April, 2%
May, 5%
July, 8%
June, 6%






## Injuries by Gender

At U.S. Ski & Snowboard, females suffer 56% of the total injuries, while males suffer 44%. The total number of injuries reported from January 2014 to September 2014 was 212; 119 of those reported were females, and 93 of those reported were from males (Bullock, Incidence of Injury in United States World Cup Mogul Skiers from 2014-2018, 2018).

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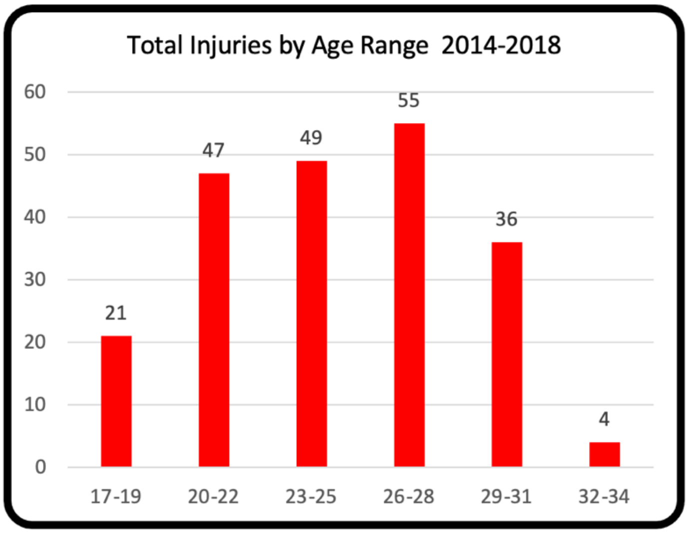
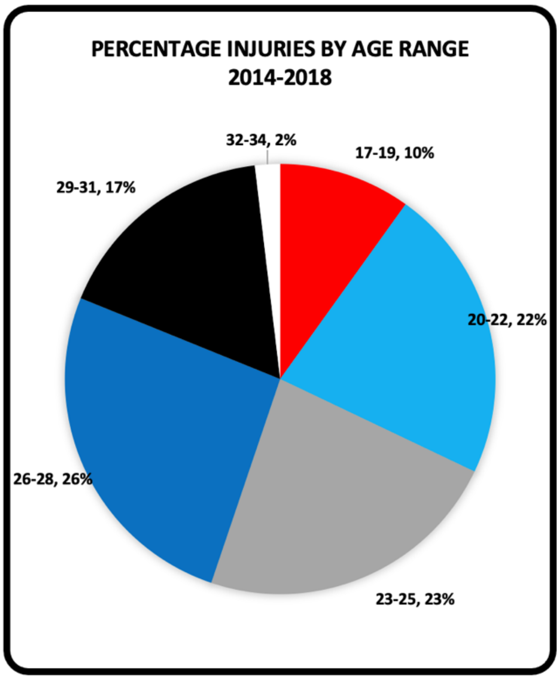
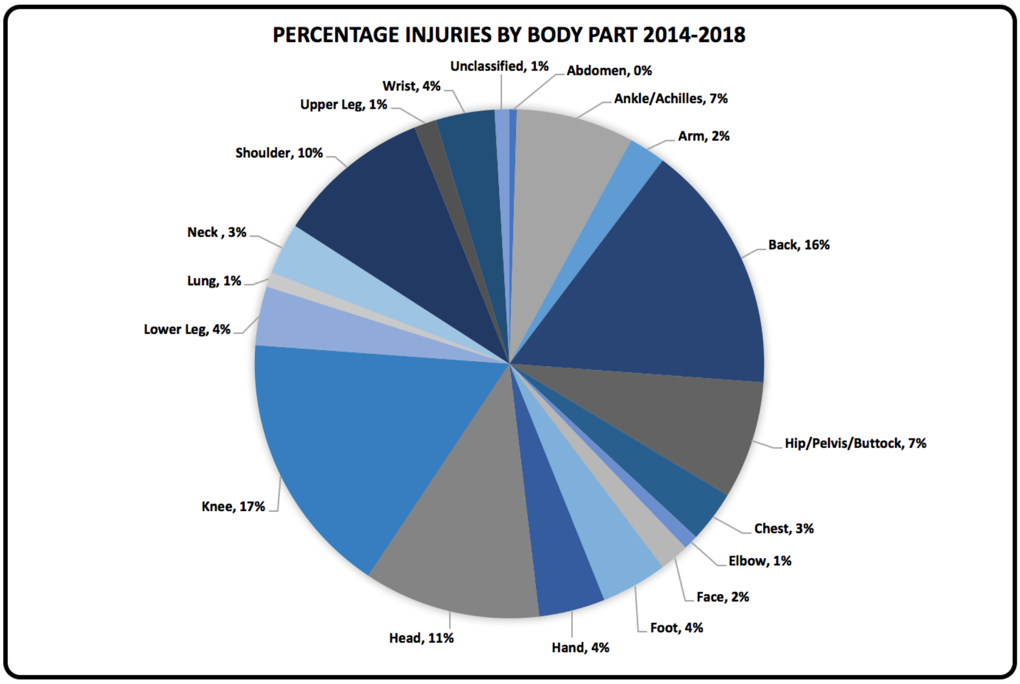
## Injuries by Age

The age of elite-level U.S. mogul skiers has ranged from 15 to 34 years of age. Historical data are not known regarding how many total athletes participated at each respective age, thus, making it difficult to discern the incident rate. However, it may be beneficial for the practitioner to be aware of those injuries reported based on age.

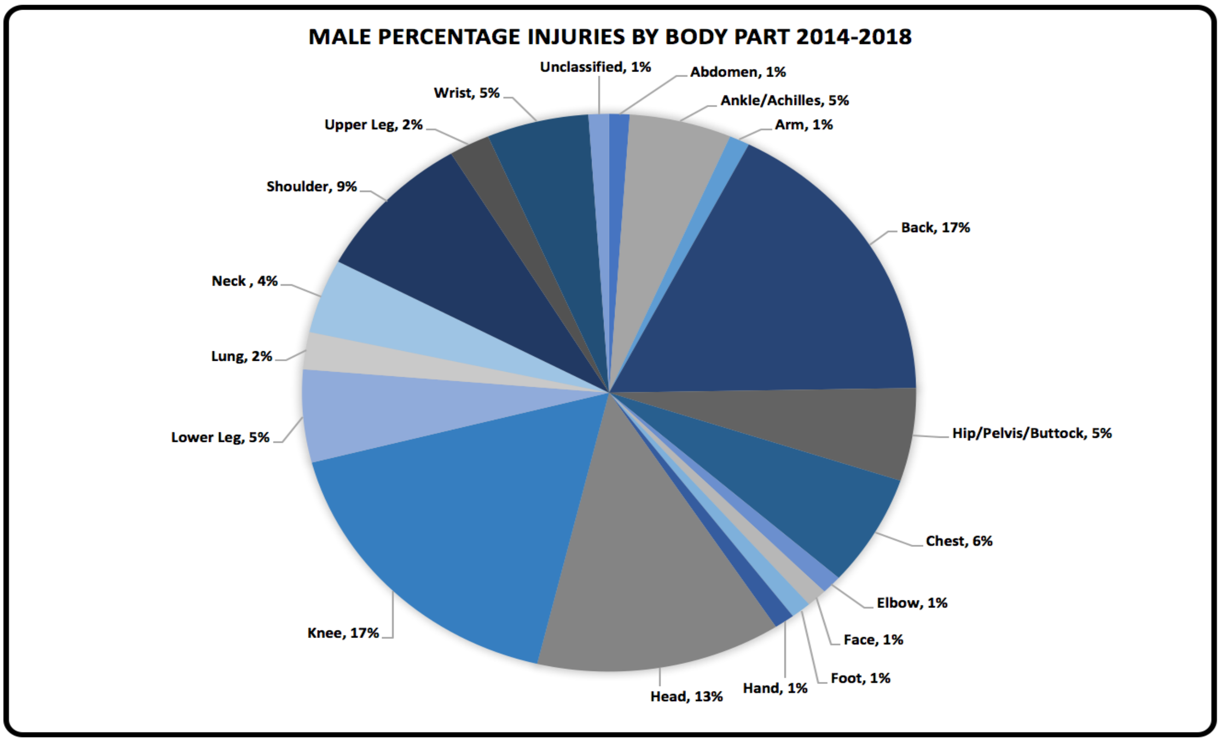




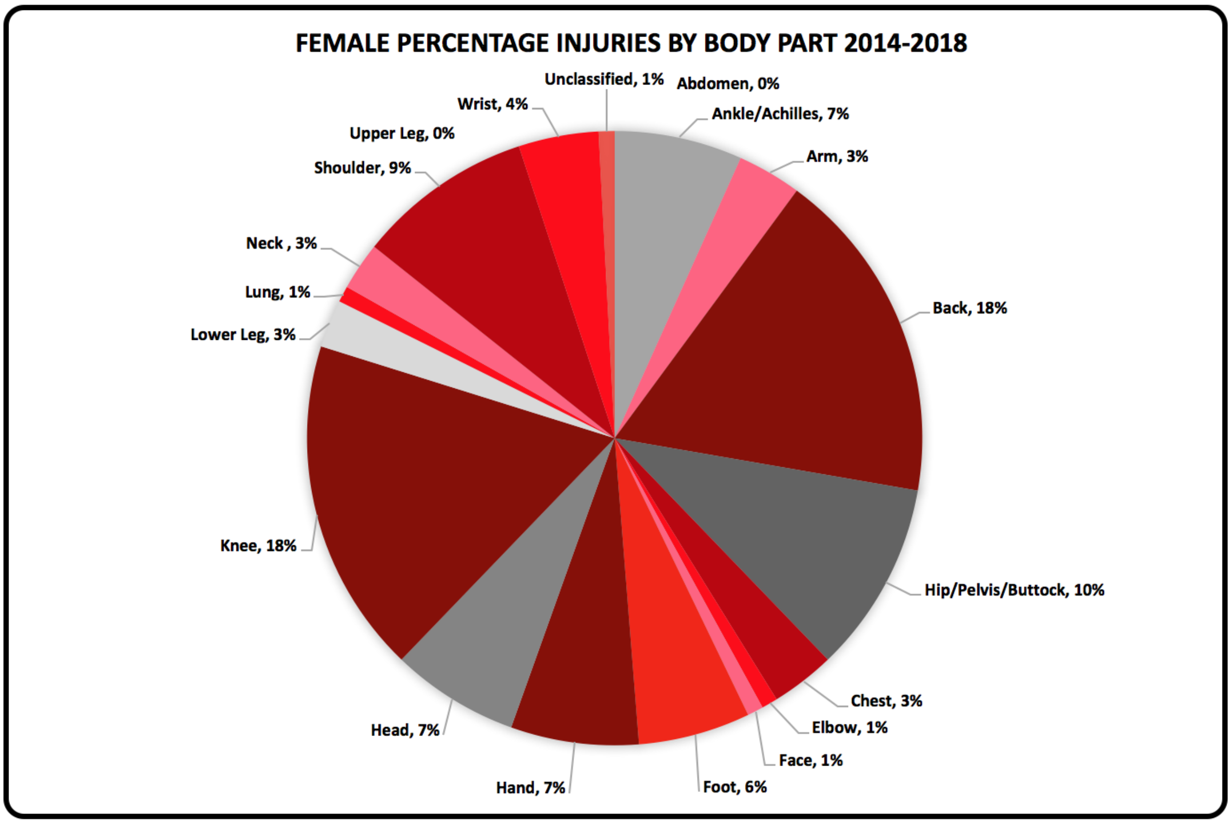

## Injuries by Body Part/Region

It has been widely reported in FIS injury data that the most commonly injured joint or body part in mogul skiers is the knee. U.S. Ski & Snowboard is no exception. However, it appears that organizationally U.S. Ski & Snowboard experiences a lower percentage of injuries to the knee than our competitors – 17% as compared to 39.2%. As seen in the data above, the knee remains the most commonly injured body part (17%); followed closely by the back (16%), head (11%), and shoulder (10%) (Bullock, Incidence of Injury in United States World Cup Mogul Skiers from 2014-2018, 2018).


## Injuries by Gender

Gender does appear to play a role in the incidence of injury based on body part/region. Females seem to experience a higher incidence of injury relative to the knee and hip complex. At the same time, males appear to experience a higher incidence of injury to the head and chest region. All other body parts/regions appear to be injured at a similar rate.



# Injury Prevention

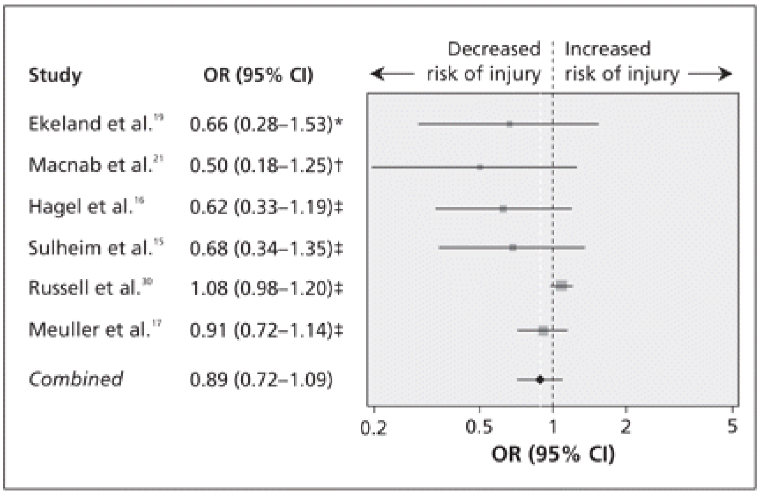
In addition to the protective devices listed below, the coaching staff, strength and conditioning practitioner, and athletes can all play an integral role in preventing injury. Adhering to principles of specificity, progression, overload, reversibility, variability/variation, and consideration of genetic factors can help limit the risk to which the athlete is exposed.

## Helmets

In a meta-analysis, Russel et al. (2010) concluded that the use of helmets had a significant protective effect against head injuries among skiers and snowboarders.

The pooled analysis showed that the risk of head injury was reduced by 35% with helmet use (95% CI 21%–46%) and that 2–5 of every ten head injuries among helmet users could be prevented (Russell, Christie, & Hagel, 2010). Although not statistically significant, there was some suggestion that helmets had a greater protective effect among males than among females; the reasons for which are unknown. These results are like other reviews of concussions and the use of protective equipment in various summer and winter activities.

It is important to note that literature on this topic has failed to define a head injury consistently. Differences in the findings may be due to the definitions used for severe head injury or the influence of confounding variables.

Although wearing a helmet reduces the risk of head injury, there is concern that helmets may increase the risk of neck injury due primarily to head to body ratio seen in children and adolescents of different ages. Pooled results from Russell et al. (2010) and other individual studies showed no significant association between helmet use and increased risk of neck injury. This is consistent with biomechanical data showing no increase in neck loads associated with helmet use in simulated snowboarding falls.

Some coaches and athletes have suggested that using helmets may provide a false sense of security and result in more aggressive or dangerous participation. Several studies have examined risk compensation (risk-taking behavior) concerning helmet use among skiers. The available evidence suggests that if helmet users exhibit compensating behavior, their level of injury risk is not higher than that of nonusers (Russell, Christie, & Hagel, 2010).

## Back Protection

Currently, there is only one published study on the use of back protectors in winter sports. That study was performed on snowboarders with seemingly inapplicable results. However, many studies exist on the use of back protection in motorsports.

| Protector | | | Drop test, EN1612 | | | Penetration test, EN1077 | |
|---|---|---|---|---|---|---|---|
| Design | | Thickness (mm) | F (kN) | F average (kN) | Safety level | (Class A) remaining distance (mm) at 37.5 cm | (Class B) remaining distance (mm) at 75 cm |
| A | Soft shell | 23 | **7.3**/ 6.6/6.2 | 6.7 | 2 | Failure | – |
| B | Soft shell | 23 | 9.9/ 10.4/**10.9** | 10.4 | 1 | Failure | – |
| C | Backpack protector | 22 | **17.1**/ 12.2/14.4 | 14.6 | 1 | 6 | Failure |
| D | Soft shell | 21 | 7.8/7.7/**7.9** | 7.8 | 2 | 3.5 | Failure |
| E | Hard shell | 26 | **7.8**/6.7/6.8 | 7.1 | 2 | 13 | 7.5 |
| F | Backpack with jumper | 45 | 8.6/**8.6**/8.4 | 8.5 | 2 | Failure | – |
| G | Soft shell | 24 | **17.2**/14.7/14.3 | 15.4 | 1 | Failure | – |
| H | Soft shell | 23 | 6.5/**7.5**/6.8 | 6.9 | 2 | Failure | – |
| I | Hard shell | 30 | **32.5**/12.4/12.1 | 19.0 | None | 12.5 | 5.5 |
| J | Hard shell | 23 | 24.7/**24.9**/22.6 | 24.1 | None | 4 | Failure |
| K | Backpack protector | 28 | 5.4/6.7/**10.0** | 7.4 | 2 | 8 | 1 |
| L | Hard shell | 17 | **15.0**/11.5/11.6 | 12.7 | 1 | Failure | – |
| M | Protection shirt | 14 | **50.0**/40.0/NA | 45.0 | None | Failure | – |

All results of the three force measurements are reported; the maximum force is shown in bold. In addition, the average force is given. Safety levels 1 and 2 refer to the threshold values defined in EN1621. 'Failure' denotes complete penetration; otherwise, the penetration depth is given.
F, failure.

Various back protectors are commercially available to prevent injuries to the spine and back. However, to assess the protective potential of current protectors, the only international standard available that refers to testing back protectors was developed for the safety gear of motorcyclists. Lacking an alternative, the standard is used by many manufacturers of snow sports protectors, although it is questionable whether the requirements of this standard are also applicable to snow sports.

There appears to be a mismatch between the expectations of athletes, the potential offered by the protector, and the means to test this potential, that is, a performance standard (Schmitt, Liechti, Michel, Sampfli, & Bruhwiler, 2010).

Results of the study demonstrate that only three configurations (see image above) failed the motorcycle standard, and half achieved safety level 2. It was found that different designs are capable of dissipating energy in the case of a direct impact such that the requirements are met. Protectors using a soft-shell approach performed better with respect to dissipating energy, but other products (including a backpack filled with a pullover jacket) passed the test. Hard-shell designs, in contrast, offered better protection in the penetration test. From an engineering point of view, it should be possible to meet both standards (Schmitt, Liechti, Michel, Sampfli, & Bruhwiler, 2010).

Even though the recent literature does not indicate that such protectors might cause harm or represent an additional injury risk, the situation is unsatisfactory. A false feeling of safety may be generated in the wearer of a given protector. Basic research concerning the mechanism of spinal injuries is needed to improve the situation since the biomechanical understanding of the issues appears to be relatively weak. It remains debatable whether a unique or modified standard for protectors designed for snow sports is needed (Schmitt, Liechti, Michel, Sampfli, & Bruhwiler, 2010).

## ACL Protection

Current best practices in anterior cruciate ligament (ACL) rupture prevention involve understanding the mechanisms of injury, preceding physical preparation, and monitoring of athlete load accompanied by appropriate volume and intensity adjustment by the coaching staff. In addition to the previously stated skiing-related mechanisms of injury, several others have been reported in the literature; these include (Hashemi, et al., 2010):

1) Anterior shear force mechanism.
2) Axial compressive load mechanism.
3) Hyperextension mechanism.
4) Valgus collapse mechanism.
5) Tibial internal rotation mechanism.
6) Combined valgus and anterior shear.
7) Combined valgus and internal tibial torque.
8) Valgus and external tibial torque.
9) Valgus, anterior tibial shear, and axial torque about the long axis of the tibia.
10) The hip extension, knee flexion paradox, which includes a combination of delayed or slow co-activation of the quadriceps and hamstrings, a dynamic ground reaction force applied while the knee is near full extension, a shallow medial tibial plateau, and a steep posterior tibial slope, and a stiff landing due to incompatible hip and knee flexion velocities.

Appropriate load management enables players to be physically prepared for the demands of training and competition and reduces the occurrence of injury and illness (Wing, 2018). Gabbett (2016) states that exposure to appropriately planned chronic load aids in protecting against increases in acute load and provides athletes with a protective effect of training against injury. These heightened fitness levels can only be developed through increased exposure to training (i.e., chronic load).

The benefits of exposing athletes to intense training are strongly supported in the literature. However, chronic intense training is not the only factor for coaches to consider. Gabbett et al. (2016) have described how high training loads alone are not the issue; how you get there is. There is currently a shift away from the total training load and toward acute spikes in training.

An athlete must be physically prepared for the demands of training and sport through exposure to progressively specific training loads, thus, increasing performance and reducing injury. This may be best achieved through moderate workloads, with an approximate moderate load increase, allowing the athlete to benefit from a protective element of training.

Currently, several data collection methods can be used, each with its strengths and weaknesses. They include: 1) session rating of perceived exertion (sRPE), 2) global positioning systems (GPS), 3) heart rate training impulse (TRIMP), and 4) wellness questionnaires.


Chapter 05

# ENVIRONMENTAL CONDITIONS

## Altitude

Freestyle mogul skiing competitions and training are frequently held at moderate to high altitudes (2000-3500m). Males and females respond very similarly to acute and chronic altitude exposure (American College of Sports Medicine; American Dietetic Association; Dieticians of Canada, 2000).

Altitude exposure is associated with significant changes in cardiovascular function (Naejie, 2010). The initial cardiovascular response to altitude is characterized by increased cardiac output with tachycardia, and no change in stroke volume, whereas blood pressure may temporarily increase slightly. After a few days of acclimatization, cardiac output returns to normal, but heart rate remains increased, so stroke volume is decreased. Pulmonary artery pressure increases without change in pulmonary artery wedge pressure. This pattern is essentially unchanged with prolonged or lifelong altitude stops. Ventricular function is maintained, with initially increased, then preserved or slightly depressed indices of systolic function and an altered diastolic filling pattern. The filling pressures of the heart remain unchanged (Naejie, 2010).

Exercise in acute and chronic high-altitude exposure is associated with a brisk increase in pulmonary artery pressure (Chapman, Stray-Gunderson, & Levine, 1998). The relationships between workload, cardiac output, and oxygen uptake are preserved in all circumstances. Still, there is a decrease in maximal oxygen consumption, which is accompanied by a reduction in maximal cardiac output. The decline in maximal cardiac output is minimal in acute hypoxia but becomes more pronounced with acclimatization. This is not explained by hypovolemia, acid-base status, increased viscosity or polycythemia, autonomic nervous system changes, or depressed systolic function. Maximal oxygen uptake at high altitudes has been modeled to be determined by matching convective and diffusional oxygen transport systems at a lower maximal cardiac output (Naejie, 2010).

Chapman et al. (1998) state that upon initial ascent to altitude, blood lactate concentrations are elevated at a given sub-maximal work level, but peak values are essentially unaltered. During more prolonged exposure to hypoxia, a reduction in blood lactate concentration has been reported at both sub-maximal and maximal exercise intensities. This phenomenon has been termed the 'lactate paradox,' i.e., despite prevailing hypoxia, lactate accumulation in blood during exercise reduces toward sea level values during sub-maximal exercise (van Hall, Calbet, Sondergaard, & Saltin, 2001). Later detailed studies have demonstrated that the low blood lactate concentration is primarily a function of a reduced net lactate release from the exercising legs (van Hall, Calbet, Sondergaard, & Saltin, 2001).

Muscle strength and maximal muscle power, determined by force generated during brief (1-5s) maximal muscle static and dynamic contractions, respectively, are generally not adversely affected by acute or chronic altitude exposure as long as muscle mass is maintained (van Hall, Calbet, Sondergaard, & Saltin, 2001). In addition, alpha-motoneuron excitability, nerve and muscle conduction velocity, and neuromuscular transmission are not impaired at altitudes exceeding 4300m. Anaerobic performance during very intense, maximal, or supramaximal exercise (e.g., Wingate test) lasting 30s is generally not adversely affected at altitude. For anaerobic performance assessments lasting longer than 30s, there are conflicting results (Fulco, Rock, & Cymerman, 1998).

Of interest to coaches and athletes, exposure to altitudes higher than 2,500m (8,200ft) may result in fluid losses beyond those associated with any exercise that might be performed (Robson-Ansley, Gleeson, & Ansley, 2013). These losses result from increased urine production and high respiratory water losses, accompanied by decreased appetite, which leads to an increased need for fluid intake. Thus, fluid intake at high altitudes should be increased to as much as 3 to 4 L per day to ensure optimal kidney function (American College of Sports Medicine; American Dietetic Association; Dieticians of Canada, 2000).

Finally, from a training standpoint, research has shown consistently that moderate-altitude living (2500 m) combined with low-altitude training (1250 m) results in a significantly greater improvement in maximal oxygen uptake and performance over equivalent sea-level training (Chapman, Stray-Gundersen, & Levine, 1998).

# Temperature

Freestyle mogul skiers are frequently exposed to very cold training and competition environments. Humans are considered homeotherms, meaning they can and must maintain a relatively constant core body temperature. When core body temperature deviates more than a few degrees from 37°C, physiologic function is altered, and the body attempts to maintain a balance between rates of heat loss and heat gain (Cappert, 2002).

