

1 Do visual fields need to be considered in classification criteria within
2 visually impaired shooting?

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Abstract

Classification within the sport of vision impairment (VI) shooting is based upon the athlete's visual function. This study aimed to determine whether more than one class of competition is needed within VI shooting on the basis of visual field loss. Qualification scores of 23 elite athletes were obtained at World Championship events in prone and standing shooting disciplines. Visual field data were obtained from classification data and from assessment at events. A standardised scoring protocol was used to determine whether athletes had function ($\geq 10\text{dB}$) or no function ($< 10\text{dB}$) at locations between 0-60 degrees eccentricity along 10 meridia. Visual field function was not associated with shooting performance in either the prone or standing disciplines ($p > 0.05$). Having measurable visual field function beyond 30 degrees made no difference to athletes' ability to shoot competitively in prone ($p = 0.65$) or standing disciplines ($p = 0.47$), although a potential impact on qualification was observed in the standing discipline. There was no evidence that loss of visual field function at any specific location adversely affected ability to shoot competitively. There is currently no evidence to consider visual fields in classification within prone or standing VI shooting, although further research is needed as the sport grows.

Keywords

Classification, Shooting, Para sport, Visual impairment, Visual field

The existing system of classification in most sports for athletes with vision impairment (VI) is performed using two basic tests of visual function, visual acuity (VA) and visual fields (VF). VA assesses resolution of central vision through the ability to read high contrast letters of decreasing size. VF assesses the extent and / or sensitivity of vision away from central fixation. The normal visual field of one eye extends to a maximum of about 100 deg temporally, 60 deg superiorly and nasally, and 75 deg inferiorly (Traquair, 1938). There are currently 3 classes within VI sport. Athletes in class B1 have VA worse than 2.6 logMAR. Athletes in B2 have VA in the range 1.5-2.6logMAR, and / or VF constricted to a diameter of <10deg. Athletes in B3 have VA in the range 1.0-1.49 logMAR, and / or VF constricted to a diameter of <40 deg. The VF diameter is defined along the axis that passes through fixation that gives the maximum extent of visual field that can be seen with a stimulus 10dB brighter than the background.

VI shooting is a new discipline in World Shooting Para Sport, officially adopted in 2019 (World Shooting Para Sport, 2019), with the ultimate aim to include the sport in the Paralympic Games. Athletes use air rifles to shoot at a target 10m away. The athlete can receive assistance from a sighted assistant with the set-up of their equipment and general positioning towards the target, but not with the actual shot. An audio signal guides the athletes' aiming, with the pitch of the signal getting higher as the aim gets closer to the centre of the target. The target consists of 10 concentric rings, with a hit in the central ring scoring 10, 9 for the next ring and so on. The 10 rings are subdivided equally into 10 score zones, with each zone representing an increment of 0.1, such that the highest score for an individual shot is 10.9. There are two disciplines within the sport: in the prone discipline, the athlete sits on a stool and can rest their arms and rifle on a table. In the standing discipline, the athlete stands and supports the weight of the rifle while shooting.

At present, most Para sports use the same visual function criteria to allow entry into VI sport and into classes within a sport, regardless of the sport or its visual requirements. However, there is consensus that additional tests measuring different aspects of visual function should be considered for inclusion in future classification systems, and the criteria used to determine eligibility for VI sport should depend on the visual demands of individual sports (Ravensbergen, Mann, & Kampen, 2016). Such sport-specific, evidence-based, classification criteria firstly need to establish the minimum impairment criteria (MIC), or the visual function required for inclusion within a version of a sport that includes adaptations for athletes with a VI. MIC are determined by considering the level of function that impairs performance in the sighted version of the sport. Once eligibility has been defined, criteria for assigning eligible athletes to different classes within the sport, or alternatively evidence for the provision of only a single class within the sport, are also needed. Sport class criteria are guided by whether performance in the adapted version of the sport varies with level of visual function.

MIC for entry into VI shooting were approved in 2019 based on VA and the additional visual function of contrast sensitivity (CS) (Myint, et al., 2016; Allen, et al., 2018). CS is the ability to discriminate differences in luminance within or between objects. Further, it has been shown that only one class is necessary within VI shooting when considering VA and CS (Allen, Latham, Ravensbergen, Myint, & Mann, 2019).

The impact of VF loss on shooting performance has not yet been examined in detail, despite the existing system of classification for VI sport including VF criteria. Loss of VF can be the consequence of inherited conditions such as retinitis pigmentosa (RP), acquired conditions such as glaucoma, or can be subsequent to other issues such as cerebrovascular accident (stroke) or trauma. Different conditions affect different parts of the visual pathway and result in different VF defects, including patterns typical of retinal disorders (e.g. peripheral constriction, central loss, arcuate and ring

patterns), or loss of similar sections of the VF of each eye (e.g. hemianopic or quadrantopic defects) typical of post-chiasmal disorders.

Preliminary analysis of the influence of VF status on VI shooting has been undertaken (Myint, et al., 2016). In 10 athletes competing in a Grand Prix event, there was no relationship between shooting performance and VF status assessed in terms of the general reduction in VF sensitivity (mean defect) sampled within the central 30 deg VF. However, subject numbers were low, VF beyond 30 deg eccentricity was not considered, and only general loss of sensitivity was considered rather than the impact of loss in specific VF locations. The peripheral VF (beyond 30 deg eccentricity) is important in reflecting self-reported visual difficulty particularly with mobility (Subhi, Latham, Myint, & Crossland, 2017), and when objectively measuring postural stability (Black, Wood, & Lovie-Kitchin, 2011; Kotecha, et al., 2012; Kotecha, Chopra, Fahy, & Rubin, 2013). Indeed, both the severity and location of peripheral visual field loss have been shown to reduce postural control and cause greater instability. Greater instability may impact shooting performance, especially in the standing discipline. It is also important to consider the location of VF loss in the determination of appropriate sport-specific classification criteria, since VF loss at different locations within the visual field may not have the same impact on performance.

The purpose of this study is to further evaluate the relationship between VF status and shooting performance in elite VI rifle shooting, in order to determine whether VF status should be a criterion for classification within VI shooting. The specific questions addressed are firstly, does VI shooting performance in either the prone or standing shooting discipline depend on the level of VF loss? Secondly, is VI shooting performance significantly affected by loss in particular locations within the VF?

