World Para Alpine Skiing – VI Classification Research Report

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Please note: The research presented in this report has either been submitted for publication and is under review. Therefore, the authors request that neither the report nor the associated presentation be duplicated or circulated without permission of the authors.

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Author Notes:
[1]Marieke Creese now works for the International Paralympic Committee (IPC). However, the research presented here was completed while Marieke was working at the University of Waterloo before she joined the IPC.
[2]The research presented here was completed during Dimitrije Lazarovski's tenure as Head of World Para Snow Sport, International Paralympic Committee.

Note from FIS:
This research project was initiated by World Para Alpine Skiing in 2015 and completed in 2020 while the sport was under the governance of the IPC. Since the completion of the project, the IPC has transferred the governance of Para Alpine to the International Ski and Snowboard Federation (FIS).

All references made in this report to World Para Alpine Skiing now applies to the FIS discipline of Para Alpine Skiing, and therefore approval is being sought from the FIS Council, after reaching the IPC for their approval and acknowledgment, for the outcomes of the research to be implemented into the FIS Para Alpine Skiing Classification Rules and Regulations.

World Para Alpine Skiing – VI Classification Research Report

Introduction

The School of Optometry & Vision Science at the University of Waterloo, Canada conducted the *VI Para Alpine Classification Research Project* to develop an evidence-based, sport-specific classification system for Para Alpine Skiing. This report provides a summary of the key findings of the research and recommendations that have be made after discussion of the research findings at the World Para Alpine Skiing – Classification Research for Athletes with Vision Impairment meeting (April 2019).

This report and its recommendations are organised under 4 key research questions as follows:

1. **What tests of vision function should be included in classification for Para Alpine Skiing?**
2. **What are the minimum impairment criteria for vision impairments in Para Alpine Skiing?**
3. **What are the most appropriate competition classes for Para Alpine Skiing?**
4. **What impact do blindfolds have on Para Alpine Skiing performance?**

At the conclusion of the World Para Alpine Skiing – Classification Research for Athletes with Vision Impairment meeting (April 2019), researchers were requested to conduct an additional study investigating how the performances of skiers with visual acuities between 0.6 – 0.9 logMAR (currently classed as NE) compared with the performances skiers are currently eligible to compete (classes B1, B2, B3). Researchers were also requested to try and collect data on skiers who were currently classified as B2 but had poor visual acuity, as none of these skiers participated in the original research project. This additional project (2019-2020 Study) addressed the key research question below, which was one of the original four research questions to be addressed:

3. **What are the most appropriate competition classes for Para Alpine Skiing?**

This report contains final recommendations for proposed rule changes based on all of research projects that were conducted and the discussion of the research findings at the World Para Alpine Skiing (WPAS) – Classification Research for Athletes with Vision Impairment meeting (April 2019).

Vision Impairment Classification Research Summary

Prior to designing and conducting this research, the researchers observed Para Alpine ski racing and met with a number of Para Alpine skiing representatives, including coaches from various countries around the world, volunteers, and technical staff, at the 2015 Para Alpine World Championships in Panorama, Canada. The researchers then prepared a report for World Para Snow Sport that identified VI classification issues that were priorities for both Para Alpine and Para Nordic skiing. This report was reviewed by the Head of World Para Snow Sport, as well as the Head Classifiers for Para Nordic and Para Alpine skiing and the IPC Medical & Scientific Department.

Based on the feedback received, the researchers developed the initial study conducted in the 2015-2016 season. During the 2015-2016 season additional feedback was sought from Para Alpine athletes, coaches, and team members about the current concerns / issues with VI classification and the research priorities that needed to be addressed. This additional feedback was incorporated into the final studies conducted in the 2016-2017 and 2017-2018 seasons. The results of the studies conducted during the 2016-2017 and 2017-2018 seasons were presented at the World Para Alpine Skiing (WPAS) – Classificaiton Research for Athletes with Vision Impairment meeting in April 2019. Based on the feedback received at this meeting, the researchers developed the final study conducted in the 2019-2020 season.

The major priority areas identified in the observations and expert consultation were:

- The current classification system did not account for the dynamic nature of the sports;
- The current classification system did not account for the wide variety of vision impairments that athletes had;
- An ideal classification system would include tests to mimic the dynamic nature of the sports and would account for the wide array of vision impairments in the sport.

These priority areas guided the researchers in the development of all of the experimental studies that were conducted. The experimental studies that were conducted are summarised below.

- **Vision Impairment-Performance Relationship Studies:** Two large studies were conducted to determine the relationship between visual function and skiing performance. The first study was conducted in the 2015-2016 season at the 2015 IPCAS Season Opener, Landgraaf, Netherlands and the USA Paralympic Nationals, Loon Mountain, USA. The second study was conducted at the 2017 Para Alpine World Championships in Tarvisio, Italy. Data collected from these studies was used to answer the following research questions:

  1. What tests of vision function should be included in classification for Para Alpine Skiing?

  3. What are the most appropriate competition classes for Para Alpine Skiing?

  The additional 2019-2020 study conducted at the 2019 IPCAS Season Opener, Landgraaf, Netherlands also addressed the following question:

  3. What are the most appropriate competition classes for Para Alpine Skiing?

- **Simulation Studies:** In a study conducted at the National Sports Center for the Disabled, Winter Park, USA, sighted skier races were asked to ski a short race course with a number of different simulated vision impairments. A wide range of visual acuity + contrast sensitivity impairments and visual field impairments were simulated to <u>determine the minimum level of visual impairment that decreased skiing performance.</u> Data from this study was used to answer the following question:

  2. What are the minimum impairment criteria for vision impairments in Para Alpine Skiing?

- **Blindfold Comparison Studies:** In a study conducted at the 2019 Para Alpine World Championships in Kranjska Gora, Slovenia, B1 skiers were asked to ski a short race course with and without their blindfolds. Data from this study was used to answer the following question:

  4. What impact do blindfolds have on Para Alpine Skiing performance in skiers in the B1 class?

Visual Function Measures

Measures of static visual acuity, dynamic visual acuity, low contrast visual acuity, contrast sensitivity, motion perception, visual field extent, colour vision, glare sensitivity, glare recovery, and light sensitivity were used in some, or all of the experimental studies described above. As some of these measures may not be familiar to you we have described each of the vision function tests below.

- **<u>Visual Acuity (Static, Dynamic, Low Contrast)</u>**

  Visual acuity measurements are based on the angular size a target subtends at the eye, or the minimum angle of resolution (MAR; Figure 1). For all of the study we conducted, we used visual acuity charts that measure visual acuity in logMAR [$\log_{10}$(MAR)], and a smaller logMAR number means better visual acuity. For example, 0.0 logMAR = 20/20 (normal vision), while 1.0 logMAR = 20/200 logMAR (low vision). It is important to note that the logMAR visual acuity scale is not a linear scale and a change of 0.1 logMAR is equivalent to a 25% change in the physical target size. The change in target size is proportional to the size of the letter (i.e. change in letter size between lines is bigger for larger letters).

  - **Static visual acuity** is a measure of how well an individual resolves high contrast, stationary (not moving) details. Static visual acuity was measured with both eyes open using the same standardised visual acuity charts that are currently used in classification. For data analysis purposes, 'Light Perception (LP)' visual acuity was recorded as 3.8 logMAR and 'No Light Perception (NLP)' visual acuity was recorded as 4.2 logMAR. These values were chosen based on previous low vision research.

- **Dynamic visual acuity** is a measure of how well an individual resolves details from a high contrast, randomly moving object. Dynamic visual acuity was measured with both eyes open using a computerised visual acuity chart.

- **Low contrast visual acuity** is a measure of how well an individual resolves low contrast (light grey on a white background) stationary details. Low contrast visual acuity was measured with both eyes open using a computerised visual acuity chart.

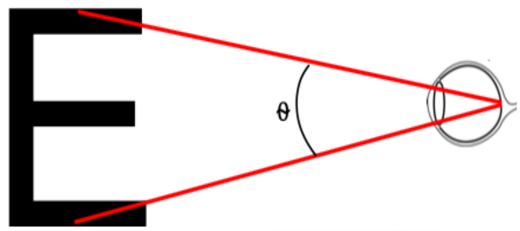

Figure 1 – Demonstration of visual angle (angular size a visual acuity target subtends on the retina)

- **<u>Contrast Sensitivity</u>**
  Contrast sensitivity measures how well someone resolves low contrast, stationary targets. In contrast sensitivity testing, all the targets (letters) are the same size, but the target contrast incrementally changes from black to very light grey. Contrast sensitivity can be measured with printed paper charts or computerised charts, and is reported in units of logCS.

- **<u>Motion Perception</u>**
  Motion perception tests measure how well someone is able to detect motion direction. In these tasks an array of moving dots were presented on a computer screen. Some dots will move in the same direction (signal) and some dots will move randomly (noise). The ratio of signal to noise dots is varied, and observers are asked to indicate the direction of the signal dots. The Motion Perception Threshold is calculated as the smallest percent (%) of signal dots needed to correctly identify the motion direction. In these studies, we used to motion directions: 1) translational motion that moved up or down on the screen, and 2) radial motion that appeared to move in or out of the screen (towards or away from the observer).

- **<u>Visual Field Extent</u>**
  Visual fields were measured under binocular conditions using a hand-held arc perimeter, which is a visual field instrument used for research (but currently not used for classification). The hand-held arc perimeter is a valuable tool for this type of research because it is portable and fits inside a suitcase.

  Arc perimeters are a type of kinetic visual field measurement where targets are moved from areas of non-seeing into areas of seeing along the principle meridians of the visual field. The arc rotates through 360 degrees to allow for measurement along any meridian of interest (Figure 2).

  Arc perimeters do not quantify subtle visual field loss well (as would be important in managing progressive visual field loss in glaucoma for example), but they are reasonably accurate for measuring absolute visual field loss (areas of seeing or not seeing) when used by a trained examiner. The figure to the right shows a type of hand-held arc perimeter, including the different targets that can be used to measure visual field; for research purposes the largest and brightest target was used for all measurements.[1]

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[1] Image from: The College of Optometrists, UK. Permiters: Assessing the visual field. https://www.college-optometrists.org/the-college/museum/online-exhibitions/virtual-ophthalmic-instrument-gallery/perimeters.html

For research purposes, visual field areas (degrees^2) were calculated based on participant's actual measured visual field extents. Analyses were conducted based on visual field areas and then equivalent visual field radii (degrees) were determined for classification.

In addition, visual field measurements were converted to a visual field score based on a modified AMA scoring grid[2] (Figure 3) to determine the visual field extent in percent. One point is given for each dot on the scoring grid that falls in the measurable visual field. The maximum possible score is 60. A full (normal) visual field will have a score of 60 or a visual field extent of 100%. If a visual score was 30 (out of 60) than the visual field extent would be 50%.