When exposed to the cold, the body loses heat through the combined effects of radiation, conduction, convection, and evaporation. While at rest, exposure to cold temperatures triggers two significant responses (Cappert, 2002): 1) thermogenesis and 2) vasoconstriction. These responses result in increased heat production and reduced heat loss.

Although not yet fully understood, the human body appears to be able to acclimate to cold environments. These changes appear to be related to increased peripheral vasoconstriction, increased metabolic heat production, and increased skin fold thickness.


The effects of cold on exercise appear to be related to reduced core body temperature. Reductions appear in the following physical capacities: 1) $VO_2$ Max, 2) dynamic strength, 3) peak power output, and 4) performance in power-related activities such as sprinting and jumping (Cappert, 2002). These are all critical considerations for the mogul skier who relies heavily upon strength and power to compete at a high level.

The strength and conditioning practitioner should be aware of the following considerations in assisting athletes to maintain a constant core body temperature:

1) Fitness Level. The improvements in cardiovascular endurance found with training appear to provide additional protection during cold exposure.
2) Skin-Fold Thickness. Subcutaneous fat provides excellent insulation, and a thicker skin fold will provide greater resistance to heat loss; however, mogul skiers tend to be relatively lean and should be monitored closely.
3) Surface area to mass ratio. The smaller the body, the larger the surface area and, thus, the greater the potential for heat loss. Mogul skiers tend to be smaller individuals at greater exposure to environmental conduction, convection, and radiation.
4) Wind. Air rushing over the skin will significantly increase convective heat loss during cold exposure.
5) Wet Clothing. Because of its more remarkable ability to conduct heat, compared with air of the same temperature, water can promote a much quicker loss of body heat.

The coaching staff and strength and conditioning practitioner should consider the following when preparing athletes for training or competition in cold environments:

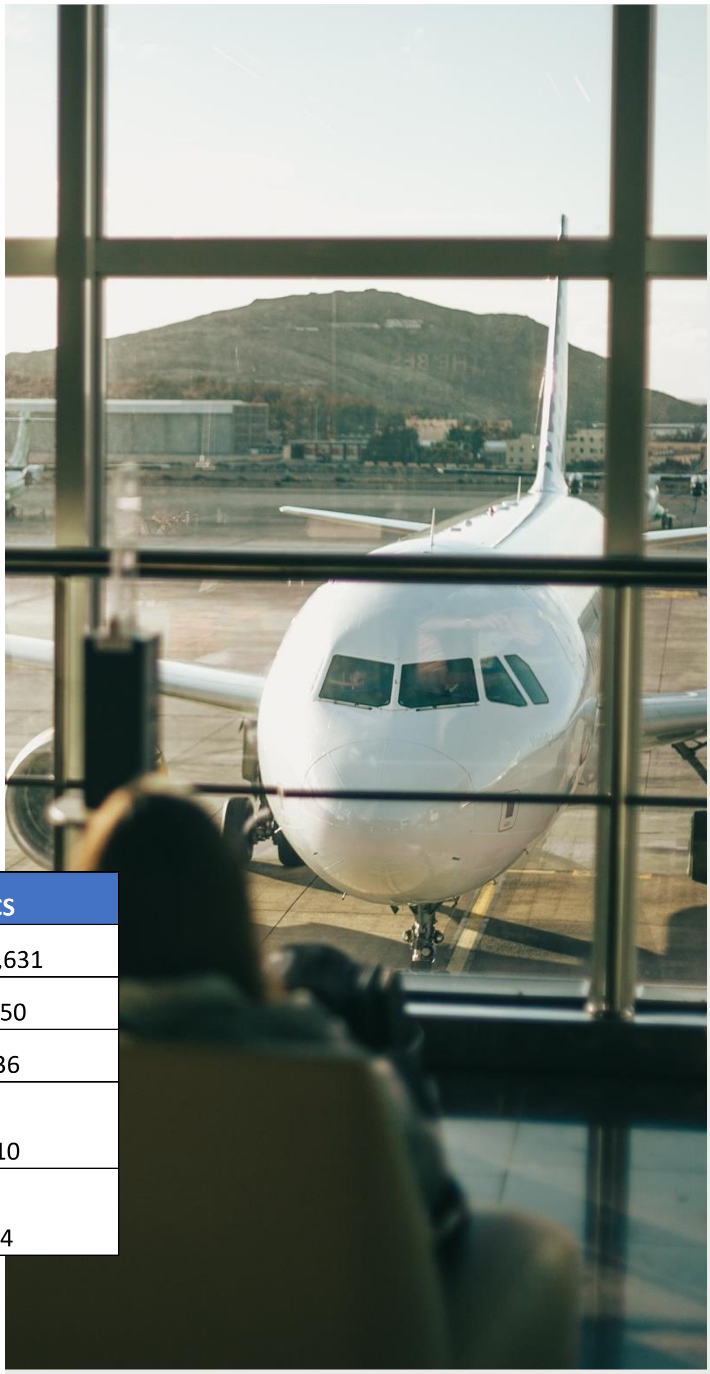
1) Proper warm-ups should be performed to increase muscle temperatures and increase blood flow to working muscles before racing or training. Tissue temperature should be increased by 3 degrees Celsius before training for optimal performance (Young & Behm, 2002).
2) Wearing appropriate clothing is essential. The insulative effects of clothing should be utilized to maintain comfort during training and competition. Clothing should be layered to take advantage of the insulating effect of air trapped between the layers. The first layer, called the base layer, should be made of fabric with moisture-wicking properties such as polypropylene. The second layer, or mid layer, should be good insulators such as wool, down or synthetic materials with similar properties. The third layer should be water and wind-resistant and can be opened or discarded to provide cooling as the body begins to produce heat. The fourth and final layer consists of clothing worn between competitive or training runs and should be waterproof and an excellent insulator. This layer should only be worn at rest and shed during activity (Cappert, 2002).
3) Athletes should be instructed to avoid rapid cooling after exercise cessation. Post-exercise hypothermia can develop because heat production has significantly fallen while heat loss remains high. Athletes should add clothing or other insulation or seek a warm environment soon after finishing a competitive or training event (Cappert, 2002).

Chapter 06

# DEMANDS OF TRAVEL

## Travel Considerations

FIS World Cup-level athletes experience frequent transmeridian travel demands. During the 2017-2018 season, World Cup athletes traveled a total of 91,631 miles to 10 different countries in a period of 7 months. Athletes often cross 8-12 time zones every 5-10 days for competition. The mode of travel varies and includes air, rail, bus, or automobile travel.  Some ground transportation could be in excess of 5 hours following transmeridian flight. How athletes and coaches manage frequent travel can be critical to the athlete's success.



| 2017-2018 WORLD CUP TRAVEL STATISTICS | |
|---|---|
| MILES TRAVELED | 91,631 |
| TIME ZONES CROSSED | 150 |
| TOTAL NUMBER OF FLIGHTS | 36 |
| TOTAL NUMBER OF COUNTRIES VISITED | 10 |
| TOTAL NUMBER OF CONTINENTS VISITED | 4 |

The unique combination of travel-related physiological, psychological, and environmental factors may have detrimental effects on an athlete's ability to recover and perform. Dependent on the direction and length of the travel, these factors may include jet lag, disruption of circadian rhythm, joint stiffness, dehydration, and sleep disruption. Mechanisms of travel fatigue are a result of transitory alterations in human physiology because of rapid air travel across multiple time zones and are commonly referred to as jet lag (Williams, Clarke, Aspe, Cole, & Hughes, 2017).

Jet lag can manifest as sleep disturbances, daytime fatigue, lack of concentration, headaches, irritability, loss of appetite, and gastrointestinal disturbances. Most symptoms associated with jet lag mainly occur because of the desynchronization between the body's internal time-keeping system and the external environment (Williams, Clarke, Aspe, Cole, & Hughes, 2017). There are two strategies, as referenced by Dr. Bill Sands (Managing Jet Lag, 2018), that seem to have the most significant amount of merit when assisting the athlete who is coping with transmeridian travel: 1) compete and train immediately upon arrival; or 2) compete and train after the body has had time to resynchronize with the current time zone. The first, competing immediately upon arrival, is somewhat impractical due to the very nature of air travel. Challenges such as delays, security screenings, and weather make planning for such a strategy impossible.

Therefore, the coach and athlete should focus their energy on acclimating as quickly as possible upon arrival at a new destination.

The coping strategies for such events include:

1) Managing Light Exposure – On arrival, depending on the timing, intensity, and duration, exposure to bright light can advance or delay the circadian phase. Athletes and coaches should time bright light exposure by avoiding bright light before the body temperature nadir and seeking bright light after (Williams, Clarke, Aspe, Cole, & Hughes, 2017).
2) Coping with and Avoiding Sleep Deprivation – Sleep deprivation can adversely affect athletic performance. It can occur from sleep loss during air travel (overnight flights) and jet lag (the need for a circadian advance or delay). It is recommended that sleep during travel be maximized to reduce these effects. Additionally, naps of less than 30 minutes are not susceptible to "sleep inertia," the fatigued state experienced upon waking from sleep (Meir, 2002).

3) Nutritional Recommendations – Food and drink requirements should be discussed with athletes prior to departure. During air travel, the dry air circulated in flight cabins can increase the likelihood of dehydration; therefore, athletes should pay special attention to fluid intake. Upon arrival, meals should coincide with the destination's time zone to aid with circadian advances or delays. Athletes should be instructed to avoid caffeine, nicotine, and other stimulants. Finally, using sleep aids, such as melatonin, L-tryptophan, or valerian root, could be beneficial for those who have difficulty coping with sleep disturbances (Meir, 2002).
4) Clothing Choices – Compression garments have been suggested to provide beneficial effects (reduction of blood pooling and venous thromboembolism) while alleviating discomfort and difficulties associated with prolonged sitting in a cramped position during air travel (Sands, Managing Jet Lag, 2018).
5) Exercise – When possible, periods of mobilization should be practiced to promote blood flow and reduce the risk of venous thromboembolism, joint stiffness, and muscle cramps that could result from long periods of inactivity during travel. While awake, athletes should stretch and move about the cabin. Upon arrival, to benefit from exercise-induced circadian phase shifts, it is recommended to perform exercise early in the morning when body temperature is lowest (Meir, 2002).
6) Behavioral Changes – The athlete and coach directly control many of the abovementioned factors. Some of the most common behavioral changes include: keeping the cabin windows down, turning off your cabin light until an hour before arrival, ensuring good sleep hygiene (e.g., avoiding caffeine, nicotine, food, and brain-stimulating activity), supplementation use (e.g., melatonin), ensuring a comfortable space (e.g., bring the right pillow, slippers, and clothing), timing and dose of exercise, and seating arrangements (Meir, 2002).
7) Individual Considerations – Jet lag effects are influenced by many individual differences in people and range from chronotype, age, fitness level, and adaptability of sleep patterns. Morning-type people who arise early and retire early are less affected by eastward travel, whereas evening-type people who retire late and arise late have less difficulty flying westward. Also, younger athletes (18-25) are less affected by jet lag symptoms as compared to older athletes (25-32). Finally, physically fitter athletes should experience less difficulty with jet lag as they have a higher capacity for stress tolerance (Williams, Clarke, Aspe, Cole, & Hughes, 2017).
8) Mental Attitude – Athletes should adopt a positive mental attitude before getting on the plane. The flight should be seen as a means to an end. Athletes should be encouraged to adopt a passive mindset and remain resistant to distractions that might cause anxiety or tension. At all times, they should keep things in perspective; delays are a part of being in transit (Williams, Clarke, Aspe, Cole, & Hughes, 2017).


Chapter 07

# SPORT AND SKILL DEMANDS

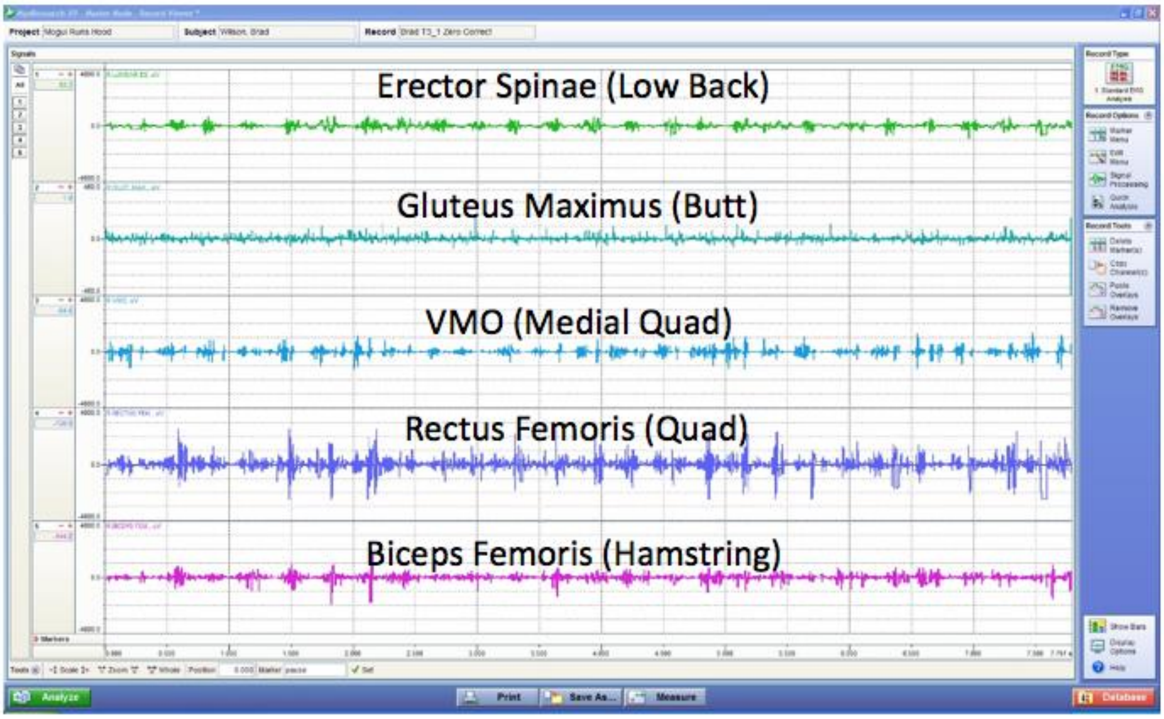
## Electromyography

To date, no published data exist on the muscle activation patterns of mogul skiers. Electromyography (EMG) is a safe, easy, and non-invasive way to objectively quantify the energy of the muscle. This, in turn, leads to a greater understanding of how the nervous system participates in the orchestration of muscle function.

In June 2018, Sands and Bullock conducted an EMG study on mogul skiers in Mt. Hood, Oregon. Four skiers, two males and two females, of distinctly different "styles" or techniques were selected for the project. The four goals of this project were as follows:

1) Decipher the relative involvement and activation of the musculature.
2) Determine the dominant motor pattern of the sport.
3) Validate a mogul-specific test.
4) Gauge the effectiveness of certain special exercises to prepare athletes.

The raw data can be seen in the images on the next page.




Raw EMG Signals Data

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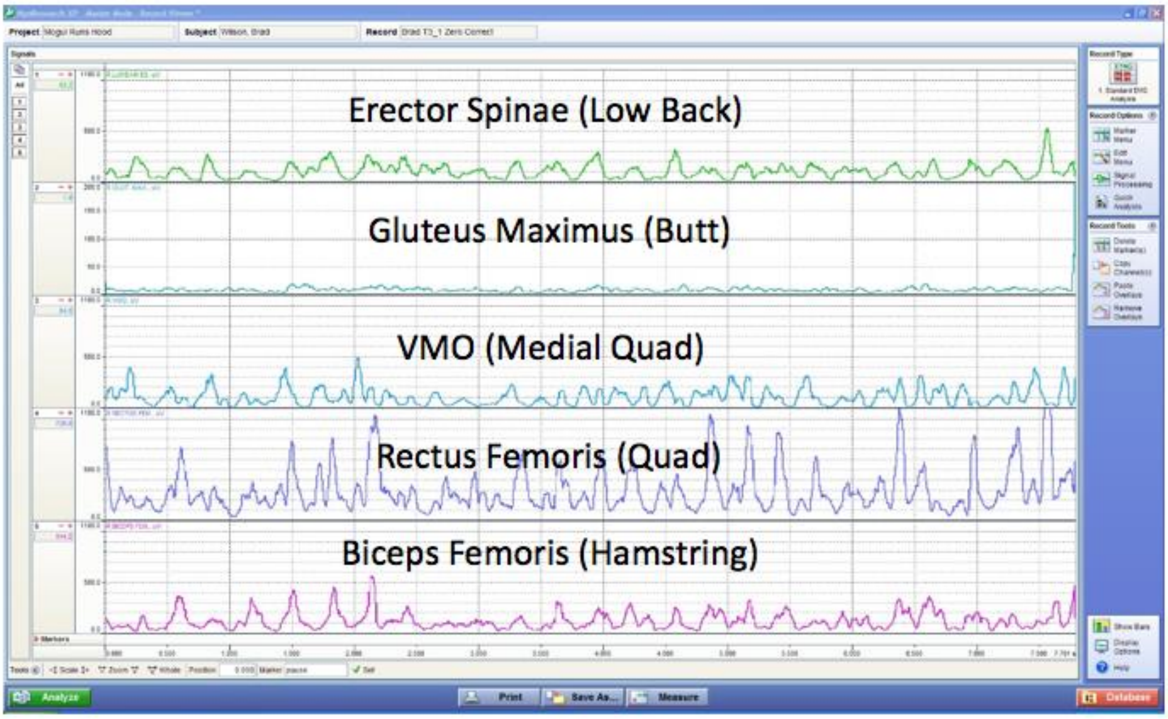
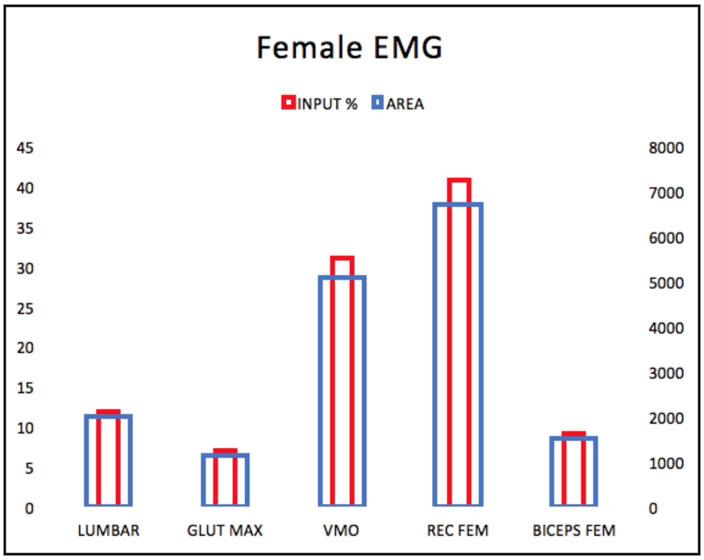
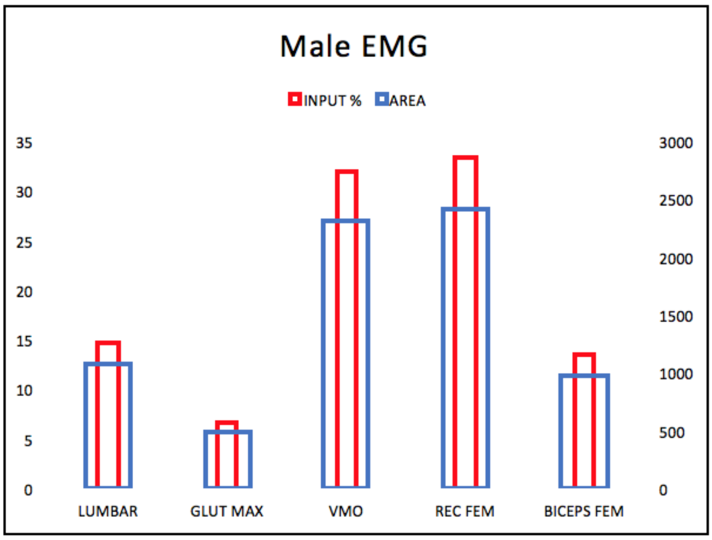



Rectified, Smoothed, and Signal Envelope (Integrated)

Sands and Bullock (2018) measured the activation of five muscles based on athlete feedback and the coach's observation of the sport. The musculature measure included: 1) Erector Spinae (low back), 2) Gluteus Maximus (buttocks), 3) Vastus Medialis Oblique (quadriceps), 4) Rectus Femoris (quadriceps), and 5) Biceps Femoris (hamstring). Results of the EMG indicate a strong similarity between genders and all ski "styles" or techniques. Dominant musculature includes the quadriceps (VMO and Rectus Femoris) and the low back (erector spinae) , while the gluteus maximus and biceps femoris activate to stabilize the knee and correct poor or inefficient body position.



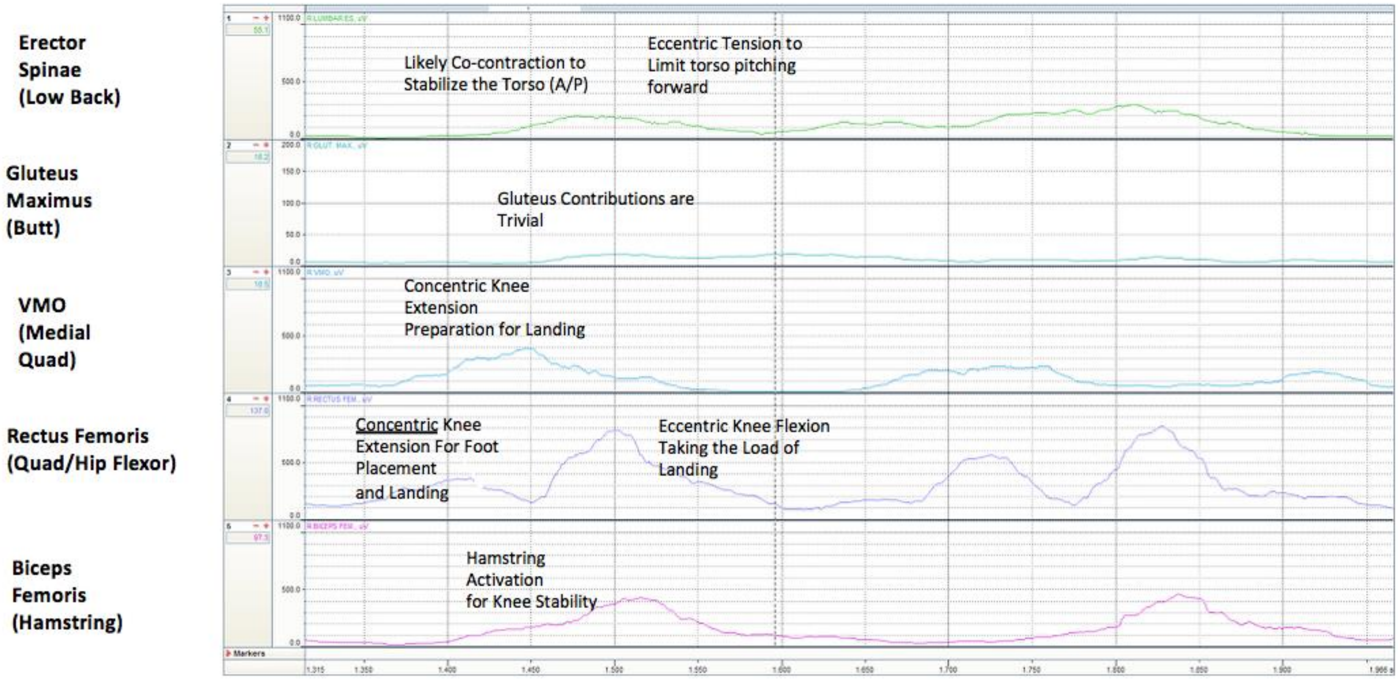




The relative input percentage for each of the muscles measured in females is as follows (Sands & Bullock, EMG of Mogul Skiers, 2018):

- Erector Spinae: 10-15%
- Glute Max: 5-10%
- VMO: 30-35%
- Rectus Femoris: 40-45%
- Biceps Femoris: 5-10%

The relative input percentage for each of the muscles measured in females is as follows (Sands & Bullock, EMG of Mogul Skiers, 2018):

- Erector Spinae: 15-20%
- Glute Max: 5-10%
- VMO: 30-35%
- Rectus Femoris: 30-35%

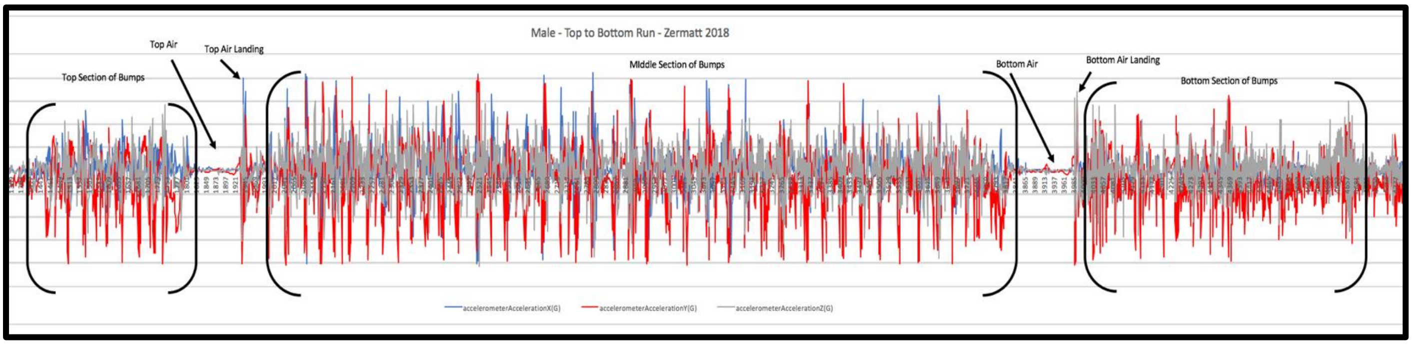



The motor pattern of mogul skiers serves to control the athlete's descent through a series of muscle actions that absorb the impact of the bumps while at the same time repositioning the athlete's feet and maintaining an upright posture of the trunk (Sands & Bullock, 2018). As the skier moves left to right across the page, one can see the motor pattern.