Methods

Participants

Participants were elite VI shooting athletes (defined as having experience of competing at an international level at least once prior to the present study), who were willing to provide their VF data and / or to have their VF assessed for the study. All gave informed consent to take part after the nature of the study was explained. The tenets of the Declaration of Helsinki were observed, and ethical approval for the study was received from the Faculty of Science and Engineering Research Ethics Committee of Anglia Ruskin University.

Twenty three athletes (14 male, 9 female) with a mean age of 49 ± 12 years (range 30-71 years) took part. Causes of vision loss were inherited retinal dystrophies including Retinitis Pigmentosa and choroideremia ($n=7$), macular dystrophies ($n=5$), glaucoma ($n=4$), congenital optic nerve disorders ($n=2$), and other causes ($n=5$: 1 case each of retinopathy of prematurity, diabetic retinopathy, cataract with nystagmus, traumatic retinal detachment, and chemical injury). Duration of vision loss was 27 ± 13 years (range 4-59 years). Duration of experience in shooting was 8 ± 4 years (range 1-22 years), and all athletes had started shooting after becoming visually impaired.

Shooting protocol

Shooting data were collected by opportunistic sampling at the 2016 International Blind Sport Federation (IBSA) World Championships in Olsztyn, Poland ($n=17$ athletes) and at the 2017 World Shooting Para Sport (WSPS) Alpine Cup in Innsbruck, Austria ($n=6$ athletes).

Competition in both prone and standing disciplines occurs across two rounds: a qualifying round followed by a final. All 23 athletes took part in both prone and standing disciplines. At the time of data collection, both male and female competitors took 60 shots in qualification in the prone

discipline. In qualification for the standing discipline, male athletes also took 60 shots while female athletes only took 40 shots. Shooting results are therefore considered as the average score per shot. Note that since these data were collected, it has been established that there are no sex based differences in performance. Since 2018, competition has been mixed, with male and female athletes competing together for the same medals and taking an equal number of shots (60) in qualification for both prone and standing disciplines.

The 8 athletes with the best qualification scores progress to the final, where scores are reset to zero. In the final for each discipline, athletes take a further ten shots, after which the athlete with the lowest score is eliminated, whilst the others remain. After each additional 2 shots the athlete with the lowest score of those remaining is eliminated until 24 shots have been taken in the final and the final rankings determined. Consequently, the nature of the elimination process means that athletes take an unequal number of shots during the final. Therefore, in the current study, the primary outcome measure was the score per shot at the end of the qualifying round as this was available for all participants.

Competitive shooting scores

In order to determine the competitive significance of any change in shooting score as a result of differences in VF status, qualifying results from the 4 most recent WSPS World Cup events in VI shooting were considered (2019 World Championships in Sydney, 2019 World Cup in Osijek, 2019 World Cup in Hannover, and 2018 World Cup in Chateauroux). In each of these events, the competition was mixed sex, and 60 qualifying shots were taken by all athletes in the prone and standing disciplines. Those athletes in the top 8 placings at the end of qualification proceeded to shoot in the final, with those in 9th place and lower playing no further part in the competition.

Table 1 shows the scores obtained by those in 1st place, and the drop in score to the 2nd and 9th placed athletes at the end of qualification in recent world class events. Scores across the 4 competitions were very consistent for the prone condition, with a variation in score of 5.6 (or 0.093 per shot) in the score of the first placed qualifier, and of 2.9 (or 0.048 per shot) in the score of the 9th placed athlete, in other words the score that just missed out on qualification for the final. The minimum drop in score between 1st and 9th place, chosen as a conservative estimate of a drop in performance that rendered an athlete 'non-competitive', was 15.8 over 60 shots, or 0.263 per shot. Therefore, in later results a drop in prone score of greater than 0.263 per shot from the maximum score per shot was considered as 'non-competitive'.

Scores in the standing discipline varied more, with the score of the first placed qualifier varying by 25.7 (or 0.428 per shot) between competitions, and the score of the 9th placed athlete varying by 23.8 (or 0.397 per shot). The minimum drop in score between 1st and 9th place was 32.4 over 60 shots, or 0.540 per shot. Therefore, in later results a drop in standing score of greater than 0.540 per shot from the maximum score per shot was considered a 'non-competitive' performance.

{Table 1 about here}

Visual function assessment

Visual acuity (VA)

Participants wore their habitual visual correction, and results are presented for the shooting eye since shooting is undertaken monocularly with an occluder blocking the contralateral eye. Distance VA was assessed with a 4m Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Ferris, Kassoff, Bresnick, & Bailey, 1982) externally illuminated to approximately 200 lux as confirmed with

a light meter, in order to standardise lighting at a reasonable level. If letters could not be read at 4m, the chart was moved to 2m or 1m if necessary, making the poorest VA that could be measured in this way 1.6 logMAR. Poorer VA was assessed with a Berkeley Rudimentary Vision Test (BRVT) (Bailey, Jackson, Minto, & Chu, 2012) to a maximum of 2.6 logMAR. Participants with Perception of Light (PL) were assigned a VA of 3.0logMAR, and those with No Perception of Light (NPL) a score of 4.0logMAR, as in previous shooting research (Myint, et al., 2016).

Contrast sensitivity (CS)

CS results are presented for the shooting eye as an average of 2 Mars chart readings (Arditi, 2005) at a working distance of 50cm, with participants assessed wearing their habitual visual correction. Results were scored letter by letter, with 0.04logCS assigned per correct letter. Participants unable to read any letters were assigned a score of 0.00logCS. Charts were externally illuminated to approximately 200 lux.

Both VA and CS were assessed for all athletes (n=23) by the authors at the shooting events in Poland and Austria.

Visual fields (VF)

A Humphrey Field Analyser (HFA) was available at the event in Poland for obtaining VF for classification purposes, which was also made available to the researchers. Athletes undergoing classification that required a VF undertook a HFA 30-2 or FF120 conducted by a technician at the request of the classifier, with the VF requested by the classifier dependent on the athlete's diagnosis and presentation. All VF data obtained in this way were shared with the researchers with the athlete's consent. In some cases, the single VF undertaken during classification provided sufficient information and an additional VF would not have provided any further useful information. E.g. an athlete with NPL and no measurable VF, or an athlete with loss entirely contained within the VF plot already assessed. In these instances, a further VF was not requested from athletes. For other athletes who had undertaken classification an additional VF was requested (either a HFA 30-2 or FF120, depending on what had not already been assessed), which was conducted by the researchers. Other athletes at this event did not need to undertake classification as they had existing valid classification status, or were classified at the event on the basis of VA alone and did not need to undertake a VF assessment as an integral part of classification. These athletes were also asked to undertake a HFA 30-2 or FF120 with the researchers, with the choice of VF dependent on the athlete's diagnosis and presentation. The HFA 30-2 was used where it could be reasonably anticipated the VF loss was confined to central field (e.g. macular diagnoses), and the FF120 where VF loss might be central and / or peripheral. VF were obtained at the Poland event for 14 athletes, with a 30-2 available for 2 athletes, a FF120 for 2 athletes, and both plots for 10 athletes.

