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Reliability and Normative Data of Computerized Dynamic Visual Acuity Tests

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Statement of Conflict of Interest: *1st, 3rd and 4th authors are independent of the company (RightEye, LLC.) with no conflicts of interest. All analysis and results are conducted by the 1st, 3rd and 4th authors. All data collection was conducted independently of RightEye by experienced vision specialists. The second author works for RightEye as a scientist, is blind to the analysis and follows all ethical considerations during the scientific and experimental process.*

ABSTRACT

Purpose: First, to create a standard for testing DVA using all three testing protocols (head still, object moving; head moving, object still; head and object moving). Second, to examine reliability of the tests. Third, provide normative data.

Methods: Participants (n = 138) were males (n = 83) and females (n = 55) between the ages of 18-44 years old. All participants were tested on the RightEye Dynamic Visual Acuity Tests to determine reliability via Cronbach's Alpha and Intraclass Correlation Coefficients (ICC). Age related differences were also examined across variables for two groups (under 30 and over 30) using t-test analysis.

Results: All Cronbach's Alphas were above an acceptable 0.7 level for reliability, ranging from .703-.953, thus demonstrating strong reliability across all tests. All ICC's were statistically significant. There were no significant differences for age group on all DVA variables (p > .05). Normative data for each variable report means, standard deviations and ranges for participants aged 18-44 years.

Conclusions: Overall conclusions show that the RightEye Dynamic Visual Acuity tests show strong reliability and can therefore be used confidently as a measure of dynamic acuity. Data was collected with multiple testers and still showed excellent reliability. Future studies should examine non-healthy populations as well as young children and older adults.

Being able to see objects as they move is the core purpose of the visual system. Dynamic visual acuity (DVA) represents "the ability to discriminate the fine parts of a moving object during relative motion between the object and the observer"[1] or simply "the ability to recognize a moving target on a horizontal plane".[2] DVA is important for many everyday activities such as maintaining balance, athletics, driving and piloting performance.[1,2] Poor DVA can also be an indication of various clinical conditions such as chronic vertiginous, labyrinthine hypofunction[3] as well as bilateral peripheral vestibular dysfunction and superior canal dehiscence syndrome.[4] Effective DVA performance occurs when the target is on the retina.[1] If the target can be maintained on the

fovea, DVA will be maintained. DVA is highly integrated with the vestibular system. The vestibular canal receptors are the main head movement sensors. The information from these sensors is used by the central nervous system (CNS) to achieve correct Vestibulo-Oculomotor Reflex (VOR) during movement[3] allowing a person to maintain stable vision during large head and/or body movements. As such, DVA is the primary measure of VOR. As critical as DVA is to everyday quality of life, a common complaint is that there is currently no standardized way of testing DVA. This is compounded by the three different methods used to test DVA. One is to move the head at a rate of two degrees per second while keeping the visual stimuli still.[6] A second is to keep the head still while visual stimuli moves (e.g. Wayne Tachistoscope Rotator). Yet a third alternative is to allow the head and visual stimuli to move.[7] Furthermore, testing position is inconsistent, with some tests being conducted while the participant sits, others while they stand and others still in a semi-tandem position.[8] Common to each of these testing methods however, is the ability to elicit the stimuli outside of a two-degree radius from the fovea to examine any change in acuity while the stimuli or person is in motion.

A second limitation of DVA testing is that there is no efficient means of testing. There is no one device that is flexible, scalable, and quantifiable, especially over several patient visits.[5] A portal laser device[5] and computer devices are recent improvements to DVA testing. However, various limitations still exist, including visual distortion for the laser beam with delays in stimuli presentation. Several computerized testing tools have been developed to test DVA in an attempt to provide quantitative outcomes.[11,12,13,14,15,16] One example of a computerized test is the NIH Toolbox[9] which provides quantitative results, but has technological issues that have prevented use of the tool since 2014. Another computerized test, used by Gottshall & Hoffer,[12]