Figure 2 Hand-held arc perimeter for the measurement of visual field

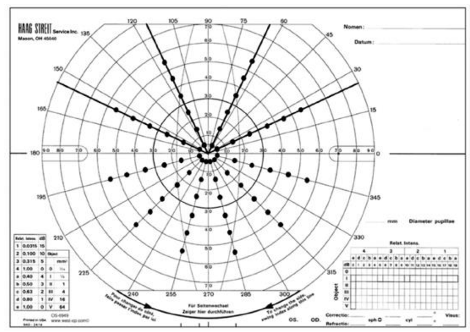

Figure 3 Modified AMA 6E Scoring Grid on a Goldman visual field scoring grid

- **Colour Vision**
  Colour vision was assessed using a large D-15 test, which requires individuals to sort colours in order (Figure 4). The pattern of errors made is assessed to determine if, and what type of, colour vision defect is present. Additionally, the errors made can be scored to come up with a colour vision error score. The colour vision error score was used in this research.

Figure 4: D-15 Colour Vision Test[3]

- **Glare Sensitivity**
  Glare sensitivity was measured by introducing a bright, binocular glare source in the line of sight, and measuring static visual acuity in the presence of the glare source. Static visual acuity in the presence of glare was compared to the baseline static visual acuity (no glare) to determine glare sensitivity in logMAR units using the following formula:

$$[\text{Static Visual Acuity}_{GLARE} – \text{Static Visual Acuity}_{BASELINE}] = \text{Glare Sensitivity}$$

- **Glare Recovery**

[2] Mann DL, Ravensbergen RHJC (2019). *Protocol for AMA-Style Analysis of Visual Field*.
[3] Image from: https://www.eyecareconcepts.com.au/blog/archives/02-2018

Glare recovery was measured by re-testing static visual acuity 1 minute after the glare source was removed. Static visual acuity measured after the glare source was removed was compared to the baseline static visual acuity (no glare) to determine glare recovery in logMAR units using the following formula:

$$[\text{Static Visual Acuity}_{\text{POST-GLARE}} - \text{Static Visual Acuity}_{\text{BASELINE}}] = \text{Glare Recovery}$$

Positive logMAR values for Glare Sensitivity and Glare Recovery indicated that visual acuity decreased (got worse) compared to baseline; negative logMAR values for Glare Sensitivity and Glare Recovery indicated that visual acuity increased (got better) compared to baseline.

- **Light Sensitivity**

  Light sensitivity was measured by increasing the surrounding light levels from 395 lux (standard clinical lighting) to approximately 1900 lux (similar to being outdoors on a moderately sunny day; this is the highest light level we could generate using artificial lights indoors) and measuring static visual acuity in the increased light level. Static visual acuity in the presence of the bright light was compared to the baseline static visual acuity (clinical lighting) to determine light sensitivity in logMAR units using the following formula:

$$[\text{Static Visual Acuity}_{\text{LIGHT}} - \text{Static Visual Acuity}_{\text{BASELINE}}] = \text{Light Sensitivity}$$

Positive logMAR values for Light Sensitivity indicated that visual acuity decreased (got worse) compared to baseline; negative logMAR values for Light Sensitivity indicated that visual acuity increased (got better) compared to baseline.

Skiing Performance

In the vision impairment-performance relationship studies, skiers' performance was quantified using race points, which were calculated based on a modified version of the World Para Alpine Skiing (WPAS) scoring system. In these studies, race points were calculated as per the WPAS rules (i.e. Points were calculated for each athlete as the average of their best 2 skiing World Para Alpine Skiing Points in the 15-month window from January 2016 to March 2017). This time period was chosen because it included the 2017 Para Alpine World Championship event where the final Vision Impairment-Performance Relationship Study was conducted.[4] The only difference was that the race points used for research purposes were recalculated using **raw time instead of the factored time that is used in WPAS competitions**, because we wanted a performance metric that was independent of the current VI classification system. The modified version of WPAS race-points ("Raw-WPAS") was chosen for this analysis, as it allowed researchers to normalize data to the specific conditions on a course on any given day, as well as between genders, and it gave a measure of consistency of performance over time. Looking at performance across seasons helps prevent erroneous conclusions based on any one skier having a particularly bad result in a specific race due to weather conditions or other extraneous factors.

In the minimum-impairment criteria and blindfold studies, **raw time** was used as the performance metric for all analyses.

Skiing Disciplines

In the preliminary 2015-2016 study, Slalom performance points were used for comparison purposes because the most skiers participated in this discipline. However, after discussion with World Para Snow Sport and sport experts,

[4] Researchers did consider using the 15-month window from January 2017 to March 2018, which would have included the 2017 Para Alpine World Championship event and the 2018 Paralympic games. However, in the 2017-2018 window there were fewer races and fewer skiers competing compared with the 2016-2017 window. Therefore, the researchers chose to use the 2016-2017 window because it provided the most data.

it was decided that Giant Slalom was a better representative discipline to use as it incorporates both technique and speed, and it has a large number of athletes participating in it.

In the 2016-2017 Vision Impairment-Performance study, all four disciplines were analysed but only the Giant Slalom results are presented in the body of this report. The results from Slalom, Super G, and Downhill are presented in Appendices A and B.

For the simulation study and the blindfold study, both conducted in the 2018-2019 season, a short Giant Slalom course was used for data collection.

Informed Consent

All of the studies conducted (2015-2016, 2016-2017, and 2019-2020) were approved by a University of Waterloo Research Ethics Board and complied with the Declaration of Helsinki. All athletes participating in all of the studies conducted provided informed consent prior to participation.

Vision Impairment-Performance Relationship Studies – Part 1: Athlete Evaluation

The two studies conducted below (2015-2016 study and 2016-2017 study) enabled us to determine **what measures of visual function should be included in athlete evaluations.**

2015-2016 Study

29 athletes, ages 12-69 years (20 male, 9 female) from 10 nations participated in this study. In this preliminary study we measured static visual acuity, contrast sensitivity, dynamic visual acuity, low contrast static visual acuity, colour vision, glare sensitivity, and glare recovery. All vision tests were measured with both eyes open (binocularly), except for glare sensitivity and glare recovery, which were measured with each eye individually because the glare test could only be used on one eye at a time.

Static visual acuity was found to be a significant predictor of Para Alpine Slalom skiing performance, and there was a trend towards colour vision being a predictive of slalom skiing performance as well.

In this preliminary study we were unable to measure contrast sensitivity on all skiers with the tests we had available to us, and glare testing could only be done on one eye at a time. Therefore, it was hard to determine if the lack of relationship between the vision functions and skiing performance was a real finding or an artefact due to not being able to measure everything on everyone. Furthermore, the skiers who participated in this study had a wide range of experience and expertise ranging from youth athletes in development programs to athletes who had attended multiple Paralympic games. With such a wide skill level in the study population, it was impossible to determine if the differences in performance were related to vision or skill. Visual field testing and motion perception testing were also not included because we did not have validated portable tests of these vision functions available to us at the time of testing.

However, despite these limitations, it was decided that **low contrast static acuity did not add any additional information** about visual function that was not already measured using the static visual acuity and contrast sensitivity tests. Additionally, **the colour vision error scores did not capture functional differences in colour vision between athletes adequately,** even though there was a trend towards significance in the colour vision data. Therefore, the low contrast visual acuity and colour vision tests were removed from the test battery, and replaced with a light sensitivity test, a binocular visual field test, and two tests of motion perception.

2016-2017 Study

To address the limitations of the 2015-2016 study, the research team returned in the 2016-2017 season to test athletes who were eligible to compete at the World Championships only, which would help ensure a minimum disparity in athlete skill level. Static visual acuity and dynamic visual acuity were re-measured using the same tests as in 2015-2016. New tests were used to measure contrast sensitivity, glare sensitivity, glare recovery, light sensitivity, visual field extent, and motion perception. All testing was done with both eyes open. More details about skier's training experience (skier's age, age started skiing, total lifetime years of training, total lifetime training hours, number of races competed in), and age of impairment onset were also collected.

Data for this study was collected at the 2017 Para Alpine World Championships in Tarvisio, Italy. 15 athletes, ages 16-58 years (8 male, 7 female) from 10 nations participated in this study. Raw-WPAS points were calculated from races that occurred between January 2016 and March 2017 only.

In Giant Slalom, having a lower **(better) static visual acuity was associated with better skiing performance**. There was a **trend towards having a lower (better) motion perception threshold also being associated with better** skiing performance (Figure 5).

Additional factors that were significantly correlated, or nearly significantly correlated with skiing performance in the other disciplines[5] were **skier's age**, **number of races completed**, **visual field extent**, **contrast sensitivity**, and **dynamic visual acuity**.

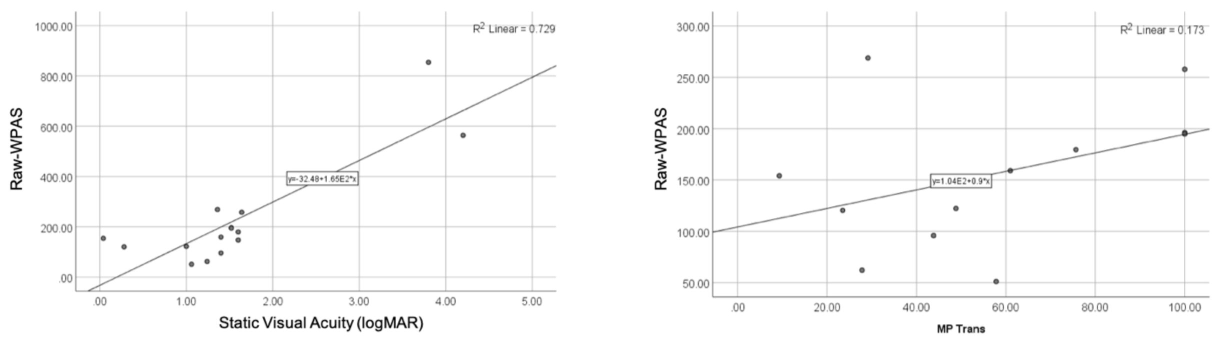

Figure 5: Each dot in the top, left, and right panels indicates one skier's data. Left Panel - This panel demonstrates the correlation between static visual acuity and Raw-WPAS points, and shows that Raw-WPAS points are lower (better) when static visual acuity is lower (better). Right Panel - This panel demonstrates the correlation between motion perception threshold (translational) and Raw-WPAS points, and shows that Raw-WPAS points are lower (better) when the motion perception threshold is lower (i.e. the presence of motion can be detected with a smaller signal).

A multivariable regression analysis statistical model was then used to look at whether or not skiing performance could be predicted based on any of the individual visual functions measured. In the 2016-2017 study data, static visual acuity was found to be highly correlated with dynamic visual acuity, contrast sensitivity, and motion perception threshold (translational). As performance on the static visual acuity test was found to be representative of performance on the dynamic visual acuity, contrast sensitivity, and motion perception threshold (translational tests), and static visual acuity had the strongest correlations with skiing performance in Giant Slalom and all the other disciplines, **static visual acuity** was chosen as the representative variable for this analysis. **Visual field extent**, **skier's age**, and **number of races** were also included as variables.

