

A Battery of Quantitative Binocular Vision Tests for Adults: Testing Protocols

Xiaoxin Chen¹, Andrew Silva^{2,3}, Fermin Retnavarathan⁴, Ewa Niechwiej-Szwedo¹, Xiaoqing Gao⁶, Daphne Maurer⁴, David I. Shore^{4,5}, Benjamin Thompson^{2,7,8}

¹Department of Kinesiology and Health Sciences, University of Waterloo ²School of Optometry & Vision Science, University of Waterloo ³Department of Psychology, Idaho State University ⁴Department of Psychology, Neuroscience & Behaviour, McMaster University ⁵The Multisensory Mind Inc. ⁶Center for Psychological Sciences, Zhejiang University ⁷Centre for Eye and Vision Research, Hong Kong ⁸Liggins Institute, University of Auckland

✉ Corresponding Authors : Xiaoxin Chen <xiaoxin.chen@uwaterloo.ca>, Benjamin Thompson <ben.thompson@uwaterloo.ca>

Citation

Chen, X., Silva, A., Retnavarathan, F., Niechwiej-Szwedo, E., Gao, X., Maurer, D., Shore, D.I., Thompson, B. A Battery of Quantitative Binocular Vision Tests for Adults: Testing Protocols. *J. Vis. Exp.* (232), e70954, doi:10.3791/70954. (2026).

Abstract

Sensory fusion and stereopsis are two crucial components of binocular depth perception. Current clinical tests do not provide a quantitative measure of sensory fusion and assess limited aspects of stereopsis. More importantly, patients who show no binocular fusion in standard clinical tests can demonstrate binocular integration and perceive depth from binocular disparity and motion cues, suggesting that current tests are insufficient to examine all aspects of binocularity. A battery of eight tests is presented here to provide a comprehensive assessment of binocular vision. These tests are designed to refine and extend existing assessments by targeting different components of binocular processing. Specifically, letter ocular dominance and plaid motion integration provide quantitative measures of sensory fusion. Binocular integration in peripheral vision is evaluated using fine- and coarse-peripheral stereopsis tests, dynamic local stereopsis, and motion parallax. Motion-in-depth is assessed by dynamic local stereopsis, the Pulfrich task, and motion parallax. An additional da Vinci stereopsis test provides qualitative insight into binocular integration by measuring the occlusion difference between the two eyes. Exemplary results are shown from a participant with normal vision. Modifications to the current protocol can be made to accommodate specific needs and to support applications in broader populations.

Introduction

Binocular vision enables accurate depth perception through three hierarchical processes. The first step is simultaneous perception, in which the observer perceives information from both eyes. Subsequently, motor and sensory fusion occur when the two eyes are aligned and receive spatially correlated images. Stereopsis is the highest level of sensory fusion and relies on the processing of binocular disparity^{1,2}. A range of clinical tests is available to assess simultaneous perception and motor fusion, for example, synoptophores, fusional vergence using prisms, and Worth 4-Dot (W4D) tests^{3,4,5}. However, quantitative assessment of sensory fusion and stereopsis outside of central vision remains limited.

The purpose of this test battery is to evaluate aspects of binocular processing that are not currently assessed.

Sensory fusion is clinically assessed using tools such as the W4D test and Bagolini striated lenses^{3,4,5}. These methods effectively determine whether a patient achieves binocular fusion or suppresses input from one eye. However, they are qualitative and unable to differentiate between patients with varying capabilities in sensory fusion. The battery of tests proposed here provides a quantitative measure of sensory fusion and interocular suppression⁶ based on the letter ocular dominance test and plaid motion integration^{7,8,9}.

Stereopsis can be assessed using various clinical tests, including the TNO, Randot, and Frisby stereo tests^{3,4,5}. While these instruments provide quantitative measures of stereoacuity, they remain limited in several aspects^{10,11}. First, these printed tests offer only a fixed range of disparity levels, separated by discrete steps. Second, stereopsis is assessed only within central vision, where visual resolution is highest^{12,13,14}. Third, printed formats measure only static stereopsis. It is well known that the processing of binocular disparity and motion information is linked at a neural level¹⁵; thus, it is important to develop tests that incorporate motion cues.