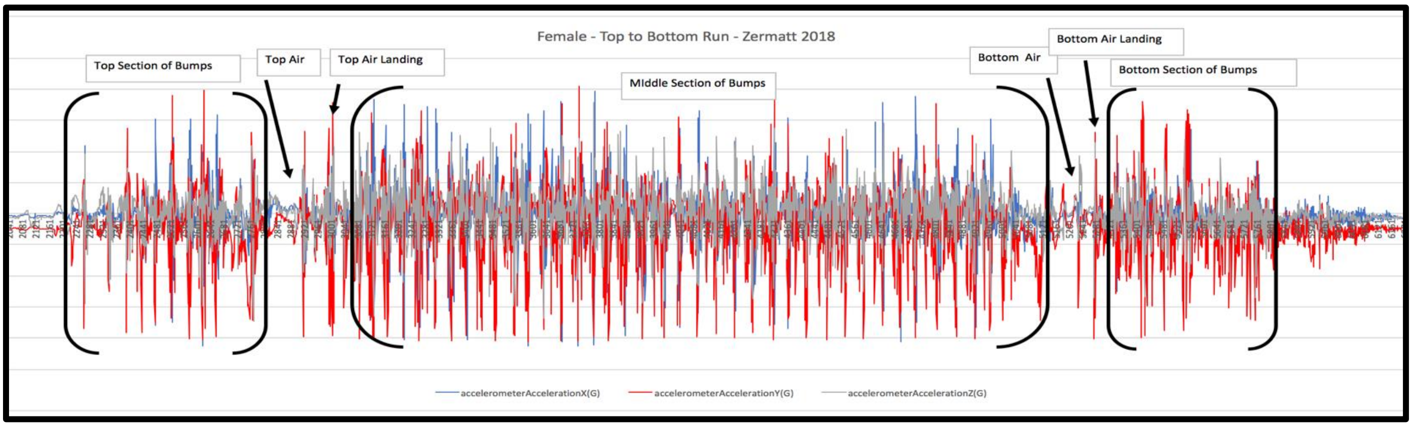
# Accelerometry

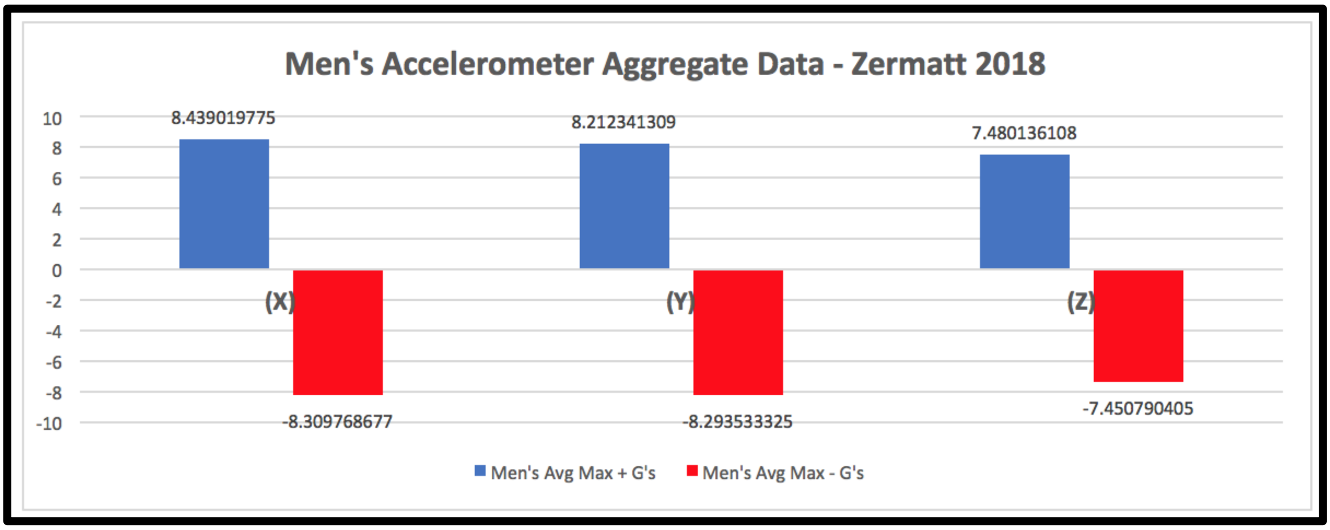
To date, no published data exist on the forces applied to and absorbed by a mogul skier, elite or novice. Unpublished data, collected and analyzed internally by Bullock and Sands, was acquired in October 2018 in Zermatt, Switzerland. That data was collected at 100hz, a sample rate which may be at the lower end of useful. However, given the lack of current literature, some training considerations could be drawn.

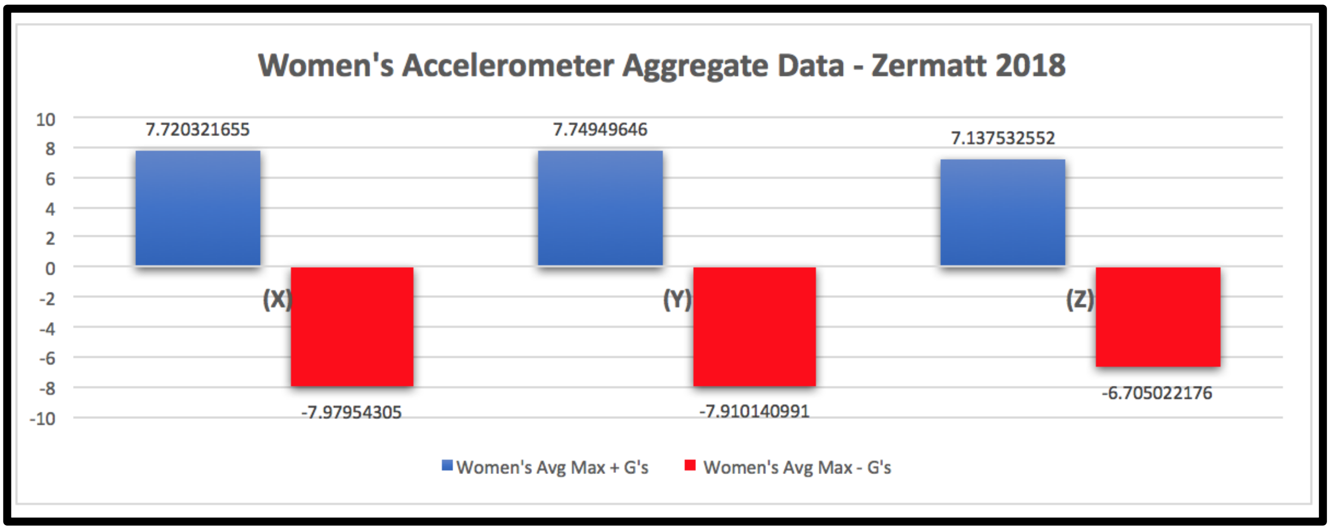
Three women and five men skied a full-length, 250-meter course, going from the top to the bottom without stopping. Participants were instructed to ski an aggressive competition run to emulate those conditions as closely as possible.




***Above:*** *Raw data from a male top-to-bottom run, Zermatt, 2018.* ***Below:*** *Raw data from a female top-to-bottom run, Zermatt, 2018.*



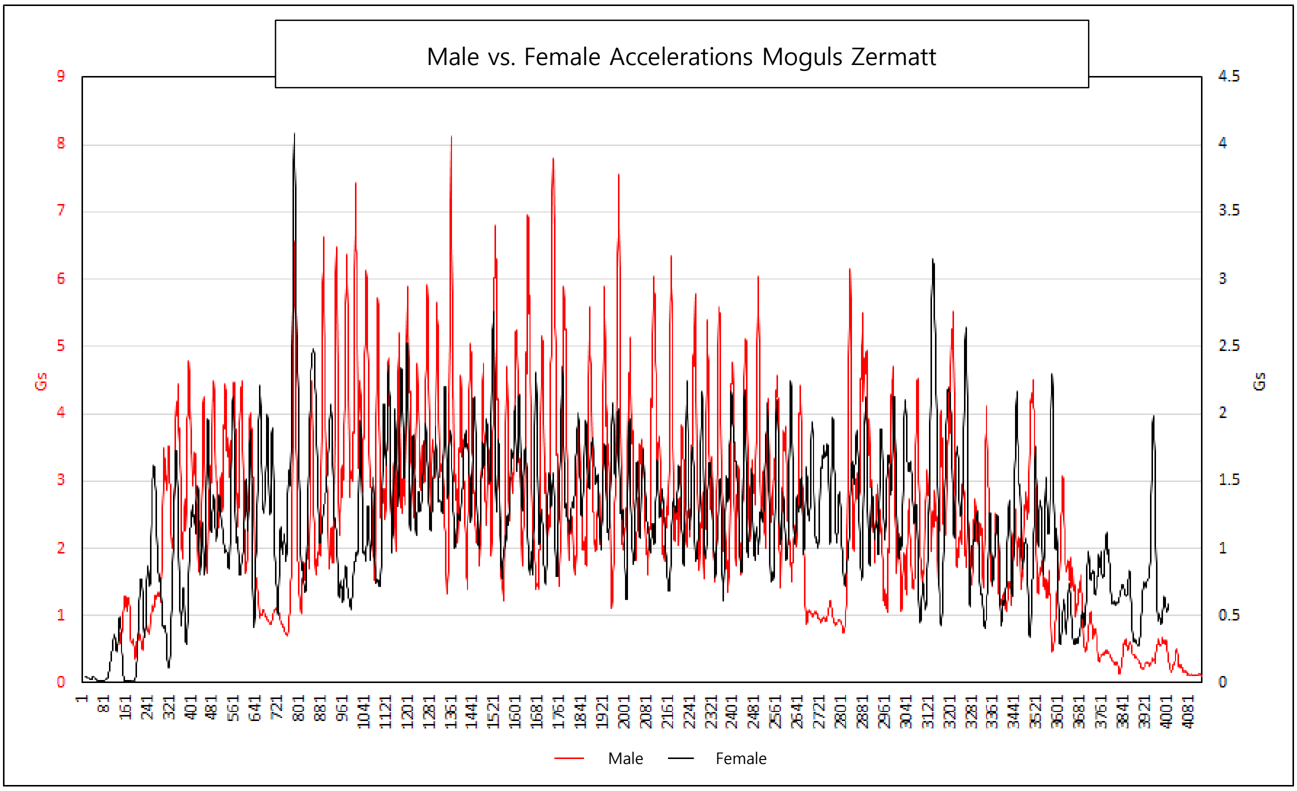




Aggregate data reveal that men experience higher average and peak G-forces than women in all planes of motion, with the most dramatic difference in the X-axis as males tend to travel down the hill at much higher speeds than females; 8.44 for males, 7.72 for females (Sands & Bullock, Accelerometry of Mogul Skiers, 2018).

Interestingly, landing forces differed slightly between the sexes: 8.29 for males and 7.91 for females (Sands & Bullock, Accelerometry of Mogul Skiers, 2018).

The final graph, on the next page, presents a male mogul skier and a female mogul skier on the same course. One might infer how each navigates the motor problem. The male appears to attack the course, while the female appears to float.




# Energy Systems

To date, no current literature exists on the physiology of mogul skiers or the quantification of relative energy system contributions for the sport. To quantify energy system contributions, a three-pronged approach has been undertaken: 1) the evaluation and application of energy system contribution of 200-m track running events, 2) the evaluation of energy system contribution from a simulated mogul course containing 39 separate 18-inch drops done at maximal speed, and 3) the evaluation of heart rate and blood lactate response from mogul skiing in a full training course in Zermatt, Switzerland.

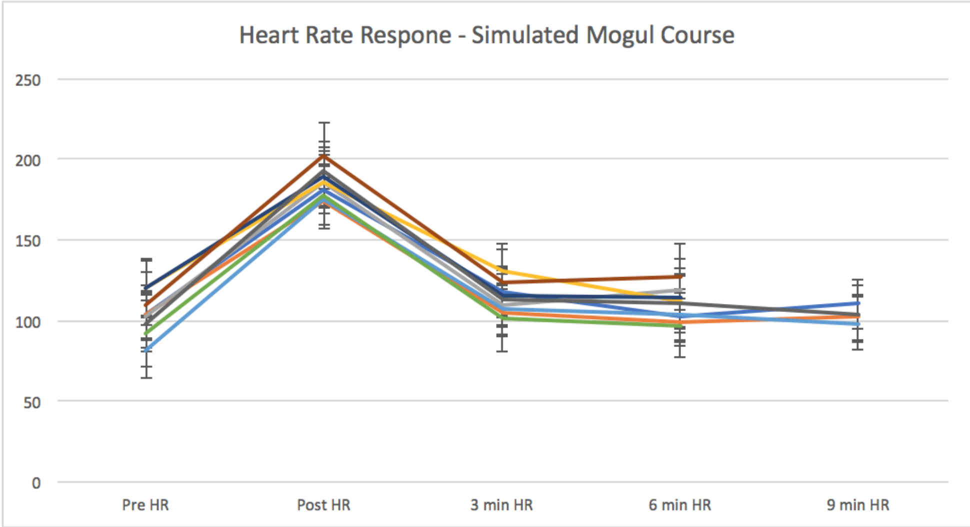
## 200 Meter Sprint Running

From a face validity standpoint, World Cup mogul skiing appears to be like that of a 200-m sprint lasting approximately the same amount of time (20-27s), with both producing a maximal effort from the athlete. For the 200-m, an anaerobic energy system contribution (based on accumulated oxygen deficit) of 28%-72% for males and 33%-67% for females is estimated (21%-79% and 22%-78% based on La/PCr measures; NS from Accumulated Oxygen Deficit estimates) (Duffield, Dawson, & Goodman, 2004).

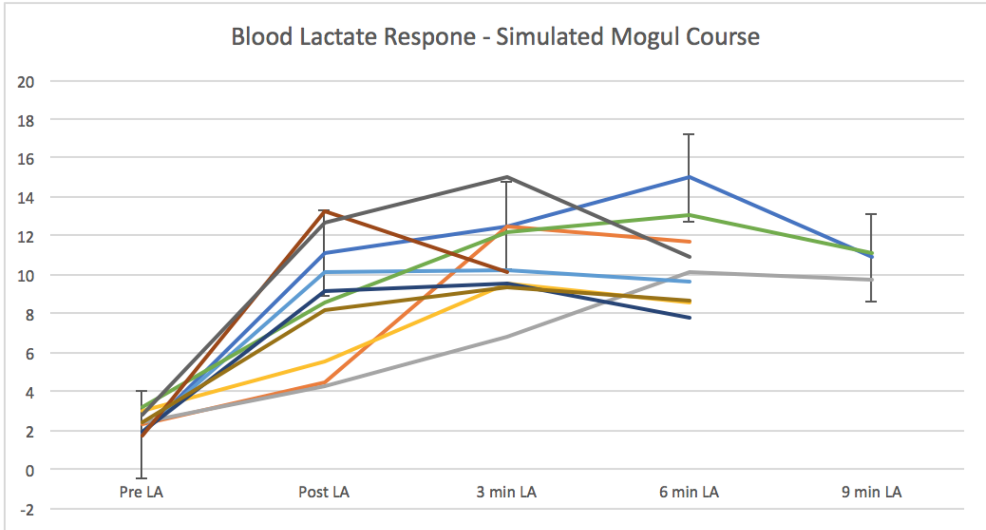
In a study by Hautier et al. (1994), blood lactate concentration was taken within three minutes of race completion in 200-m runners at the Cameroon national championships. Upon completion, the 12-national level male sprinters' blood lactate averaged 10.3mmol·l$^{-1}$(SD 0.8). The results of this study suggest that at the velocities studied, anaerobic glycolysis contributes to at least 55% of the energy expenditure related to sprint running the 200-m (Hautier, et al., 1994). Numerous studies have shown similar results regarding energy system contribution and blood lactate accumulations (see tables on the net page).

| | AOD | | La/PCr | |
|---|---|---|---|---|
| Event | **% aerobic** | **% anaerobic** | **% aerobic** | **% anaerobic** |
| **100-m** | | | | |
| Male | **20.6** (±7.9) | **79.4** (±7.9) | **8.9** (±3.3) | **91.1 *** (±3.3) |
| | (13 - 35) | (65 – 87) | (6 – 14) | (86 – 94) |
| Female | **25.0** (±7.4) | **75.0** (±7.4) | **10.9** (±5.8) | **89.1 *** (±5.8) |
| | (17 – 33) | (67 – 83) | (6 – 19) | (81 – 94) |
| **200-m** | | | | |
| Male | **28.4** (±7.9) | **71.6** (±7.9) | **20.7** (±8.5) | **79.3 #** (±8.5) |
| | (17 - 40) | (60 – 83) | (14 – 35) | (65 - 86) |
| Female | **33.2** (±8.0) | **66.8** (±8.0) | **22.0** (±7.7) | **78.0** (±7.7) |
| | (26 – 45) | (55 – 74) | (15 – 28) | (72 – 85) |


| | 100-m Male | 200-m Male | 100-m Female | 200-m Female |
|---|---|---|---|---|
| Race time (s) | 11.5 (±0.4) | 23.8 * (± 1.1) | 13.1 (±0.5) | 26.8 # (±1.2) |
| Peak race $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | 17.85 (±8.53) | 32.19 * (±7.31) | 13.92 (±7.04) | 26.59 (±12.25) |
| % peak $\dot{V}O_2$ | 33.0 (±12.9) | 56.6 * (±13.2) | 31.7 (±18.3) | 59.2 (±27.5) |
| Peak race HR (bpm) | 175 (±10) | 186 (±11) | 189 (±11) | 190 (±11) |
| % HR max | 91 (±5) | 93 (±4) | 99 (±1) | 99 (±1) |
| Peak $[La^-]_b$ ($mMol \cdot l^{-1}$) | 9.0 (±1.5) | 10.4 (±3.0) | 8.7 (±1.7) | 10.8 (±2.3) |
| Race AOD ($ml\ O_2eq \cdot kg^{-1}$) | 17.4 (±4.4) | 28.4 (±3.7) | 12.4 (±2.9) | 22.5 (±3.0) |
| La/PCr anaerobic total ($ml\ O_2eq \cdot kg^{-1}$) | 45.9 (±5.1) | 50.1 (±9.4) | 45.2 (±5.2) | 52.6 (±7.4) |
| Total Energy Cost ($ml\ O_2 \cdot kg^{-1} \cdot m^{-1}$) | 0.218 (±0.046) | 0.198 (±0.012) | 0.166 * (±0.035) | 0.169 (±0.014) |
| Speed ($m \cdot s^{-1}$) | 8.6 (±0.2) | 8.4 (±0.4) | 7.7 (±0.3) | 7.4 (±0.5) |




*Left:* One test session (five males, five females) conducted on May 30, 2018, the second such test in the pilot study.




## Simulated Mogul Course

In the spring of 2018, Sands and Bullock devised a simulated mogul course that consists of three sections of 13 x 18-inch drop jumps broken up by two sections of 13 x 18-inch box jumps. When performing the test, males wore a weight vest adding 10% of their current body weight, while females performed the test with no additional weight. The athletes were instructed to "ski" down the course traversing left and right, just as they would on a mogul course until they reached the bottom. The athlete then jumped rapidly back to the top, descended again in the same fashion, jumped one final time to the top, and descended in the same fashion to the bottom. The athlete was timed, heart rate was monitored and recorded, and blood lactates were taken pre, post, and every three minutes until peak blood lactate was achieved (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

This test has been validated using EMG for both relative muscular input and motor pattern similarities (Sands & Bullock, EMG of Mogul Skiers, 2018).

As illustrated on the previous page, time to completion of the test for females averages 33.19 seconds and for males 31.55 seconds, making the test slightly longer than a competitive mogul run (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

Heart rate climbs quickly throughout the test, peaking upon completion at an average of 91% of maximum in men and 94% of maximum in women (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

Blood lactate concentration typically peaks between one and three minutes upon test completion, with an average peak of 11.80mmol·l$^{-1}$ among all participants (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

Women appear to have a higher average peak blood lactate than men at 11.98mmol·l$^{-1}$ and 11.73mmol·l$^{-1}$ respectively (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

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## Mogul Course Training

In the fall of 2018, athletes at a training camp in Zermatt, Switzerland, replicated the testing protocol used on the simulated mogul course first to quantify the energy system contribution of a training run and second, further validate the use of the simulated mogul course as a tool for preparing athletes for the sport of mogul skiing. A third goal of the camp was to evaluate the energy system contribution regarding a single full day of training.

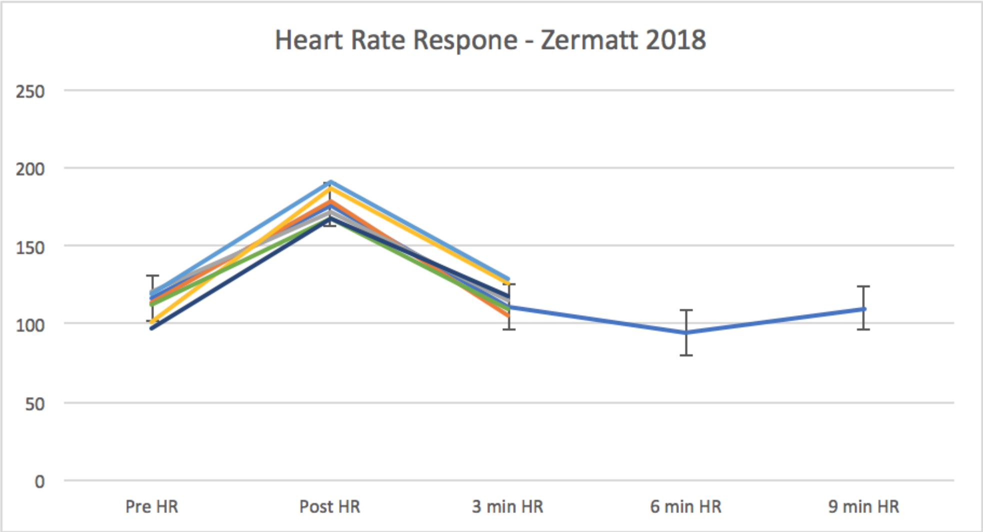
Just as in the simulated mogul course, the athlete was timed, and heart rate was monitored and recorded. Blood lactate was taken pre, post (30-90s upon completion of the run based on coaching), and every three minutes until peak blood lactate accumulation was achieved (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

As illustrated on the next page, time to completion of a single training run for females averages 27.84 seconds and for males 28.82 seconds, making these training runs slightly shorter than the simulated mogul course. All timing for this project was completed using the Free Lap timing system (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

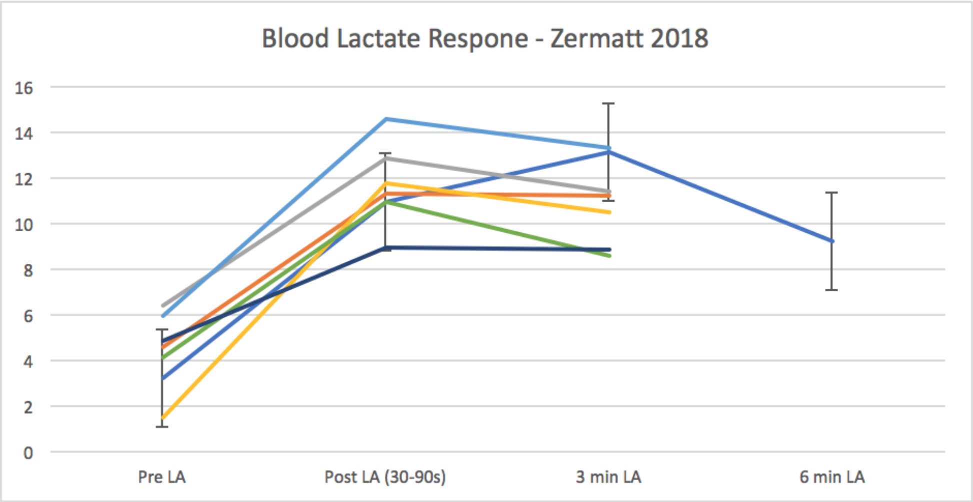
Heart rate climbs quickly throughout the run, peaking at an average of 89% of max upon completion among all participants (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018).