Factors that were significant predictors of skiing performance in Giant Slalom were **static visual acuity** and **skier's age**. **Static visual acuity** and **skier's age** were also significant predictors of skiing performance in Slalom. In Super G, **static visual acuity** only was found to be a significant predictor of performance, and in Downhill **no variables** were found to be predictive of skiing performance.

[5] See Appendix A for detailed results from Slalom, Super G, and Downhill.

Simulation Studies – Minimum Impairment Criteria

In order to determine the **minimum impairment criteria** for Para Alpine skiing, we recruited sighted, experienced Alpine skiers (coaches and youth and Masters ski club members) at the National Sports Center for the Disabled, Winter Park, USA. 11 skiers (11 male; 37.91 ± 18.9 yrs, range 17 to 64 yrs) participated in this study and all skiers were either racers or coaches with ski racing experience. All skiers were asked to ski two short, 10 gate Giant Slalom race courses while wearing either clear goggles to simulate habitual (or normal) vision or simulated vision impairment goggles of different levels of vision impairment. The racecourses were not the same for all skiers, however all the race courses were set by experienced course setters and the gate settings were similar to Giant Slalom race courses. To account for the fact that the racecourses were not the same for all skiers, baseline (no impairment, clear goggle) data was taken for each athlete on each course, and researchers calculated how much the simulated impairments changed the skier's times from baseline. Researchers then compared how much skier's times changed from baseline rather than each skier's raw times with each of the different simulated impairments.

The simulated vision impairment goggles either impaired visual acuity and contrast sensitivity simultaneously (because it is impossible to impair one without affecting the other) or decreased the binocular peripheral visual field. Skiers completed a total of 20 skiing trials in the study (10 per course), and were asked to try and maintain a consistent, challenging (70-80%) pace across the trials. The first and last trial for every skier on each course was completed with clear goggles (4 trials total). The middle 16 trials consisted of the 14 simulated vision impairments and two additional clear goggle trials to monitor fatigue across the trials. Apart from the first and last trials, the goggles skiers were assigned for each trial were randomly assigned. Time to complete each run was measured.

No differences in race times were found across the clear goggle trials on either run, which indicated that skiers could maintain a consistent pace, and that fatigue was not a factor that needed to be accounted for.

To determine the impact of the simulated vision impairments on performance, the average trial time for the clear goggle conditions was calculated for each skier on each course. The difference from average baseline for each individual simulated vision impairment trial time was then calculated. All trial time difference data were then normalised to allow for comparison between participants. Only the visual acuity and visual field results will be presented here, because contrast sensitivity was not a recommended test for athlete inclusion.

Visual Acuity

Eight different levels of visual acuity impairments were simulated from approximately 0.1logMAR to 1.6logMAR in 0.2 to 0.3logMAR intervals (Figure 6).

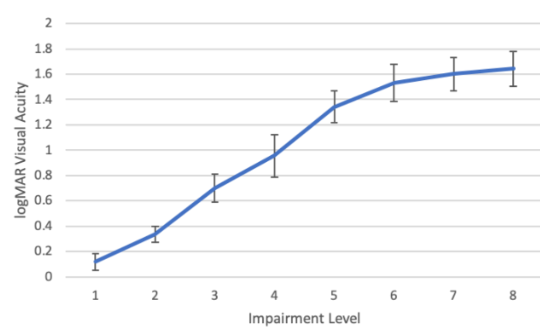

Figure 6: Average simulated visual acuities (logMAR) for all skiers in the study for each simulated visual acuity impairment level. Error bars indicate the variability (standard deviation) of the data between skiers.

The difference from baseline times (Figure 7, Left panel) gradually increased with each level of impairment, which means skiers got slower with each reduction in their visual acuity. Skiing performance decreased significantly from baseline at 0.99logMAR (Impairment Level 5), however skiing performance in some athletes changed before this impairment level, and in other athletes skiing performance did not decrease until after this level. Additionally, the statistically significant difference in performance at Impairment Level 5, was consistent with approximately a 5 second decrease in skiing performance. In recognition that statistical significance may not equate to sport significance, the investigators used additional statistical analysis methods called "receiver operator characteristics, or ROC analysis", "Youden's J" and "decision trees" to identify the optimal visual acuity minimum impairment criteria.

ROC analysis determines the sensitivity and specificity of each possible cut-off point. Both sensitivity and specificity are measured on a scale of 0 to 1. On this scale, scores closer to 1 are better. A minimum impairment criterion with good *sensitivity* would include as many skiers as possible who are performing worse than expected (i.e. assumed to have a genuine impairment). However, if the minimum impairment criterion is set too low, it will have poor *specificity*, which means skiers without genuine impairments may also be included. A minimum impairment criterion with a high *specificity*, but poor *sensitivity* would end up excluding people from competition who have genuine impairments. To find a balance between sensitivity and specificity for the minimum impairment criteria, Youden's J analysis was used, because Youden's J optimises both sensitivity and specificity.

Decision tree analyses start with the whole data set and then split it into two groups that are the most similar or homogeneous. The splitting continues as long as different groups can be clearly defined in the data. For the purposes of the research done hear, the decision tree created separated the skiers' performances into 'expected' (same as no impairment) or 'below-expected' (worse than no impairment) groups.

Figure 7 (Right panel) shows the sensitivity and specificity for different possible minimum impairment criteria for visual acuity. A minimum impairment criterion with good *sensitivity* would include as many skiers as possible who are performing worse than expected (i.e. assumed to have a genuine impairment). However, if the minimum impairment criterion is set too low, it will have poor *specificity*, which means skiers without genuine impairments may also be included. A minimum impairment criterion with a high *specificity*, but poor *sensitivity* would end up excluding people from competition who have genuine impairments. To find a balance between sensitivity and specificity for the minimum impairment criteria, Youden's J analysis was used. Youden's J optimises both sensitivity and specificity and found that a cut-off value of **0.59 logMAR** is ideal (sensitivity = 0.93, specificity =0.88).

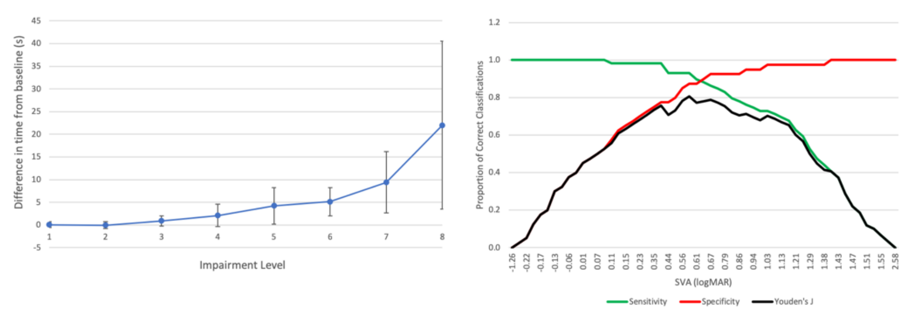

Figure 7: Left Panel – Average difference in time from baseline for each impairment level, for all skiers. Error bars indicate the variability (standard deviation) of the data between skiers. Right Panel – Minimum impairment criteria for visual acuity. Sensitivity (green line), specificity (red line), and Youden's J (black line – the 'optimal' combination of sensitivity and specificity) for each possible visual acuity criterion.

Visual Field

Six different levels of visual field impairments were simulated as shown in Figure 8. Skier's visual field extents were restricted from approximately 97% (12996 degrees^2) to 29% (1137 degrees^2) in approximately 13% intervals.

The difference from baseline times (Figure 9, Right panel) gradually increase with each level of impairment, which means skiers got slower with each reduction in their visual field extent. Skiing performance decreased significantly from baseline at visual field area 1968.4 degrees^2 (39% visual field extent; Impairment Level 5), however skiing performance in some athletes changed before this impairment level, and in other athletes skiing performance did not decrease until after this level. Therefore, receiver operator characteristics analysis was performed to identify the optimal visual field extent minimum impairment criteria.

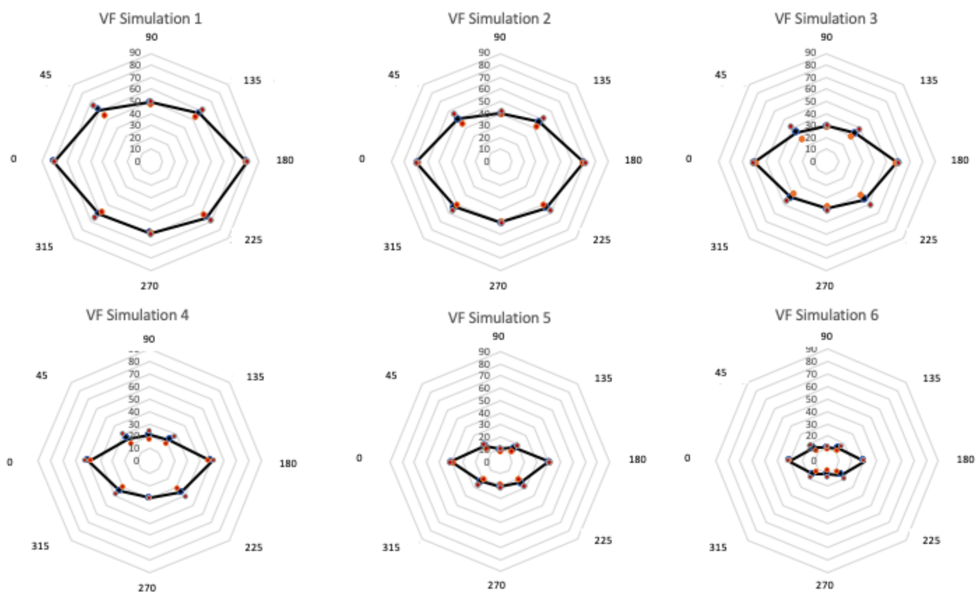

Figure 8: Average simulated visual field extent (%) and visual field traces for all skiers in the study for each simulated visual field impairment level. Red dots bars indicate the variability (standard deviation) of the data between skiers.

Figure 9 (Right panel) shows the sensitivity and specificity for different possible minimum impairment criteria for visual field. To find a balance between sensitivity and specificity for the minimum impairment criteria, Youden's J analysis was used. Youden's J at the intersection of the sensitivity and specificity curves was 0.536 (sensitivity = 0.75, specificity = 0.79) and corresponded to an equivalent VF of 35° radius (52.9%; area = 3892.2 degrees^2).