Three athletes (two with macular degeneration and one with Retinitis Pigmentosa) declined to undertake a VF test conducted by the researchers at the Poland event. However, Henson 30-2 VF data collected at a previous event in 2015 (Myint et al., 2016) were available for all these athletes. There were two key reasons for an athlete to decline to undertake a VF or an additional VF. Firstly, VF testing can be difficult, time-consuming and demoralising for people with low vision. This is particularly the case for static field assessment in those with extensive loss, where a long time can be spent waiting to observe very few visible stimuli ^{1,2}. Secondly, the rooms used for classification and VF testing were in a different location to the shooting range at the event and was not always convenient to attend for those athletes who did not need to undergo classification.

No VF equipment was available at the event in Austria to assess the 6 athletes shooting here. Five athletes provided VF data from previous classification, which dated from 2014. For these athletes

with non-contemporaneous VF, causes of visual loss were congenital optic nerve disorder, congenital glaucoma (2 athletes), cataract with nystagmus, and Retinitis Pigmentosa. Whilst these conditions were self-reported as stable by the athletes, there is the possibility that the VF may have changed between the VF test in 2014 and the shooting data collection in 2017. From the classification data of athletes shooting in Austria, a full field plot only was available for 3 athletes (an HFA FF120, and 2 kinetic plots (one Goldmann, one Octopus)), and 2 athletes provided both central (30-2) and full field (FF120) plots. One further athlete (with a congenital optic nerve disorder) had Henson 30-2 VF data collected at a previous event in 2015.

In total, static threshold central field tests (0-30 deg eccentricity) were available for 18 athletes. Field tests assessing both central and peripheral fields (0-60 deg eccentricity; suprathreshold HFA FF120 and kinetic paradigms) were available for 17 athletes. Static threshold and suprathreshold field paradigms assess sensitivity at specific VF locations, while kinetic perimetry assesses the extent of the VF to a target of specific brightness. In all cases, monocular fields from the athletes' shooting eye were used for further analysis.

Visual field analysis

Since VF were obtained using different methods for each athlete, a standardised method of scoring was utilised to facilitate comparison between athletes, which was based on, but not identical to, the protocols of the American Medical Association (AMA) (American Medical Association, 2000).

Two grids were produced with points arranged on meridia 25, 65, 115, 155, 195, 225, 255, 285, 315, 345 degrees around fixation. Points were spaced every 10 deg eccentricity: at 5, 15 and 25 deg for central field plots, and at 15, 25, 35, 45, 55 deg for full field plots. There were 60 data points overall, with 30 at eccentricities <30deg, and 30 at eccentricities between 30 and 60deg. Figure 1 illustrates these locations.

{Figure 1 about here}

The data points used differ from those in AMA protocols, which includes points spaced every 2 deg within the central 10 deg, and then every 10 deg to a maximum of 55 deg eccentricity. The rationale for reducing the number of points scored within the very central 10 deg was firstly because the VF plots available did not give such emphasis to the central 10 deg of field. The available plots that gave most detail in this region of the VF (HFA 30-2) have points spaced every 6 deg, with only 4 points assessed within the central 8 deg. Secondly, the intention was to eliminate bias in scoring towards the central field and to give equal weight to all locations within the VF, making no assumptions regarding the importance of any part of the VF, as is the case in current classification criteria (International Blind Sports Federation, 2018) (World Para Athletics, 2018).

The grids were used to determine whether function was 10dB or better (seen) or worse than 10dB (unseen) at each of the specified points. Firstly, the areas of the VF plots that were 'seen' or 'unseen' were determined as follows. Kinetic isopters were plotted with a Goldmann III4e stimulus, equivalent to 10dB: points within the isopter were considered as seen, and those outside as unseen. Static suprathreshold fields were assessed with a Goldmann III 10dB stimulus, resulting in points that were either seen or unseen at 10dB. Static threshold VF points of sensitivity 10dB or greater were considered as seen, and <10dB thresholds as unseen. A pseudoisopter was drawn by hand around the 'seen' areas of the static VFs. The appropriate grid (Figure 1) was then overlaid on the VF plots and grid points were categorised as seen or unseen at a cut-off value of 10dB based on whether the point fell within the isopter or not.

For central field plots, points could be classified out to 25 deg. For full field plots, points from 15 to 55 deg eccentricity were considered. For some athletes therefore, data were available at 15 and 25 deg from more than one field plot, and points were considered 'seen' or 'unseen' if both plots agreed. In the event of disagreement between field plots (i.e. point seen in one field, but not in the other) the plot with better function was used.

For some athletes, data were not available for all field points. In these cases, data were interpolated from available evidence. There were 6 athletes for whom peripheral VF data (>30 deg) were not available: in 4 instances these were athletes with peripheral visual loss whose intact field was <30 deg, and it was assumed that peripheral field was unseen; in 1 case an athlete with central field loss within 30 deg was assumed to have functioning peripheral field; in 1 case an athlete with hemianopic loss was assumed to have a peripheral pattern of loss matching the loss in central field. There were 5 athletes for whom data within 10 deg from fixation was not available through lack of central VF to supplement the FF120 plot. Performance was assumed to match that in the near periphery (10-20 deg).

Scores were then derived from the VF data for all athletes for the full field (0-60 deg eccentricity), and into subdivisions for central field (0-30 deg eccentricity; i.e. points at 5, 15 and 25 deg) and peripheral field (30-60 deg; i.e. points at 35, 45, and 55 deg). Each score is scaled such that the minimum score (no points seen) was 0, and the maximum score (all points seen) was 100.

Analysis

Data were analysed using Microsoft Excel, and IBM SPSS version 26. Parametric analysis of shooting scores utilised 2-tailed t-tests (repeated measures for within-subject comparisons, and independent for between-subject comparisons). Non-parametric comparisons of shooting scores with VF scores were undertaken using Kendall tau correlations (comparison of continuous variables), Mann Whitney U tests (comparison of continuous and categorical variables) and chi-square analysis (comparison of categorical variables). G*Power v3.1.9.4 (Faul, Erdfelder, Lang, & Buchner, 2007) was used for power calculations.

