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Assessment of Visual Function and Performance in Paralympic Judo for Athletes with Vision Impairment

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SIGNIFICANCE: Paralympic judo currently requires all athletes to compete against each other in one class irrespective of their level of vision impairment (VI). Recent evidence suggests that multiple classes are required to enhance fairness, yet it remains unclear how many classes are necessary and what vision tests should be used to define those classes.

PURPOSE: The aim of this study was to quantify the relationship between vision and performance in judo for individuals with VI. The results were expected to inform the development of evidence-based criteria to structure Paralympic judo competition.

METHODS: The visual function of 53 elite VI judokas was assessed using a test battery that included tests of visual acuity (VA), contrast sensitivity, light sensitivity, depth perception, motion perception, visual search, and central visual field. Performance was assessed by measuring the ratio of fights won across all competitions the participants took part in in the 2 years before and after vision testing. Pearson correlation coefficients and decision tree analyses were used to determine the relationship between vision and performance. Partial correlations were also conducted to determine the unique ability of each measure of visual function to predict judo performance.

RESULTS: Visual acuity was the best predictor of judo performance and remained the only visual function related to performance when controlling for correlations between VA and other visual functions. Decision tree analyses suggested to split athletes into two groups for more legitimate competition, using a cutoff point around 2.6 logMAR. Within each of the two resulting subgroups, no correlations remained between any of the visual functions and performance.

CONCLUSIONS: The results of this study suggest that VI judo competition should be split into separate categories for partially sighted and functionally blind athletes. The inclusion of visual functions in addition to VA does not improve the ability to predict performance in VI judo.

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Paralympic sports provide opportunities for people with impairment to participate and excel in sport competitions. Athletes competing in Para sports are grouped together or classified for competition based on the type and severity of their impairment. The aim of Paralympic classification is to promote participation by people with impairment by minimizing the impact of impairment on the outcome of competition.¹ Classification should maximize the likelihood that Paralympic medals are awarded to the best athlete within each classification category rather than to the athlete with the least impairment.²

Vision impairment (VI) is one of the three main types of eligible impairments for Paralympic sports, along with physical and intellectual impairments. The International Paralympic Committee defines VI as an impairment of the eye structure, the optic nerve or pathways, or the visual cortex.³ Most VI sports currently allocate athletes to one of three sport classes (B1 to B3 for athletes with the most to the least severe degree of impairment), based on an assessment of the athlete's visual acuity and/or visual field (Table 1). Both visual acuity and visual field are measured monocularly and with the best possible optical correction for each eye, with the test results of the best eye used for classification.

The current classification criteria used across most VI sports have been criticized for lacking scientific basis because the same three classes are used for basically all sports despite the contrasting visual demands of the different sports.^{4,5} In 2007, the International Paralympic Committee issued in their *International Paralympic Committee Classification Code* that all Para sports must develop evidence-based classification systems that are based on scientific evidence showing the relationship between impairment and performance in that sport.⁶ The current criteria used across most VI sports are not evidence based; instead, they are based largely on the World Health Organization's definitions of low vision and blindness.⁷ An evidence-based system of classification is also necessarily sport specific because the impact of an impairment on performance in all likelihood will differ across sports (e.g., the impact of an arm amputation is different in basketball from that in soccer). Likewise, because the visual demands of sports differ, the impact of a VI on performance will also vary across sports. Vision impairment sports therefore need to develop their own sport-specific classification criteria that minimize the impact of VI on the outcome of competition in each sport.⁵

Judo is one of the Paralympic sports that caters for athletes with VI, and judo currently does not have an evidence-based system of

TABLE 1. Current sport class criteria used across most visually impaired sports, including visually impaired judo

Sport class	Visual acuity	Visual field
B3	1.0–1.4 logMAR	<20° radius
B2	1.5–2.6 logMAR	<5° radius
B1	Worse than 2.6 logMAR	Not possible to qualify as B1 on the basis of visual field

classification in place. Athletes competing in VI judo are currently allocated to one of the three sport classes used across most VI sports (B1 to B3). However, in judo competition, athletes from all three sport classes (ranging from partially sighted to fully blind) all compete together, meaning that VI judo effectively has only one sport class. To assist with this, the rules in VI judo are adapted to better suit those with low vision: athletes start the match with a two-handed grip on their opponent in place, rather than starting 4 m apart without established contact as occurs in able-sighted judo.⁸ However, recent research suggests that the most severely impaired athletes remain disadvantaged despite this adaptation to the sport. Several studies have shown that functionally blind athletes are substantially less successful in VI judo than their partially sighted opponents.^{9–11} These studies call for competition to be split into (at least) two sport classes. A recent database study that related classification data with the competition performance of nearly 300 VI judokas suggested that this split could be made on the basis of visual acuity.¹² That study identified a possible cutoff point between classes at 2.5 logMAR. However, the analysis had several limitations. First, the optimal cutoff point for visual acuity remained unclear, with bootstrap analyses showing that the optimal cutoff might vary anywhere between 2.0 and 3.5 logMAR. Second, visual acuity data were drawn from a database with the testing conducted by different clinicians (“classifiers”) at various venues and potentially using different test procedures. Moreover, classifiers are known to not always establish the exact level of visual acuity, particularly if it is worse than 2.6 logMAR, largely because their goal is to find the correct class rather than determine the exact level of visual function.¹² Finally, all visual acuity results were found when testing the best eye only, following the current classification regulations, yet athletes in many sports (including judo) compete using both eyes. There is a widely held desire for any new classification criteria to be based on the test results when testing both eyes together.^{4,5}