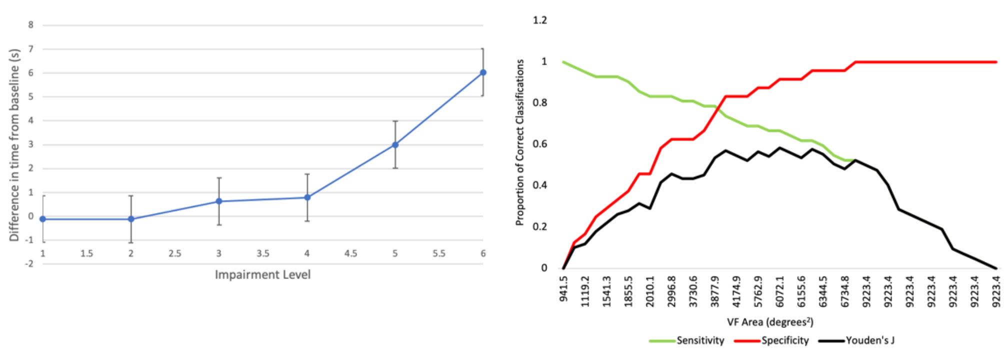

Figure 9: <u>Left Panel</u> – Average difference in time from baseline for each impairment level, for all skiers. Error bars indicate the variability (standard deviation) of the data between skiers. <u>Right Panel</u> – Minimum impairment criteria for visual field extent. Sensitivity (green line), specificity (red line), and Youden's J (black line – the 'optimal' combination of sensitivity and specificity) for each possible visual acuity criterion.

A decision tree analysis confirmed that a visual field area = 6072.1 degrees^2 (44° radius; 55%) was the strongest predictor of poorer performance. When visual field area was 6072.1 degrees^2, the next best predictor of poor performance was a static visual acuity of ≤ 0.59 logMAR. Youden's J at the intersection of the sensitivity and specificity curves for area = 6072.1 degrees^2 was 0.584 (sensitivity = 0.92, specificity = 0.67).

As sensitivity and specificity were more balanced at the intersection point of the ROC curves, a visual field cut-off of ≤35 degrees radius was recommended for the sport.

Consideration of both the ROC curves and the decision tree analysis suggests that a static visual acuity worse than 0.59logMAR negatively impacts skiing performance and confirms that a visual field extent ≤35 degrees radius[6] negatively impacts skiing performance in the non-adapted form of the sport.

Vision Impairment-Performance Relationship Studies – Part 2: Sport Classes

In addition to allowing us to determine what tests should be included in athlete evaluation, data from the 2016-2017 study could be used to determine the **most appropriate Sport Classes for Para Alpine Skiing.** Data from the 2019-2020 study was also used for this purpose.

2016-2017 Study

To examine the relationship between visual impairment and performance for the determination of sport classes, we used a hierarchical clustering analysis to determine if there were unique groups within the population of skiers that performed differently. Comparison of the unique groups could shed further insight into whether or not these groups had different visual abilities, as well as what aspects of vision are most important for Alpine skiing. All vision and experience variables were included in this cluster analysis, in order to account for other factors that may affect skiing performance.

Raw-WPAS performance points were used as an outcome measure in this analysis, which identified 3 distinct groups in Giant Slalom[7] that performed significantly different (Figure 10, Left panel). For comparison purposes, Raw-WPAS points for each athlete in their current Sport Classes (B1, B2, B3) are also included in Figure 10 (Right panel).

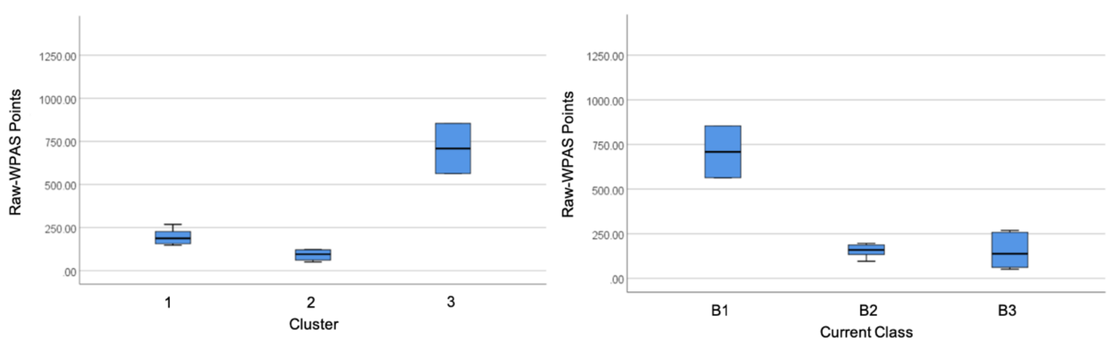

Figure 10: Left Panel – Raw-WPAS points for each unique cluster identified by the hierarchical cluster analysis. Right Panel – Raw-WPAS points for each current competition class (B1, B2, B3) for the same athletes included in the hierarchical cluster analysis.

Raw-WPAS points and **static visual acuity** were the only variables found to be significantly different between the Clusters (Figure 11). None of the other vision or experience variables were different between the Clusters.

[6] Please note, in the original reports presented at the April 2019 meeting, the estimated visual field cutoff was <40 degrees radius, pending confirmation of how visual fields should be scored from the IPC. Once confirmation of how to score visual fields was obtained, the final cutoff value was determined to be ≤35 degrees radius.

[7] See Appendix B for results of hiearchical cluster analysis in Slalom, Super G, and Downhill.

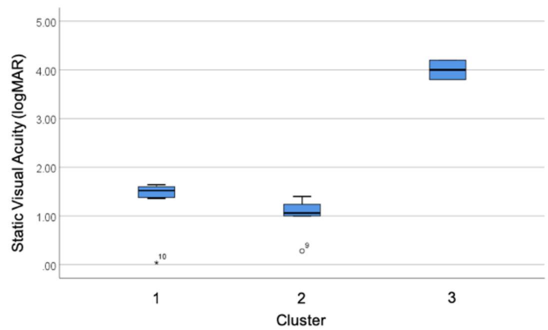

Figure 11: Static visual acuity distribution for each of the three clusters found in Giant Slalom based on Raw-WPAS points. The boxes represent the first to third quartiles, the band in the box represents the median value, and the error bars indicate minimum and maximum data for each cluster.

Comparison of static visual acuity between clusters demonstrates that static visual acuity was significantly different between Clusters 2 and 3, but there was no difference in static visual acuity between Clusters 1 and 2 or Clusters 1 and 3. It is important to note that in Clusters 1 and 2 there are no athletes with light perception or no light perception vision (i.e. no measurable visual acuity). Athletes with light perception or no light perception static visual acuities were only in Cluster 3.

Looking at the cluster data it there is an obvious difference in performance between skiers with measurable visual acuity and skiers with light perception or no light perception vision. This difference in performance suggests that the skiers with light perception or no light perception vision should be in a different class than skiers with measurable static visual acuities.

2019-2020 Study

Twenty-two athletes from 9 nations participated in this study. Two athletes were excluded from the analysis because they did not meet the study eligibility criteria. Thus, the final analysis presented below is based on 20 athletes from 9 nations.

Binocular measures of static visual acuity, dynamic visual acuity, contrast sensitivity, motion perception, visual field extent, glare sensitivity, glare recovery, and light sensitivity were collected on every skier in this study.

Athletes were also asked to complete a detailed questionnaire about their lifetime skiing training and racing experience. The same questionnaire that had been used in previous studies was again used in this study. The skier experience variables collected in this analysis were: skier’s age, age when they started skiing, age of onset of the vision impairment, and total lifetime hours of skiing. Skiers were also asked about the total number of races they had competed in, however, some skiers only had experience competing in able-sighted sport, while others only had experience competing in adapted sport. Due to the variability in the racing backgrounds of the skiers, this variable was removed from further analysis.

All skiers completed 6 slalom races (3 runs on day one and 3 runs on day two, on 6 different courses as per the sport rules) over the course of the study. Skiers currently classed as NE ran as forerunners on each run, and their race times were recorded. **As all skiers were competing on the same course at the same time, researchers were able to compare raw race times rather than the modified version of World Para Alpine Skiing (WPAS) points that had been used in previous studies.**

Researchers looked at total race time on day 1 and day 2 (total sum time of runs 1 to 3 each day), as well as each individual run on day 1 and day 2. Only slalom race times were examined, as slalom races were the only events the skiers competed in.

To examine the relationship between visual impairment and performance for the determination of sport classes, we used a hierarchical clustering analysis to determine if there were unique groups within the population of skiers that performed differently. The unique performance groups were compared in order to determine whether or not these groups had different visual abilities, as well as what aspects of vision were most important for Alpine skiing. All vision and experience variables were included in this cluster analysis, in order to account for other factors that may affect skiing performance.

Raw time was used as the outcome measure in this analysis, which identified 3 distinct groups that performed significantly differently in Slalom Race 1 (Total Time; Figure 12, Left Panel) and Slalom Race 2 (Total Time; Figure 13, Left Panel) For comparison purposes, Raw Total Time for each athlete in their current Sport Class (NE, B1, B2, B3) are also included in Figure 12 and 13 (Right panel).

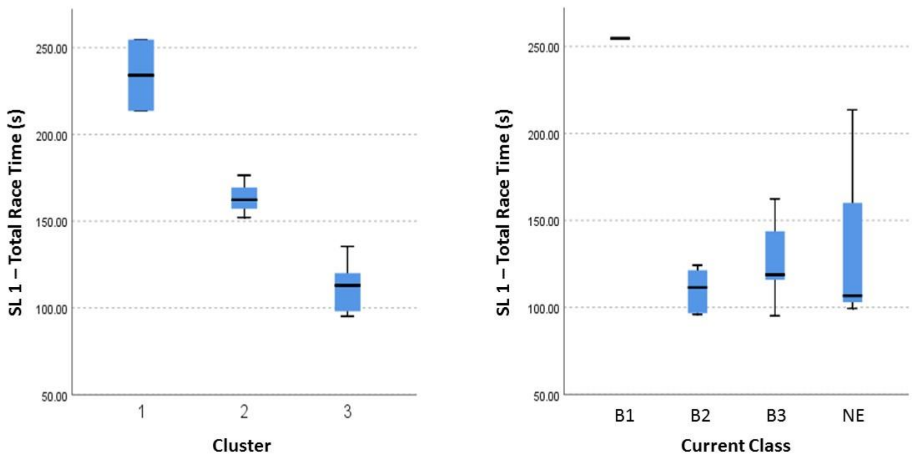

Figure 122: Left Panel – Raw Total Time for Slalom Race 1 for each unique cluster identified by the hierarchical cluster analysis. Right Panel – Raw Total Time for each current competition class (B1, B2, B3, NE) for the same athletes included in the hierarchical cluster analysis.