measures only one type of DVA (head moving, object still). The computerized test used in Muinos & Ballesteros[11] provides no directions for head movement or stability throughout the test which allows people to respond differently to the stimuli, potentially confounding the results. The Nike SPARQ Sensory Training Station, is another computerized test that has been found to be reliable[15] and provides comparative data enabling athletes to know where they fall compared to their peers. This test uses a protocol for measuring DVA that is stimuli moving and head moving; it does not include head still or object still protocols. Nevertheless, this is a significant improvement in the ability to test DVA for this protocol of assessment. However, some limitations still exist. Per Poltavski & Biberdorf[16] the Nike SPARQ Sensory Training Station still needs to be evaluated in terms of construct validity and only measures one DVA protocol (both stimuli and head are moving). The Polomar Universal Optotype (Palomar Petit, Palomar Mascaro & Palomas Mascaro, 2008) was recently examined by Quevedo and colleagues.[13,14] This test is beneficial in that it presents stimuli in diverse trajectories, sizes, and speeds to measure DVA. To evaluate saccadic eye movements, a standard Hart chart was used, which is a time-based activity where the user is required to quickly identify numbers or letters in a sequence and call results aloud. Although a long-held tool of optometry, Hart charts infer a gross measurement of saccadic eye movements. Eye tracking provides a more robust, specific, and accurate way to measure such movements.[17] The NeuroCom inVision system tests DVA using the head moving, object still protocol and is specifically used to document impairment in the Vestibular Ocular Reflex (VOR) and gaze stabilization. Reliability results were examined by Riska and Hall[27] and revealed poor-to-fair for DVA loss scores. Inter-rater reliability ranged from poor to excellent. Age differences and normative data were also provided.

Still other computerized DVA tests exist[18,19,20,21] and although progress has been made, to date there is no one device that utilizes all three DVA testing procedures. Furthermore, the ability to provide quantitative, highly specific eye-tracked results with inherent eye movement behavior built into the test is a current limitation of DVA testing. Often, testing focuses on either the testing of VOR through a head moving, target still or the free movement of the head and the object, but not all three types of DVA testing. The RightEye DVA tests include: a) head moving, object still, b) head still, object moving and, c) both head and object moving. The Landolt-C, the gold standard optotype, is used as stimuli as it is known to be culturally neutral, age and literacy independent.[22] Multiple studies have examined the reliability of computerized versions of DVA testing.[27] Results in reliability vary widely depending on the study sample, equipment and algorithm and settings used.[27] Validity by design is not reported and this may also account for the variability in results. The purpose of this paper is to test the reliability (test-retest and intraclass correlation coefficients) for all three computerized DVA testing protocols and normative data for non-clinical conditions.

METHOD
Participants

One hundred and thirty-eight participants were selected for this study and were recruited for testing through advertisements placed on the internet, social media, bulletin boards, and via word of mouth. Participants were between the ages of 18-44 years (M = 22, SD = 3.7), 55 were female and 83 were male.

All participants passed pre-screening requirements. Exclusion criteria included participation in professional sport, abnormal neurological, psychiatric or vision disorders. Additionally, participants who had consumed alcohol or drugs in the 24 hours before the test, were excluded from the study. All participants provided informed consent to participate in this study in accordance with IRB procedure. Participants were compensated with a $20 gift card to any number of local restaurants.