Although classification is currently determined by tests of visual acuity and visual field, other measures of visual function in addition to, or even instead of visual acuity and visual field, might prove to be a better way to assess the visual capabilities of a judo athlete. To guide the development of new classification criteria for VI sports, the International Paralympic Committee, together with the International Blinds Sports Federation, adopted a joint position stand on the sport-specific classification of athletes with VI.⁵ This position stand highlights that additional measures of visual function may be needed for sport-specific classification in VI sports. Particularly in a dynamic sport such as judo, there may be other aspects of vision that better predict whether an athlete's performance would be impaired either in addition to or instead of visual acuity and/or visual field. Indeed, a panel of experts in VI judo argued that additional measures of visual function such as motion perception and light sensitivity, parameters that are not currently measured

during classification, may need to be included for classification in judo.¹³ Research should assess which (combination of) measures of visual function best predict judo performance and should therefore be included in classification to increase the likelihood that athletes compete against others with similar levels of activity limitation.

The aim of this study was to quantify the relationship between VI and performance in VI judo. Participants were recruited during two major international VI judo competitions (the 2017 European Championships and the 2018 Pan-American Championships) where we assessed the habitual visual function of participants using a vision test battery specifically designed for people with low vision (including tests of visual acuity, contrast sensitivity, motion perception, light sensitivity, visual search, and central visual field). Visual function was related to the performance of participants in all official international competitions the athletes took part in in the 2 years before and after the time of testing. The results of this study were expected to provide guidance on the most appropriate number of sport classes for competition in VI judo, on the cutoff points between those classes, and of the vision tests that should be included in classification for the sport.

METHODS

Participants

Fifty-three elite VI judokas, representing 16 different national federations, agreed to participate in the study (38 male, 15 female; mean $\pm$ standard deviation age, 27.9 ± 8.8 years). Participants were all athletes who competed at either the 2017 International Blinds Sports Federation Judo European Championships in Walsall, United Kingdom, or the 2018 International Blinds Sports Federation Pan-American Judo Championships in Calgary, Canada. Participants were informed before the event that research would take place and that athletes could voluntarily participate at any time convenient to them during their stay at the respective competitions or subsequent training camps. Athletes were explicitly informed that their test results would not be shared with classifiers or administrators and that participation in this study would in no way impact their existing classification status. The local ethics committee approved the study, and all participants provided written informed consent before taking part in the study. Immediately before participation, the contents of the consent form were summarized by one of the researchers. Participants were also allowed to bring a sighted guide who was allowed to read the consent form before the participant signed it.

Procedures and Materials

Testing consisted of two parts. First, participants were interviewed about their developmental history to establish the background of their impairment and to quantify their judo training history. Second, participants were assessed on a vision test battery specifically designed for people with (very) low vision.

Developmental and Training History

A modified version of the Developmental History Athlete Questionnaire^{14,15} was used to establish the developmental and training history of participants. The modified Developmental History Athlete Questionnaire established the age at which participants acquired their VI and how it had progressed over their life span. Next, each athlete's total accumulated training hours was estimated by

establishing the age at which he/she started judo and by quantifying the number of hours per week and months per year spent in training and competition from that year onward.

Vision Test Battery

Classification is currently determined using the test results of the best eye only and when testing with the best possible optical correction. For classification research, however, the International Paralympic Committee–International Blinds Sports Federation joint position stand suggests that testing to establish the impairment-performance relationship should evaluate the habitual vision that athletes use during competition.⁵ Unless otherwise stated, all tests were therefore performed binocularly and using any visual correction that would be worn during competition. Before proceeding to the vision tests, participants were asked whether they would normally wear any optical correction (e.g., contact lenses) during judo competition. When they did, the tests were performed with that correction in place and, otherwise, without any correction, to ensure the visual function tested was the habitual visual function participants used during competition.