Blood lactate concentrations typically peak between one and three minutes upon completion of the test, with an average peak of 11.90mmol·l$^{-1}$ among all participants (Sands & Bullock, Energy System Demands of Mogul Skiers, 2018). It is important to note that blood lactate was not taken immediately post-run in all cases but rather between 0 and 90 seconds upon completion of the run as a matter of practicality.

Seven athletes were tested in Zermatt, 2018: two females and five males. Thus, small sample size may be a limiting factor to this information. Additionally, the Zermatt mogul course is located at 12,400 feet in the Swiss Alps, making elevation a second consideration for interpreting these results.




*Left:* Heart rate and blood lactate graphs of a single run, with a recovery period in Zermatt 2018.

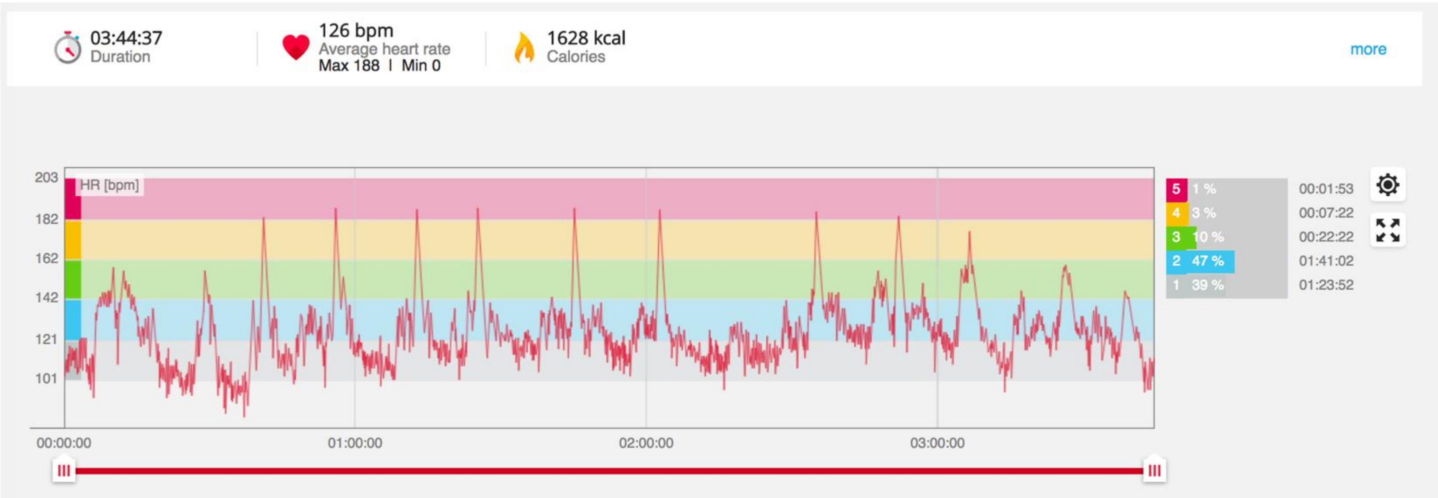



It is important to note that while the sport of mogul skiing, in and of itself, is very anaerobic (see above), the nature of a singular training session appears to stress the athlete across multiple energy systems. This stress-induced, therefore, is highly variable depending upon the content of that training session. The coaching staff and performance personnel need to understand the load, both acutely and chronically, that is being placed on the individual athletes. In short, while one training session is conducted, the stress on each athlete is likely very different.

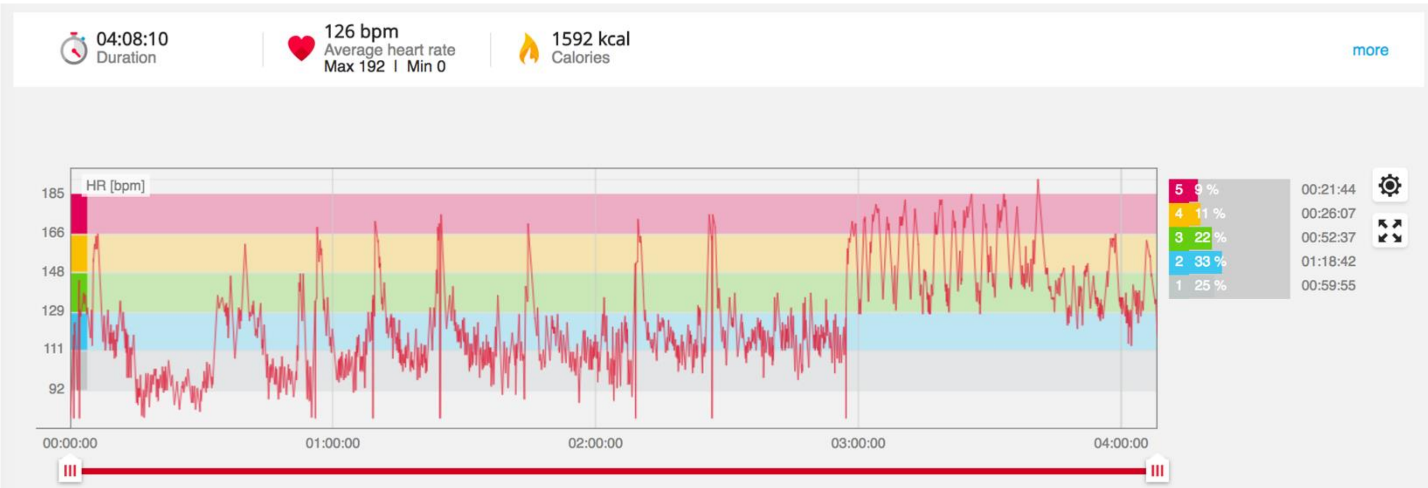
# Heart Rate Data

Below are some sample training sessions taken in Zermatt, Switzerland; Wolf Creek, Colorado; Mt. Hood, Oregon; and the Utah Olympic Park water ramps using Polar H10 heart rate monitors. Training sessions are captioned for context.

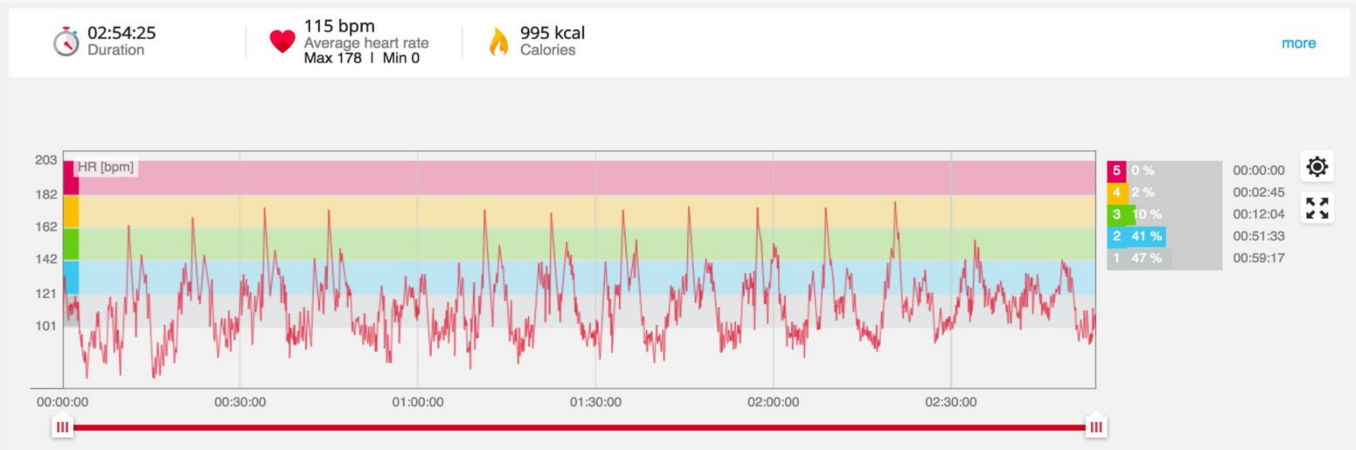
One training session conducted in Zermatt in 2018. This graph is typical of a mogul skiers training sessions where the emphasis is on skiing the course. **Content of this session:** Top-to-bottom training with sectioned skiing at the end of the training session.



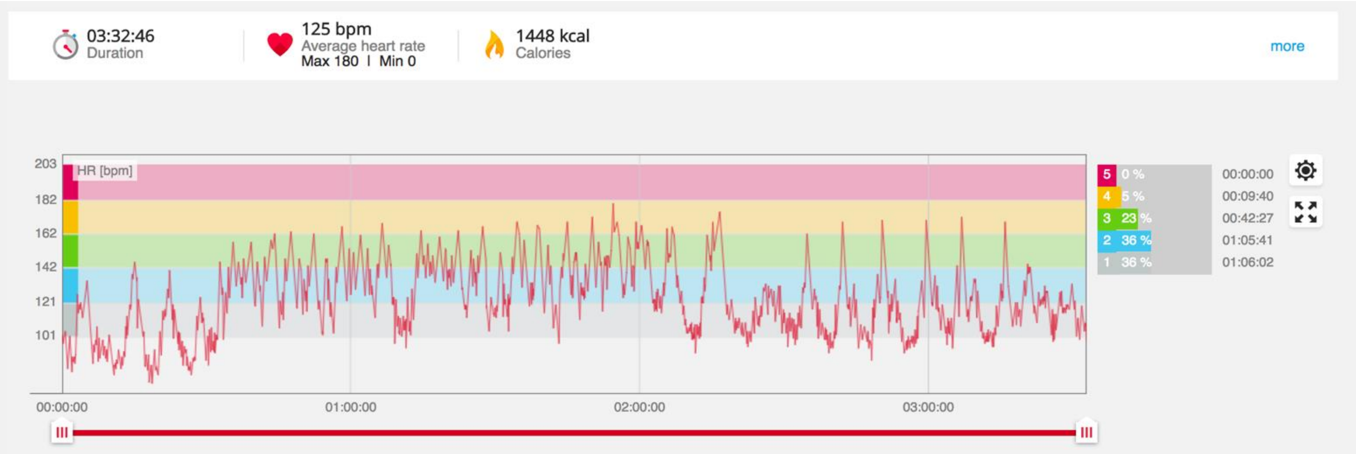

One training session conducted in Zermatt in 2018. This graph is typical of a mogul skier's training sessions with an emphasis on jumping. **Content of this session:** Top-to-bottom training with jump training (hiking) at the end of the training session.



One training session conducted in Wolf Creek, CO, in 2018. This graph represents the training of a partial course (150m). **Content of this session:** Partial course training. 150m course with one jump and longer free skiing outrun.

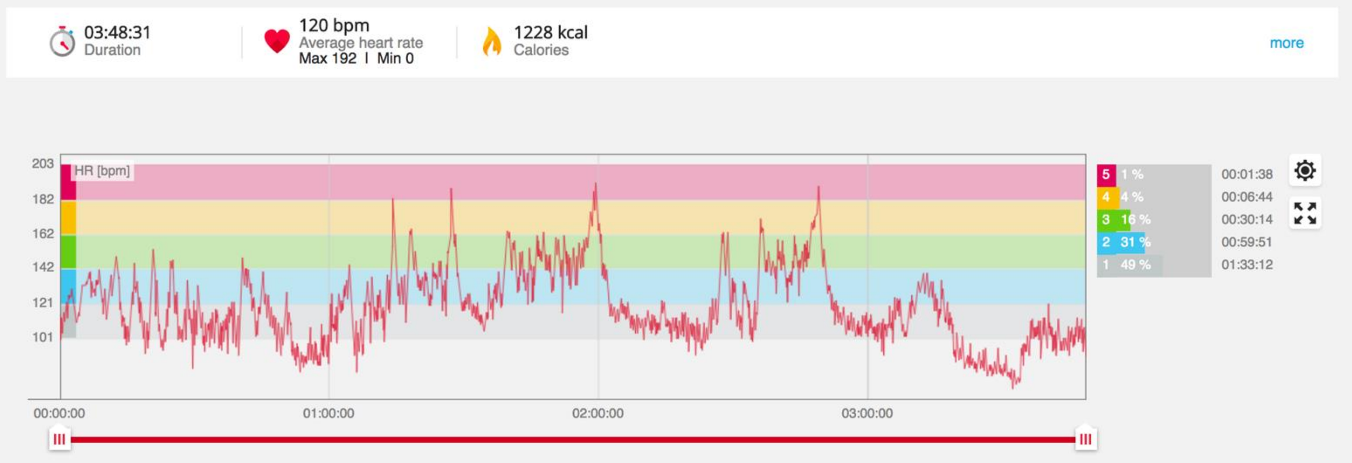



One training session conducted in Wolf Creek, CO, in 2018. This graph represents the training of a partial course (150m). **Content of this session:** Partial course training. 150m course with one jump and longer free skiing outrun.

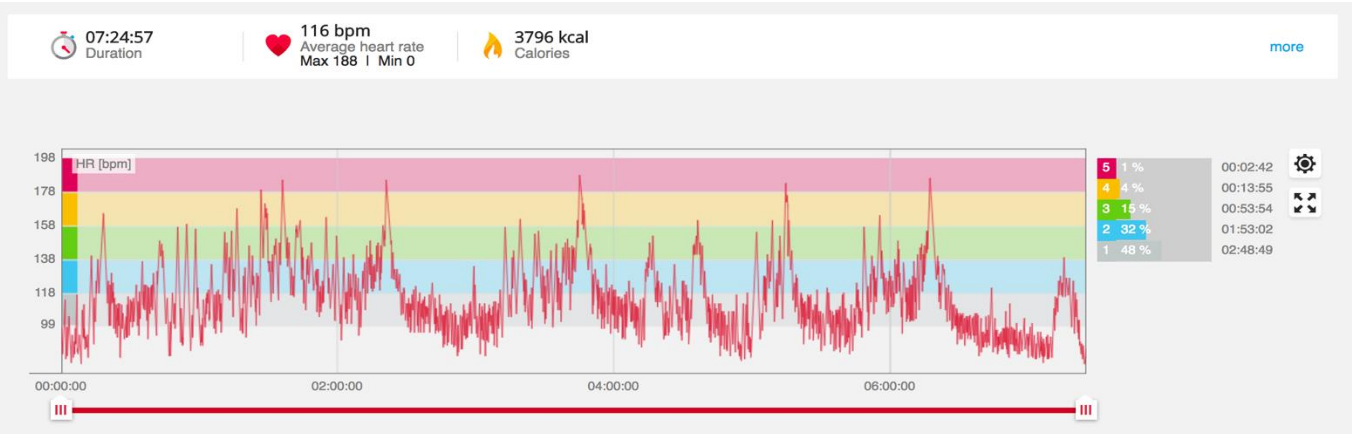



One training session conducted in Park City, UT, in 2018. This graph represents training at the water ramps at Utah Olympic Park. **Content of this session:** Water ramp jump training. Athletes jump and hike several flights of stairs back to the top.

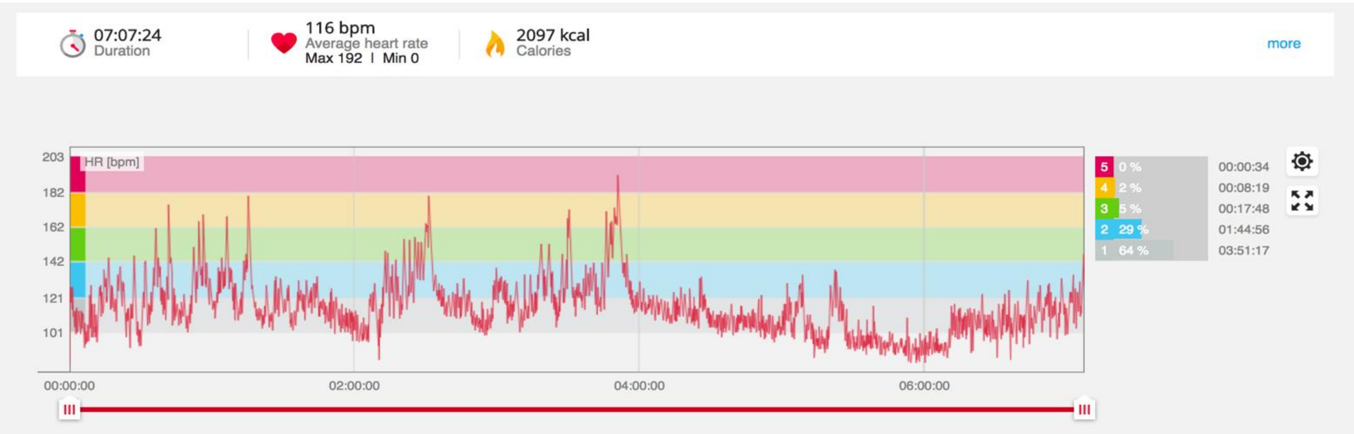
Competition Day - Single Moguls in Ruka, Finland, December 2018. Women's session #1 of a split session. This graph shows two competition runs - Q1/Q2. **Content of this session:** Moguls training, qualification #1, and qualification #2.

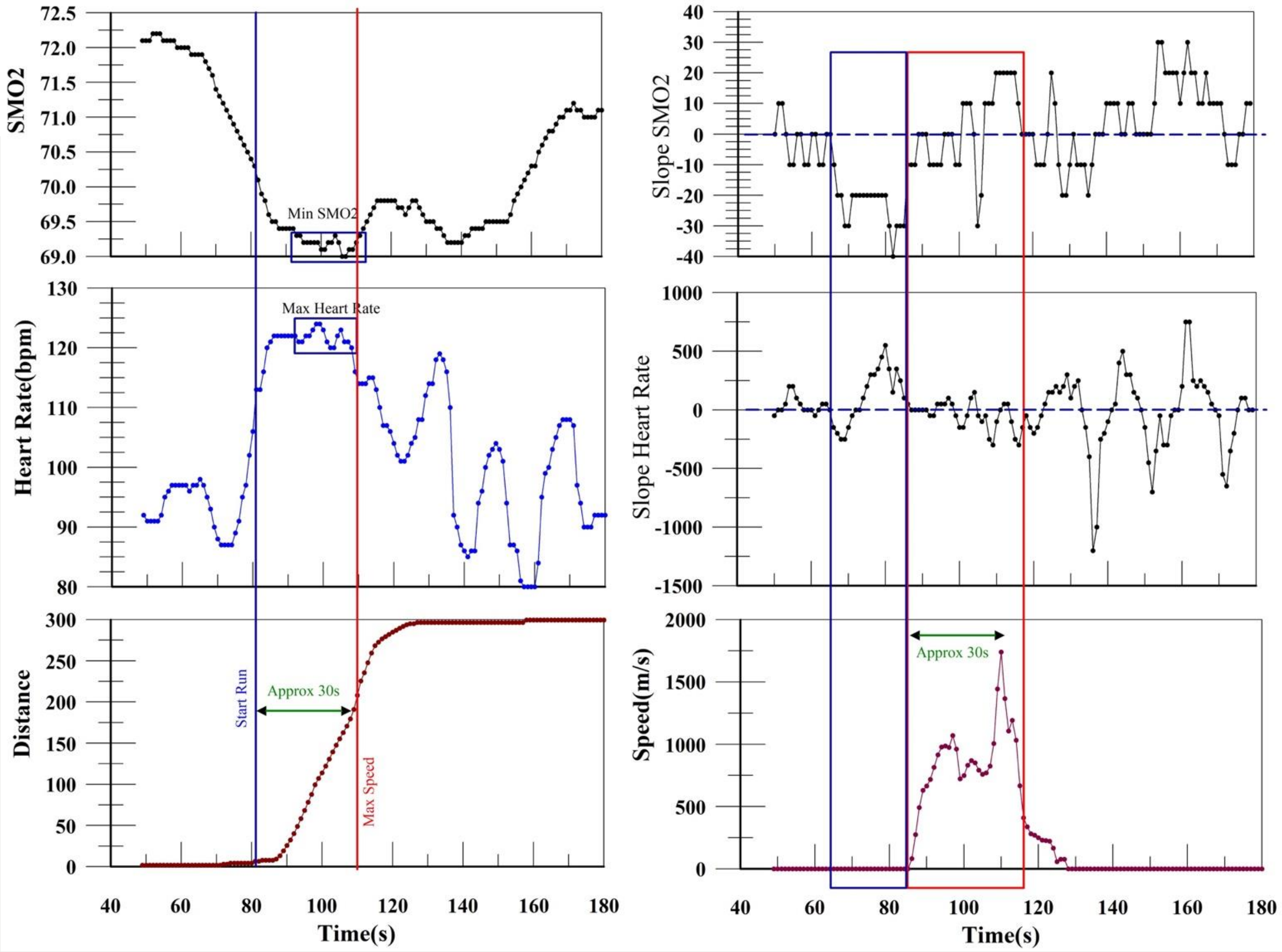



Competition Day - Single Moguls in Ruka, Finland, December 2018. Men's session, a singular long session with multiple runs. This graph shows three competition runs – Q1, Q2, and F1. **Content of this session:** Moguls training, qualification #1, qualification #2, finals training, finals #1.




Competition Day - Dual Moguls in Thaiwoo, China, December 2018. This graph shows four training and two competition runs. **Content of this session:** Moguls training, Round of 16, round of 8.






# Muscle Oxygen Saturation

The Humon near-infrared spectroscopy device measures hemoglobin saturation in muscle tissue. This technology has only recently been acquired by U.S. Ski & Snowboard and has never been used on freestyle mogul skiers prior to its current application. In December 2018, Bullock and Sands acquired and analyzed data from a Thaiwoo, China, official training session that featured top to bottom competition simulated mogul runs.

The 2018 data revealed that muscle oxygen saturation ($SMO_2$) reaches its minimum at about the same time as maximal heart rate is achieved. This is probably obvious and expected. These two systems will likely covary as one is involved in supplying the other.

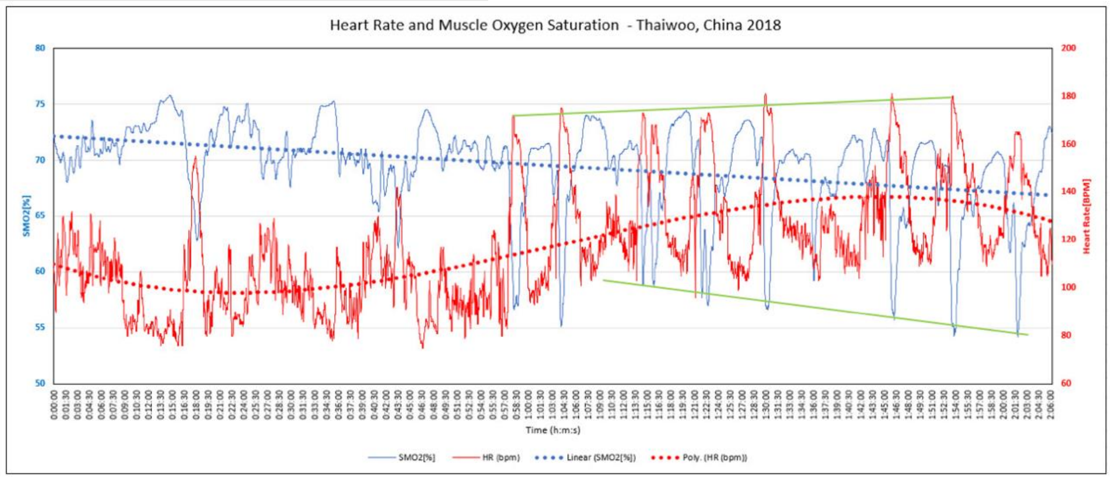
The six graphs above describe muscle oxygenation, heart rate, and distance covered. The three on the right are "rate-oriented" graphs, the rate of change of muscle oxygenation, heart rate, and position (i.e., speed). The left-side graphs show that the metabolic response of the athlete occurred in two phases. There is a rapid drop in muscle oxygenation immediately before the race, likely due to the state of arousal, followed by a slower decline in rate (right side) and magnitude (left side). The $SMO_2$ continues to decline during the race but more slowly (indicated by the negative portion of the top-right graph). As oxygen saturation declines immediately before the race, note that heart rate increases dramatically (middle-right graph) to compensate.