Materials and Equipment

The participants were seated in a stationary (non-wheeled) chair that could not be adjusted in height at a desk within a quiet, dimly lit private testing room in a commercial office or local library (see Figure 1). The participants were asked to look at an NVIDIA 24-inch 3D Vision monitor that could be adjusted in height which was fitted with an SMI 12" 120 Hz remote eye tracker connected to an Alienware gaming system, and a Logitech (model Y-R0017) wireless keyboard and mouse. Participants' heads were constrained using a headrest (Cambridge Research Systems SKU: N2000) where required and unconstrained when the protocol called for free head movement.
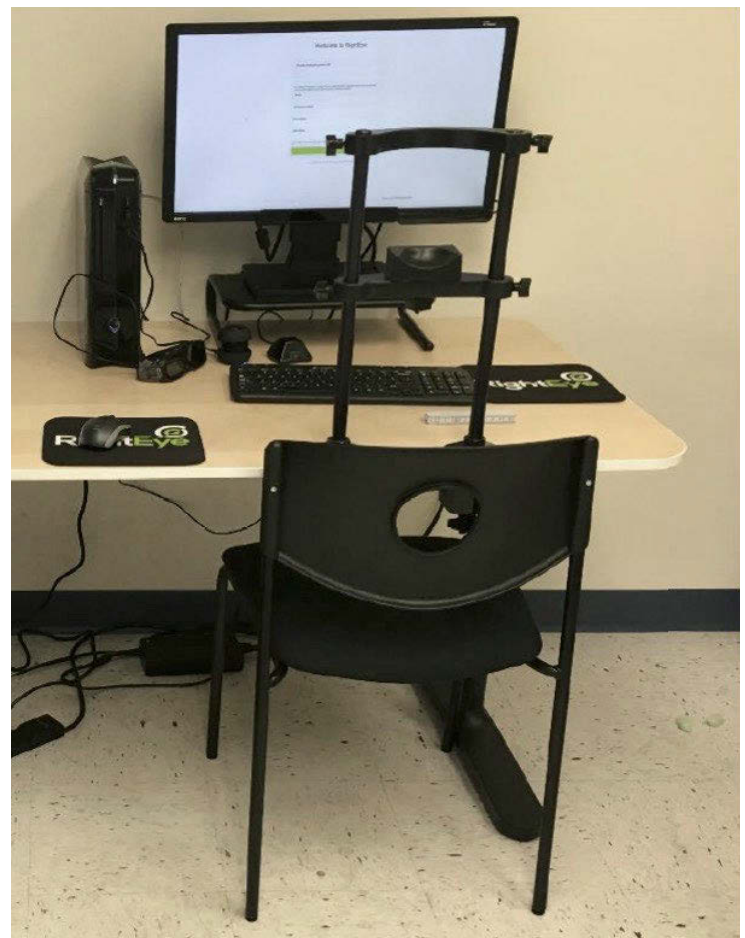
Figure 1: Testing set

Testing Procedure

After informed consent, participants were asked to complete a pre-screen questionnaire and an acuity vision screen where they were required to identify 4 shapes at 4mm in diameter. If any of the acuity vision questions were incorrectly answered the participant was excluded from the study. If any of the pre-screen questions were answered positively then the participant was excluded from the study.

Participants then sat in front of the RightEye eye tracking system and were measured at an exact distance of 60cm (ideal positioning within the head box range of the eye tracker) from the eye tracker for standardization before testing. A nine-point calibration was conducted with points spanning the computer screen. Participants needed to pass all 9-points to proceed with testing.

Upon successful calibration, the three tests commenced. Tests were completed in random order each during each testing session. Written instructions and animations were provided before each test to model appropriate behavior. The tests commenced immediately after one another. Once complete the process was immediately repeated for test-retest reliability. All three tests use the Landolt-C stimuli that appears with the gap open either to the left, right, up, or down. The participant is required to press the arrow key that corresponds to the direction that is open in the C.

Validity by Design

Validity by design, also considered "face validity" or "priori validity" is concerned with whether the test seems to measure what is being claimed. The RightEye DVA tests have several validity by design elements build into each test. These fall into two categories: 1. test stimuli, and 2. test logic and flow.

In addition, to ensure overall testing accuracy, each tester is trained on how to run each test with accuracy and consistency. Each tester is given one hour of dedicated training concluding with a test in the form of a demonstration to an experienced tester requiring a "passing" grade prior to testing any participants. Test logic and flow: after careful consideration of various clinical testing protocols such as the ATS-HOTV Visual Acuity Test Protocol as well as discussions with leaders in the field of optometry and ophthalmology, it was decided that the most effective testing protocol would be the three-phase approach. Phase one is practice, phase two is screening and phase three is testing. In the practice phase, a total of two practice trials are given before the screening phase starts. During the screening phase, the participants have one attempt per testing level; for DVA1 this is stimuli size, for DVA2 and DVA3 this is speed of the stimuli. If they respond correctly, then the next, more difficult, testing level is shown until they respond incorrectly. Once they respond incorrectly, the testing phase begins at that level. The purpose of the screening phase is to reduce testing time by getting participants in the general area of their individual threshold before requiring multiple correct responses at the testing phase. In the testing phase, if the subjects correctly respond to 3 of 3 or 3 of 4 stimuli then the testing level gets more difficult. Participants see no more than 4 stimuli at any one level of difficulty. If they get 2 incorrect responses the stimuli get easier. When the participants fail a testing level, that is, get more than one trial wrong within a level of difficulty during the testing phase, the next stimuli is shown at a lower level of difficulty, if passed, the test ends and the score reported is the last passed level. Specifically considering accuracy of results, the three-phase logic provides the most likely consideration of: a) limiting testing time to reduce the possibility of fatigue, b) reducing the ability to guess due to presenting multiple stimuli at each testing level. Error handling, such as known location of the participants' eyes on the screen, further enhances the confidence that the participant was not guessing, because the eyes can be confirmed as "on the stimuli" target when the

response was made. All such test logic and flow decisions enhance the RightEye DVA tests' validity by design, providing further confidence in the accuracy of the result.