Visual Acuity

The Berkeley Rudimentary Vision Test¹⁶ was used to determine visual acuity in logMAR units, with higher values representing poorer vision. The Berkeley Rudimentary Vision Test uses three sets of cards that are shown to the participant from different distances. With the single tumbling E and the grating cards, visual acuity can be measured up to 2.9 logMAR. The task for the participant is to indicate in which direction (up, down, left, or right) the openings of the single tumbling E are facing or whether the grating stripes are positioned horizontally or vertically. For participants unable to resolve the gratings (i.e., with visual acuity worse than 2.9 logMAR), testing continued with the white field perception and black and white discrimination cards. In case the participant could not discriminate black from white, a pen torch was held 40 cm from the participant to assess whether the athlete had light perception or no light perception. For analysis purposes, a numerical value was assigned to white field perception of 3.2 logMAR, black and white discrimination of 3.5 logMAR, light perception of 3.7 logMAR, and no light perception of 4.0 logMAR. These values were based on previous literature¹² and the recommendations on the Berkeley Rudimentary Vision Test cards.

Contrast Sensitivity

The numbered version of the MARS Letter Contrast Sensitivity Test (Mars Perceptrix Corporation, Chappaqua, NY) was used to assess contrast sensitivity. In this test, participants are required to read gray-scale numbers of decreasing contrast printed on a white card. Participants were required to continue reading until two consecutive mistakes were made. Following test instructions, the score in logCS was determined by the contrast of the final number identified correctly minus a correction for single mistakes made before that point. Lower logCS scores represent worse vision. Athletes whose vision was too poor to perform the test were assigned a dummy value of 0 logCS for the purpose of analyses.

Light Sensitivity

The MARS Letter Contrast Sensitivity Test was also used to test light sensitivity, where contrast sensitivity was compared with and without the presence of bright lighting simulated using the Brightness Acuity Tester.¹⁷ The Brightness Acuity Tester (Marco Ophthalmic, Jacksonville, FL) is a handheld device with which participants look through a small hole in the center of a hemisphere that directs light

toward the participant's eye. Because the Brightness Acuity Tester is designed for monocular testing, light sensitivity was assessed on the eye with the best acuity (or the dominant eye if acuity was equal in the two eyes). Contrast was first tested monocularly while viewing through the Brightness Acuity Tester with the light source off, and then again with the light source turned on at the highest intensity (400 fL). The percentage loss in contrast sensitivity between the first and second tests was calculated as the measure of light sensitivity (where an increasingly positive value indicates greater sensitivity to light). Athletes whose vision was too poor to perform the test in the first condition with the Brightness Acuity Tester off were assigned a dummy value of 101% for the purpose of analyses.

Depth Perception

A custom-made modified version of the Howard-Dolman test¹⁸ was used to assess depth perception (Fig. 1). One vertical white rod (20-mm diameter) with a white ball at the top (100-mm diameter) was placed 300 mm to the left of and at equal height (555 mm above table surface) to an identical target placed on a rail. Participants sat 1.5 m from the stationary (left) target, and their task was to move the right target until it was the same distance from them as the left target. Participants could move the right target forward and backward using a handheld joystick, with an electronic motor used to control the position of the target. The custom-made device automatically determined the forward/backward distance between the two targets (measured in millimeters). The background of the test was black, and a black barrier blocked the participant's lower field of view to remove any visual cues from the base and rail of the targets.

The test consisted of two conditions presented in a randomized order across participants. In the first condition, the sliding target was placed at the far end of the slider (~390 mm further away than the stationary target). Participants were asked to move the target toward them to the position where they believed it to be aligned with the stationary target (i.e., so the two targets were the same distance from them). This task was completed two times. In the second condition, the sliding target started closer to the participant (~390 mm closer than the stationary target), and the participant was asked to move the target away to align the two targets. This was again performed two times. The mean absolute error in millimeters across all four trials was used as the outcome measure for depth perception. Athletes whose vision was too poor to perform the test were assigned a dummy value of 400 mm, which is larger than the farthest possible distance between the two targets.

Motion Perception

A custom-made computer-based test was used to assess global motion perception. A random-dot kinematogram was used where participants in a forced-choice task were required to determine whether a collection of dots shown on a computer screen was moving upward or downward.^{19–21} Participants sat 66 cm from a 27-in Apple Thunderbolt display (Apple Inc., Cupertino, CA; refresh rate, 60 Hz; resolution, 2560 × 1600 pixels) that showed a square envelope (25 × 25°) in which 100 moving dots briefly appeared (radius, 0.83°; dot lifetime, 0.2 seconds; speed, 6°/s). Participants started with six familiarization trials in which all 100 dots moved in the same direction either upward or downward (i.e., 100% coherence). When participants responded correctly to at least four of six practice trials, the test continued onto the full protocol. If participants scored less than four of six trials correctly, then the test was explained again, and the familiarization trials repeated. The