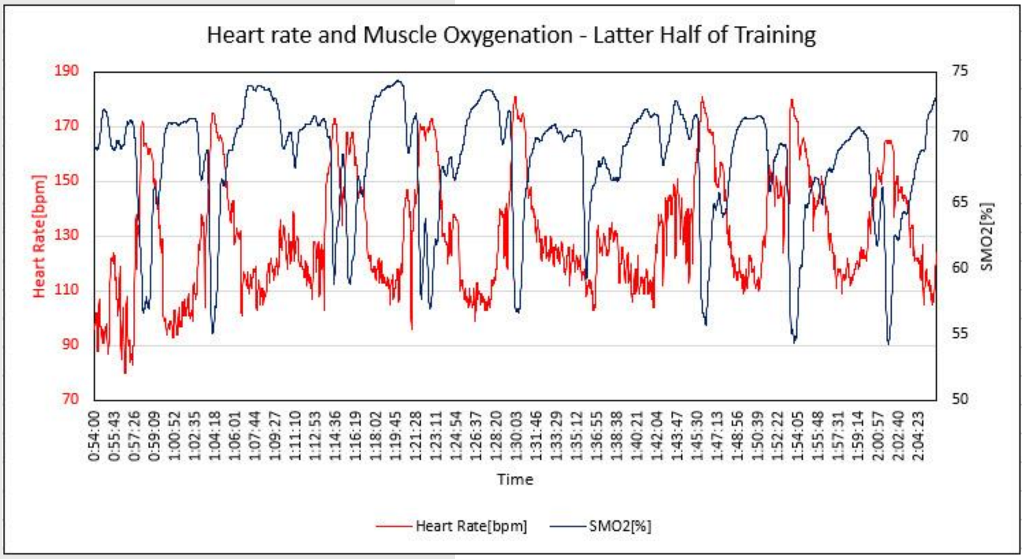
The most rapid decline in the rate of change of oxygen saturation occurs about mid-race. This is roughly coincident with a further decline in heart rate. As such, both systems attempting to oxygenate the muscle are doing rather poorly. This may be related to muscle tension now partially occluding blood supply to the thigh. As the race nears the end, the muscle oxygenation increases in rate but not magnitude. At this moment, heart rate is decreasing in both rate and magnitude. This may indicate a maximum capability of oxygen saturation at this point. These parameters may be helpful to test in future training tasks and durations.

The above information shows that the Humon device should probably be included during training for short-term stamina such that the exercise task(s) mimic these results. From a physical preparation standpoint, lactate buffering and training with blood flow restriction (BFR) may also be merited for these athletes, especially in those with an advanced training age.

The two graphs below display data collected in Thaiwoo, China, in December 2018, the top graph is an entire training session, and the bottom graph is the second half of a training session. Note that the second half of the training session looks quite different; as such, the data from 54 minutes to the end has been extracted.

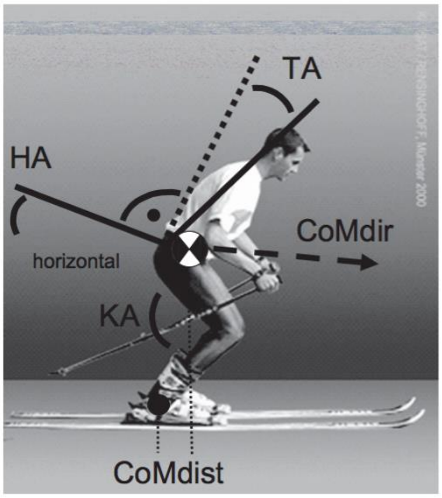
Of importance are the peaks of heart rate and the minimums of $SMO_2$. As training proceeds, their inverse relationship is portrayed quite clearly. As the athlete begins top-to-bottom training, heart rate response eclipses 180 bpm while $SMO_2$ declines below 55%. As the athlete's training duration extends, his heart rate response peaks, and his $SMO_2$ levels decline steadily with each run (green lines). This may be a sign of increasing fatigue or perhaps trying harder.



# Biomechanics

To date, there are just two published studies on the biomechanics of mogul skiing. In one such study, Kurpers and McAlpine (2009) examined the effects of using a force measurement device on riding technique in mogul skiing. That study was completed on professional mogul skiers (instructors or competitors). It analyzed knee angle, side and forward lean of the trunk and hip, and path of the body's center of mass.  This study was done on an indoor mogul course to accommodate the difficulties of filming. Unfortunately, the other study, by Ikegami et al., was published in 1994 before the advent of man-made mogul courses with standardized specs and jumps; however, some conclusions may still be drawn. More research in this area is needed.




*Above:* Graphical illustration of kinematic parameters investigated (KA=Knee Angle, TA=forward lean of the trunk, HA=forward tilt of the hip in a world coordinate system, CoMdir=path of the body's center of mass, CoMdist=horizontal distance of CoM and a point halfway between both ankle joint centers.

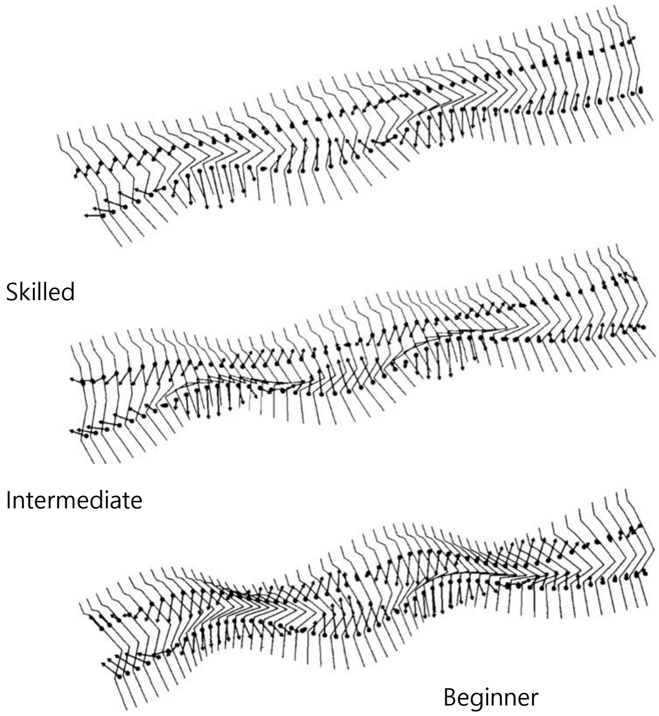
| | Normal | | Initial | | Familiarised | |
|---|---|---|---|---|---|---|
| Parameters | Mean | St.Dev. | Mean | St.Dev. | Mean | St.Dev. |
| InsideKneeFlexionMax [deg] | 93 | 5 | 101 | 12 | 91 | 9 |
| InsideKneeExtensionMax [deg] | 135 | 10 | 133 | 11 | 131 | 11 |
| OutsideKneeFlexionMax [deg] | 96 | 9 | 106 | 8 | 94 | 9 |
| OutsideKneeExtensionMax [deg] | 137 | 11 | 142 | 10 | 135 | 6 |
| SideFlexHipMin [deg] | −20 | 6 | −19 | 4 | −18 | 4 |
| SideFlexHipMax [deg] | −3 | 8 | −1 | 6 | 1 | 7 |
| FrontFlexHipSt [deg] | 29 | 11 | 30 | 8 | 28 | 10 |
| FrontFlexHipF [deg] | 29 | 7 | 25 | 11 | 22 | 10 |
| FrontFlexHipMin [deg] | 4 | 10 | 1 | 8 | 2 | 9 |
| FrontTiltTrunkSt [deg] | −10 | 4 | −11 | 4 | −11 | 4 |
| FrontTiltTrunkF [deg] | −12 | 3 | −16 | 5 | −13 | 4 |
| FrontTiltTrunkMax. [deg] | −5 | 2 | −6 | 3 | −6 | 3 |
| CoM_foot [mm] | 323 | 59 | 280 | 77 | 261 | 71 |

Kurpers and McAlpine assessed body motion over three runs using 3D video analysis. A four-camera high-speed video system (Simi Motion with Basler A602f cameras) mounted to the walls of the building collected video footage at 101 Hz. Knee angles ranged from 77° to 156° degrees. The average knee flexion on the inside legs was greater than on the outside. For the hips and upper body, several parameters were calculated, which may be used to characterize the forward-leaning of the skier. On average, lateral flexion of the upper trunk against the hip segment (SideFlex) shows a flexion away from the turning direction, as expected in parallel turns. The front flexion of the upper trunk against the hip segment was similar at the start and end of the swing, i.e., on top of the moguls and straighter in the dip between moguls, indicated by a smaller angle. The forward inclination of the hip is less negative when going through the dip, indicating a more upright posture according to a combined knee and hip extension in this phase. The sideways movement of the hip shows almost exclusively negative values, indicating a slight left tilt compared with the standing trial (Kurpiers & McAlpine, 2009).

*Above Left: Mean Values and Standard Deviations of Kinematic Parameters for the Three Relevant Runs (F = at Finish, Min = Minimum, Max = Maximum, CoM = Centre of Mass, CoM foot = Horizontal Distance Between CoM and a Point Half Way Between Both Ankle Joint Centers)*

One must proceed with caution when interpreting the above information, as certain limitations exist. First, the sample size used in the study was relatively small (8 individuals). Second, the study was completed on an indoor mogul course to keep the moguls' height consistent, a condition that rarely, if ever, takes place in the field. Third, participants only skied over four bumps which may explain the slightly asymmetric sideways orientation of the hip segment. On a continuous mogul run, the hip orientation would be expected to be symmetric (Kurpiers & McAlpine, 2009).

The fundamentals of the ski turn have remained relatively unchanged over time.  The parallel turn is initiated down the kinetic chain to provide sufficient force to complete a turn (Arndt, 1992). As described by Arndt (1992), the initiation of the turn begins at the hip and continues through the knee joint to the ankles and feet, whereby force is applied to the edges of the ski. The turning force in advanced skiing is provided by the rotation of the lower limbs against the relatively stable, larger upper body mass. A more significant friction force is developed by edging the skis into the snow to overcome centrifugal force and gravity forces (Arndt, 1992).




*Above:* A stick depiction of a mogul skier’s body showing the vertical displacement of the head, shoulders, trunk and hips.
Top = Skilled
Middle = Intermediate
Bottom = Beginner

Arndt (1992) gave a two-dimensional kinematic description of the movements necessary for a skier to maintain balance despite the rapid changes in ground reaction force from the snow surface experienced when skiing down the fall line over two uniform bumps constructed on a gentle slope. In the study, a comparison was made between skilled and intermediate skiers that showed accelerations in the lower body, and the range of joint motion at the knees and hip of the skilled skier were large. In contrast, the accelerations and trajectory of the upper body were relatively stable. The skilled skiers actively extended the hip and knee immediately after skiing over the bump. This prevented the skier’s body from falling down the far side of the mogul and from receiving the impact force of the snow surface after the bump (Arndt, 1992). This observation was validated by Sands and Bullock (2018) in a study using EMG on mogul skiers.

Unpublished data using a single-subject case study from Bullock, Martin, and McDermott (2022) using the Noraxon MyoMotion motion capture device is perhaps the best source of information on biomechanics in mogul skiing. In October 2019, Noraxon MyoMotion markerless sensors (16) were affixed to one male and one female national team mogul skier during a training run in Zermatt, Switzerland, a course largely considered to be a World Cup-caliber venue. Data was collected at 100Hz. Sensor placement locations can be found in the image on the next page.

Sensor Placement Locations:

| | |
|---|---|
| **Head** | Middle of the back of the head |
| **Upper Thoracic** | Below C7 in line with the spinal column, but high enough to not be affected by upper trapezius muscle movement |
| **Lower Thoracic** | In line with the spinal column at L1/T12. Strap belt will be positioned on lower ribs on the front side of the body. |
| **Pelvic** | Body area of sacrum |
| **Upper Arm** | Midway between the shoulder and elbow joints, lateral to the bone axis |
| **Forearm** | Posterior and distal, where there is a low amount of muscle tissue |
| **Hand** | Dorsal |
| **Thigh** | Frontal and distal half, where there is a lower amount of muscle displacement during motion |
| **Shank** | Front and slightly medial to be placed along the tibia |
| **Foot** | Upper foot, slightly below the ankle |

Following data collection, a ten-bump section, timestamp from 38-43 seconds, was selected for deeper analysis based on the uniformity of course conditions and consistency of the data collected. Data were smoothed using a low pass $4^{th}$ Order Butterworth filter at 6Hz to remove bump impact noise.

Descriptive statistics and graphical representation were generated for each gender and hip and knee kinematics, including an ensemble for both flexion and joint angular velocities of these joints. Finally, a graphical representation was generated for the entirety of the run displaying flexion and joint angular velocity for the hip and knee joints.

# Male Biomechanics Data

The graphs below display the descriptive statistics for the male athlete. The peak range of motion in a given cycle for the hip was 91° degrees and the athlete utilized ranges from 37° degrees to 137 ° degrees across all cycles. Peak hip extension joint angular velocity was 789 ° degrees/second, while hip flexion angular velocity peaked at 533 ° degrees/second.

Knee range of motion peaked at 85 ° degrees with the minimum joint angle of 19 ° degrees and a maximum of 105 ° degrees across all cycles. Knee extension angular velocity peaked at 623 ° degrees/second, and knee flexion velocity peaked at 530 ° degrees/second.

**MALE HIP ANGLES**

| | MIN | MAX | MEAN | ROM |
|---|---|---|---|---|
| **CYCLE 1** | 55.3859 | 131.3712 | 93.3305 | 75.9853 |
| **CYCLE 2** | 55.3859 | 137.3382 | 93.6835 | 81.9523 |
| **CYCLE 3** | 62.0613 | 131.4712 | 95.5371 | 69.4099 |
| **CYCLE 4** | 56.4023 | 118.4889 | 81.7799 | 62.0866 |
| **CYCLE 5** | 46.5614 | 126.7264 | 82.4665 | 80.1651 |
| **CYCLE 6** | 46.5614 | 121.4984 | 87.884 | 74.9371 |
| **CYCLE 7** | 37.4751 | 128.9803 | 82.6008 | 91.5052 |
| **CYCLE 8** | 37.4751 | 127.5300 | 87.5832 | 90.0549 |
| **CYCLE 9** | 61.0705 | 135.4393 | 94.93 | 74.3687 |
| **MEAN** | 50.9310 | 128.7604 | 88.8662 | 77.8295 |

**MALE KNEE ANGLES**

| | MIN | MAX | MEAN | ROM |
|---|---|---|---|---|
| **CYCLE 1** | 34.3057 | 105.282 | 71.6816 | 70.9763 |
| **CYCLE 2** | 34.3057 | 96.2376 | 65.3654 | 61.9319 |
| **CYCLE 3** | 32.9425 | 102.1674 | 70.8035 | 69.2249 |
| **CYCLE 4** | 32.9425 | 82.9803 | 59.9990 | 50.0378 |
| **CYCLE 5** | 19.4397 | 99.2718 | 59.8904 | 79.8322 |
| **CYCLE 6** | 19.4397 | 91.2833 | 57.8663 | 71.8436 |
| **CYCLE 7** | 19.6051 | 105.3554 | 62.1607 | 85.7503 |
| **CYCLE 8** | 19.6051 | 102.6594 | 70.7587 | 83.0543 |
| **CYCLE 9** | 29.8031 | 90.7298 | 63.8894 | 60.9267 |
| **MEAN** | 26.9321 | 97.3297 | 64.7128 | 70.3975 |

**MALE HIP ANGULAR VELOCITY**

| | MIN* | MAX |
|---|---|---|
| **CYCLE 1** | -400.4 | 619.6 |
| **CYCLE 2** | -452.8 | 789.40 |
| **CYCLE 3** | -533.2 | 624.10 |
| **CYCLE 4** | -419.8 | 545.40 |
| **CYCLE 5** | 528.0 | 644.1 |
| **CYCLE 6** | -290.5 | 650.0 |
| **CYCLE 7** | -416.0 | 605.90 |
| **CYCLE 8** | -290.8 | 703.20 |
| **CYCLE 9** | -303.2 | 658.00 |
| **MEAN** | -403.9 | 648.9 |

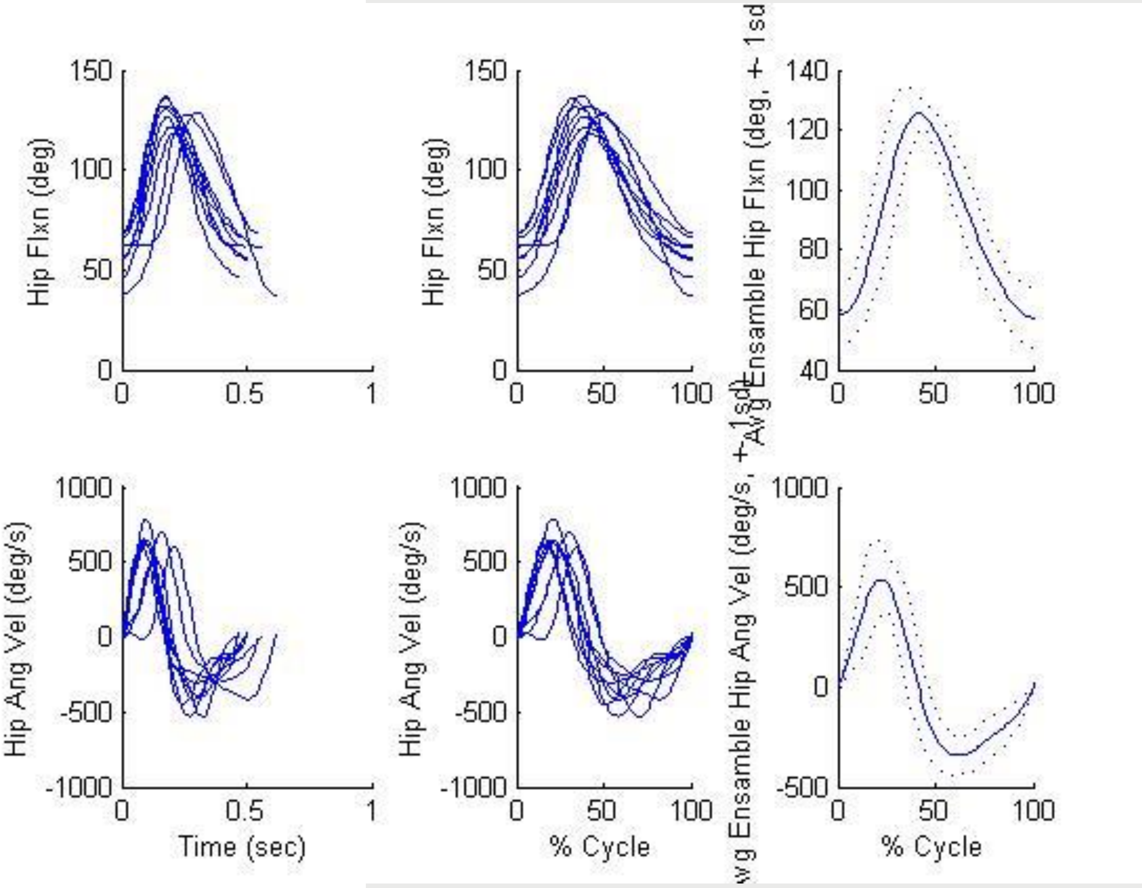
*** (-) = hip flexion**

**MALE KNEE ANGULAR VELOCITY**

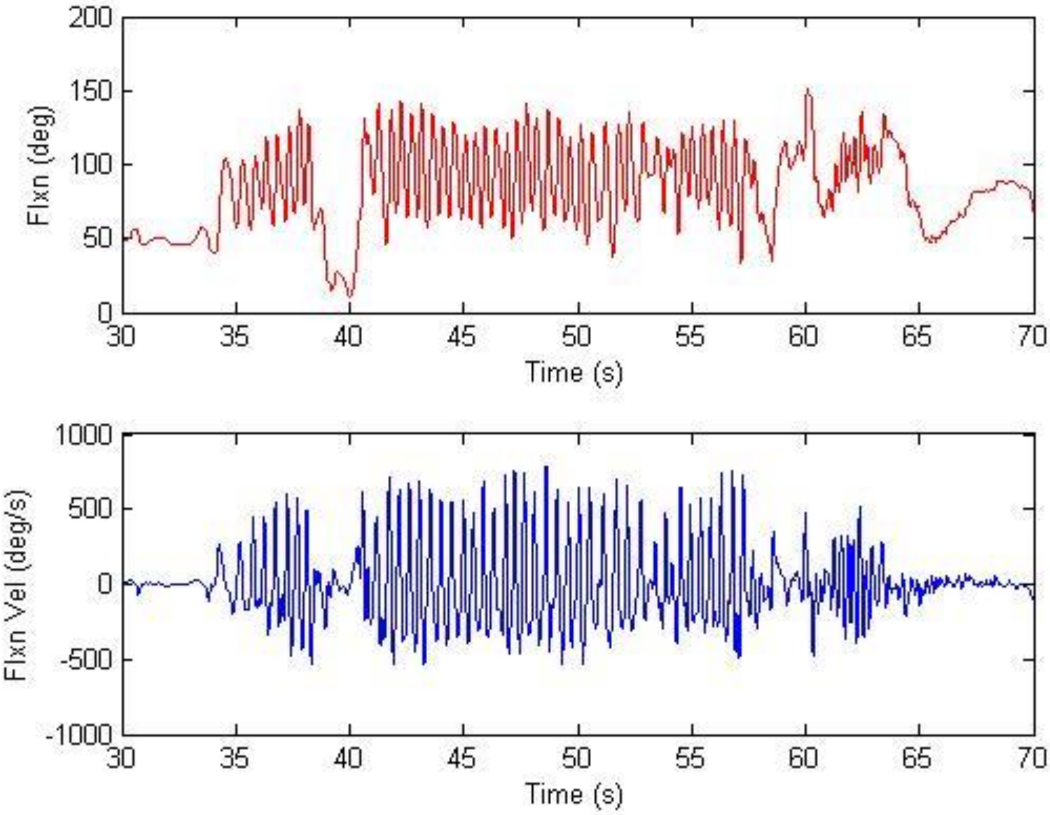
| | MIN* | MAX |
|---|---|---|
| **CYCLE 1** | -382.0 | 425.3 |
| **CYCLE 2** | -255.6 | 610.9 |
| **CYCLE 3** | -373.6 | 455.1 |
| **CYCLE 4** | -244.9 | 489.4 |
| **CYCLE 5** | -504.0 | 457.5 |
| **CYCLE 6** | -366.9 | 509.6 |
| **CYCLE 7** | -530.7 | 496.2 |
| **CYCLE 8** | -379.8 | 623.1 |
| **CYCLE 9** | -288.9 | 400.5 |
| **MEAN** | -369.602 | 496.4213 |

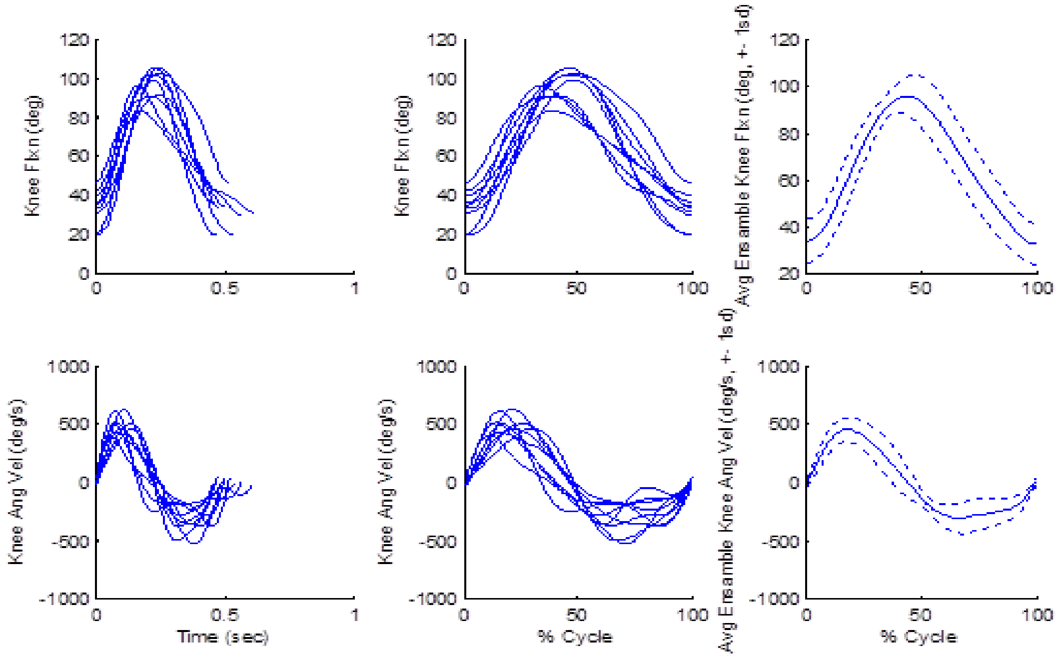
*** (-) = Knee Flexion**

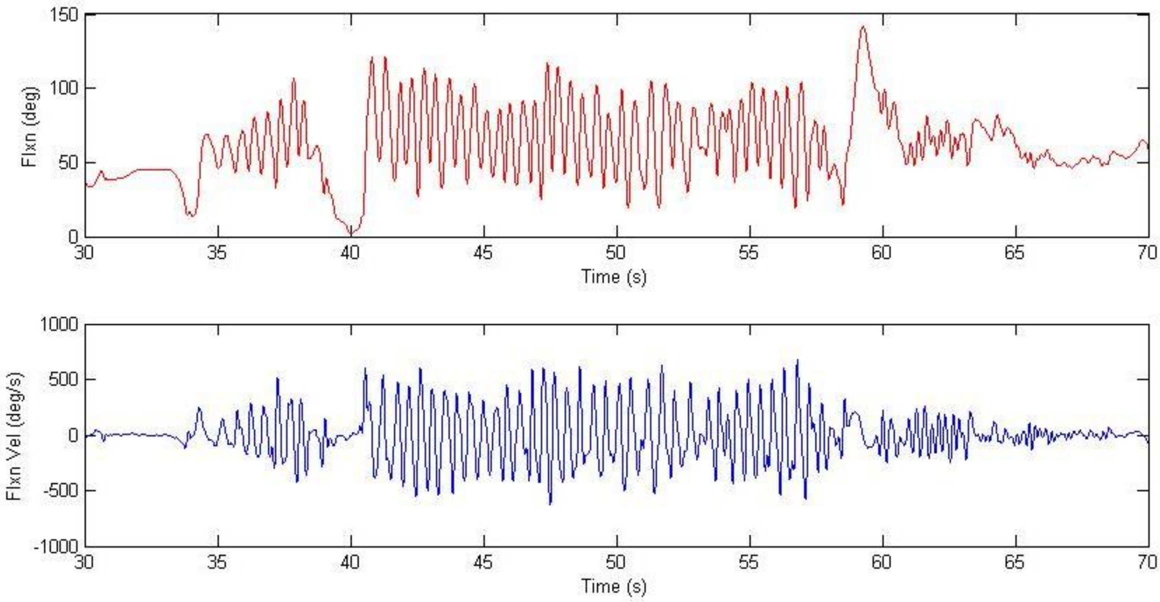
*Left:* Descriptive statistics of the hip and knee joints for a male mogul skier in Zermatt, Switzerland, during a training run.