Results

Shooting

The average score per shot for the prone discipline was 10.38 ± 0.24 (95% confidence interval (CI) 9.91 – 10.85), while for the standing discipline it was 9.90 ± 0.33 (95% CI 9.25 – 10.55). Prone scores were significantly ($t(df22)=8.21$, $p<.001$; effect size (Cohen's d) 1.66) higher than those for standing. The results of the two disciplines were considered separately.

Scores did not differ by athlete sex for either prone ($t(df21)=-0.84$, $p=.41$) or standing ($t(df21)=0.25$, $p=.80$) disciplines. Male and female results have been combined in further analyses.

Visual function

Table 2 indicates the level of athletes' visual function in their shooting eye. Larger logMAR scores for VA indicate poorer acuity, with 1.0logMAR (6/60, 20/200) being the level at which VI athletes would be classified as B3 under current criteria in other sports. All athletes had measureable VA apart from 2 who had NPL and were assigned a VA of 4.0 logMAR. Larger logCS scores for CS indicate better function. Average scores for younger normally-sighted subjects are 1.72 ± 0.06 logCS (Dougherty et al., 2005). A score of lower than 1.05logCS indicates 'significant' CS loss, and greater difficulty with visual tasks such as reading (Whittaker & Lovie-Kitchin, 1993; Latham & Tabrett, 2012). We have previously

suggested that a CS score of smaller than $1.05\log CS$ should allow classification as a VI athlete for shooting if CS is considered alone, or less than $1.33\log CS$ if considered alongside VA (Allen, et al., 2018). VF scores are scaled from 0-100, with 0 indicating no function in the field area, and 100 indicating function at all locations. Three athletes had no measurable VF function in either central or peripheral field. Two athletes had VF loss in the central field only. The remaining 18 athletes had loss of VF function in both central and peripheral field, and included 12 with no measurable peripheral field and some central field function, and 6 with some function in both central and peripheral field. Visual function data were not normally distributed, and non-parametric statistics are therefore used in further analyses.

{Table 2 about here}

Comparison of shooting score with visual field status

There is no significant relationship between shooting performance (as indicated by the average score per shot) in the prone discipline and VF status (Figure 2 and Table 3). There is also no significant relationship between variability in prone shooting score (as indicated by the standard deviation in each athlete's shooting score) and VF status (Table 4). Neither shooting performance nor variability scores are related to the VF score out of 100.

{Figure 2 and Tables 3 and 4 about here}

For the standing discipline, the score that emphasises central VF (0-30 deg) was not significantly correlated with shooting ability (Table 3). The relationship between peripheral VF and shooting score was slightly stronger when standing, as compared to prone, although not significant. However, it is noted that conclusions are limited by the low number of athletes with any measurable peripheral VF ($n=8$ of 23). Investigating this further, there is no statistically significant difference in standing shooting score ($U=33.0$, $z=-1.74$, $p=.09$) between those athletes with no peripheral VF (30-60 score = 0; $n=15$; median score 9.89) and those with some peripheral VF (30-60 score >0 ; $n=8$; median score 10.13), although the effect size was moderate ($r=-0.36$). Power calculation indicates that for a difference of this magnitude to be significant at an alpha value of 0.05 and power of 0.95, a sample size of 424 athletes would be required. It was also considered whether having measurable peripheral VF function made a difference to the athletes' ability to shoot competitively. Chi-square analysis (Table 5) indicated no evidence that athletes with peripheral VF function were more likely to obtain a competitive shooting score in either the prone (X^2 0.21, df 1, $p=0.65$) or standing events (X^2 0.52, df 1, $p=0.47$).

{Table 5 about here}

It may be considered that division of the VF at 30 deg eccentricity into 'central' and 'peripheral' portions does not distinguish whether athletes with extremely restricted central VF may be disadvantaged in the sport. Chi-square analysis was repeated to consider whether athletes ($n=13$) with no measurable peripheral VF (30-60 VF score of 0) and poor functioning central field (0-30 VF score of 0-33%) were less likely to achieve scores compatible with qualification for the final than other athletes ($n=10$). There was no difference in athletes' ability to shoot competitively in either the prone (X^2 0.31, df 1, $p=0.58$) or standing disciplines (X^2 0.18, df 1, $p=0.67$).

Variability in performance in the standing discipline was also not associated with VF status (Table 4). In this instance, the relationship between central (0-30 deg) VF scores and variability was slightly stronger, but again not significant ($p=.12$).

To provide more granularity to the analysis of whether the location of VF loss impacts on shooting performance in either discipline, Figure 3 compares the scores of athletes with visual function at each VF location assessed to those without function. If those without function performed less competitively than those with function at that location (a reduction in performance of more than 0.263 per shot in prone, or more than 0.540 in standing) the sector is coloured. There is no evidence that loss in any specific area of the visual field is detrimental to performance.

{Figure 3 about here}

Discussion

VI shooting is a new discipline in World Shooting Para Sport, and the ultimate aim is to include the sport in the Paralympic Games, using sport-specific classification criteria to define entry into the sport and classes within the sport. The aim of the current research was to use VF data gathered from international Para shooters to evaluate the relationship between VF status and shooting performance in elite VI rifle shooting, in order to determine whether VF status should be a criterion for classification in different classes within VI shooting.

Results from the current study show that in prone VI shooting, the level of visual field between 0 and 60 deg eccentricity of an athlete makes no difference to performance within the sport, supporting and extending previous findings (Myint et al. 2016), and indicating that no more than one class within VI shooting is needed on the basis of VF. Since there was also no evidence for the requirement of more than one class when considering VA and CS (Allen, Latham, Ravensbergen, Myint, & Mann, 2019), the recommendation remains that only one class is needed within VI shooting.

For the standing discipline there is a possibility that having residual function in peripheral VF (between 30 and 60 deg) may have the potential to give a slight competitive advantage to athletes. Athletes with some peripheral VF had a median score of 0.24 higher per shot than those with no peripheral VF. This difference was not statistically significant, and a drop in score of 0.24 per shot would not have made a difference to an athlete finishing first at the end of qualifying in 3 of the 4 most recent World Cup events (Table 1). However, in the event at Chateauroux, a drop in score of 0.24 per shot would have moved the athlete placed first at the end of qualification to 4th place. Such a drop in score would also have made the difference between an athlete qualifying for the final (in 8th place) and failing to progress to the final (in 9th place) in 3 of the 4 events, only being consistent with maintaining a position in the final at the event in Sydney (Table 1).