Dynamic Visual Acuity 1 – head moving, object still (DVA1). Using a 200 metronome sound at a rate of 2-hertz, participants rotates their head left and right while keeping their eyes focused on the black box in the center of the screen. At random intervals, the box will change to show a Landolt-C. Stimuli is shown for 2- seconds and a total of two practice trials were given. Stimuli is shown between 0-2 seconds randomly between trials if the eyes are positioned within the black "cue" box. Stimuli begins at a 20-100 size before the three-phase approach to testing is employed. Output is reported as the stimuli size.

Validity by Design for DVA1: One integral feature affecting the accuracy of this test is the eye tracking technology's ability to recognize when the participant is looking at the target. If the target is not being viewed, the eye tracker recognizes this and does not allow the next stimuli to be presented. Furthermore, a message appears saying "look at the stimuli". This ensures a person is viewing the stimuli when responding.

A second part of DVA accuracy is the ability to follow the metronome at a rate of 2 hertz. To ensure this was done correctly all testers are given specific training on how to conduct the test. As part of the testing protocol participants were given practice trials where the timing of head movement in coordination with the metronome was practiced and observed by the trained tester. If assistance was needed the tester would rotate the head of the participant at the rate of 2 hertz.

Dynamic Visual Acuity 2 – head still, object moving (DVA2). At random starting intervals, a Landolt-C moves across the screen from left to right at speeds ranging from 3 to 63 miles per hour. The size of the Landolt-C is a constant 20-100 and moves across the screen and disappears. The participant is given up to 2 seconds to respond after the stimuli disappears from the screen. Stimuli is shown between 0-2 seconds at random intervals between trials. The participant is required to keep their head still and in the chin rest while moving their eyes only to see the stimuli. Once the participant reads the instructions the three-phase testing approach begins. Output is reported as speed of the stimuli (miles per hour) and reaction time (time it took to respond by pressing an arrow key).

Validity by design for DVA2: To ensure the head was still during this test a chin rest was used (see Figure 1). This constrained head motion, requiring the participant to rotate their eyes to foveate on the stimuli and respond accurately.

Dynamic Visual Acuity 3 – head and object moving (DVA3). DVA3 is the same as DVA2 except the participant has free head movement while watching the stimuli.

Validity by design DVA 3: To allow for free head movement during this test the participant was not constrained with the chin rest. Instructions by the tester specifically instructed the participant to "move your head freely to track the stimuli".

Data Analysis

Reliability of the three DVA measures was evaluated using Intraclass Correlation Coefficients (ICC) between testing sessions. In addition, test-to-test reliability was evaluated with Cronbach's Alpha (CA) and the Standard Error of Measurement (SEM) for each ICC. Alpha level was set at $p < .05$ for all statistical test. The ICC indicates the relative reliability and is interpreted using the following criteria ICC > 0.75 specifies excellent reliability and $0.4 <$ ICC$>.74$ represents fair to good reliability.[23] Age related differences were analyzed using group differences in each variable for two groups (under 30 and over 30) as well as a correlational analysis with age and average score across test 1 and test 2 for all DVA variables.

Table 1: Normative statistics for all variables from test 1 to test 2.