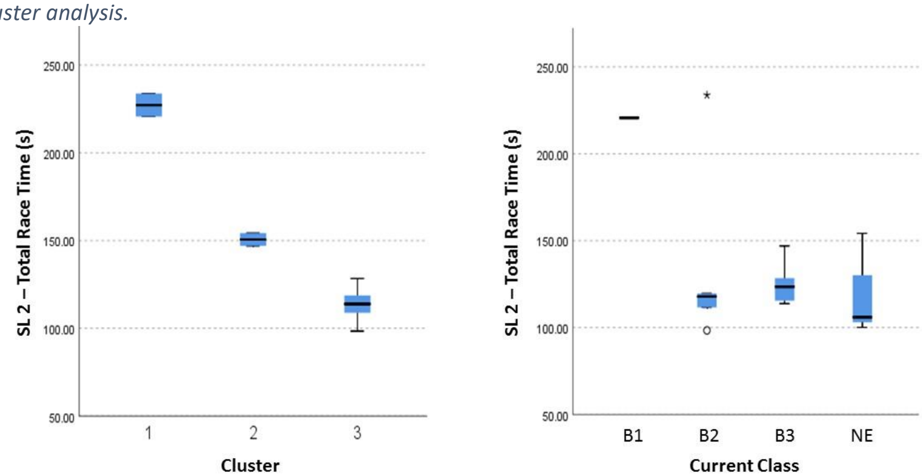

Figure 13: Left Panel – Raw Total Time for Slalom Race 2 for each unique cluster identified by the hierarchical cluster analysis. Right Panel – Raw Total Time for each current competition class (B1, B2, B3, NE) for the same athletes included in the hierarchical cluster analysis.

Raw race time was the only variable found to be significantly different between the clusters (Tables 1 and 2) on the total race times from Day 1 and Day 2 and each individual run. On Day 1-Run 2 and Day 2-Run 1 only, **total training hours** was also found to be significantly different between clusters. None of the other vision or experience variables were different between the clusters.

Table 1: Experience and visual function variables between clusters (mean ± standard deviation) for Total Race Time on Day 1 (Run 1 + Run 2 + Run 3). Variables that were significantly different between clusters are listed at the top of the table (shaded grey). All other variables (not shaded) were not significantly different between clusters. "NLP" refers to "No Light Perception Vision", "LP" indicates "Light Perception" vision and "NM" or "Not Measurable" indicates that it was not possible to obtain a measurement on this visual function test for athletes in this Cluster.

	Cluster 1 (n=2)	Cluster 2 (n=3)	Cluster 3 (n=12)
Race Time	**213.60 s, 254.72 s**	**163.65 ± 12.24 s**	**111.42 ± 12.88 s**
Skier Age	26 yrs, 30 yrs	19.3 ± 7.8 yrs	23.5 ± 10.1 yrs
Skiing Start Age	2 yrs, 28 yrs	11.5 ± 7.1 yrs	11.5 ± 8.5 yrs
Impairment Onset Age	11 yrs, 0 yrs	0.5 ± 0.5 yrs	5.8 ± 9.7 yrs
Total Training Hours	2024 hrs, 224 hrs	1664.0 ± 1660.3 hrs	2182.4 ± 1686.9 hrs
Static Visual Acuity	0.86 logMAR, NLP = 1	1.17 ± 0.39 logMAR	1.46 ± 0.73 logMAR
Visual Field Extent	38.3 %, 0.0 %	46.7 ± 11.7 %	45.3 ± 33.0 %
Dynamic Visual Acuity	0.90 logMAR, NM	1.47 ± 0.40 logMAR	1.62 ± 0.56 logMAR
Contrast Sensitivity	1.42 logCS, NM	0.79 ± 0.55 logCS	0.57 ± 0.70 logCS
Translational MP	15.3 %, NM	59.3 ± 27.9 %	49.1 ± 21.2 %
Radial MP	12.2 %, NM	46.7 ± 28.1 %	40.8 ± 26.2 %
Glare Sensitivity	0.00 logMAR, NM	0.15 ± 0.18 logMAR	-0.04 ± 0.17 logMAR
Glare Recovery	-0.06 logMAR, NM	0.08 ± 0.13 logMAR	0.22 ± 0.20 logMAR
Light Sensitivity	0.02 logMAR, NM	0.06 ± 0.11 logMAR	-0.04 ± 0.21 logMAR

Table 2: Experience and visual function variables between Clusters (mean ± standard deviation) for Total Race Time on Day 2 (Run 1 + Run 2 + Run 3). Variables that were significantly different between clusters are listed at the top of the table (shaded grey). All other variables (not shaded) were not significantly different between clusters. "NLP" refers to "No Light Perception Vision", "LP" indicates "Light Perception" vision and "NM" or "Not Measurable" indicates that it was not possible to obtain a measurement on this visual function test for athletes in this Cluster.

	Cluster 1 (n=2)	Cluster 2 (n=2)	Cluster 3 (n=11)
Race Time	**233.78 s, 220.68 s**	**150.61 ± 5.13 s**	**113.50±9.22 s**
Skier Age	16 yrs, 30 yrs	21.5 ± 6.4 yrs	21.8 ± 7.8 yrs
Skiing Start Age	4 yrs, 28 yrs	8.0 ± 8.5 yrs	11.6 ± 9.0 yrs
Impairment Onset Age	0 yrs, 0 yrs	6.0 ± 7.1 yrs	3.2 ± 5.9 yrs
Total Training Hours	240 hrs, 224 hrs	1171.0 ± 1203.5 hrs	2193.9 ± 1657.0 hrs
Static Visual Acuity	1.60 logMAR, NLP = 1	1.11 ± 0.35 logMAR	1.38 ± 0.77 logMAR
Visual Field Extent	47.5 %, 0.0 %	46.7 ± 11.8 %	44.7 ± 32.4 %
Dynamic Visual Acuity	1.70 logMAR, NM	1.30 ± 0.57 logMAR	1.54 ± 0.62 logMAR
Contrast Sensitivity	0.18 logCS, NM	0.98 ± 0.62l ogCS	0.72 ± 0.75 logCS
Translational MP	39.0 %, NM	38.0 ± 32.1 %	57.0 ± 22.7 %
Radial MP	13.0 %, NM	18.4 ± 8.8 %	47.9 ± 28.3 %
Glare Sensitivity	0.00 logMAR, NM	0.02 ± 0.03 logMAR	0.19 ± 0.21 logMAR
Glare Recovery	0.00 logMAR, NM	-0.04 ± 0.03 logMAR	0.04 ± 0.10 logMAR
Light Sensitivity	0.00 logMAR, NM	-0.02 ± 0.06 logMAR	0.03 ± 0.07 logMAR

Looking at the cluster data, there appears to be an obvious difference in performance between skiers with measurable visual acuity and skiers with light perception or no light perception vision. This difference in performance suggests that the skiers with light perception or no light perception vision should be in a different class than skiers with measurable static visual acuities.

Within the skiers with measurable static visual acuity (Clusters 2-3), there does not appear to be any obvious performance differences between groups that are related to visual function. To investigate whether or not static visual acuity and visual field (the two tests recommended for inclusion in classification in 2019) had any difference on skiing performance the researchers graphed race time as a function of static visual acuity or visual field (Figures 14 and 15).

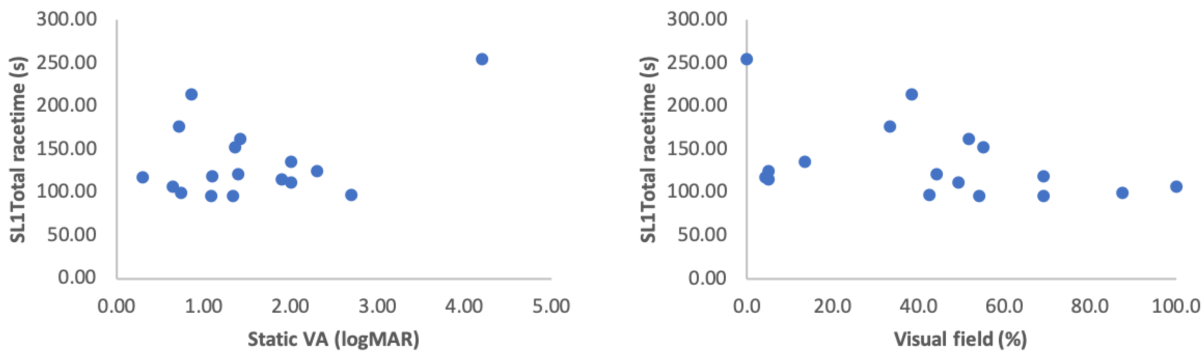

Figure 14: Each dot in the left and right panels indicates one skier's data. Left Panel - This panel demonstrates the correlation between static visual acuity and total raw time on Day 1; this panel shows that total raw time is similar between athletes with measurable static visual acuity. Right Panel - This panel demonstrates the correlation between visual field extent and total raw time on Day 1. In this panel, it can be seen that total raw time is similar between athletes, regardless of the extent of their visual field. In both panels it can be seen that athletes with NLP vision appear to perform very differently than athletes with measurable static visual acuity.

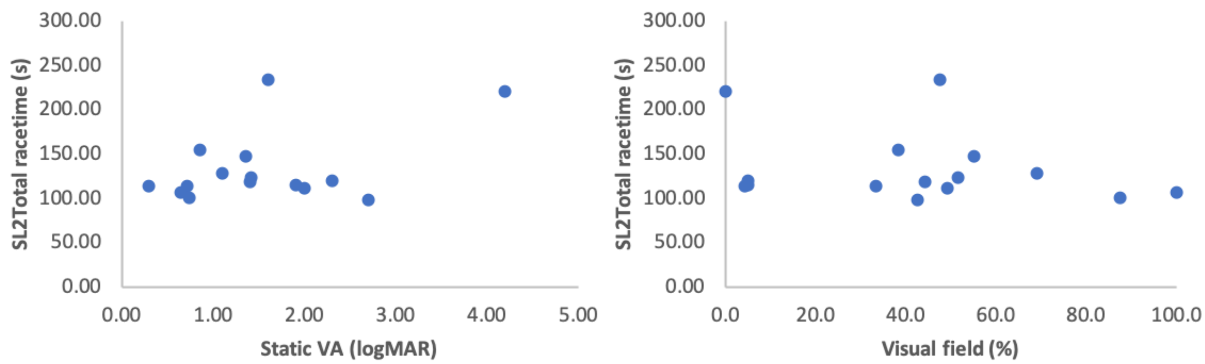

Figure 15: Each dot in the left and right panels indicates one skier's data. Left Panel - This panel demonstrates the correlation between static visual acuity and total raw time on Day 2; this panel shows that total raw time is similar between athletes with measurable static visual acuity. Right Panel - This panel demonstrates the correlation between visual field extent and total raw time on Day 2. In this panel, it can be seen that total raw time is similar between athletes, regardless of the extent of their visual field. In both panels it can be seen that athletes with NLP vision appear to perform very differently than athletes with measurable static visual acuity.

For reference, the static visual acuity and visual field extent data from the slalom data collected at the 2017 Para Alpine World Championships from the 2016-2017 season is included below (Figure 16). The performance metric for this data was raw-performance points rather than raw time (as discussed in the appended report). In Figure 16 you can see the lack of data on current B2 skiers with poor static visual acuity (Left Panel), however this data gap has been addressed in the present study (Figures 14, 15) and will be discussed further below. The data from 2016-2017 is consistent with the data from the present study, in that skiing performance appears to be similar between athletes with measurable static visual acuity. Performance also appears to be similar between athletes, regardless of the extent of their visual field loss.