FIGURE 1. Depth perception test. Participants needed to move the right target using a handheld joystick until it was the same distance from them as the left target.

test was stopped if participants could not correctly identify at least four of six trials at their second attempt. For the actual test, a one-up-two-down staircase procedure with five reversals was used to determine the threshold coherence level where global motion could be correctly identified in 66.6% of the presentations. The coherence started at 100% and used a decreased rate of 25% (where noncoherent dots moved in other directions) before the first reversal, and a decreased and increased rate of 10% after the first reversal. Participants recorded their forced-choice response using the upward and downward arrows on a keyboard. Each trial was presented for up to 8 seconds, in which time participants were required to respond, and a missed response was recorded as an incorrect response. The test was designed in Psykinematrix (KyberVision Japan LLC, Sendai, Japan).²² Those participants who could not complete the test were assigned a dummy value of 101% coherence.

Visual Search

A custom-made test of visual search was created to be suitable for individuals with very low vision.^{23,24} In a series of computer-based visual search trials, participants were required to identify whether a circle was present among a grid that otherwise contained only squares (presented on the same 27-in Apple monitor). The visual search test contained three difficulty levels. Starting with the easiest level, participants were shown a 3×3 grid of black shapes (8.3° in width) on a white background. For the intermediate level, an 8×8 grid was used with shapes of 2.6° in width. Finally, the most difficult level used a 15×15 grid with a shape size of 0.83° in width. The distance between shapes was 1° for all conditions.

Participants first performed six familiarization trials, using the easiest test level, in which the circle was present four times. To continue to the full test protocol, participants were required to score at least four of six correct responses. In case they did not reach this, the task was explained again, and the familiarization trials repeated. The test was aborted if participants could not reach the four of six criteria at their second attempt. The full test consisted of 18 trials for each level of difficulty, where the circle

was present in 12 of 18 trials. Both the order of the trials and the location of the circle were randomized. Each trial was presented for up to 30 seconds during which the participant needed to respond. Participants responded using the upward or downward arrow key to indicate either the circle was present (upward key) or absent (downward key). A missed response was marked as incorrect. A test level was aborted if the participant was unable to correctly identify four of the first six trials. The mean response times in each of the three difficulty levels over all trials where a circle was present were summed and used as the main outcome value. Participants unable to complete the test were assigned a dummy value of 30 seconds for each condition they could not complete (i.e., participants who could not complete any of the three conditions received a total score of 90 seconds).

Central Visual Field

The Berkeley Central Visual Field Test²⁵ was used to estimate the integrity of the central visual field (equipment for automated perimetry was not available at competition venues). The same 27-in Apple monitor was placed 40 cm from the participant to test the central 10° (radius). Participants were instructed to fixate toward the intersection of two diagonal lines throughout the test and to respond by pressing the spacebar on a keyboard whenever they saw a stimulus (a black dot with a size of 0.4° of visual angle) presented in their periphery. In total, 50 stimuli appeared within a 10° radius along 1 of 10 meridians ($25, 65, 115, 155, 195, 225, 255, 285, 315,$ and 345°) at each of 5 eccentricities ($1, 3, 5, 7,$ and 9°). Each stimulus had a lifetime of 250 milliseconds, and interstimulus times varied randomly between 900 and 1300 milliseconds. The percentage of stimuli seen was used as the measure of the visual field. Athletes who could not perform the test were assigned a dummy value of 0%.

Judo Performance

To assess competitive judo performance, match results were collected from the Website of the International Blind Sports Federation and from the International Blinds Sports Federation's archived

competition results for all international tournaments in which the participants competed in the 2 years before and after their date of vision testing. To do so, match data were collected for a total of 18 competitions held between August 2015 (i.e., 2 years before the 2017 European Championships) and May 2020 (i.e., 2 years after the 2018 Pan-American championships). A 4-year window was required to include a sufficient number of available competitions. Performance was measured by calculating each athlete's win ratio, that is, the total number of wins divided by the total number of fights within the 4-year time frame. Because of the knockout system used in most judo competitions, competitors are potentially out of the competition after losing their first match. A minimum of two competitions was therefore required for inclusion in the study. Participants who failed to meet this criterion were excluded from further analysis. Because of this knockout system, an average judoka loses more matches than he/she wins, and therefore, the average win ratio of judokas is less than 0.5.

Data Analysis

Data for male and female participants were combined for all analyses, as earlier research suggested that the impairment-performance relationship in judo should not be impacted by sex.¹² Pearson correlation coefficients were calculated to determine the relationship (1) between judo performance and other factors that could influence performance (the age at which participants started judo, participants' current age, the age at which participants were first diagnosed with VI, the number of years participants had been training judo, the number of years participants had been competing in VI judo, and participants' estimated total judo training volume); (2) between judo performance and each measure of visual function; and (3) between each of the measures of visual function. Partial correlations were also conducted to determine the unique contribution of each measure of visual function when predicting judo performance.