	Mean	Median	SD	Standard Error	95% CI for Mean		Min	Max	Range	Interquartile Range	Kurtosis	Variance
					Lower Bound	Upper Bound						
DVA1 Test 1	15.10	12.50	4.72	.403	14.27	15.86	10.00	40.00	30.00	2.72	7.40	22.29
DVA1 Test 2	15.34	15.0	4.94	.423	14.52	16.20	10.00	40.00	30.00	2.72	6.38	24.48
DVA2 RT (ms) Test 1	639.79	640.45	93.70	7.92	622.82	654.18	366.00	934.00	568.00	76.00	1.45	8779.9
DVA2 RT(ms) Test 2	641.40	640.45	91.19	7.66	624.71	655.05	477.00	893.00	416.00	88.00	1.05	8315.9
DVA2 speed (mph)	7.81	5.00	5.837	.488	6.99	8.92	0.00	23.00	23.00	6.00	0.88	34.04
DVA2 speed (mph) Test 2	8.46	8.00	5.88	.497	7.57	9.53	3.00	23.00	20.00	7.00	0.329	34.66
DVA3 RT (ms) Test 1	652.95	646.42	101.73	8.44	634.07	667.47	422.00	935.00	513.00	107.00	0.489	10350.2
DVA3 RT (ms) Test 2	640.15	645.00	93.81	8.04	624.19	656.01	384.00	967.00	583.00	102.00	1.88	8800.99
DVA3 speed (mph) Test 1	7.35	8.00	4.62	.38	6.71	8.23	3.00	23.00	20.00	6.00	1.577	21.38
DVA3 speed (mph) Test 2	8.34	8.00	5.06	.427	8.29	9.18	3.00	23.00	20.00	5.00	0.631	25.62

RT = Reaction Time; mph = miles per hour, ms = milliseconds

Table 2: Test-Retest reliability assessed using Cronbach's Alpha (CA), Intraclass Correlation Coefficients (ICC), and Standard Error of Measurement (SEM).

	CA	ICC	SEM Trial 1	SEM Trial 2
DVA1 dynamic visual acuity	.953	.953*	.4019	.4211
DVA2 reaction time (mph)	.851	.741*	.7639	.7627
DVA2 speed (mph)	.703	.701*	.4966	.5011
DVA3 reaction time (ms)	.780	.639*	.6603	.8595
DVA3 speed (mph)	.758	.758*	.3936	.4324

*p<.05

Table 3: Descriptive statistics for age

Age Group		DVA1	DVA2 reaction time (mph)	DVA2 speed (mph)	DVA3 reaction time (ms)	DVA3 speed (mph)
Under 30 years	Mean	15.17	638.31	7.96	645.07	7.48
	Standard Deviation Median	4.86	92.92	5.82	105.08	4.64
		12.50	639.45	5.00	643.21	5.00
Over 30 years	Mean	14.32	658.84	7.40	653.57	7.00
	Standard Deviation Median	2.40	106.61	4.40	40.73	2.36
		13.75	641.45	8.00	646.42	8.00

RESULTS

Reliability

Descriptive statistics are found in Table 1. Cronbach's Alpha, Intraclass Correlation Coefficients (ICC), and associated SEM for test reliability (Test 1 & Test 2) are reported in Table 2. Observations on each variable demonstrated strong reliability. All Cronbach's Alpha are above an acceptable level of .7 which is considered ideal.[24] Calculated SEMs suggest of the measures are capable of accurate assessment of dynamic visual acuity. All ICC were statistically significant at the $p < .05$ level. In addition, separate paired-samples t-tests were conducted to evaluate whether trial 1 was significantly different from trial 2 for each DVA measure and each demonstrated a non-significant finding. The test-retest reliability and internal consistency does provide a clear indication that these are in fact measuring DVA.

Age Differences

There were no significant differences for groups on all DVA variables (see Table 3). In addition, there was no significant correlation for age and DVA variables ($p > .05$). The correlation for age and DVA 1, visual acuity, produced a slight negative correlation ($r = -.035$), while age and DVA 2, Reaction time (ms) and age and DVA 3, reaction time (ms), both produced low positive correlations ($r = .169$; $r = .212$, respectively). Whereas correlations with Age and DVA 2 speed as well Age and DVA 3 speed produced small negative correlations ($r = -.121$; $r = -.127$, respectively).

DISCUSSION

Although there are several studies which have examined computerized DVA testing,[9,11,12,13] the results vary and no device easily assesses all three DVA testing procedures. The purpose of this study was to determine the test-retest reliability of the RightEye DVA tests and to provide normative data in healthy adults.

Reliability

Overall, the RightEye DVA testing system demonstrated good reliability. The Intraclass Correlation Coefficients produced good to excellent scores for all three DVA measures. In addition, trial-to-trial reliability evaluated with Cronbach's Alpha (CA) produced scores above .7 which is viewed as excellent. The SEM indicates each DVA measure is accurate. For SEM the general indication as reliability increases SEM decreases and lower SEM demonstrate less variance in scores and more accurate test.