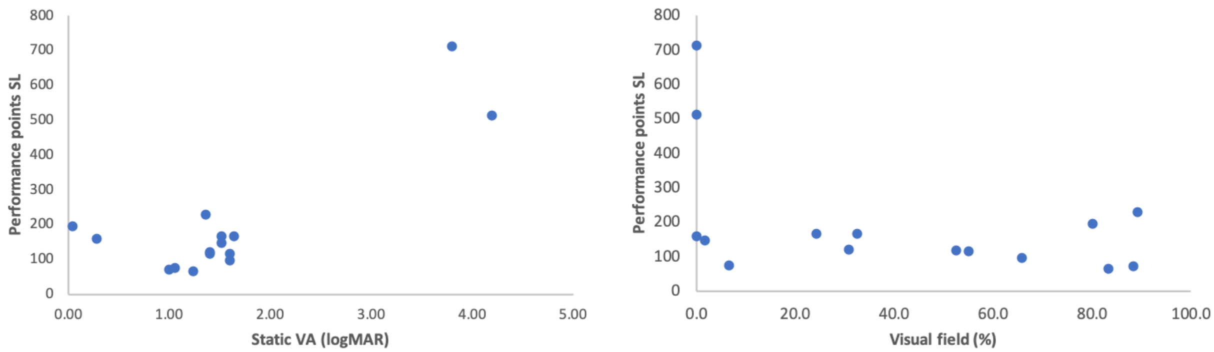

Figure 16: Each dot in the left and right panels indicates one skier's data. Left Panel - This panel demonstrates the correlation between static visual acuity and raw performance points from skiers competing at the 2017 Para Alpine World Championships; this panel shows that raw performance points are similar between athletes with measurable static visual acuity and worse in athletes with light perception or no light perception vision. Right Panel - This panel demonstrates the correlation between visual field extent and raw performance points from skiers competing at the 2017 Para Alpine World Championships. In this panel, it can be seen that raw performance points are similar between athletes, regardless of the extent of their visual field. In both panels, it can be seen that athletes with NLP vision appear to perform very differently than athletes with measurable static visual acuity.

Performance of skiers currently classed as NE

Based on the data collected in this study, it appears that skiers currently classed as NE do not appear to perform differently than skiers currently classed as B2 or B3. Skiers who are currently classed as B1 appear to perform differently than all skiers classed as NE, B2, or B3, and this is consistent with the findings of the previous research project.

The results of this study would suggest that the NE skiers could potentially compete in one class with the B2 and B3 skiers, **however,** it is important to remember that the data collected in the 2019-2020 study was collected on relatively inexperienced skiers. Unfortunately, it is not possible to collect data in a group of more elite skiers classed as NE (i.e. skiers eligible for World Championship competition), as these skiers are not racing in either Para sport or able-sighted competitions at this time. **Therefore, the researchers would recommend that for the time being, skiers with static visual acuities of 0.6 to 0.9 logMAR compete in their own class (AS14). If a new class was included, a sports class factor would also need to be determined.** Going forward, additional data will need to be collected to determine if these athletes should remain in their own separate sport class or not.

Performance of B2 skiers with poor static visual acuity

In the original research project, researchers were able to recruit skiers with static visual acuities ranging from 0.04 to 1.64 logMAR, in addition to skiers with LP (light perception) and NLP (no light perception) vision (Figure 16, Left Panel). In the 2020 study at Landgraaf, researchers were able to recruit skiers with static visual acuities ranging from 0.30 to 2.70 logMAR, including four skiers who would fall into the category of B2 skiers with poor visual acuity (1.90 logMAR acuity or worse; Figures 14 and 15, Left Panel).

Based on the data collected in the 2019-2020 study, it appears that current B2 skiers with poor visual acuity (1.90 logMAR acuity or worse) do not appear to perform differently than skiers currently classed as NE, B2, or B3, and current B2 skiers with poor visual acuity do appear to perform better than skiers with LP or NLP vision.

The results of this study would suggest that B2 skiers with poor static visual acuity could potentially compete in the same class as B2 skiers with better visual acuity, B3 skiers, and the NE skiers, **however**, it is important to remember that the data collected in the 2019-2020 study was collected on relatively inexperienced skiers. What we cannot tell from both of these studies, is if there are no B2 skiers with poor static visual acuity competing at the World Championship level because they are not competitive, or if they were simply unavailable to participate in the research. In consideration of feedback from sport experts received at the World Para Alpine Skiing – Classification Research for Athletes with Vision Impairment meeting (April 2019), that B2 athletes with poor static acuity often do not appear to be able to compete with B2 athletes with better static visual acuity, **the researchers would recommend that for the time being, skiers that are currently classed as B2 (AS12) with poor static visual acuity compete in a separate class than athletes with better static visual acuities.** Going forward, additional data will need to be collected to determine if these athletes should remain in their own separate sport class or not. Alternatively, **there may be a benefit to pilot the proposed changes to B2/B3 class alongside the existing system to collect additional data.**

Blindfold Comparison Study

Currently, there is no evidence available on the effect blindfolds have on skiing performance in individuals with severe vision impairments. It is possible that athletes with some amount of vision or light perception might have an advantage over athletes with no light perception. However, it is also possible that an athlete's limited remaining vision is not helpful and could actually impair their performance by distracting the athlete from the auditory information provided by their guide. Therefore, the purpose of this study was to investigate the impact of blindfolds on Para Aline skiing performance in Para Alpine skiers classified as B1.

One B1 skier was recruited for this study during the 2019 Para Alpine World Championships in Kranjska Gora, Slovenia. The skier's visual acuity was measured, and the skier was asked to ski a short 10 gate Giant Slalom race course four times. The skier skied with their own guide at all times. On two of the trials, the skier wore their blindfold (Condition A), and on the remaining two trials, the skier did not wear their blindfold (Condition B). The order of the blindfold / no blindfold conditions (ABBA or BAAB) was randomised. Skier's time to complete each trial was recorded, and trial times were compared between the two conditions. The skier was also asked how they felt about skiing with and without the blindfolds.

The skier who completed this study had no light perception vision. The skier skied between 1 to 1.5 seconds faster while wearing their blindfold compared to not wearing it (Figure 12). However, the skier had no preference for either blindfold condition.

A similar study was conducted in Para Nordic skiing (with 4 skiers) and the use of blindfolds made no difference in skiing performance of Para Nordic skiers classified as B1 either.

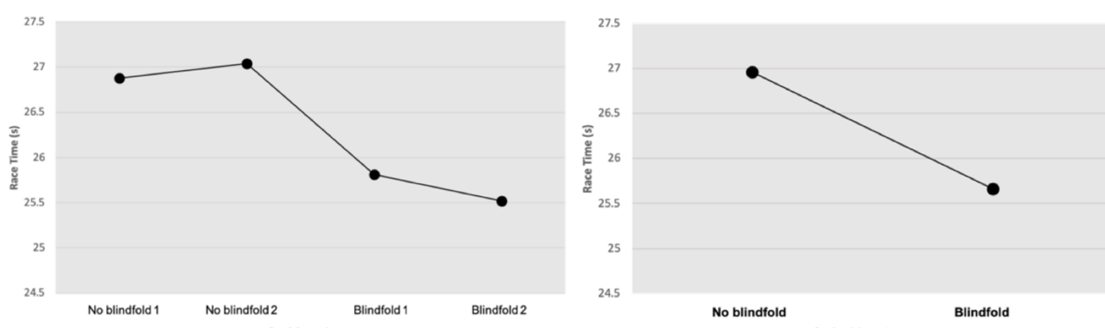

Figure 13:<u>Left Panel</u> – Each data point represents one raw-race time measure for the skier on each condition. <u>Right Panel</u> – Overall average race time for the skier in each condition (No blindfold, With blindfold).

Recommendations – proposals for classification rules changes to World Para Alpine Skiing Classification Rules and Regulations, Appendix 2

The recommendations are presented below.

1. **What are the recommended vision function tests for inclusion in VI classification for Para Alpine Skiing?**

Tests of binocular static visual acuity and binocular visual field should be used for classification.

Dynamic visual acuity, contrast sensitivity, and motion perception threshold (translational) are also associated with Para Alpine Skiing performance; however, performance on the static visual acuity test is closely related to performance on these three tests. Therefore, static visual acuity is a good representative test, and additional tests of dynamic visual acuity, contrast sensitivity, and translational motion perception do not need to be added to classification.

In addition and following recommendation of earlier expert meetings and the IPC Position Statement on the sport specific classification of athletes with vision impairments (IPC Handbook, Section 2, Chapter 4.6), visual acuity and visual field will be measured with binocular focus. The measurements of vision will be completed with both eyes together, since this more appropriately reflects how an athlete uses their vision in Para Alpine Skiing.

2. **What are the recommended minimum impairment criteria for vision impairments in Para Alpine Skiing?**

The minimum impairment criteria for visual acuity be set at 0.6 logMAR. If an athlete has a visual acuity better than 0.6 logMAR, they can also qualify to compete if their visual field extent is less than or equal to 35 degrees radius.

3. **What are the recommended competition classes for Para Alpine Skiing?**

There should be 4 Sport Classes for Para Alpine Skiing for the coming season. The Sport Classes are as follows:

AS14: Binocular static visual acuity of 0.6 to 0.9 logMAR OR binocular visual field extent ≤35 degrees radius.
AS13: Binocular static visual acuity of 1.0 to 1.7 logMAR
AS12: Binocular static visual acuity of 1.8 to 3.5 logMAR
AS11: Binocular static visual acuity of light perception or no light perception vision only

The data collected in the 2017-2018 (elite World Championship eligible skiers) and the 2019-2020 (Landgraaf) studies suggest that static visual acuity is a better indicator of skiing performance than visual field extent. However, visual field extent is important for determining eligibility to compete in the sport. Therefore, the researchers recommend that visual field extent be used to determine sport eligibility and that static visual acuity be used to determine sport class. Skiers in the AS14, AS13, and AS12 classes would compete without blindfolds. Only skiers in the AS11 class would compete with blindfolds, although blindfolds should be optional in this class.

4. **What impact do blindfolds have on Para Alpine Skiing performance?**

Blindfolds should be optional in the most severe, AS11 class (athletes with light perception and no light perception vision).

Blindfolds did not appear to have a significant impact on skiing performance on skiers currently classed as AS11, however only one athlete completed this study.

<u>The final names of the classes are at the final discretion of WPAS.</u>

Future Opportunities and Implementation

While the full translation of research into classification practice has not been explored in this report, it is recommended any change is adequately considered, well planned and clearly communicated. Additionally, any system that is implemented should be monitored through the collection of data over time to measure the success and plan for any future change.

World Para Alpine Skiing – VI Classification Research Report – Appendix A

Vision Impairment-Performance Relationship Studies – Part 1: Athlete Evaluation

The correlation analysis results for Slalom, Super G, and Downhill are presented below. Giant Slalom results were presented in the main document. As a reminder, in Giant Slalom **static visual acuity** was significantly correlated with skiing performance and there was a trend towards **motion perception threshold (translational motion)** being associated with performance.