Decision tree analyses using the unbiased recursive partitioning algorithm²⁶ were run to determine whether or not the data could be split into multiple groups that would be characterized by distinct levels of visual function and have different levels of performance, and if so, what vision tests characterize the groups and what the ideal cutoff point(s) between these groups should be. To assess the stability of the decision tree, we examined the variability in cutoff selection(s) by bootstrapping 10,000 random resamples of our data using the toolkit for stability assessment of tree-based learners.²⁷ For each of the 10,000 bootstrap samples, a separate decision tree was built. The number of splits and the distribution of the split points over all decision trees were determined. Bootstrapping is based on the assumption that the sample population mirrors the actual population. To assess this assumption, we compared the distribution of win ratios within our sample across the different current sport classes (e.g., B1 to B3) with the same distribution over the entire population of athletes who competed at least twice within any of the competitions for which we included data in this study.

RESULTS

Judo Performance

Within the analyzed 4-year period, participants, on average, competed in 5.2 ± 2.7 competitions (mean $\pm$ standard deviation), with an average win ratio of 0.35 ± 0.23 . Of all 53 participants, 4 athletes

participated in only one competition within the analyzed time frame, with an average win ratio of 0.08 ± 0.17 , suggesting that they were not internationally competitive. Therefore, those participants were excluded, leaving 49 participants for further analysis.

Factors That Could Influence Judo Performance

Table 2 shows the correlations between the win ratio and variables that could explain variance in judo performance and therefore could potentially confound any relationship between vision and performance. The age at which participants started to take part in judo was the only variable that was significantly correlated with win ratio ($r = -0.36$, $P = .01$). However, Fig. 2 suggests that this correlation was mainly driven by three athletes who started to practice judo at a markedly older age than the others (≥ 35 years). After excluding these three athletes, the relationship between the age of starting judo and performance was no longer significant ($r = -0.17$, $P = .25$), whereas the relationship between all other possible confounding factors and performance remained nonsignificant (Table 2). We therefore excluded these three athletes (leaving 46 athletes for further analyses) and continued to use win ratio as our measure of performance (rather than adjusting it according to any confounding factors).

Relationship between Visual Function and Judo Performance

Table 3 shows that visual acuity was the only measure of visual function that was significantly correlated with judo performance ($r = -0.33$, $P = .02$; Fig. 3). When replacing missing values with dummy values for those athletes who could not perform all visual function tests, significant correlations were also found for contrast sensitivity ($r = 0.31$, $P = .04$), depth perception ($r = -0.30$, $P = .04$), visual search ($r = -0.30$, $P = .04$), and central visual field ($r = 0.32$, $P = .03$).

When replacing missing values with dummy values, all visual functions correlated significantly with visual acuity (Table 4). Therefore, partial correlations between visual functions and performance were conducted while controlling for visual acuity to determine whether the inclusion of the other measures of vision provided additional information when visual acuity was already known. Table 5 shows that, when controlling for visual acuity, no association remained between any of the measures of visual function and performance. We therefore continued with visual acuity as the main

TABLE 2. Correlations between possible confounders and judo performance

Possible confounder	Correlation possible confounder and win ratio	
	All athletes included (n = 49)	Age starting judo ≥ 35 y excluded (n = 46)
Age starting judo	$-0.36^* (P = .01)$	$-0.17 (P = .25)$
Current age	$-0.16 (P = .29)$	$0.02 (P = .91)$
Age first diagnosed	$0.03 (P = .83)$	$0.04 (P = .77)$
Years of judo training	$0.20 (P = .17)$	$0.14 (P = .34)$
Years competing VI judo	$0.02 (P = .87)$	$-0.02 (P = .89)$
Total training hours judo	$0.19 (P = .22)$	$0.12 (P = .47)$

* $P < .05$. VI = visually impaired.

FIGURE 2. Relationship between age of at which participants started to practice judo and their win ratio over all tournaments participated in the 2 years before and after vision testing. The blue line shows the linear fit between all data points. The red line shows the linear fit after exclusion of the three athletes who started judo at a later age (≥ 35 years).

measure of visual function to determine whether the participant group should be split into multiple sport classes.