For both prone and standing disciplines, the VI adapted form of the sport utilising auditory guidance appears successful in allowing eligible athletes, even with severe visual loss, the opportunity to compete effectively in the sport.

It is perhaps unsurprising that VF should have little to no impact on shooting performance. The shooting target is stable and subtends only 0.25 deg from a distance of 10m, such that even those with a very restricted VF would be able to see the target. However, peripheral vision is relevant to the maintenance of postural stability, which is valuable for the steady standing stance need to shoot accurately. It has previously been shown that those with greater visual field loss have poorer postural stability (Black, Wood, Lovie-Kitchin, & Newman, 2008), although it appears this can be compensated for to at least some extent by increased reliance on vestibular and somatosensory information in the absence of visual information (Turano, Herdman, & Dagnelie, 1993; Black, Wood, Lovie-Kitchin, & Newman, 2008; Kotecha, et al., 2012; Kotecha, Chopra, Fahy, & Rubin, 2013).

Further research to directly assess the relationship between visual function, postural stability, and performance in VI shooting would be valuable.

The sample size for this study has been limited by the number of athletes competing at an elite level in this sport. While the differences in shooting score between those athletes with and without peripheral VF would require a sample size of over 400 to reach statistical significance, in 2020 there are fewer than 50 athletes worldwide registered or in the process of registering for VI shooting. VI shooting is currently a Para sport, but is not yet included in the Paralympics, which might allow the sport to grow. Therefore, while there is no evidence at present that more than one class is required within VI shooting, the study should be repeated with a larger sample size as the sport gains in popularity in order to provide a definitive answer, particularly for the standing discipline. As the sport grows and the heterogeneity of the athletes increases there will be a larger pool of elite athletes that can be drawn on for further research.

In addition to increasing sample size, further research should give careful consideration to the VF assessments used. In the present study, a variety of VF tests currently accepted for classification were used so as to utilise data from all eligible participants. As noted, people with VI generally dislike doing VF tests and making participation possible whilst restricting the additional time athletes spent in testing during a competition was important to maximise the sample size. Maximising the sample size resulted in three particular limitations. One was that some of the VF data pre-dated the shooting competition by 2-3 years. It is possible that for some competitors with progressive ocular conditions, their VF data may have overestimated their actual function at the time of the competition. This applied to 9 of the 23 athletes. Secondly, the variety of sources for the VF data is not ideal. Static and kinetic VF are measured in different ways, with static testing assessing discrete points and kinetic testing assessing specific meridians. Different static VF tests use different point locations, and different numbers of test points. It is relevant to note however that while different VF paradigms (threshold, suprathreshold and kinetic) result in slightly different results, all have been shown to relate similarly to perceived visual difficulty (Subhi et al., 2017). Ideally, all participants would undertake the same range of VF tests, which would cover both the full extent of VF to at least 60 deg eccentricity and additionally would provide finer granularity to the data in the central VF (e.g. HFA 10-2 paradigm). This latter point leads to the third limitation: that the present study does not explore in detail the potential impact of very restricted central fields and VF defects very close to fixation. Whilst it is relevant to note that foveal visual function in the form of visual acuity and contrast sensitivity have indicated that only one class is required within VI shooting (Allen et al., 2019), the possible effects of scotomas close to the fovea should be examined in future work.

Nonetheless, the present study is able to comment on the impact of VF status in greater detail than previously (Myint et al., 2016), with the advantage of using shooting data from athletes in real competitive environments.

The present study also provides no comment on the necessity of considering VF status in the minimum entry criteria (MIC) for inclusion in VI shooting. To address this question, comparison of performance in sighted shooters in the non-adapted form of the sport with varying levels of field loss would be required in order to determine the minimum level that affected performance.

In summary, this study provides no evidence that visual field influences performance in the prone discipline of visually impaired shooting, and only one VI class is currently warranted within Shooting Para Sport. For the standing discipline, while further research with larger sample sizes is required to reach a definitive conclusion as the sport grows, there is little evidence so far that visual field has an impact on shooting performance that should influence classification criteria.