All tasks in the proposed battery aim to address these limitations by applying rigorous psychophysical methods, including adaptive procedures and the method of constant stimuli. The battery consists of eight tests (**Table 1**), targeting different components of depth perception. The tasks are designed to provide precise

estimates of the individual thresholds for sensory fusion, stereopsis in peripheral vision^{16,17,18}, and perception of motion-in-depth^{19,20,21,22}.

This protocol requires minimal equipment, with most components easily replaced with standard commercial materials or purchased from a specialized vendor for the mirror stereoscope. The response box is optional and can be 3D-printed. The full test battery is best suited to research environments where longer testing durations are feasible (approximately 85 min, plus instructions, practice trials, and breaks). Nevertheless, subsets of these tests can yield quick and valuable insights into specific aspects of binocular vision (**Table 1**) for researchers and clinicians, especially peripheral stereopsis and motion-in-depth, domains that are not currently tested in clinical settings. With a basic understanding of psychophysical principles and minimal Python programming, these tasks can be modified to suit different research or clinical needs.

Task	Features	Stimulus eccentricity	Methodology	Formal test duration (min)
Letter ocular dominance	Sensory fusion	3.75°	Two 1-up-1-down staircases & the method of constant stimuli	7
Plaid motion integration	Sensory fusion	0°	3 one-minute trials	3
Fine peripheral stereopsis	Central & peripheral stereopsis	0° & 10°	2-interval forced choice; 1-up-2-down staircases	20 (4 min per location)
Coarse peripheral stereopsis	Peripheral stereopsis	5°	15 trials per condition	5
Dynamic local stereopsis	Motion-in-depth; central & peripheral stereopsis	6°	2-interval forced choice; 1-up-2-down staircases	25 (5 min per location)
The Pulfrich task	Stereopsis from temporal disparity	Full screen	The method of constant stimuli	12
Motion parallax	Occlusion; motion-in-depth	4°	1-up-2-down staircases	10
Da Vinci stereopsis	Occlusion; binocular integration	1.5°	10 trials per condition	3

Total test duration				85
---------------------	--	--	--	----

Table 1: Overview of tasks in the battery. Description of the eight tasks included in the battery. Note that test durations do not include practice and breaks.

Protocol

This study protocol was approved by the University of Waterloo Office of Research Ethics (44843) and the McMaster Research Ethics Board (1733). All procedures were conducted in accordance with the principles outlined in the Declaration of Helsinki. Written informed consent was obtained prior to their participation. For specifications regarding the test stimulus, please refer to **Supplementary File 1**.

1. Prepare equipment setup

1.

Set up the mirror stereoscope as shown in **Figure 1**.
2.

Position the monitor at a viewing distance of 99.5 cm.
- NOTE:**

The viewing distance is the sum of three components: the distance from the monitor to one of the large mirrors, the distance between the large and small mirrors, and the

distance from one of the small mirrors to the chinrest. At this distance, each pixel on the monitor subtended.

$$\tan^{-1}\left(\frac{0.595/3840}{0.995}\right) \times \frac{180^\circ}{\pi} \approx 0.0089^\circ \approx 32.12 \text{ arcsec.}$$

3.

Change viewing distance based on individual hardware, interested eccentricities, and a desired pixel size.
4.

Perform gamma calibration for the monitor for luminance, red, green, and blue separately.
5.

Measure the width of the screen in centimeters.
6.

Open PsychoPy Coder. Click the **Monitor** icon at the top for monitor calibration and settings.
7.

In the pop-up **PsychoPy Monitor Center** window, click **New** to create a new monitor. Input correct viewing distance, screen size in pixels, screen width, minimum and maximum luminance, and gamma values for grey-scale, red, green, and blue colors. Click **Save**.