Splitting Participants on the Basis of Visual Function and Performance

The main decision tree suggested a split in the data at a visual acuity of 2.6 logMAR. Judokas with a visual acuity of 2.6 logMAR or better ($n = 30$) had an average win ratio of 0.48 ± 0.17 (mean $\pm$ standard deviation). Judokas with a visual acuity worse than 2.6 logMAR ($n = 16$) had an average win ratio of 0.31 ± 0.26 (mean $\pm$ standard deviation). A t test confirmed that this difference in win ratio was significant and showed a large effect size ($t_{22,01} = 2.3$, $P = .03$, $d = 0.8$). Bootstrapping confirmed a split into at least two sport classes in 62.5% of the 10,000 samples, with a single split suggested in 60.5% of all cases and a second

split in 2% of cases. The most frequently selected cutoff point was 2.5 logMAR (selected in 15.2% of all 10,000 cases), followed by 2.6 (13.4%), 1.7 (10.1%), and 2.4 (7.7%). Bootstrapping thus seemed to confirm a split at or around 2.6 logMAR.

After splitting the data into two groups, visual acuity no longer correlated with judo performance in either of the resulting groups. For the partially sighted athletes with visual acuity ≤ 2.6 logMAR, a small yet insignificant trend remained ($r = -0.20$, $P = .29$). For functionally blind athletes with visual acuity > 2.6 logMAR, an insignificant trend was also visible ($r = 0.40$, $P = .13$), yet the positive slope suggests that, if anything, it is the athletes with the worse vision who tend to perform better rather than worse. Although the decision tree analysis suggested that only one split was necessary on the basis of visual acuity, it remained possible that further splits could be made within those groups on the basis of other measures of visual function. We therefore considered the relationship between visual function and performance after splitting the data into the two groups at 2.6 logMAR (Table 6). No significant relationships remained in either group between any of the measures of visual function and performance. Multiple regression analysis further showed that no combination of measures significantly predicted performance within the functionally sighted group ($F_{7,22} = 1.7$, $P = .16$, adjusted $R^2 = 0.14$). The same analysis was unnecessary for the group of functionally blind athletes given that almost all athletes could not perform the other tests of visual function. These findings suggest that no further splits in the data were required when taking into account the additional measures of visual function.

Finally, we sought to check whether the performance level of the participants in our study was representative of that of the wider VI judo population. Fig. 4 shows the level of performance across the three current sport classes (i.e., B1 to B3) for the participants within our sample and compares it with the same distribution of

TABLE 3. Correlations between visual function and judo performance

Visual function	Correlation visual function and win ratio	
	Missing values removed	Missing values replaced
Visual acuity	$-0.33^* (P = .02)$	$-0.33^* (P = .02)$
Contrast sensitivity	$-0.09 (P = .69)$	$0.31^* (P = .04)$
Depth perception	$0.21 (P = .30)$	$-0.30^* (P = .04)$
Motion perception	$-0.06 (P = .80)$	$-0.02 (P = .89)$
Light sensitivity	$-0.02 (P = .98)$	$0.13 (P = .39)$
Visual search	$-0.13 (P = .55)$	$-0.33^* (P = .03)$
Visual field	$0.19 (P = .40)$	$0.32^* (P = .03)$

* $P < .05$.

FIGURE 3. Relationship between visual acuity and judo performance.

performance when including the entire population of athletes who competed at least twice in any of the tournaments for which we collected data in this study (comprising 22 competitions held between 2015 and 2020). The B1 athletes included in our sample performed better than did those in the entire population. The performance of the B2/B3 athletes was comparable, although our sample included relatively less better-performing athletes. In conclusion, the current sample shows similarities but, if

anything, may underestimate any discrepancies in performance between the existing B1 and B2/B3 classes.

DISCUSSION

The aim of this study was to quantify the relationship between VI and performance in VI judo. We visited two major VI judo

TABLE 4. Correlations between visual functions

Visual function	1	2	3	4	5	6	7
Missing values removed							
1. Visual acuity	—						
2. Contrast sensitivity	−0.51*	—					
3. Depth perception	0.43*	−0.63†	—				
4. Motion perception	0.16	−0.17	−0.16	—			
5. Light sensitivity	−0.76	0.06	−0.04	0.17	—		
6. Visual search	0.51†	−0.54†	0.20	0.23	−0.11	—	
7. Visual field	−0.24	0.68‡	−0.19	−0.55*	−0.43	−0.56*	—
Missing values replaced							
1. Visual acuity	—						
2. Contrast sensitivity	−0.82‡	—					
3. Depth perception	0.89‡	−0.81‡	—				
4. Motion perception	0.51‡	−0.50‡	0.63‡	—			
5. Light sensitivity	−0.42†	0.53‡	−0.38†	−0.23	—		
6. Visual search	0.86‡	−0.89‡	0.90‡	0.62‡	−0.43*	—	
7. Visual field	−0.65‡	0.84‡	−0.61‡	−0.60‡	0.43†	−0.75‡	—

* $P < .05$. † $P < .01$. ‡ $P < .001$.