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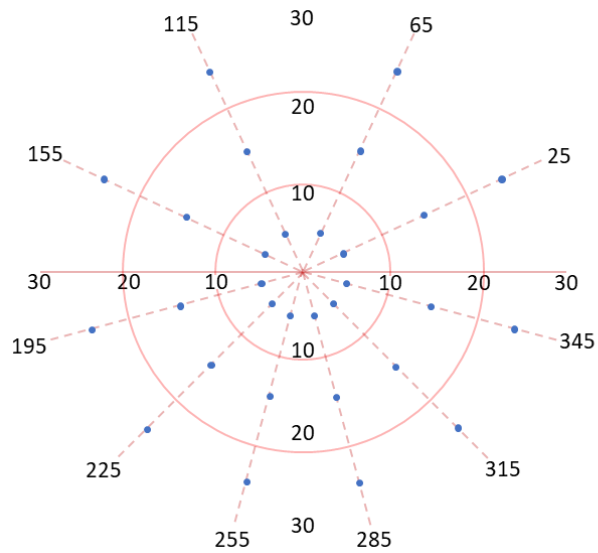
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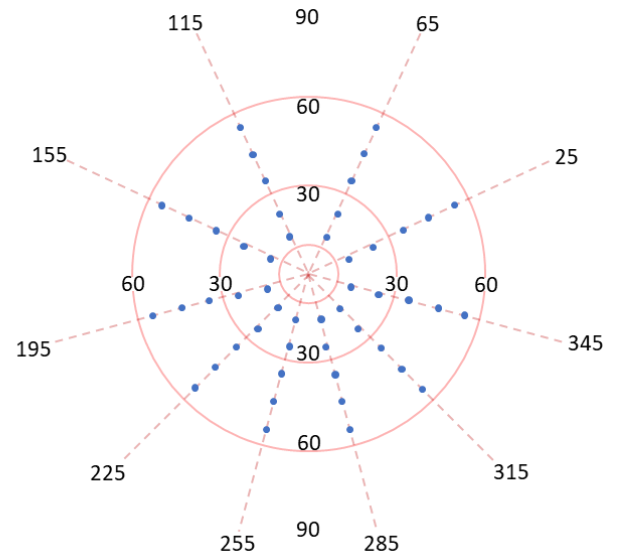
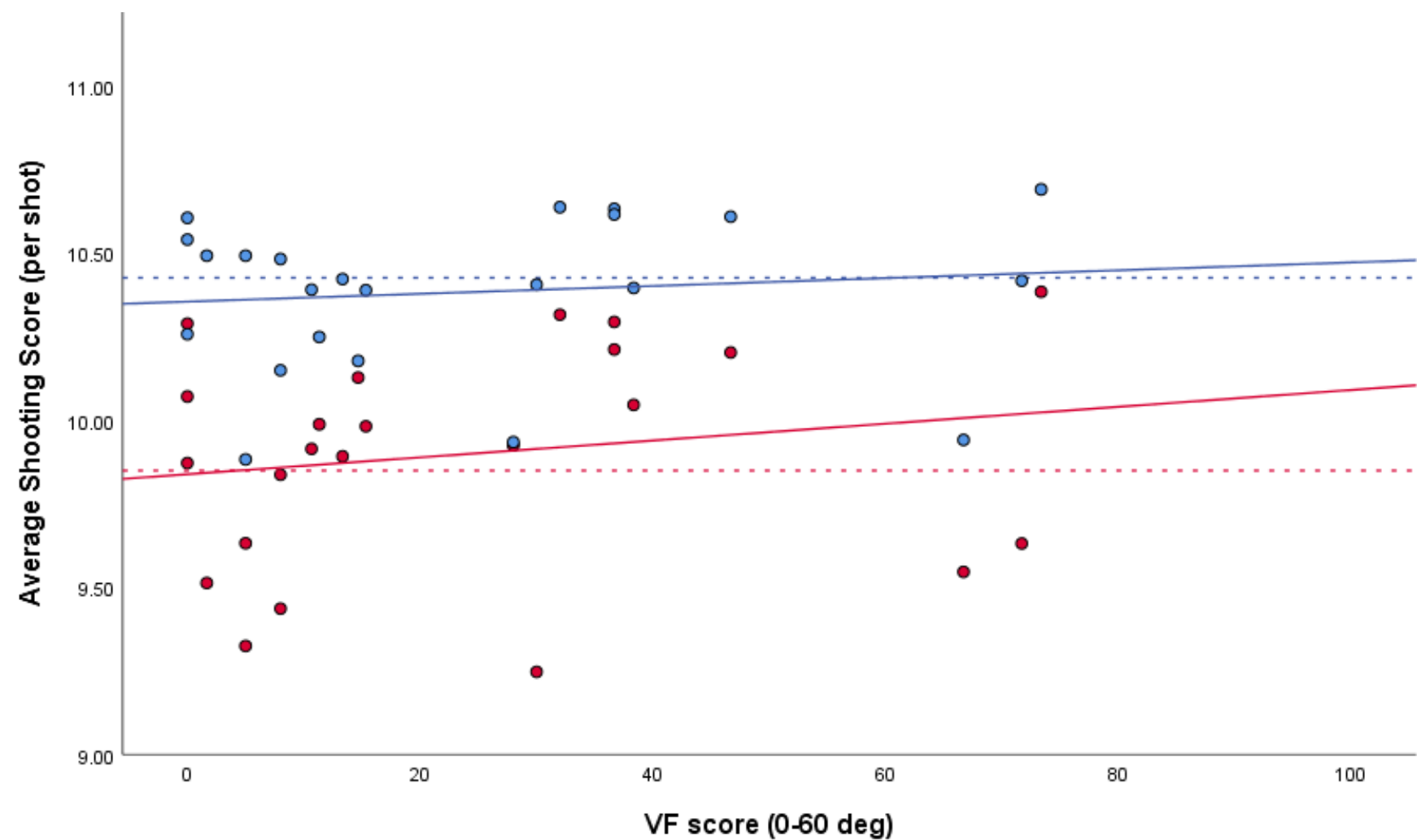


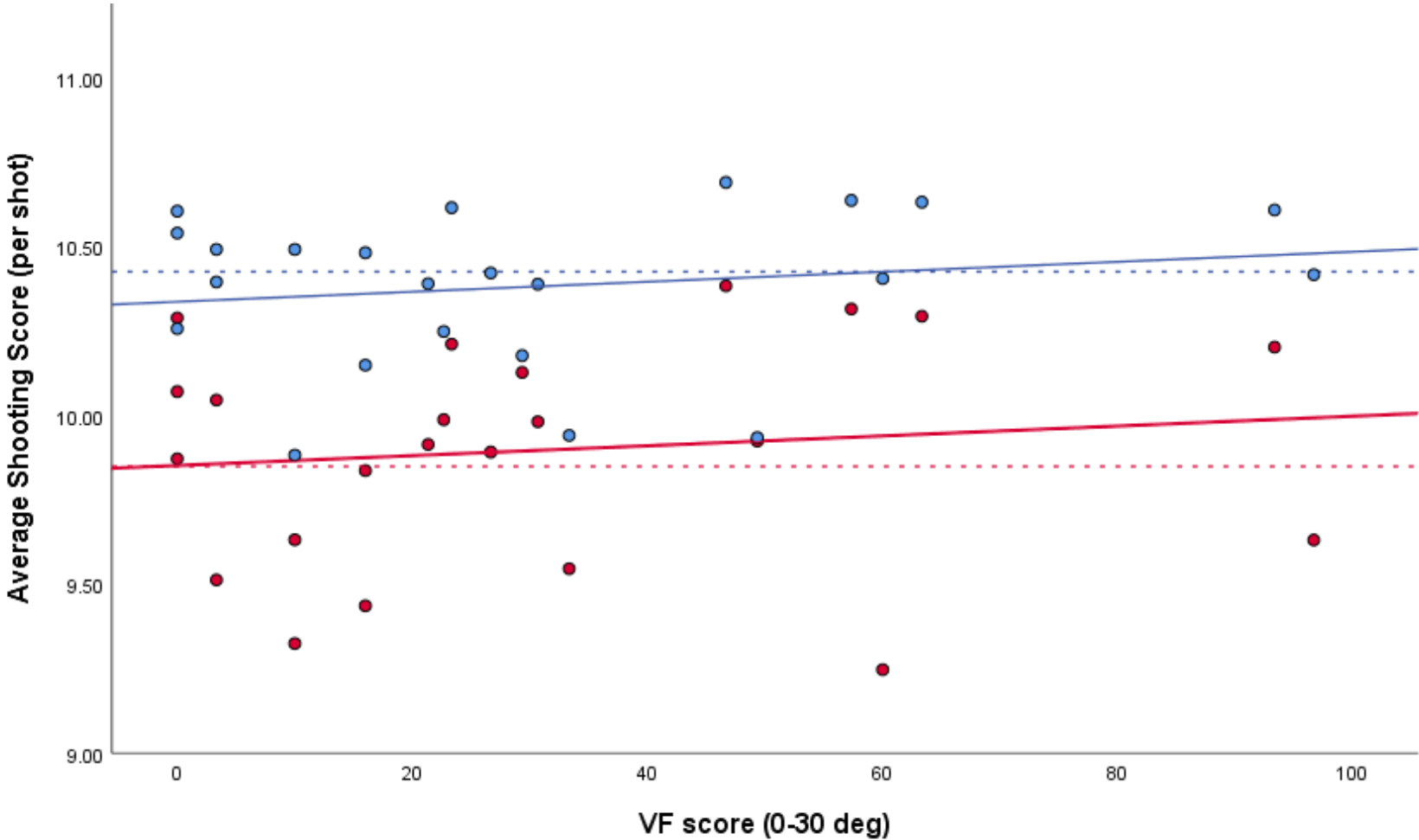
Figure 1. Overlay grids used to categorise VF status at locations across the VF. Grids were scaled appropriately to the VF plot and overlaid on the VF output. VF status at each grid point was categorised as 'seen' or 'unseen' at a cut-off value of 10dB based on performance in the same area of the plot. A. Grid used for 0-30 deg VF plots. B. Grid used for 0-60 deg VF plots.