Age-related factors further indicate good reliability of RightEye DVA. The correlations were non-significant for Age which is expected given the age of the population tested. In previous work, DVA is shown to decrease with age.[25] In our sample, there was not a likely enough variation in age to demonstrate a significant age effect. However, the correlations for age were in the expected direction and did provide further indication of the reliability of this test.

The reliability of the RightEye test demon-strated equal or better reliability compared

to other tests. For example, Herdman and colleagues[18] demonstrated an ICC of 0.87 for normal populations and ICC of 0.83 for patients with vestibular deficits. Herdman and colleagues[18] also found a significant relationship between age and DVA scores was related to increase in variance for the older populations. Using the NIH toolbox, Rine et al.[26] demonstrated a wider range of ICC scores for DVA measures than was found here and only moderate reliability. Specifically, the ICCs ranged from 0.29 to 0.69. Even given the ICC values, the authors did report the NIH toolbox (which is currently unavailable) as a reliable and valid measure. Riska and Hall[27] recently evaluated the Neuorcom InVision system (based on the NIH toolbox) to test DVA and while it also produced low to excellent reliability (ICCs = 0.323 - 0.957), it is limited in only being able to assess active head movements.

Normative Data

A third purpose is to provide normative data showing expected outcomes for non-clinical conditions to examine differences in various clinical conditions in future experiments. Per Cohen's[28] and Hulley et al.[29] guideline, a sample size of 138 is acceptable for normative guidelines in this type of study. Representation of males and females were adequate. In this study, ages ranged from 18-44. Per developmental literature, DVA improves gradually between infancy to seventeen years of age,[30] then drops with aging.[31,32] Static visual acuity is thought to be almost constant until about 40 years of age after which it decreases gradually,[33,34] whereas DVA is thought to start to decrease at an earlier age and more greatly than SVA.[30] Therefore, caution should be taken outside of these parameters when applying such norms. Future studies should examine children and older adults. Furthermore, these norms are based on a normal (non-clinical) population. Future research should develop norms for clinical populations (e.g. concussed

individuals) and for elite populations (e.g. professional athletes).

Testing Protocol

Within research on DVA, it is often difficult to compare across many studies especially as protocols, sample sizes, equipment, optotypes, algorithms, head velocity, testing distance and even environmental conditions vary considerably. According to Riska & Hall[27] such differences may contribute to reliability of a test. Consistency in this protocol may have therefore contributed to the reliability of the results. Other important test differences can include the logic or algorithmic development of the score or final output. Such logic influences the amount of "guessing" or invalid results that could influence the outcome. Test logic for the RightEye DVA tests follows the Amblyopia Treatment study – HOTV testing logic. Logic from this protocol has been widely used and accepted in many past research studies[24,35] including use in different ages, gender and ethnic groups. Along with the E-ETDRS protocol it is the most widely used protocol for acuity testing and is also used in many commercial products (e.g. Precision Vision, Visual Acuity Test). Such logic and protocol development lends to further confidence in the outcomes of this study.

Limitations

The data was collected with multiple testers and demonstrated excellent reliability, however, future studies should consider inter-rater reliability to ensure testing remains consistent across many testing sites. Future work will need to examine the sensitivity and specificity of this measure as well as examine the validity with a clinical population (e.g., patients with vestibular deficits). Furthermore, extending the age ranges to younger and older adults are important next steps.

Additional steps need to be taken to quantify head movement for DVA1 to ensure

the accuracy of timing with the metronome in a quantitative manner, rather than by design (qualitative). Additional error proofing should also be added to DVA2 and DVA3 to show the eyes were tracking on the target to give further confidence in the validity of the results. Finally, the amount of head movement could be an additional metric for consideration of DVA3. It was be interesting to know which participants, that is those with more, or less, head movement did better.

CONCLUSIONS

The purpose of the current study was to examine the reliability of DVA using three different protocols (head still, object moving; object moving, head still; head and object moving). Normative data was also examined for healthy adults. Results reveal very high reliability. Normative data and test logic follow recommended standards. In conclusion, the RightEye DVA tests are shown to be a reliable measure of DVA for healthy adults.

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