TABLE 5. Partial correlations between visual function and performance controlling for VA

Visual function	Correlation visual function and win ratio controlling for VA
Contrast sensitivity	0.06 ($P = .67$)
Depth perception	-0.02 ($P = .92$)
Motion perception	0.18 ($P = .23$)
Light sensitivity	-0.01 ($P = .93$)
Visual search	-0.08 ($P = .59$)
Visual field	0.15 ($P = .33$)

VA = visual acuity.

competitions, where we assessed the visual function of elite VI judokas using a battery of tests of visual function. Visual function was related to the competitive success of athletes taking part in international competitions over a 4-year period. We found that visual acuity was the only visual function related to performance in judo when controlling for correlations between visual acuity and other visual functions. The current study suggests that those VI judo athletes with visual acuity at or better than 2.6 logMAR experience greater competitive success than do those with visual acuity worse than 2.6 logMAR, implying that VI judo should be split into two classes with a cutoff between classes at or around a visual acuity of 2.6 logMAR.

The use of visual acuity as the main measure of visual function in classification is sometimes criticized for not being sufficiently representative of what is required for functional vision in sports.^{4,21} In agreement with this view, a panel of experts in VI judo believed that the inclusion of additional measures of visual function may improve classification in judo.¹³ However, we found that the inclusion of additional measures of visual function besides visual acuity, including both existing and newly developed tests, did not improve the ability to predict the capability of athletes in VI judo. This does not necessarily mean that the other measures of visual function that we tested are not important in judo but rather, most likely, that, if an athlete has poor visual acuity, then most other measures tend to be poor as well. The significant correlations between visual acuity and the other measures of visual function show that visual acuity offers a good approximation for performance on a variety of other tests such as contrast sensitivity or depth perception that may otherwise be considered more functional for sports performance. Interestingly, as opposed to the opinions of the aforementioned expert panel, motion perception did not correlate with performance (or with visual acuity). Within a dynamic sport such as judo, it may seem surprising that the ability to perceive motion was not related to performance. One explanation for this finding may be that, because both judokas start a VI judo match in contact with each other, those judokas may only need to visually detect the position of the opponent and their limbs (e.g., their foot or arm positions) to guide their actions. The detection of the movement speed and direction of an opponent may be less important, or perhaps judokas are able to compensate by relying on tactile/kinesthetic information rather than vision to perceive motion (i.e., tactile motion perception).^{28,29}

The current study shows that VI impacts performance in VI judo in a nonlinear fashion, with relatively homogenous levels of performance possible when athletes are allocated to one of two groups.

The implication of our results is that VI judo competition should be split into two classes, with a cutoff point at or around a visual acuity of 2.6 logMAR. The main decision tree found a split at 2.6 logMAR, but additional bootstrap analyses most frequently selected 2.5 logMAR as the optimal cutoff point (15.2% of cases), followed by 2.6 logMAR (in 13.4% of cases). Visual function and performance were no longer associated with each other within either of the groups created by the split at 2.6 logMAR, suggesting that there is no competitive advantage within those groups for the athletes with better vision. That result provides reassurance that athletes within those two classes should be able to compete equitably with each other.

The findings largely advocate a split into two classes yet are not entirely inconsistent with the current one-class system. The best-performing participant in our study was actually an athlete with only light perception remaining (i.e., a current B1 athlete), and conversely, some participants with relatively good visual function did not perform well at all. Moreover, Fig. 3 provides some suggestion that the negative correlation between visual function and performance is driven at least in part by four athletes with a win ratio of 0. However, there did not seem to be anything unique about those participants in terms of their age or training history that would justify their exclusion from our analyses. Although the bootstrap analysis showed that no split in the group was necessary in a substantial number of cases (37.5% of 10,000 cases), this may be an overestimation of what would be expected in the wider population. Bootstrapping is predicated on the assumption that the sample used for analysis provides an accurate representation of the wider population, whereas we found that there may be a bias in our data set toward an overrepresentation of better-performing B1 athletes and/or an underrepresentation of better-performing B2/B3 athletes. This means that, if anything, our study may have underestimated the likelihood of a split. On balance, the findings suggest that the current one-class system does not achieve the goal of classification, which is to minimize the impact of impairment on the outcome of competition.¹ This conclusion is in agreement with previous empirical work⁹⁻¹² and the opinion of experts,¹³ which suggest splitting VI judo into two sport classes.

The suggested split at or around 2.6 logMAR found in this study is consistent with previous research, which showed that the current B1 athletes perform worse than do the current B2 and B3 athletes.⁹⁻¹¹ However, these studies were largely conducted by

TABLE 6. Correlations between visual function and judo performance after splitting the data on the basis of VA

Visual function	Correlation visual function and win ratio	
	VA ≤2.6 logMAR	VA >2.6 logMAR
VA	-0.20 ($P = .29$)	0.40 ($P = .13$)
Contrast sensitivity	0.15 ($P = .43$)	NA
Depth perception	0.01 ($P = .97$)	NA
Motion perception	0.28 ($P = .14$)	0.21 ($P = .43$)
Light sensitivity	0.05 ($P = .79$)	NA
Visual search	-0.13 ($P = .51$)	NA
Visual field	0.25 ($P = .25$)	NA

Athletes with VA >2.6 logMAR could not perform most of the additional tests of visual function, meaning that no correlations could be calculated for most visual functions in this group. VA = visual acuity.