*Above:* Hip angular velocity and flexion ensemble. *Below:* Graphical representation of hip angular velocity and flexion.






*Above Top:* Knee angular velocity and flexion ensemble.

*Above Bottom:* Graphical representation of knee angular velocity and flexion.

# Female Biomechanics Data

The graphs below display the descriptive statistics for the male athlete. The peak range of motion in a given cycle for the hip was 55 ° degrees, and the athlete utilized ranges from 26 ° to 84 ° degrees. Peak hip extension joint angular velocity was 450 ° degrees/second, while hip flexion angular velocity peaked at 344 ° degrees/second.

Knee range of motion peaked at 77 ° degrees with a minimum joint angle of 21 ° degrees and a maximum of 101 ° degrees. Knee extension angular velocity peaked at 637 ° degrees/second, and knee flexion velocity peaked at 447 ° degrees/second.

**FEMALE HIP ANGLES**

| | MIN | MAX | MEAN | ROM |
|---|---|---|---|---|
| **CYCLE 1** | 38.2475 | 75.5912 | 57.8724 | 37.3437 |
| **CYCLE 2** | 26.861 | 82.1687 | 58.5681 | 55.3077 |
| **CYCLE 3** | 26.861 | 82.4475 | 56.4774 | 55.5865 |
| **CYCLE 4** | 34.0116 | 83.7229 | 58.0853 | 49.7112 |
| **CYCLE 5** | 34.1006 | 77.9671 | 57.3123 | 43.8665 |
| **CYCLE 6** | 29.0695 | 83.8388 | 57.2267 | 54.7693 |
| **CYCLE 7** | 29.0695 | 84.0021 | 58.5192 | 54.9326 |
| **CYCLE 8** | 39.142 | 84.197 | 59.0418 | 45.055 |
| **CYCLE 9** | 40.0919 | 82.9094 | 57.4319 | 42.8174 |
| **MEAN** | 33.0505 | 81.8716 | 57.8372 | 48.8211 |

**FEMALE KNEE ANGLES**

| | MIN | MAX | MEAN | ROM |
|---|---|---|---|---|
| **CYCLE 1** | 30.3295 | 101.9835 | 69.2721 | 71.654 |
| **CYCLE 2** | 21.8984 | 97.2664 | 62.6818 | 75.368 |
| **CYCLE 3** | 21.8984 | 94.7373 | 61.0818 | 72.8389 |
| **CYCLE 4** | 22.9487 | 98.9230 | 62.3819 | 75.9743 |
| **CYCLE 5** | 28.2699 | 100.0943 | 65.6119 | 71.8244 |
| **CYCLE 6** | 22.9451 | 100.7589 | 64.0896 | 77.8138 |
| **CYCLE 7** | 22.9451 | 90.5067 | 57.0661 | 67.5616 |
| **CYCLE 8** | 29.2393 | 94.4777 | 59.1889 | 65.2384 |
| **CYCLE 9** | 27.5818 | 93.0611 | 58.9156 | 65.4793 |
| **MEAN** | 25.3396 | 96.8677 | 62.2544 | 71.5281 |

**FEMALE HIP ANGULAR VELOCITY**

| | MIN* | MAX |
|---|---|---|
| **CYCLE 1** | -242.3119 | 351.0913 |
| **CYCLE 2** | -344.8173 | 374.0012 |
| **CYCLE 3** | -287.3181 | 423.9522 |
| **CYCLE 4** | -183.4667 | 450.5957 |
| **CYCLE 5** | -179.5533 | 380.4947 |
| **CYCLE 6** | -305.5301 | 372.2019 |
| **CYCLE 7** | -234.7190 | 445.6721 |
| **CYCLE 8** | -204.5876 | 379.2042 |
| **CYCLE 9** | -219.7133 | 366.7731 |
| **MEAN** | -244.6686 | 393.7763 |

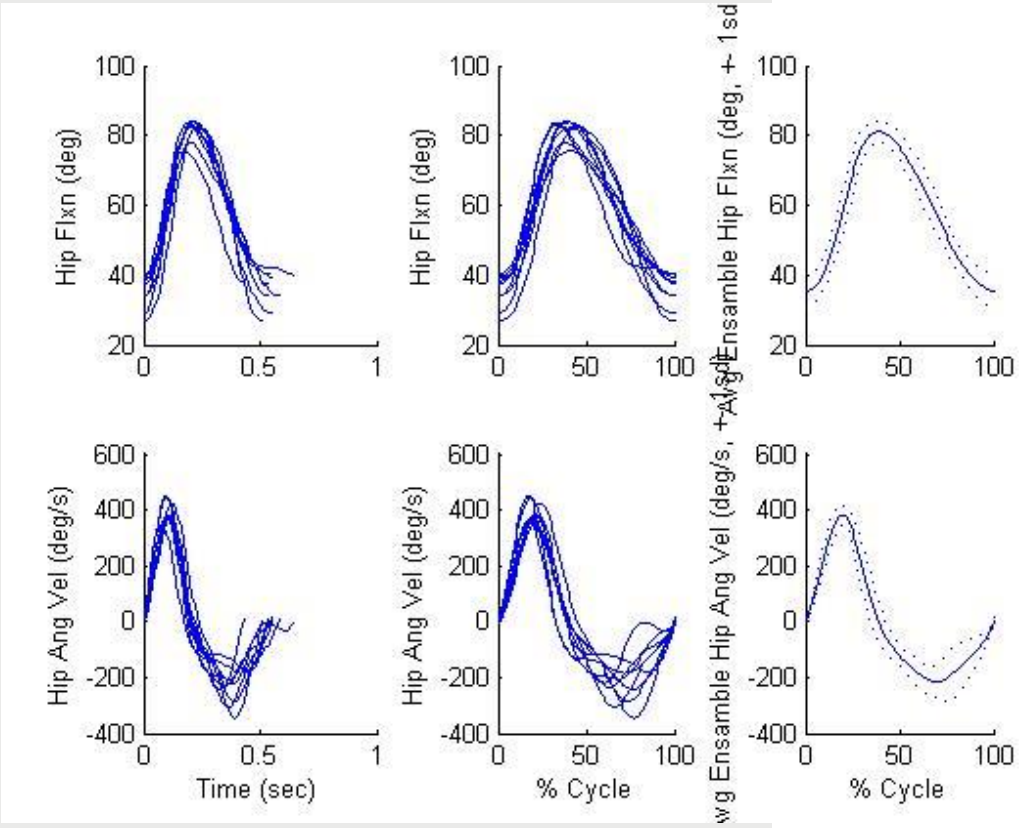
*** (-) = hip flexion**

**FEMALE KNEE ANGULAR VELOCITY**

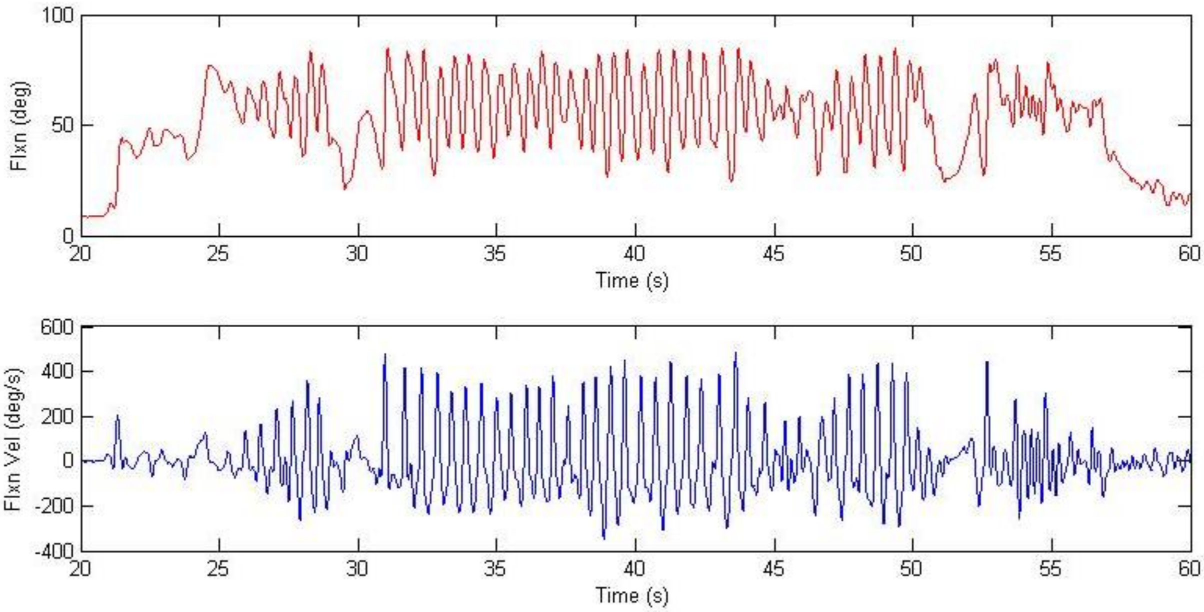
| | MIN* | MAX |
|---|---|---|
| **CYCLE 1** | -457.2 | 579.9 |
| **CYCLE 2** | -408.4 | 430.4 |
| **CYCLE 3** | -396.5 | 546.3 |
| **CYCLE 4** | -447.2 | 416.2 |
| **CYCLE 5** | -418.7 | 637.9 |
| **CYCLE 6** | -497.8 | 547.4 |
| **CYCLE 7** | -276.3 | 455.8 |
| **CYCLE 8** | -417.8 | 529 |
| **CYCLE 9** | -359.2 | 425.7 |
| **MEAN** | -408.8036 | 507.6176 |

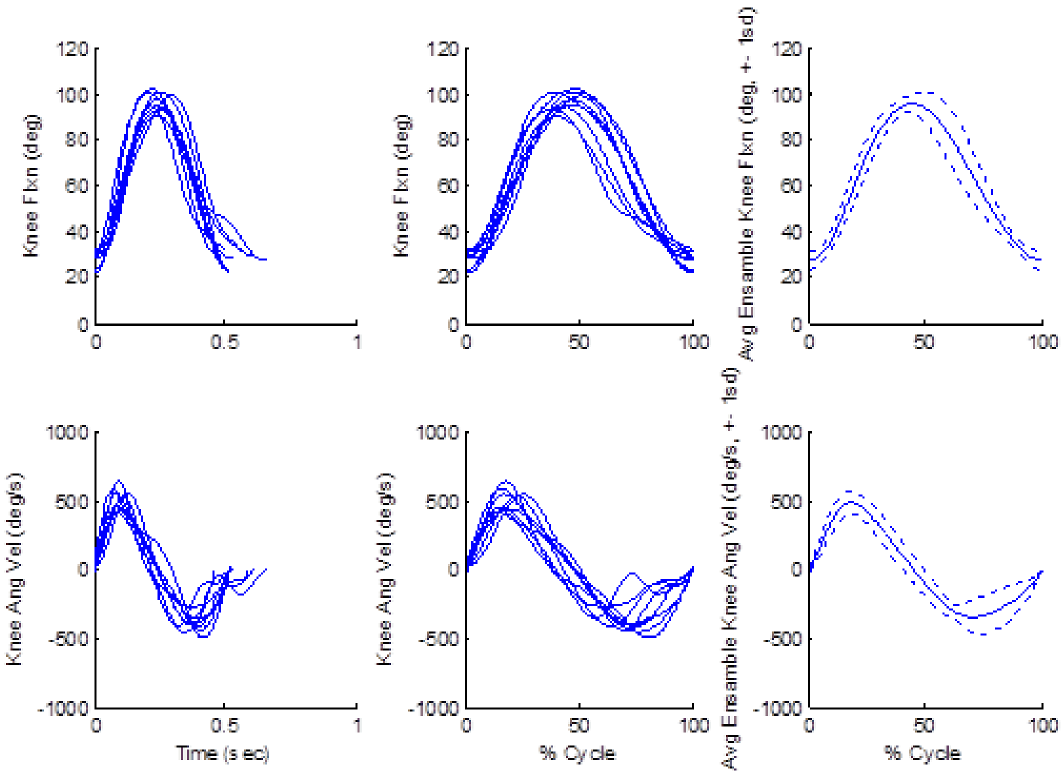
*** (-) = Knee Flexion**

*Above:* Descriptive statistics of the hip and knee joints for a female mogul skier in Zermatt, Switzerland, during a training run.

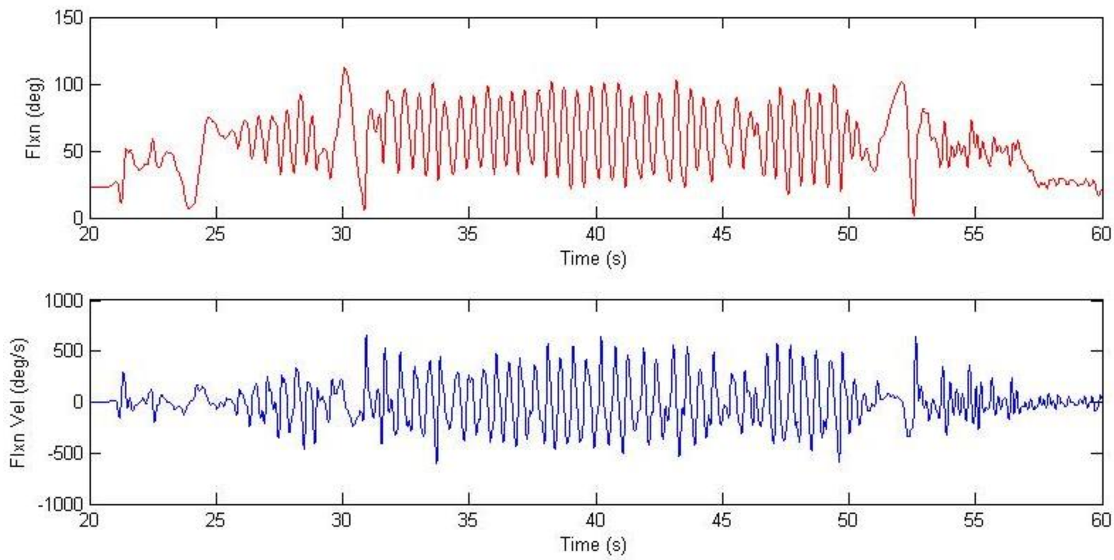



*Above:* Hip angular velocity and flexion ensemble. *Below:* Graphical representation of hip angular velocity and flexion.






*Above:* Knee angular velocity and flexion ensemble. *Below:* Graphical representation of knee angular velocity and flexion.




Discussion: Minimum knee and hip angles occur at peak extension. Maximum flexion of knee and hip angle occur at peak flexion. Hip joint angle is represented as a relationship of the femur relative to the pelvis (see sensor placement table) - a smaller angle indicating the pelvis's tilt relative to the femoral position.

Further analysis would identify the position of the trunk relative to the pelvis.

Chapter 08

# ATHLETE PROFILE

U.S. Ski & Snowboard National Team athletes can undergo several test batteries at the Center of Excellence (COE) in Park City, UT. These tests are generally not required, but many athletes participate in such testing two or more times per year. Athlete participation ranges from sporadic and inconsistent to complete and consistent.

The test batteries are administered by the High-Performance Department via the Athlete Development personnel. The data from these tests were entered into five databases consisting of Excel™ spreadsheets housed on the U.S. Ski & Snowboard COE servers. These data were entered manually by the testers with varying levels of vigilance and accuracy (Sands, The Quantified Mogul Skier, 2017).

The fundamental question from this report was: Do the tests administered by the COE personnel discriminate the competitive caliber of national team mogul skiers?

To test this question, Sands (The Quantified Mogul Skier, 2017) hypothesized that the tests and test batteries did not discriminate between athlete groups (null) and that the alternative hypothesis was that the tests and test batteries did discriminate.

The groups were defined as Non-Olympic Games and World Ski Championships (Non) or Olympic Games or World Ski Championships athletes (OlyWSC). Group membership was based on whether the athlete competed at World Cup level at some time during the six years of the collected data or remained below the World Cup level for the six years. The group data were obtained by querying the FIS performance database.

Initial assessment of the athletes showed a difference between the groups in age for all tests. Thus, all comparative analyses involved the Analysis of Covariance (ANCOVA) with age at the time of the test as the covariate. The use of a covariate allows the data to be adjusted based on the covariate; this denotes that the analysis is carried out by statistically equating all the athletes in age.

Data of statistical significance is indicated by bolding and shading, $p<0.05$.

# Anthropometric Data

**Group Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| **Test Age** | **Non** | **21.93** | **3.49** | **19** |
| | **OlyWSC** | **23.99** | **2.64** | **45** |
| Height (cm) | Non | 174.33 | 5.84 | 19 |
| | OlyWSC | 175.46 | 4.51 | 45 |
| **Mass (kg)** | **Non** | **68.27** | **5.78** | **19** |
| | **OlyWSC** | **74.05** | **3.28** | **45** |
| Subscapular (mm) | Non | 8.19 | 2.00 | 19 |
| | OlyWSC | 8.83 | 1.72 | 45 |
| Triceps (mm) | Non | 7.07 | 1.96 | 19 |
| | OlyWSC | 6.16 | 1.00 | 45 |
| **Biceps (mm)** | **Non** | **3.58** | **.73** | **19** |
| | **OlyWSC** | **3.18** | **.50** | **45** |
| Iliac Crest (mm) | Non | 11.57 | 4.77 | 18 |
| | OlyWSC | 10.10 | 3.21 | 41 |
| Supraspinale (mm) | Non | 7.51 | 3.63 | 19 |
| | OlyWSC | 6.57 | 2.06 | 45 |
| Abdominal (mm) | Non | 11.68 | 5.00 | 19 |
| | OlyWSC | 11.53 | 3.88 | 45 |
| **Thigh (mm)** | **Non** | **11.10** | **5.87** | **19** |
| | **OlyWSC** | **7.71** | **1.26** | **45** |
| Calf (skinfold, mm) | Non | 6.39 | 4.06 | 19 |
| | OlyWSC | 5.12 | .82 | 45 |
| **Upper Arm Relaxed Girth (cm)** | **Non** | **30.05** | **2.47** | **19** |
| | **OlyWSC** | **31.32** | **1.77** | **45** |
| **Upper Arm Flexed Girth (cm)** | **Non** | **32.44** | **2.46** | **19** |
| | **OlyWSC** | **33.85** | **1.66** | **45** |
| **Waist Girth (cm)** | **Non** | **75.41** | **4.66** | **19** |
| | **OlyWSC** | **79.24** | **2.98** | **45** |
| **Hips Girth (cm)** | **Non** | **93.63** | **3.67** | **19** |
| | **OlyWSC** | **95.86** | **2.41** | **45** |
| **Mid-Thigh-R Girth (cm)** | **Non** | **51.53** | **4.69** | **19** |
| | **OlyWSC** | **54.57** | **2.75** | **45** |
| **Mid-Thigh-L Girth (cm)** | **Non** | **51.62** | **4.90** | **19** |
| | **OlyWSC** | **53.96** | **2.86** | **45** |
| Calf Girth (cm) | Non | 33.66 | 8.06 | 19 |
| | OlyWSC | 35.45 | 1.28 | 45 |
| Humerus Condylar Breadth (cm) | Non | 6.96 | .41 | 14 |
| | OlyWSC | 7.18 | .36 | 36 |
| **Femur Condylar Breadth (cm)** | **Non** | **9.30** | **.42** | **14** |
| | **OlyWSC** | **9.60** | **.14** | **36** |
| Sum 7 Skinfolds (mm) | Non | 55.52 | 21.03 | 19 |
| | OlyWSC | 49.10 | 7.78 | 45 |
| Sum 4 Skinfolds (mm) | Non | 40.82 | 17.21 | 19 |
| | OlyWSC | 34.60 | 7.36 | 45 |
| Percent Fat (4 Skinfolds) | Non | 16.03 | 4.52 | 19 |
| | OlyWSC | 15.48 | 2.18 | 45 |
| Endomorphy Score | Non | 2.20 | .78 | 19 |
| | OlyWSC | 2.08 | .39 | 45 |
| Mesomorphy Score | Non | 1.00 | 5.57 | 19 |
| | OlyWSC | 2.47 | 4.77 | 45 |
| **Ectomorphy Score** | **Non** | **2.70** | **.87** | **19** |
| | **OlyWSC** | **2.04** | **.82** | **45** |

***Initial Descriptive Statistics - Males***

Independent t-test

Statistical significance is indicated by bolding, $p < 0.05$.

**Group Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| **Test Age** | **Non** | **21.61** | **1.71** | **12** |
| | **OlyWSC** | **23.61** | **3.62** | **73** |
| Height (cm) | Non | 163.71 | 3.34 | 12 |
| | OlyWSC | 165.57 | 5.05 | 73 |
| Mass (kg) | Non | 60.73 | 3.96 | 12 |
| | OlyWSC | 59.90 | 5.26 | 73 |
| Subscapular (mm) | Non | 13.58 | 4.12 | 12 |
| | OlyWSC | 14.00 | 2.84 | 73 |
| Triceps (mm) | Non | 10.56 | 2.73 | 12 |
| | OlyWSC | 9.69 | 2.32 | 73 |
| Biceps (mm) | Non | 5.91 | 2.05 | 12 |
| | OlyWSC | 5.34 | 1.91 | 73 |
| Iliac Crest (mm) | Non | 15.79 | 6.08 | 9 |
| | OlyWSC | 15.01 | 3.58 | 63 |
| Supraspinale (mm) | Non | 9.03 | 2.67 | 12 |
| | OlyWSC | 9.58 | 2.91 | 73 |
| Abdominal (mm) | Non | 16.48 | 7.67 | 12 |
| | OlyWSC | 14.45 | 4.34 | 73 |
| **Calf (skinfold, mm)** | **Non** | **20.16** | **6.56** | **12** |
| | **OlyWSC** | **20.74** | **4.38** | **73** |
| Thigh (mm) | Non | 11.43 | 2.78 | 12 |
| | OlyWSC | 12.48 | 3.73 | 73 |
| Upper Arm Relaxed Girth (cm) | Non | 27.42 | 2.41 | 12 |
| | OlyWSC | 27.31 | 1.16 | 73 |
| Upper Arm Flexed Girth (cm) | Non | 29.01 | 2.39 | 12 |
| | OlyWSC | 28.70 | .90 | 73 |
| Waist Girth (cm) | Non | 68.14 | 4.55 | 12 |
| | OlyWSC | 67.40 | 2.96 | 73 |
| Hips Girth (cm) | Non | 93.99 | 5.00 | 12 |
| | OlyWSC | 94.15 | 3.90 | 73 |
| Mid-Thigh-R Girth (cm) | Non | 51.12 | 2.61 | 12 |
| | OlyWSC | 50.69 | 3.43 | 73 |
| Mid-Thigh-L Girth (cm) | Non | 51.10 | 2.67 | 12 |
| | OlyWSC | 50.69 | 3.50 | 73 |
| Calf Girth (cm) | Non | 34.15 | .59 | 12 |
| | OlyWSC | 33.47 | 1.78 | 73 |
| Humerus Condylar Breadth (cm) | Non | 6.19 | .34 | 12 |
| | OlyWSC | 6.20 | .22 | 63 |
| Femur Condylar Breadth (cm) | Non | 8.95 | .19 | 12 |
| | OlyWSC | 8.74 | .36 | 63 |
| Sum 7 Skinfolds (mm) | Non | 87.14 | 23.95 | 12 |
| | OlyWSC | 86.29 | 15.12 | 73 |
| Sum 4 Skinfolds (mm) | Non | 59.03 | 23.38 | 12 |
| | OlyWSC | 57.83 | 10.11 | 73 |
| Percent Fat (4 Skinfolds) | Non | 19.16 | 5.78 | 12 |
| | OlyWSC | 18.94 | 2.51 | 73 |
| Endomorphy Score | Non | 3.40 | .93 | 12 |
| | OlyWSC | 3.42 | .62 | 73 |
| **Mesomorphy Score** | **Non** | **3.96** | **.65** | **12** |
| | **OlyWSC** | **2.02** | **3.53** | **73** |
| **Ectomorphy Score** | **Non** | **1.94** | **.58** | **12** |
| | **OlyWSC** | **2.43** | **.53** | **73** |

***Initial Descriptive Statistics - Females***

Independent t-test

Statistical significance is indicated by bolding, $p < 0.05$.