- **Slalom:** Factors that were significantly correlated with skiing performance were **visual field extent** and **skier's age**. There was also a trend towards **static visual acuity** being a predictor of performance (Figure A1). Skiers with larger visual fields and younger ages performed better in Slalom, as did skiers with better (lower) static visual acuities.

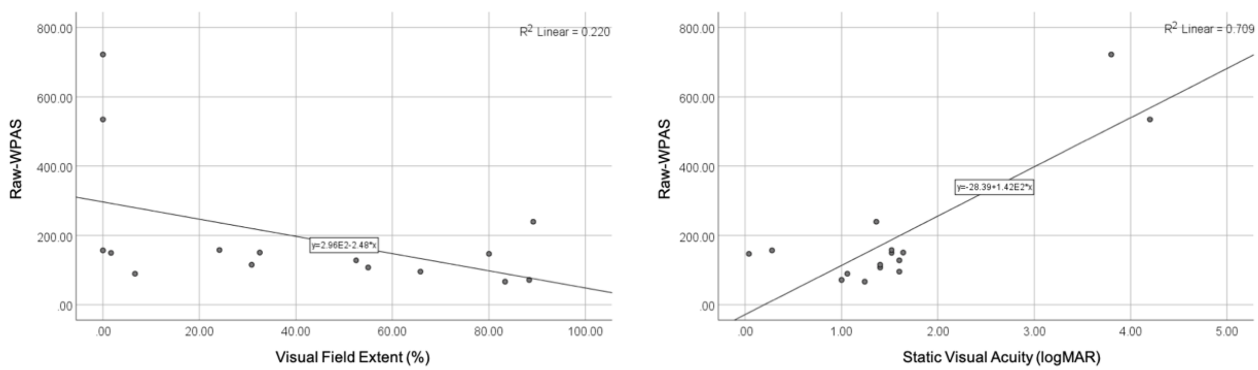

Figure A1: Slalom Data - Each dot in the left and right panels indicates one skier's data. Left Panel - This panel demonstrates the correlation between visual field extent and Raw-WPAS points, and shows that Raw-WPAS points are lower (better) when visual field extent is larger(better). Right Panel - This panel demonstrates the correlation between static visual acuity and Raw-WPAS points. In this panel, it can be seen that Raw-WPAS points are lower when static visual acuity is better (lower).

- **Super G:** Factors that were significantly correlated with skiing performance were **static visual acuity, motion perception threshold (translational)**, and **number of races completed**. There was also a trend towards **dynamic visual acuity** being correlated with performance. Skiers with lower (better) static and dynamic visual acuities, lower (better) motion perception thresholds, and who competed in more Super G races performed better. (Figure A2)

- **Downhill:** Factors that were significantly correlated with skiing performance were **static visual acuity**, and **dynamic visual acuity**. There was also a trend towards **contrast sensitivity** and **motion perception threshold (translational)** being associated with performance. Skiers with lower (better) static and dynamic visual acuities performed better, as did skiers with higher (better) contrast sensitivity and lower (better) motion perception thresholds. (Figure A3)

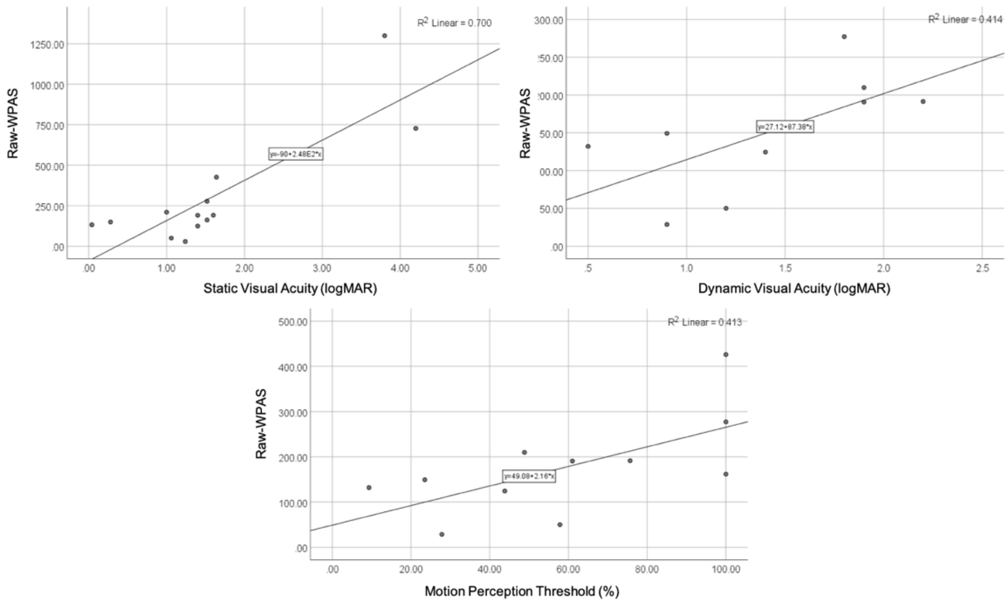

Figure A14: Super G Data - Each dot in the left, right, and bottom panels indicates one skier's data. <u>Left Panel</u> - This panel demonstrates the correlation between static visual acuity and Raw-WPAS points, and shows that Raw-WPAS points are better when static visual acuity is lower (better). <u>Right Panel</u> - This panel demonstrates the correlation between Raw-WPAS points and dynamic visual acuity, and shows that Raw-WPAS points are better when dynamic visual acuity is better (lower). <u>Bottom Panel</u> - This panel demonstrates the correlation between motion perception threshold and Raw-WPAS points, and shows that Raw-WPAS points are lower (better) when motion perception threshold is lower (better).

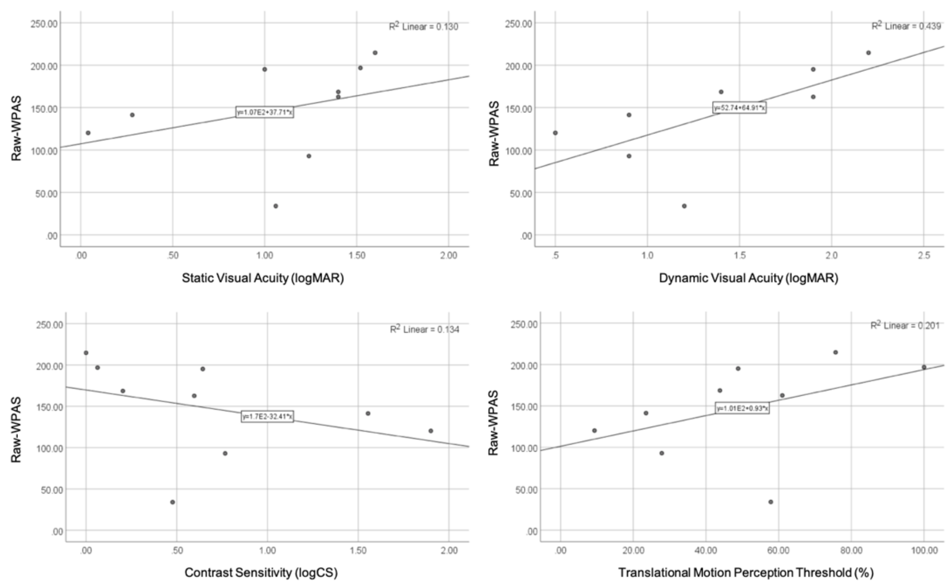

Figure A15: Downhill Data - Each dot in the left and right panels indicates one skier's data. <u>Top Left Panel</u> - This panel demonstrates the correlation between static visual acuity and Raw-WPAS points, and shows that Raw-WPAS points are better when static visual acuity is lower (better). <u>Top</u> <u>Right Panel</u> - This panel demonstrates the correlation between dynamic visual acuity and Raw-WPAS points. In this panel, it can be seen that Raw-WPAS points are lower when the dynamic visual acuity is lower (better). <u>Bottom Left Panel</u> – This panel demonstrates the correlation between contrast sensitivity and Raw-WPAS points, and shows that Raw-WPAS points are better when Contrast Sensitivity is higher (better). <u>Bottom Right Panel</u> - This panel demonstrates the correlation between motion perception threshold(translational) and Raw-WPAS points. Raw-WPAS points are better when motion perception threshold is lower (better).

World Para Alpine Skiing – VI Classification Research Report – Appendix B

Vision Impairment-Performance Relationship Studies – Part 2: Sport Classes

Hierarchical clustering analysis was used to examine the relationship between visual impairment and performance for the determination of sport classes. Unique groups within the population that perform differently can be found using this technique. Comparison of the unique groups could shed further insight into whether or not these groups had different visual abilities, as well as what aspects of vision are most important for Alpine skiing. All vision and experience variables were included in this cluster analysis, in order to account for other factors that may affect skiing performance. Raw-WPAS performance points were used as the outcome measure.

- **Slalom:** Two distinct groups were identified that performed significantly differently in Slalom (Figure B1, Left panel). For comparison purposes, Raw-WPAS points for each athlete in their current competition class (B1, B2, B3) are also included in Figure B1 (Right panel).

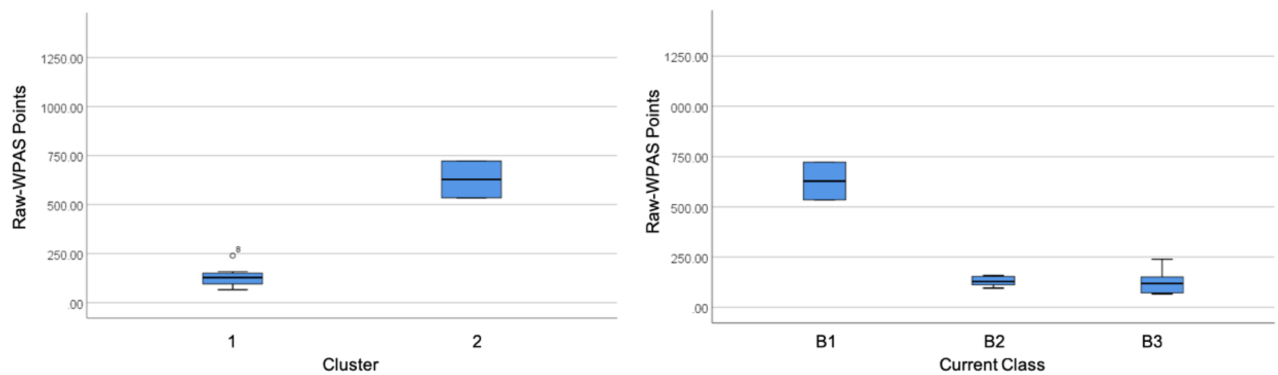

Figure B1: Left Panel – Raw-WPAS points for each unique cluster identified by the hierarchical cluster analysis. Right Panel – Raw-WPAS points for each current competition class (B1, B2, B3) for the same athletes.