FIGURE 4. Distribution of performance across sport classes for the athletes included in this study (left panel) and for all athletes who competed at least twice in any of the tournaments for which data were collected for this study (right panel).

comparing the performance of athletes across the three competition classes rather than directly establishing the relationship between visual function and performance. A recent database study we conducted in a sample of nearly 300 athletes did examine the direct relationship between visual acuity and judo performance based on existing classification data.¹² That study found that a split was necessary at 2.5 logMAR, but additional bootstrap analyses suggested that the optimal cutoff point may lie anywhere between 2.0 and 3.5 logMAR. Visual acuity was, however, assessed in that study using monocular rather than binocular measurements, and visual acuity measurements were collected by classifiers for the purpose of classification rather than by researchers for the purpose of research. The results of the current study seem to confirm that, indeed, a split on the basis of visual acuity around 2.5 to 2.6 is optimal, even when testing visual acuity with both eyes together. However, it remains challenging to establish whether 2.5 or 2.6 logMAR would be the optimal cutoff point, especially as only one athlete in the current sample had a visual acuity of 2.6 logMAR. Although additional research may provide further understanding of the impact of impairment on performance for judokas with visual acuity around 2.6 logMAR, these analyses would likely remain limited because of the very few athletes competing internationally with this level of visual acuity. Besides scientific arguments, ethical considerations may also be necessary in choosing an appropriate cutoff, for instance, when research data are inconclusive about the classification of athletes with a visual acuity of 2.6 logMAR. If those athletes were required to compete against functionally blind athletes, then there is a risk that they may hold an advantage over their competitors. Conversely, if required to compete in the class for athletes with better vision, that athlete could be at a disadvantage. Discourse between scientists, sport philosophers, and policy makers may be required to determine the most favorable outcome for the integrity of the Para sport movement.^{2,30}

Determining an athlete's level of performance is not straightforward within a complex interactive sport such as judo. Skilled performance results from a highly dynamic and complex interaction between two combatants who constantly need to coadapt their movements to each other.³¹ Judo allows for the use of a wide range of offensive and defensive techniques and tactics, and judokas typically develop their own style of play that suits their physical, physiological, and perceptual capabilities. An expert panel judged that

many different aspects of judo performance are impacted by VI, including offensive and defensive skills in both the standing and ground fight.¹³ A limitation in a certain aspect of performance (e.g., the ability to perform a foot sweep) might not readily result in a decrease in overall performance because athletes might resort to a different pattern of play (e.g., increased use of hip techniques). In the current study, performance was measured using each athlete's win ratio over the course of multiple events. This measure provides a good understanding of the overall capability of judokas to perform against different opponents across multiple competitions. However, although an overall measure of performance such as win ratio seems useful to show if performance is impacted by VI, it is limited in providing an understanding of how this impact manifests. Further efforts to quantify specific performance parameters in judo might lead to a better understanding of how VI affects more specific patterns of play in judo. Kons et al.⁹ recently began to explore how VI impacts additional variables that underpin performance in VI judo, including the match time and the variability in the actions executed by the athlete. The development of additional performance parameters next to overall measures such as win ratio may provide a deeper understanding of how VI impacts patterns of play and performance in judo.

The assessment of visual field in this study was limited to testing the integrity of the central visual field rather than the full field. Although visual field is not required to make the primary determination of whether an athlete is functionally blind or partially sighted, it remains possible that the group of partially sighted athletes could be further split into groups with different performance levels on the basis of their visual field size. For instance, the loss of critical areas of the visual field (e.g., the inferior field to see the opponent's feet) could result in a competitive disadvantage when competing against others with an intact inferior field. However, an assessment of existing classification data has shown that only 8.4% of athletes in VI judo currently qualify to compete on the basis of visual field loss.¹² It is therefore questionable whether a separate subgroup would ever really be required or feasible on the basis of visual field loss. Nonetheless, further work is required to examine the impact of visual field loss on judo performance and, in particular, whether those with visual field loss but good acuities should be eligible to compete in VI judo.

CONCLUSIONS

Vision impairment impacts performance under the current system of classification in VI judo. The results of this study suggest

that VI judo competition should be split into separate categories for partially sighted and functionally blind athletes. The inclusion of additional measures of visual function besides visual acuity does not improve the ability to predict performance in VI judo.

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