# Height

**Tests of Between-Subjects Effects**

Dependent Variable: Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 4.214 | 1 | 4.214 | .171 | .681 | .003 | .069 |
| OlyampWSC | 10.931 | 1 | 10.931 | .443 | .508 | .007 | .100 |
| Error | 1505.888 | 61 | 24.687 | | | | |
| Total | 1964328.340 | 64 | | | | | |
| Corrected Total | 1527.340 | 63 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Standing Height ANCOVA – Males***

Dependent Variable: Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 174.456[a] | 1.182 | 172.092 | 176.819 |
| OlyWSC | 175.408[a] | .752 | 173.903 | 176.912 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.38.

***Above: Age-Adjusted Descriptive Statistics Standing Height (cm) - Males***

**Tests of Between-Subjects Effects**

Dependent Variable: Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 58.754 | 1 | 58.754 | 2.536 | .115 | .030 | .350 |
| Group | 54.782 | 1 | 54.782 | 2.364 | .128 | .028 | .330 |
| Error | 1900.081 | 82 | 23.172 | | | | |
| Total | 2324806.790 | 85 | | | | | |
| Corrected Total | 1994.652 | 84 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Standing Height ANCOVA – Females***

Dependent Variable: Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 163.288[a] | 1.414 | 160.474 | 166.102 |
| OlyWSC | 165.642[a] | .565 | 164.518 | 166.766 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.33.

***Above: Age-Adjusted Descriptive Statistics Standing Height (cm) - Females***

# Body Mass

**Tests of Between-Subjects Effects**

Dependent Variable: Mass (kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **137.007** | **1** | **137.007** | **8.911** | **.004** | **.127** | **.836** |
| **Group** | **270.290** | **1** | **270.290** | **17.580** | **.000** | **.224** | **.985** |
| Error | 937.886 | 61 | 15.375 | | | | |
| Total | 336386.380 | 64 | | | | | |
| Corrected Total | 1521.624 | 63 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Body Mass ANCOVA – Males***

Dependent Variable: Mass (kg)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|
| Non | 69.006[a] | .933 | 67.141 | 70.872 |
| OlyWSC | 73.740[a] | .594 | 72.552 | 74.927 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.38.

***Above: Age-Adjusted Descriptive Statistics Body Mass (kg) - Males***

**Tests of Between-Subjects Effects**

Dependent Variable: Mass (kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 30.958 | 1 | 30.958 | 1.189 | .279 | .014 | .190 |
| Group | 13.937 | 1 | 13.937 | .535 | .467 | .006 | .112 |
| Error | 2135.639 | 82 | 26.044 | | | | |
| Total | 308365.760 | 85 | | | | | |
| Corrected Total | 2173.730 | 84 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Body Mass ANCOVA – Females***

Dependent Variable: Mass (kg)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|
| Non | 61.038[a] | 1.500 | 58.055 | 64.021 |
| OlyWSC | 59.851[a] | .599 | 58.659 | 61.043 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.33.

***Above: Age-Adjusted Descriptive Statistics Body Mass (kg) - Females***

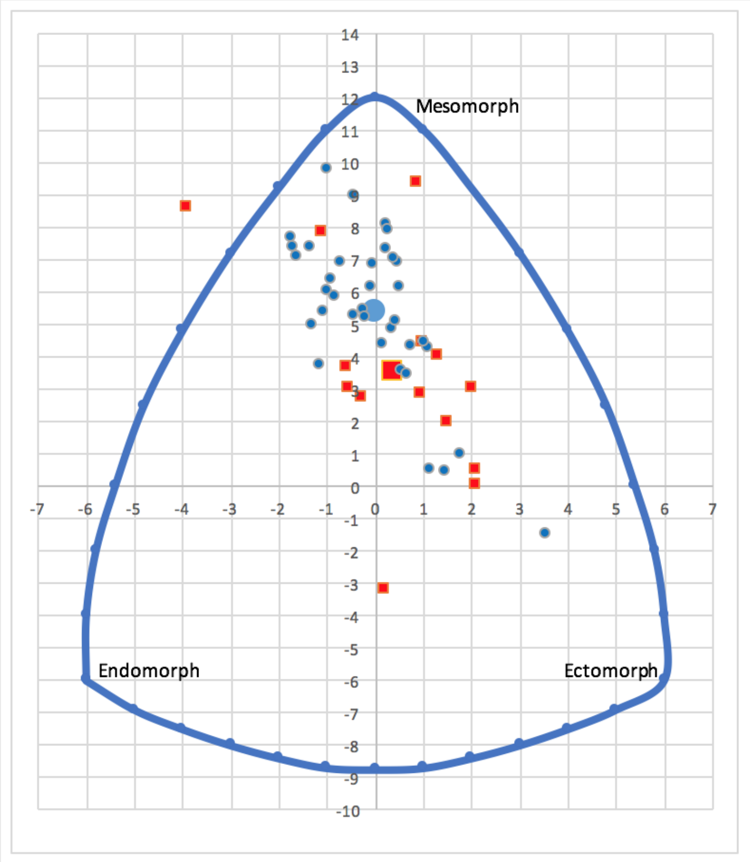
# Body Type

**Somatograph.**

Male Moguls Skiers.

Red Squares = Non

Blue Circles = OlyWSC

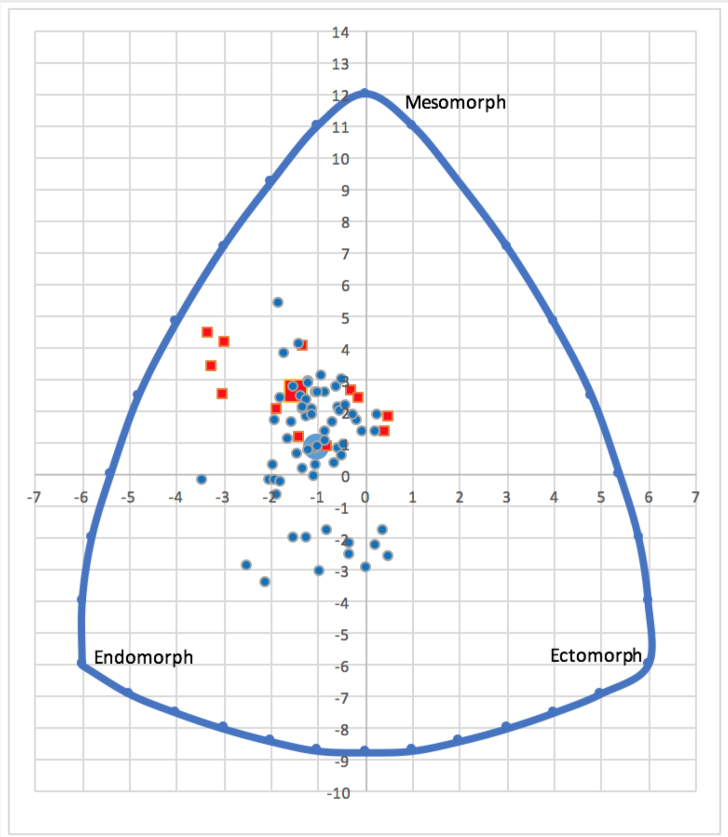



**Somatograph.**

Female Moguls Skiers.

Red Squares = Non

Blue Circles = OlyWSC



# Percent Body Fat

**Tests of Between-Subjects Effects**

Dependent Variable: Sum 7 Skinfolds (mm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[b] |
|---|---|---|---|---|---|---|---|---|
| TestAge | .057 | 1 | .057 | .000 | .986 | .000 | .000 | .050 |
| Group | 500.430 | 1 | 500.430 | 2.874 | .095 | .045 | 2.874 | .386 |
| Error | 10620.024 | 61 | 174.099 | | | | | |
| Total | 177700.883 | 64 | | | | | | |
| Corrected Total | 11170.576 | 63 | | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Sum Seven Skinfolds ANCOVA – Males***

Dependent Variable: Sum 7 Skinfolds (mm)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 55.539[a] | 3.139 | 49.261 | 61.816 |
| OlyWSC | 49.098[a] | 1.998 | 45.103 | 53.093 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.38.

***Above: Age-Adjusted Descriptive Statistics Sum Seven Skinfolds (mm) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: Sum 7 Skinfolds (mm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 940.355 | 1 | 940.355 | 3.532 | .064 | .041 | .459 |
| Group | 12.003 | 1 | 12.003 | .045 | .832 | .001 | .055 |
| Error | 21834.061 | 82 | 266.269 | | | | |
| Total | 657407.240 | 85 | | | | | |
| Corrected Total | 22781.956 | 84 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Sum Seven Skinfolds ANCOVA – Females***

Dependent Variable: Sum 7 Skinfolds (mm)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 85.461[a] | 4.795 | 75.923 | 94.999 |
| OlyWSC | 86.563[a] | 1.915 | 82.752 | 90.373 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.33.

***Above: Age-Adjusted Descriptive Statistics Sum Seven Skinfolds (mm) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: Percent Fat (4 Skinfolds)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 9.927 | 1 | 9.927 | 1.068 | .305 | .017 | .174 |
| Group | 8.458 | 1 | 8.458 | .910 | .344 | .015 | .156 |
| Error | 566.866 | 61 | 9.293 | | | | |
| Total | 16244.053 | 64 | | | | | |
| Corrected Total | 580.906 | 63 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Sum Percent Fat ANCOVA – Males***

Dependent Variable: Percent Fat (4 Skinfolds)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|
| Non | 16.233[a] | .725 | 14.783 | 17.683 |
| OlyWSC | 15.395[a] | .462 | 14.472 | 16.319 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.38.

***Above: Age-Adjusted Descriptive Statistics Percent Fat – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: Percent Fat (4 Skinfolds)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 23.032 | 1 | 23.032 | 2.366 | .128 | .028 | .330 |
| Group | .086 | 1 | .086 | .009 | .925 | .000 | .051 |
| Error | 798.379 | 82 | 9.736 | | | | |
| Total | 31420.451 | 85 | | | | | |
| Corrected Total | 821.878 | 84 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Sum Percent Fat ANCOVA – Females***

Dependent Variable: Percent Fat (4 Skinfolds)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|
| Non | 18.893[a] | .917 | 17.069 | 20.717 |
| OlyWSC | 18.986[a] | .366 | 18.258 | 19.715 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.33.

***Above: Age-Adjusted Descriptive Statistics Percent Fat – Females***

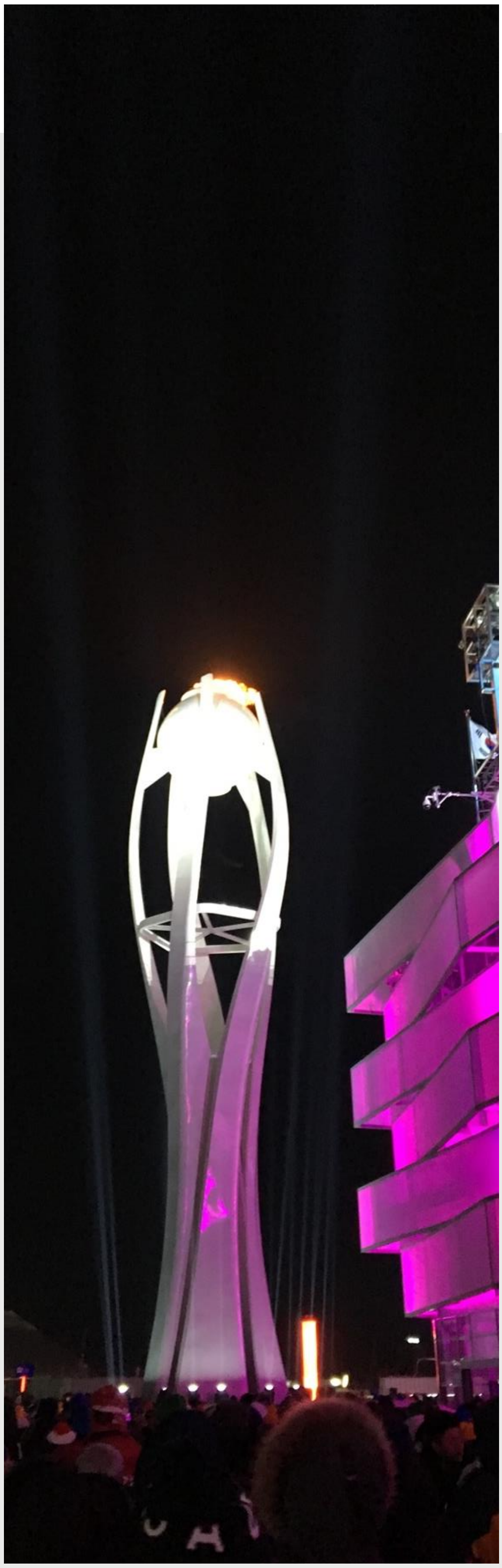
# Male Physical Capacities

**Group Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| **Test Age** | **Non** | **21.81** | **2.98** | **39** |
| | **OlyWSC** | **24.31** | **2.65** | **62** |
| **Body Mass (kg)** | **Non** | **67.32** | **4.08** | **39** |
| | **OlyWSC** | **74.15** | **3.84** | **62** |
| **Iso Squat Force (N)** | **Non** | **1880.76** | **186.51** | **39** |
| | **OlyWSC** | **2213.72** | **228.55** | **52** |
| **Iso Squat Force (kgf)** | **Non** | **191.72** | **19.01** | **39** |
| | **OlyWSC** | **225.66** | **23.30** | **52** |
| **Scaled Iso Squat (kg)** | **Non** | **2.85** | **.20** | **39** |
| | **OlyWSC** | **3.04** | **.22** | **52** |
| **SJ Height (cm)** | **Non** | **43.73** | **5.28** | **35** |
| | **OlyWSC** | **48.62** | **5.26** | **54** |
| **SJ Force (N)** | **Non** | **1613.73** | **122.87** | **35** |
| | **OlyWSC** | **1721.59** | **151.48** | **53** |
| **SJ Power (W)** | **Non** | **2594.21** | **392.72** | **35** |
| | **OlyWSC** | **3066.78** | **357.70** | **52** |
| **SJ Scaled Power (W/kg)** | **Non** | **38.52** | **5.99** | **35** |
| | **OlyWSC** | **41.37** | **3.94** | **52** |
| **SJ Velocity (m/s)** | **Non** | **2.47** | **.20** | **35** |
| | **OlyWSC** | **2.66** | **.19** | **54** |
| **CMJ Height (cm)** | **Non** | **51.63** | **5.16** | **38** |
| | **OlyWSC** | **55.17** | **6.01** | **58** |
| **CMJ Force (N)** | **Non** | **1661.37** | **217.83** | **38** |
| | **OlyWSC** | **2026.16** | **290.27** | **58** |
| **CMJ Power (W)** | **Non** | **3005.24** | **460.04** | **38** |
| | **OlyWSC** | **3459.39** | **411.44** | **58** |
| CMJ Scaled Power (W/kg) | **Non** | 44.78 | 7.31 | 38 |
| | **OlyWSC** | 46.55 | 4.35 | 58 |
| **CMJ Velocity (m/s)** | **Non** | **2.74** | **.20** | **38** |
| | **OlyWSC** | **2.86** | **.24** | **58** |

***Initial Descriptive Statistics - Males***

Statistical significance is indicated by bolding, $p < 0.05$.



# Female Physical Capacities

**Group Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| **Test Age** | **Non** | **21.00** | **2.57** | **33** |
| | **OlyWSC** | **23.48** | **3.67** | **92** |
| Body Mass (kg) | Non | 61.62 | 4.76 | 33 |
| | OlyWSC | 60.01 | 4.98 | 91 |
| Iso Squat Force (N) | Non | 1504.55 | 195.53 | 31 |
| | OlyWSC | 1455.90 | 211.73 | 85 |
| Iso Squat Force (kgf) | Non | 153.37 | 19.93 | 31 |
| | OlyWSC | 148.41 | 21.58 | 85 |
| Scaled Iso Squat (kg) | Non | 2.48 | .27 | 31 |
| | OlyWSC | 2.48 | .34 | 85 |
| SJ Height (cm) | Non | 34.13 | 4.33 | 28 |
| | OlyWSC | 32.72 | 4.68 | 70 |
| SJ Force (N) | Non | 1352.57 | 195.82 | 28 |
| | OlyWSC | 1298.65 | 110.06 | 68 |
| **SJ Power (W)** | **Non** | **2077.95** | **371.18** | **28** |
| | **OlyWSC** | **1899.70** | **371.45** | **68** |
| SJ Scaled Power (W/kg) | Non | 33.62 | 5.62 | 28 |
| | OlyWSC | 31.77 | 5.39 | 68 |
| **SJ Velocity (m/s)** | **Non** | **2.21** | **.21** | **28** |
| | **OlyWSC** | **2.08** | **.19** | **69** |
| **CMJ Height (cm)** | **Non** | **38.42** | **4.10** | **25** |
| | **OlyWSC** | **35.53** | **6.49** | **81** |
| CMJ Force (N) | Non | 1476.39 | 183.00 | 31 |
| | OlyWSC | 1434.73 | 188.51 | 78 |
| **CMJ Power (W)** | **Non** | **2325.76** | **354.34** | **31** |
| | **OlyWSC** | **2123.54** | **394.20** | **79** |
| **CMJ Scaled Power (W/kg)** | **Non** | **37.75** | **4.69** | **31** |
| | **OlyWSC** | **35.49** | **5.98** | **79** |
| **CMJ Velocity (m/s)** | **Non** | **2.44** | **.23** | **31** |
| | **OlyWSC** | **2.28** | **.32** | **79** |

***Initial Descriptive Statistics - Females***

Statistical significance is indicated by bolding, $p < 0.05$.

# Strength and Power

**Tests of Between-Subjects Effects**

Dependent Variable: Iso Squat Force (kgf)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 256.813 | 1 | 256.813 | .549 | .461 | .006 | .113 |
| **Group** | **19860.495** | **1** | **19860.495** | **42.463** | **.000** | **.325** | **1.000** |
| Error | 41158.889 | 88 | 467.715 | | | | |
| Total | 4122854.293 | 91 | | | | | |
| Corrected Total | 67089.200 | 90 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Peak Isometric Squat Force (Kg) ANCOVA – Males***

Dependent Variable: Iso Squat Force (kgf)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 192.551[a] | 3.641 | 185.316 | 199.786 |
| OlyWSC | 225.035[a] | 3.115 | 218.845 | 231.226 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.17.

***Above: Age-Adjusted Descriptive Statistics Peak Isometric Squat Force (Kg) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: Iso Squat Force (kgf)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **15119.506** | **1** | **15119.506** | **47.552** | **.000** | **.296** | **1.000** |
| **Group** | **3767.111** | **1** | **3767.111** | **11.848** | **.001** | **.095** | **.927** |
| Error | 35928.821 | 113 | 317.954 | | | | |
| Total | 2652399.452 | 116 | | | | | |
| Corrected Total | 51606.913 | 115 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Peak Isometric Squat Force (Kg) ANCOVA – Females***

Dependent Variable: Iso Squat Force (kgf)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 159.684[a] | 3.331 | 153.085 | 166.283 |
| OlyWSC | 146.107[a] | 1.963 | 142.218 | 149.995 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.78.

***Above: Age-Adjusted Descriptive Statistics Peak Isometric Squat Force (Kg) – Females***

## Tests of Between-Subjects Effects

Dependent Variable: Scaled Iso Squat (kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | .024 | 1 | .024 | .533 | .467 | .006 | .112 |
| **Group** | **.796** | **1** | **.796** | **17.550** | **.000** | **.166** | **.985** |
| Error | 3.993 | 88 | .045 | | | | |
| Total | 800.015 | 91 | | | | | |
| Corrected Total | 4.835 | 90 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Relative Isometric Squat Force (Kg/Kg) ANCOVA – Males***

Dependent Variable: Scaled Iso Squat (kg)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2.839[a] | .036 | 2.767 | 2.910 |
| OlyWSC | 3.044[a] | .031 | 2.983 | 3.105 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.17.

***Above: Age-Adjusted Descriptive Statistics Relative Isometric Squat Force (Kg/Kg) – Males***

## Tests of Between-Subjects Effects

Dependent Variable: Scaled Iso Squat (kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **3.232** | **1** | **3.232** | **41.570** | **.000** | **.269** | **1.000** |
| **Group** | **.327** | **1** | **.327** | **4.210** | **.042** | **.036** | **.530** |
| Error | 8.786 | 113 | .078 | | | | |
| Total | 725.580 | 116 | | | | | |
| Corrected Total | 12.018 | 115 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Relative Isometric Squat Force (Kg/Kg) ANCOVA – Females***

Dependent Variable: Scaled Iso Squat (kg)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2.573[a] | .052 | 2.470 | 2.676 |
| OlyWSC | 2.446[a] | .031 | 2.386 | 2.507 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.78.

***Above: Age-Adjusted Descriptive Statistics Relative Isometric Squat Force (Kg/Kg) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 58.077 | 1 | 58.077 | 2.119 | .149 | .024 | .302 |
| **Group** | **563.319** | **1** | **563.319** | **20.553** | **.000** | **.193** | **.994** |
| Error | 2357.064 | 86 | 27.408 | | | | |
| Total | 196997.898 | 89 | | | | | |
| Corrected Total | 2922.037 | 88 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Height (cm) ANCOVA – Males***

Dependent Variable: SJ Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 43.331[a] | .927 | 41.489 | 45.174 |
| OlyWSC | 48.879[a] | .734 | 47.419 | 50.339 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.31.

***Above: Age-Adjusted Descriptive Statistics Static Jump Height (cm) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **426.245** | **1** | **426.245** | **25.456** | **.000** | **.211** | **.999** |
| **Group** | **157.937** | **1** | **157.937** | **9.432** | **.003** | **.090** | **.860** |
| Error | 1590.716 | 95 | 16.744 | | | | |
| Total | 109572.535 | 98 | | | | | |
| Corrected Total | 2057.066 | 97 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Height (cm) ANCOVA – Females***

Dependent Variable: SJ Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 35.240[a] | .804 | 33.644 | 36.835 |
| OlyWSC | 32.276[a] | .497 | 31.289 | 33.262 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.46.

***Above: Age-Adjusted Descriptive Statistics Static Jump Height (cm) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Power (W)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 182947.314 | 1 | 182947.314 | 1.326 | .253 | .016 | .207 |
| **Group** | **4698455.275** | **1** | **4698455.275** | **34.064** | **.000** | **.289** | **1.000** |
| Error | 11586125.04 | 84 | 137930.060 | | | | |
| Total | 736384133.5 | 87 | | | | | |
| Corrected Total | 16440766.83 | 86 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Power (W) ANCOVA – Males***

Dependent Variable: SJ Power (W)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2572.167[a] | 65.630 | 2441.654 | 2702.680 |
| OlyWSC | 3081.619[a] | 53.090 | 2976.044 | 3187.193 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.27.

***Above: Age-Adjusted Descriptive Statistics Static Jump Power (W) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Power (W)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **2147540.702** | **1** | **2147540.702** | **18.464** | **.000** | **.166** | **.989** |
| **Group** | **1495753.131** | **1** | **1495753.131** | **12.860** | **.001** | **.121** | **.944** |
| Error | 10816643.54 | 93 | 116307.995 | | | | |
| Total | 379266408.5 | 96 | | | | | |
| Corrected Total | 13594335.13 | 95 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Power (W) ANCOVA – Females***

Dependent Variable: SJ Power (W)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2157.128[a] | 67.033 | 2024.014 | 2290.242 |
| OlyWSC | 1867.094[a] | 42.047 | 1783.597 | 1950.592 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.47.

***Above: Age-Adjusted Descriptive Statistics Static Jump Power (W) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Scaled Power (W/kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **113.530** | **1** | **113.530** | **5.019** | **.028** | **.056** | **.601** |
| **Group** | **257.351** | **1** | **257.351** | **11.377** | **.001** | **.119** | **.915** |
| Error | 1900.081 | 84 | 22.620 | | | | |
| Total | 142943.620 | 87 | | | | | |
| Corrected Total | 2183.711 | 86 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Relative Power (W/Kg) ANCOVA – Males***

Dependent Variable: SJ Scaled Power (W/kg)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 37.970[a] | .840 | 36.299 | 39.641 |
| OlyWSC | 41.740[a] | .680 | 40.388 | 43.092 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.27.

***Above: Age-Adjusted Descriptive Statistics Static Jump Relative Power (W/Kg) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: SJ Scaled Power (W/kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **403.083** | **1** | **403.083** | **15.640** | **.000** | **.144** | **.975** |
| **Group** | **203.025** | **1** | **203.025** | **7.877** | **.006** | **.078** | **.793** |
| Error | 2396.891 | 93 | 25.773 | | | | |
| Total | 103092.342 | 96 | | | | | |
| Corrected Total | 2867.674 | 95 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Static Jump Relative Power (W/Kg) ANCOVA – Females***

Dependent Variable: SJ Scaled Power (W/kg)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 34.705[a] | .998 | 32.723 | 36.686 |
| OlyWSC | 31.326[a] | .626 | 30.083 | 32.568 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.47.