509 A.



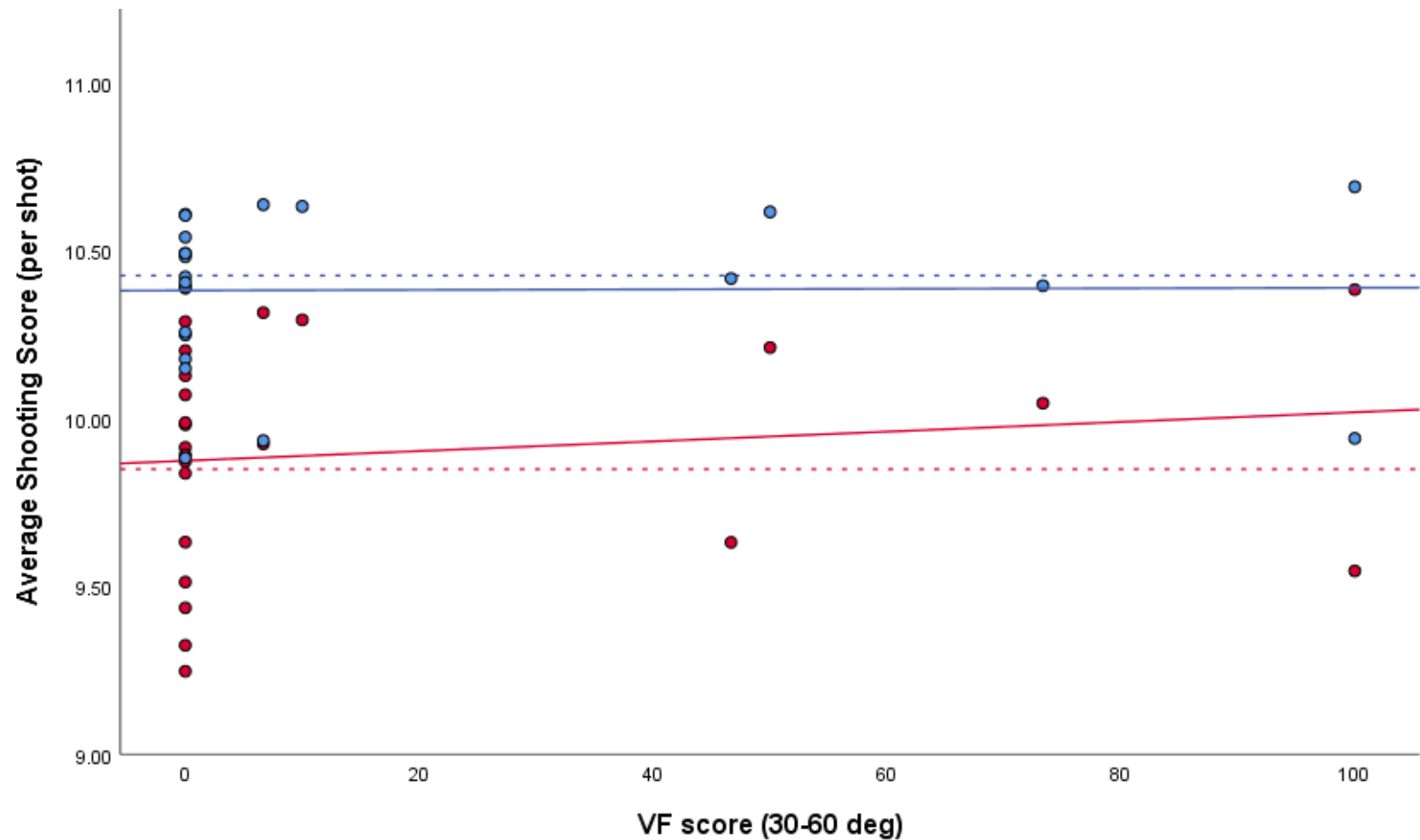
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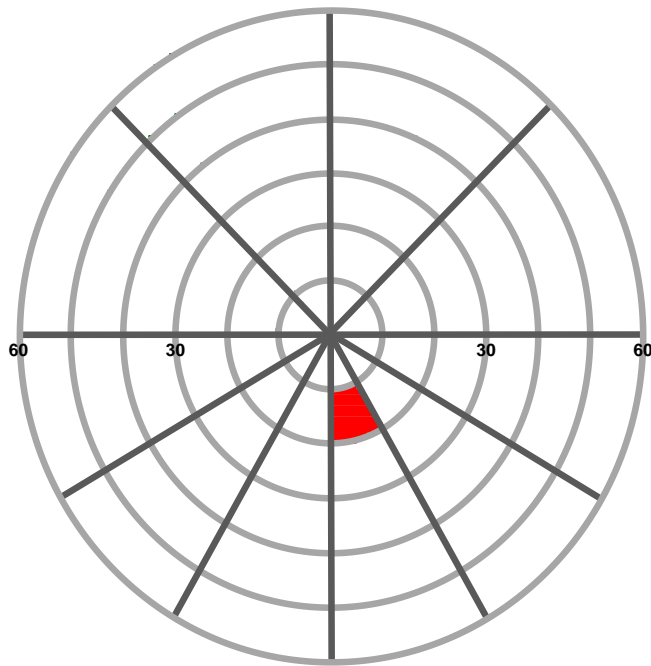
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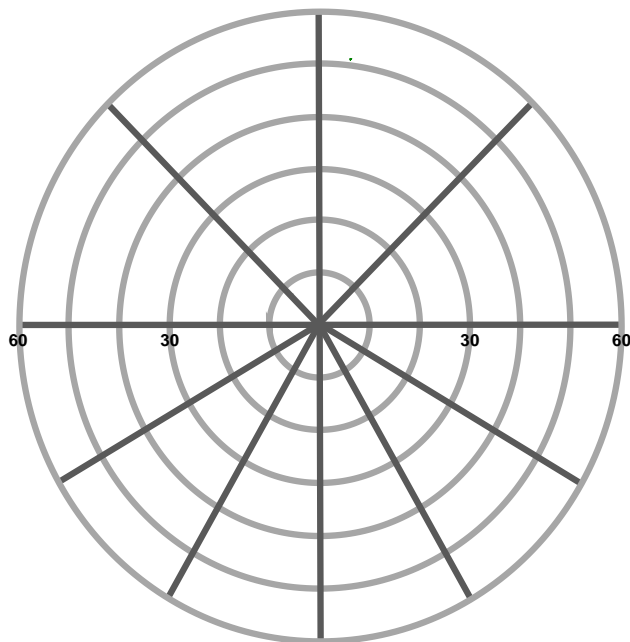
Figure 2 (A-C). Average shooting score in prone (blue) and standing (red) disciplines compared to VF scores (A: full field (0-60deg), B: central field (0-30 deg), C: peripheral field (30-60 deg)). VF scores for all categories outlined could be between 0 and 100. The solid line represents a line of best fit to the data, and the dotted line the 'non-competitive' score (maximum score minus the drop in performance indicating an athlete might not qualify for the final in an elite event).