Raw-WPAS points, number of races, static visual acuity, and visual field extent were the only variables found to be significantly different between the Clusters (Figure B2). It is important to note that in Cluster 1 there are no athletes with light perception or no light perception vision (i.e. no measurable visual acuity or no visual field extent). Athletes with light perception or no light perception static visual acuities and no visual field extent (0% visual field) were only in Cluster 2.

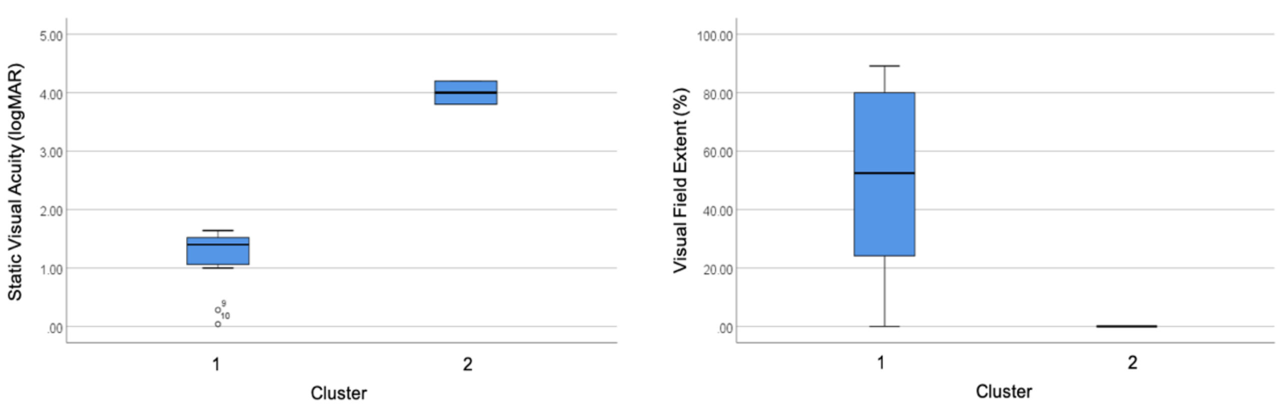

Figure B2: Left Panel – Static visual acuity distribution for the two clusters. Right Panel – Visual field extent for the two clusters. In both Panels the boxes represent the first to third quartiles, the band in the box represents the median value, and the error bars indicate minimum and maximum data for each cluster.

- **Super G:** Four distinct groups were identified that performed significantly differently in Super G (Figure B3, Left panel). Cluster 1 had 10 athletes in it, and Clusters 2, 3, and 4 each had 1 athlete in them. For comparison purposes, Raw-WPAS points for each athlete in their <u>current competition class (B1, B2, B3)</u> are also included in Figure B3 (Right panel).

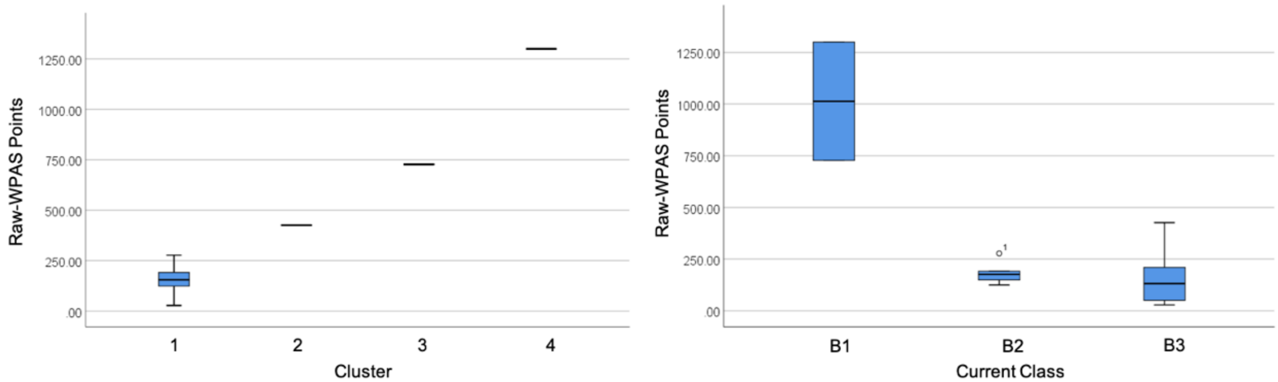

Figure B3: <u>Left Panel</u> – Raw-WPAS points for each unique cluster identified by the hierarchical cluster analysis. <u>Right Panel</u> – Raw-WPAS points for each current competition class (B1, B2, B3) for the same athletes. Single horizontal lines indicate a single athlete.

<u>Raw-WPAS points</u> and <u>static visual acuity</u> were the only variables found to be significantly different between the Clusters (Figure B4). It is important to note that in Clusters 1 and 2 there are no athletes with light perception or no light perception vision (i.e. no measurable visual acuity or no visual field extent). Athletes with light perception or no light perception static visual acuities and no visual field extent (0% visual field) were only in Clusters 3 and 4.

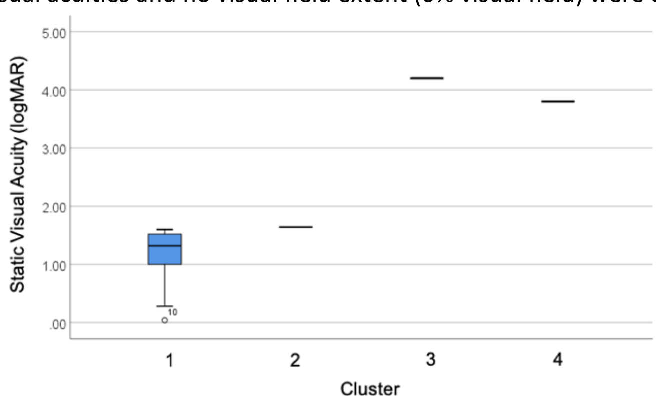

Figure B4: Static visual acuity distribution for each of the four clusters. The boxes represent the first to third quartiles, the band in the box represents the median value, and the error bars indicate minimum and maximum data for each cluster. Single horizontal lines indicate a single athlete.

- **Downhill:** Two distinct groups were identified that performed significantly differently in Downhill (Figure B5, Left panel). For comparison purposes, Raw-WPAS points for each athlete in their <u>current competition class (B1, B2, B3)</u> are also included in Figure B5 (Right panel).

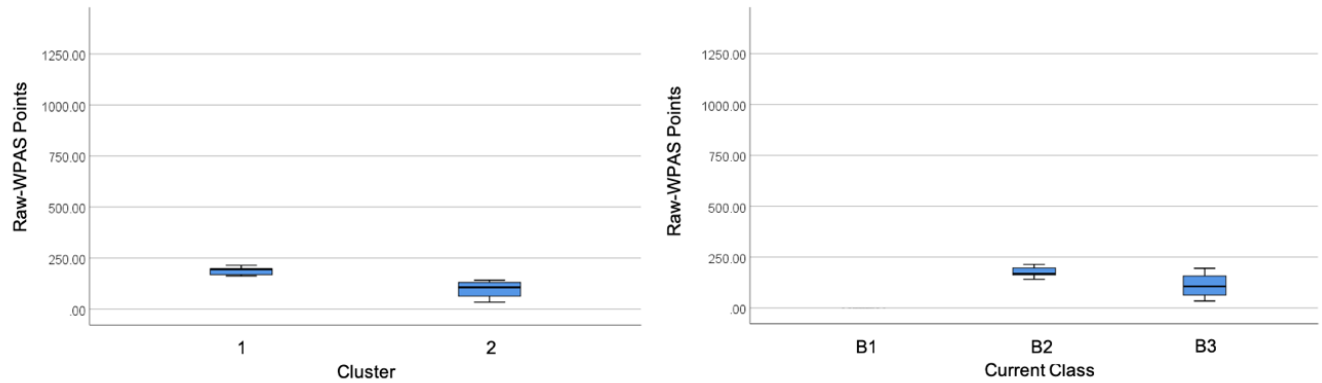

Figure B5: *<u>Left Panel</u> – Raw-WPAS points for each unique cluster identified by the hierarchical cluster analysis. <u>Right Panel</u> – Raw-WPAS points for each current competition class (B1, B2, B3) for the same athletes.*

<u>Raw-WPAS points</u> and <u>dynamic visual acuity</u> were the only variables found to be significantly different between the Clusters (Figure B6). <u>Static visual acuity,</u> <u>contrast sensitivity</u>, and <u>motion perception threshold (translational)</u> were also nearly significantly different between Clusters. It is important to note that in Downhill, all of the athletes had measurable visual acuities. There were no athletes with light perception or no light perception vision (i.e. no measurable visual acuity or no visual field extent) competing at all, so it was not possible to collect data on how these athletes perform in this discipline.

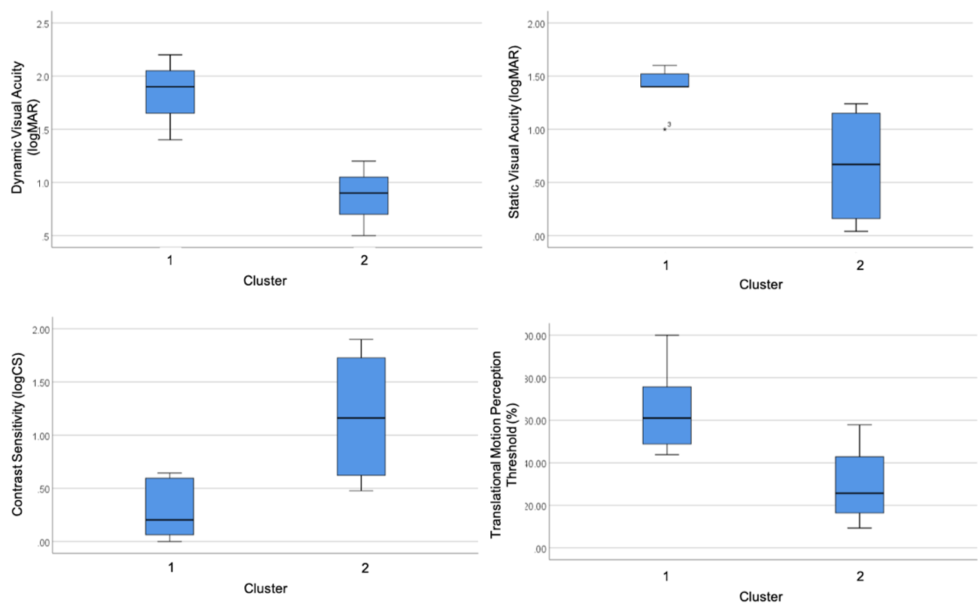

Figure B6: *<u>Top Left Panel</u> – Dynamic visual acuity distribution for each cluster. <u>Top Right Panel</u> – Static visual acuity distribution for each cluster. <u>Bottom Left Panel</u> – Contrast sensitivity distribution for each cluster. <u>Bottom Right Panel</u> – Translational motion perception threshold distribution for each cluster. For all panels, the boxes represent the first to third quartiles, the band in the box represents the median value, and the error bars indicate minimum and maximum data for each cluster.*