***Above: Age-Adjusted Descriptive Statistics Static Jump Relative Power (W/Kg) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 74.503 | 1 | 74.503 | 2.330 | .130 | .024 | .327 |
| **Group** | **361.161** | **1** | **361.161** | **11.296** | **.001** | **.108** | **.914** |
| Error | 2973.434 | 93 | 31.972 | | | | |
| Total | 280841.903 | 96 | | | | | |
| Corrected Total | 3336.006 | 95 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Height (cm) ANCOVA – Males***

Dependent Variable: CMJ Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 51.154[a] | .968 | 49.233 | 53.076 |
| OlyWSC | 55.476[a] | .769 | 53.948 | 57.003 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.29.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Height (cm) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Height (cm)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **802.860** | **1** | **802.860** | **27.790** | **.000** | **.212** | **.999** |
| **Group** | **359.235** | **1** | **359.235** | **12.434** | **.001** | **.108** | **.937** |
| Error | 2975.739 | 103 | 28.891 | | | | |
| Total | 142909.835 | 106 | | | | | |
| Corrected Total | 3938.027 | 105 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Height (cm) ANCOVA – Females***

Dependent Variable: CMJ Height (cm)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 39.618[a] | 1.099 | 37.439 | 41.798 |
| OlyWSC | 35.156[a] | .601 | 33.963 | 36.349 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.62.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Height (cm) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Power (W)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| TestAge | 380532.123 | 1 | 380532.123 | 2.070 | .154 | .022 | .296 |
| **Group** | **5027388.014** | **1** | **5027388.014** | **27.343** | **.000** | **.227** | **.999** |
| Error | 17099259.77 | 93 | 183863.008 | | | | |
| Total | 1054781996 | 96 | | | | | |
| Corrected Total | 22215021.87 | 95 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Power (W) ANCOVA – Males***

Dependent Variable: CMJ Power (W)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2971.610[a] | 73.382 | 2825.889 | 3117.331 |
| OlyWSC | 3481.419[a] | 58.349 | 3365.550 | 3597.288 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.29.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Power (W) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Power (W)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **3441033.233** | **1** | **3441033.233** | **29.582** | **.000** | **.217** | **1.000** |
| **Group** | **2069968.463** | **1** | **2069968.463** | **17.795** | **.000** | **.143** | **.987** |
| Error | 12446408.30 | 107 | 116321.573 | | | | |
| Total | 539816901.8 | 110 | | | | | |
| Corrected Total | 16797810.64 | 109 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Power (W) ANCOVA – Females***

Dependent Variable: CMJ Power (W)

| Group | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|
| Non | 2408.792[a] | 63.130 | 2283.645 | 2533.940 |
| OlyWSC | 2090.961[a] | 38.837 | 2013.971 | 2167.951 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.49.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Power (W) – Females***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Scaled Power (W/kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Observed Power[b] |
|---|---|---|---|---|---|---|---|
| **TestAge** | **197.824** | **1** | **197.824** | **6.444** | **.013** | **.065** | **.710** |
| **Group** | **179.032** | **1** | **179.032** | **5.832** | **.018** | **.059** | **.666** |
| Error | 2855.098 | 93 | 30.700 | | | | |
| Total | 204914.476 | 96 | | | | | |
| Corrected Total | 3125.114 | 95 | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Relative Power (W/Kg) ANCOVA – Males***

Dependent Variable: CMJ Scaled Power (W/kg)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 44.009[a] | .948 | 42.126 | 45.892 |
| OlyWSC | 47.052[a] | .754 | 45.554 | 48.549 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 23.29.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Relative Power (W/Kg) – Males***

**Tests of Between-Subjects Effects**

Dependent Variable: CMJ Scaled Power (W/kg)

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[b] |
|---|---|---|---|---|---|---|---|---|
| **TestAge** | **679.921** | **1** | **679.921** | **26.230** | **.000** | **.197** | **26.230** | **.999** |
| **Group** | **309.222** | **1** | **309.222** | **11.929** | **.001** | **.100** | **11.929** | **.928** |
| Error | 2773.560 | 107 | 25.921 | | | | | |
| Total | 147162.179 | 110 | | | | | | |
| Corrected Total | 3567.137 | 109 | | | | | | |

b. Computed using alpha = .05

***Above: Age-Adjusted Counter Movement Jump Relative Power (W/Kg) ANCOVA – Females***

Dependent Variable: CMJ Scaled Power (W/kg)

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Non | 38.920[a] | .942 | 37.052 | 40.789 |
| OlyWSC | 35.036[a] | .580 | 33.886 | 36.185 |

a. Covariates appearing in the model are evaluated at the following values: Test Age = 22.49.

***Above: Age-Adjusted Descriptive Statistics Counter Movement Jump Relative Power (W/Kg) – Females***


Chapter 09

# COACHING OBSERVATIONS

## The Cost of Doing Business

The cost of doing business in the sport of mogul skiing is quite severe and is perhaps one of the most contentious points at U.S. Ski & Snowboard. Arguments about athlete funding materialize frequently, even to the extent that mogul athletes, with the organization's support, conducted their own private fundraising events. As of this writing, there are a total of 6 funded athletes (40%) on the U.S. Freestyle Moguls Team (Bullock, The Financial Cost of Mogul Skiing on the World Cup, 2018). During the 2018-2019 season, each funded athlete has both the preparatory and competitive financial costs subsidized by U.S. Ski & Snowboard. The total cost to subsidize the 2018-2019 preparatory period is $21,027.05 per athlete (Bullock, The Financial Cost of Mogul Skiing on the World Cup, 2018).

It is essential for the coach, practitioner, and athlete to understand the relative cost of doing business and how much each training opportunity costs, thus, providing a monetary value to each training event. As each athlete ultimately completes a different quantity of work, the author has provided a range of costs using the highest and lowest training quantity from each camp.

Briefly, each training event costs the athlete (or U.S. Ski & Snowboard for those funded) between $25.58 and $43.81 per training event (Bullock, The Financial Cost of Mogul Skiing on the World Cup, 2018). In other words, each time the athlete completes a jump, drill, section, or attempts a top to bottom, he or she can expect to pay somewhere between $25.58 and $43.81 for that attempt.

The image below provides the detail of each training camp from the 2018-2019 preparatory period, the costs associated with it, and the cost per training attempt for both the highest volume and lowest volume completed at the camp (Bullock, The Financial Cost of Mogul Skiing on the World Cup, 2018).

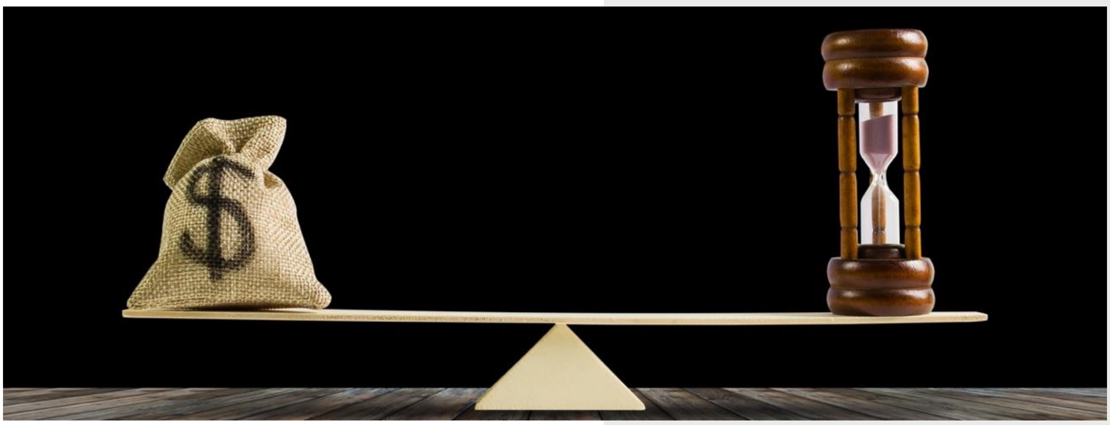
| | Squaw | Hood #1 | Hood #2 | Hood #3 | Zermatt | Wolf Creek | Sum of Prep |
|---|---|---|---|---|---|---|---|
| **Total Cost (All Funded Athletes)** | $13,090.36 | $13,082.80 | $18,947.19 | $14,313.97 | $56,267.31 | $10,460.68 | $126,162.31 |
| **Total Cost (Per Funded Athlete)** | $2,181.73 | $2,180.47 | $3,157.87 | $2,385.66 | $9,377.89 | $1,743.45 | $21,027.05 |

| | Training Events | Total Volume | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **ROI (High Volume)** | **Jumps** | 0 | 106 | 121 | 99 | 162 | 58 | **546** |
| | **Drills/Flats** | 22 | 0 | 11 | 19 | 35 | 12 | **77** |
| | **Sections** | 45 | 0 | 26 | 19 | 39 | 50 | **134** |
| | **Attemped T to B Runs** | 0 | 0 | 0 | 0 | 65 | 0 | **65** |
| | **Total Training Events** | **67** | **106** | **158** | **137** | **301** | **120** | **822** |
| | **Cost Per Training Event** | ***$32.56*** | ***$20.57*** | ***$19.99*** | ***$17.41*** | ***$31.16*** | ***$14.53*** | ***$25.58*** |

| | Training Events | Total Volume | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **ROI (Low Volume)** | **Jumps** | 0 | 69 | 93 | 64 | 91 | 20 | **337** |
| | **Drills/Flats** | 20 | 10 | 9 | 0 | 25 | 4 | **48** |
| | **Sections** | 44 | 0 | 22 | 0 | 25 | 20 | **67** |
| | **Attempted T to B Runs** | 0 | 0 | 0 | 0 | 28 | 0 | **28** |
| | **Total Training Events** | 64 | 79 | 124 | 64 | 169 | 44 | 480 |
| | **Cost Per Training Event** | ***$34.09*** | ***$27.60*** | ***$25.47*** | ***$37.28*** | ***$55.49*** | ***$39.62*** | ***$43.81*** |

The monetary cost of doing business is not the only consideration for the coach, practitioner, and athlete. One must also consider the time investment. Team members spend considerable time attending training camps, both domestic and abroad, with the singular purpose of sporting skill development. The table on the next page provides details regarding the total number of minutes spent training at each camp and the approximate number of minutes spent on skill development each day.

Again, as each athlete ultimately completes a different quantity of training, the author has provided a range of time invested using the highest quantity and the lowest quantity from each camp.  At each training camp, the athlete spends between 0.93 and 1.63 minutes training sporting skill development (Bullock, The Time Investment and Return on Investment During Preparation of World Cup Mogul Skiers, 2018).  Implications for the athlete are extreme and place the utmost priority on each opportunity he or she is presented.



| | Squaw | Hood #1 | Hood #2 | Hood #3 | Zermatt | Wolf Creek | Sum of Prep |
|---|---|---|---|---|---|---|---|
| Total Number of Days At Camp | 9 | 7 | 7 | 7 | 25 | 7 | 62 |

| | |
|---|---|
| Time per Jump (s) | 4 |
| Time per Drill/Flat (s) | 8 |
| Time per Section (s) | 14 |
| Time per T to B completed (s) | 28 |

***All times approximate and taken from video.**

| | Training Events | Total Volume (Minutes Invested) | | | | | |
|---|---|---|---|---|---|---|---|
| ROI -Minutes (High Volume) | **Jumps** | 0.00 | 7.07 | 8.07 | 6.60 | 3.87 | 3.87 | **29.47** |
| | **Drills/Flats** | 2.93 | 0.00 | 1.47 | 2.53 | 4.67 | 1.60 | **10.27** |
| | **Sections** | 10.50 | 0.00 | 6.07 | 4.43 | 9.10 | 11.67 | **31.27** |
| | **Attemped T to B Runs** | 0 | 0 | 0 | 0 | 30.33 | 0 | **30.33** |
| | **Total Time Training (min)** | **13.43** | **7.07** | **15.60** | **13.57** | **47.97** | **17.13** | **101.33** |
| | **Training Time (minutes/day)** | ***1.49*** | ***1.01*** | ***2.23*** | ***1.94*** | ***1.92*** | ***2.45*** | ***1.63*** |

| | Training Events | Total Volume (Minutes Invested) | | | | | |
|---|---|---|---|---|---|---|---|
| ROI - Minutes (Low Volume) | **Jumps** | 0.00 | 4.60 | 6.20 | 4.27 | 6.07 | 1.33 | **22.47** |
| | **Drills/Flats** | 2.67 | 1.33 | 1.20 | 0.00 | 3.33 | 0.53 | **6.40** |
| | **Sections** | 10.27 | 0.00 | 5.13 | 0.00 | 5.83 | 4.67 | **15.63** |
| | **Attemped T to B Runs** | 0.00 | 0.00 | 0.00 | 0.00 | 13.07 | 0.00 | **13.07** |
| | **Total Time Training (min)** | 12.93 | 5.93 | 12.53 | 4.27 | 28.30 | 6.53 | 57.57 |
| | **Training Time (minutes/day)** | ***1.44*** | ***0.85*** | ***1.79*** | ***0.61*** | ***1.13*** | ***0.93*** | ***0.93*** |

# The Weather

The weather presents another unique challenge to the sport and has implications for athlete preparation. The sport of mogul skiing requires specific circumstances for training to occur. Foremost, the temperatures proceeding the training camp must be ideal for adequate snowfall. Assuming sufficient snowfall and course/training venue construction, ideal conditions on arrival involve minimal snow/fog/rain to provide the athletes with the necessary visibility to train the course safely. Finally, wind speed needs to be minimal (less than 35kph) to operate most uphill transit, especially when en route to a glacier training site (Bullock, The Influence of Weather on World Cup Mogul Skiing Preparation, 2018).

Many training days are lost each year due to inclement weather conditions. The graph below shows the number of days (6) lost due to weather during the 2018-2019 preparatory period. A total of 12.3% of all scheduled training days were lost due to weather conditions at the training site or transit to and from the course (Bullock, The Influence of Weather on World Cup Mogul Skiing Preparation, 2018).

Given the potential for loss of training (skill development) opportunities, coaches and athletes should attempt to capitalize on each day they are able to train. The moguls coaching staff encourages athletes to pursue each day with purpose and resist the urge to wait or "get to it tomorrow" as that future opportunity is far from guaranteed. This is a fact of training that should be acknowledged by the coach and strength and conditioning practitioner, as this could result in abrupt and unavoidable spikes in training volume and intensity during skill development periods.

| Venue | Days Planned | Days Lost | Days Realized |
|---|---|---|---|
| **Squaw** | 7 | 0 | 7 |
| **Hood #1** | 6 | 1 | 5 |
| **Hood #2** | 6 | 1 | 5 |
| **Hood #3** | 6 | 0 | 7 |
| **Zermatt** | 18 | 4 | 14 |
| **Wolf Creek** | 6 | 0 | 6 |
| **Total** | 49 | 6 | 43 |
| **Percentage Lost: 12.3%** | | | |

# Team Sport Culture

The U.S. Freestyle Mogul Team consists of men and women who are both friends and competitors. This presents a unique challenge to the team's culture as the individuals develop relationships while simultaneously competing for a podium position, world rank, Olympic and World Ski Championship participation, and athlete funding. They do all this while sharing a room, plane, train, bus, car, course, and gym throughout the year. Such close quarters and high stakes make the nature of these relationships vital to the success of both the individual and the team.

Culture is considered one of the most prominent contributors to the success of organizations, especially sport organizations (Cole & Martin, 2018). It is considered by some to be the most important element in ensuring strategic success.  With this in mind, coaches and practitioners should maintain a conscious understanding of culture to better ensure its influence is strong and positive.

According to Cole and Martin (2018), a team's culture depends on four elements: 1) stability, 2) depth, 3) breadth, and 4) integration. Stability is present when the culture and its associated values are constant and hard to change despite personnel turnover. Depth of culture is achieved when it becomes embedded in everything the group does, and values influence decisions without conscious implementation. Breadth occurs when the culture is present in a team's functional areas from top to bottom. Finally, integration refers to how well cohesion is achieved between behaviors, values, and rituals.


The creation of a strong culture is a conscious effort and requires six necessary triggers to solicit its establishment; they include:

1) Those who have the most formal and informal influence on team direction and peer behavior must embrace the values of the culture.
2) The values must be reinforced via formal and informal means.
3) When in crisis, the leaders lean on team values.
4) The leaders must emphasize situations to reinforce the established values.
5) There is a strict selection of members to the team who will embrace the values.
6) The values are reinforced by rewarding the expression of the desired culture.

Regarding team and organizational structure, those with a laterally coordinated structure perform better and have a greater ability to innovate (Cole & Martin, 2018). This premise is supported by current literature as well as the experience of the author. In an investigation of firms with less than 500 staff in England, it was observed that those who employed decentralized decision-making (lateral coordination) achieved better results from clients (Cole & Martin, 2018). This same sentiment has been echoed in team sports, in which Johnson and colleagues (2012) studied the effectiveness of collective leadership in the All Blacks, New Zealand's world-renowned rugby team. The All Blacks informal collective leadership model (since formalized) has helped them amass an astounding 85.4% winning percentage between 2004 and 2011. Given the individual nature of mogul skiing, it seems logical that such a system should be employed.

Many business and athletic literature authors identify leadership style as central to the conscious influence of team and organizational culture. Through descriptive surveys, Cole and Martin (2018) found that sports teams preferred a coach who uses transformational leadership. The surveys also revealed that transformational leadership influenced culture most significantly. This approach is in stark contrast to the alternative, transactional coaching, whereby the leader(s) help team members achieve short-term goals, focusing on the athlete's relationship with that goal. Transformational coaching has the underlying goal of assisting the athlete in personal growth, such that the athlete acquires skills that will empower him or her to deal with such related issues in the future. Mogul skiing and life on the U.S. Ski & Snowboard team are transitional. Some athletes may have stints off the team or in the rehabilitative process that limit their contact with coaches; thus, a player transaction is likely to occur. It is the opinion of the author that such barriers to transformational leadership should attempt to be overcome through communication and the development of relationships that center around people rather than results.

During the 2018-2019 preparatory period, the U.S. Freestyle Mogul Team spent significant time establishing team values and a culture of shared beliefs and goals. The team values can be seen in the chart below.

| US Freestyle Mogul Team Values 2018-2019 | |
|---|---|
| **Communication** | **Dominant** |
| We will communicate individually and as a group | We will follow through |
| We will speak our minds | We will be the most successful mogul team in the world |
| **Grit** | We will win the day |
| We will take ownership | We will strive for mastery |
| We will learn from our mistakes and successes | **Respect** |
| We will be tough | We will respect everyone's time |
| We will be intentional everyday | We will listen to each other with an open mind |
| **Real** | **Leadership** |
| Positive or negative we will be open and honest | We will be ambassadors for the sport and the nation |
| **Trust / Supportive** | **Unique** |
| We will stand up for each other no matter what | We will be coached as individuals and act as a team |
| | We will create a team that people want to join |

Significant steps have been made to improve organizational structure and leadership style from an athlete and a coaching standpoint. There are very few mandatory requirements for athletes, but rather opportunities for improvement and education are made available. Coaches, in the case of younger athletes, dictate programming. However, in the case of more experienced athletes' coaches act more as consultants in a shared process. From time to time, all athletes need to be challenged, reminded of values, and in response, the coaching staff and practitioner should expect the athlete to rise to meet that challenge.

# Skill Development

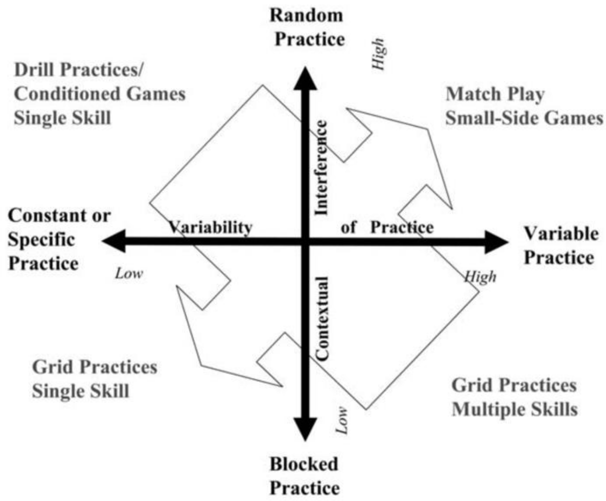
Athletes spend most of their time trying to refine and develop technical and behavioral skills. In contrast, much less effort is spent attempting to improve or refine aspects of fitness. Not surprisingly, a significant investment of time and practice is required to reach an elite level of performance. It is believed by many that athletes have a genetic gift for their sport and that those gifts cannot be learned or trained, only inherited. However, while hereditary factors play a role, an individual's skills are highly modifiable and adaptable to training. Every skier must practice for many hours to develop and refine their skill set.

When discussing the development of skills, particularly ski and air skill, five myths pervade the process (Williams & Hodges, 2005):

1) *Demonstrations are consistently effective in conveying information to the learner.* The main reason for using a demonstration is to provide the learner with a visual template for the desired movement pattern. Widespread acceptance of demonstration as an essential method of conveying information to the learner should be questioned. Although demonstrations usually facilitate the instruction process, they are sometimes no more effective than verbal instruction. In certain instances, they may hinder the learning and long-term retention of motor skills. Coaches and practitioners would be wise to employ demonstrations using multiple developmental examples to avoid constraining the learning process.

2) *Specific, blocked practice of a single skill is essential for skill learning.* Skills can be practiced in a blocked or random manner under constant (specific) or variable conditions. It is traditional for coaches to begin the instruction process with blocked, constant practice of a single skill before progressing to drill practices and eventually to random, variable practice conditions. The problem with this approach is that coaches typically judge their effectiveness by observing players' performance during the training session. The difficulty for coaches is that considerable evidence exists to suggest that several of the interventions used during the instruction process affect performance and learning in different ways. Coaches should be cognizant that variability in movement and context characteristics are essential to develop a more expansive, generalized motor program to cope with various similar but different situations. Finally, and most importantly, an awareness that while specific blocked training is better for performance, variable, random practice is more effective for skill learning.

4) *Augmented feedback from a coach should be frequent, detailed, and provided as soon as possible after the skill has been performed.* There are two types of feedback available to the learner. Intrinsic feedback is available as a natural consequence of performing an action, as the skier will be able to see, feel, and sometimes hear the consequence of specific movements. Extrinsic feedback can be provided by a coach or teammate immediately following the movement or later using video observation. Coaches need to be aware of how these different feedback sources work alone and in conjunction with other instructional techniques. Providing augmented feedback on every trial has a beneficial effect on performance but a detrimental effect on skill learning. Coaches should engage the learner in the problem-solving process and resist the urge to provide feedback on every practice attempt.




*Above:* Image depicting the construct of a practice relative to skill development and performance (Williams & Hodges, 2005).

2) *Prescriptive coaching is always better for skill acquisition than instructional approaches based on learning by guided discovery.* Prescriptive coaching is often thought of as hands-on or authoritative, whereby the coach has all the necessary knowledge, which must be passed on to the learner. Evidence suggests an overly prescriptive approach results in skills less resistant to psychological stress and more prone to fading over time than skills learned through guided discovery. Coaches should emphasize learning through guided discovery. Thus, allowing players to take responsibility for their development, finding unique solutions to movement problems through exploration and discovery. This more hands-off approach may be more effective in developing skiers who can apply their skills in various performance situations. This task does not imply that the importance of coaching is diminished, merely that the role needs to be redefined so that there is greater awareness of how coaches can shape and guide rather than dictate the learning process.

3) *Game intelligence skills are not amenable to practice and instruction.* Coaches consider that game intelligence improves purely as a result of playing experience and that it is not possible or, at best, too challenging to develop structured training programs to improve these skills. However, empirical evidence indicates that the acquisition of game intelligence skills can be mediated through appropriate interventions. A typical approach would be to film from the learner's perspective and identify course conditions or other circumstances, thereby underlying effective anticipation.

In addition to the actual structure and content of training, coaches should consider the methods they choose to cue athletes when trying to alter a motor pattern or solve a motor problem. Interestingly, and in contrast to other variables studied in the motor learning literature, a person's attentional focus often has a similar influence on both immediate performance (i.e., during the practice phase when focus instructions are given) and learning, which reflects a more permanent change in the capability to perform a skill (i.e., after a specific interval and without instructions or reminders) (Wulf, 2013).

Empirical evidence has amassed for the benefits of adopting an external focus on the intended movement effect (e.g., on the ski or jump) relative to an internal focus on body movements. Such a strategy positively affects desirable traits in moguls skiing, including balance, accuracy (ability to repeat a task), movement efficiency, muscular activity, maximum force production, speed, and endurance (Wulf, 2013).

Much emphasis has been given to this process by the coaching staff; however, many traditional habits still exist and, likely, may never fade. Ratings of perceived performance, as reported daily by athletes, rarely drop below a four (on a 1-7 Likert scale), indicating that performance may never suffer enough to enhance significant skill development. Such strategies will require continued emphasis and a willingness by the athlete to have a difficult day to advance their skill set. It is the author's experience that making a cognizant change to training structure and content, as well as the delivery method, is very difficult and, for the time being, will require a conscious effort.

Chapter 10

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