523 A.



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525 B.



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527 **Figure 3.** A) prone, B) standing. Each sector of the graph represents a VF location assessed using the
528 scoring system applied to the VF data. White sectors indicate that the score of those without
529 function at this location was not competitively different (difference of <0.263 per shot for prone, or
530 <0.540 per shot for standing) from those with function at this location. Red sectors indicate that
531 athletes without field function at this location scored worse than those with field function to an
532 extent that they would not qualify for an elite level final (>0.263 for prone, or >0.540 for standing).

533

Table 1. Scores at the end of qualification in 4 recent World Cup events: note that this is reference data from 2018/19, and not data from the study population. For each discipline (prone and standing), the leading score (1st place) is given, along with the difference in score between 1st and 2nd place, the difference in score between 1st and 9th place (the highest score that did not qualify for the final), and the difference in score between 8th and 9th places (the difference between qualifying and not qualifying for the final). In each case total score and the difference in score is across 60 shots, and the average score or drop in score per shot is provided in brackets.

	1 st place total score (average per shot)	Drop in score to 2 nd place (average per shot)	Drop in score to 9 th place (average per shot)	Drop in score from 8 th to 9 th place (average per shot)
Prone				
Sydney	605.1 (10.085)	1.0 (0.017)	15.9 (0.265)	2.6 (0.043)
Osajik	610.7 (10.178)	10.6 (0.170)	18.6 (0.310)	0.9 (0.015)
Hannover	608.1 (10.135)	1.6 (0.169)	15.8 (0.263)	2.4 (0.040)
Chateauroux	609.1 (10.152)	5.7 (0.169)	16.7 (0.278)	1.8 (0.030)
Standing				
Sydney	556.4 (9.273)	17.5 (0.292)	52.4 (0.873)	17.4 (0.290)
Osajik	554.2 (9.237)	17.7 (0.295)	53.3 (0.888)	6.4 (0.107)
Hannover	569.2 (9.487)	33.9 (0.565)	74.2 (1.237)	2.6 (0.043)
Chateauroux	543.5 (9.058)	1.1 (0.018)	32.4 (0.540)	1.1 (0.018)

Table 2. Descriptive statistics of the visual function in the shooting eye of the VI athletes. VF scores for all categories outlined could be between 0 and 100.

Function	Median	25-75% IQR	Min	Max
VA (logMAR)	1.02	0.60-1.66	0.10	4.00
CS (logCS)	0.36	0.10-1.08	0.00	1.28
Full VF (0-60 deg)	15	5-37	0	73
Central VF (0-30 deg)	23	10-49	0	97
Peripheral VF (30-60 deg)	0	0-10	0	100

Table 3. Kendall tau (T) correlation coefficients assessing the relationship (p) between average shooting score per shot (as a measure of performance) and VF status at different eccentricities.

VF score	Prone shooting score		Standing shooting score	
	T	p	T	p
0-60 deg	0.10	.53	0.23	.13
0-30 deg	0.04	.79	0.12	.44
30-60 deg	0.17	.32	0.26	.12

Table 4. Kendall tau (T) correlation coefficients assessing the relationship (p) between standard deviation in each athlete's shooting score (as a measure of variability) and VF status at different eccentricities.

VF score	Prone shooting score		Standing shooting score	
	T	p	T	p
0-60 deg	0.07	.65	0.04	.81
0-30 deg	0.15	.32	0.24	.12
30-60 deg	-0.03	.85	-0.14	.42

Table 5. Comparison of shooting performance by those with no (30-60 deg VF score = 0) and some measureable peripheral VF (30-60 deg VF score > 0). Shooting performance is categorised as non-competitive for scores <10.427 per shot for prone or <9.850 for standing. No differences in competitiveness are observed for the prone (χ^2 0.21, df 1, p=0.65) or standing (χ^2 0.52, df 1, p=0.47) disciplines.

	Prone			Standing		
	No peripheral VF	Some peripheral VF	Total	No peripheral VF	Some peripheral VF	Total
Competitive score	6	4	10	9	6	15
Non-competitive score	9	4	13	6	2	8
Total	15	8	23	15	8	23