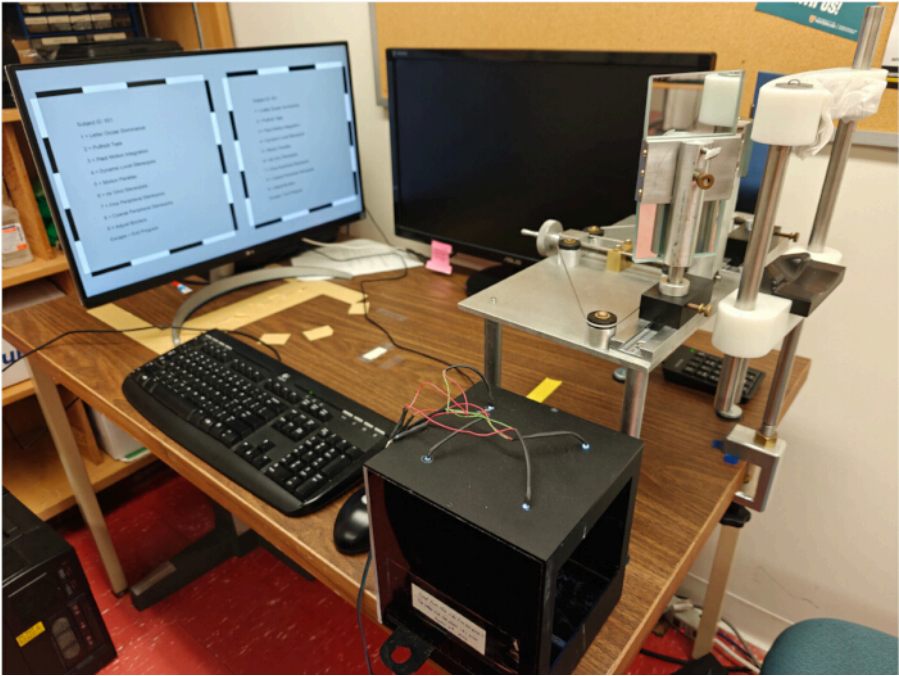


Figure 1: Experimental setup. Experimental setup showing a monitor, a mirror stereoscope, a chinrest, a response box, a keyboard, a mouse, and a numeric pad for participants. [Please click here to view a larger version of this figure.](#)

2. Start the experiment

NOTE: This step provides general instructions for running practice tests and formal tests. Specific instructions for each task are provided in steps 3–10.

1. Open **BinocularBattery.py** in PsychoPy Coder.
2. Modify the monitor information in the script, including monitor name, refresh rate, and resolution according to the monitor being used.
3. Click the **Run experiment** button at the top.
4. Instruct a participant to look through the mirror stereoscope.
 1. Ask the participant if they see a cross in the middle, comprised of a vertical line and a horizontal line. If not, ask the participant whether they need the vertical line to move to the left or right.
 2. Use the left and right arrow keys to move the vertical line towards that direction, until the participant sees the vertical line in the middle of the horizontal line. Press **Enter** to continue.
5. Assign and input a participant ID in the program for the participant. At the Main Menu screen, use the numeric pad to select each task.
 1. Start by running a practice test.
 1. Provide instructions for each task as provided below in steps 3–10.
 2. Complete the practice test and evaluate results.

NOTE: Some tasks do not provide accuracy scoring (i.e., letter ocular dominance, plaid motion integration, and Pulfrich). Refer to the Representative Results section for guidance on interpreting performance for these tasks.
 3. If practice results are below 80% correct (for accuracy-based practices) or are unexpected (for tasks without accuracy scoring), press **Enter** and select the test to restart a practice.

4. Proceed to run a formal test when a participant's results are above 80% correct (for accuracy-based practices) or are consistent and interpretable (for tasks without accuracy scoring) for the last two practice tests.

NOTE: If a participant's performance remains below 80% correct or inconsistent across several practice tests despite proper instruction, the experimenter should abort the task, as results may be unreliable.

2. Run a formal test.
 1. Instruct the participant to perform the task.

NOTE: Throughout testing, it is critical to remind the participant to maintain fixation on the fixation cross, if present.
 2. After completion, evaluate the results of the formal test.

NOTE: If the results appear unusual, a second formal test may be performed to confirm the findings.
 3. Press Enter to return to the Main Menu and select the test again.

3. Run letter ocular dominance

NOTE: One formal test consists of two 1-up-1-down staircases and the method of constant stimuli.

1. Present the letter ocular dominance stimulus as shown in **Figure 2A**. Instruct the participant to fixate the central cross while paying attention to the luminance of two letters presented above and below the fixation cross.
2. Instruct the participant to use keys **8** or **5** on a numeric pad to indicate which letter (top or bottom) appeared brighter while fixating the central cross.

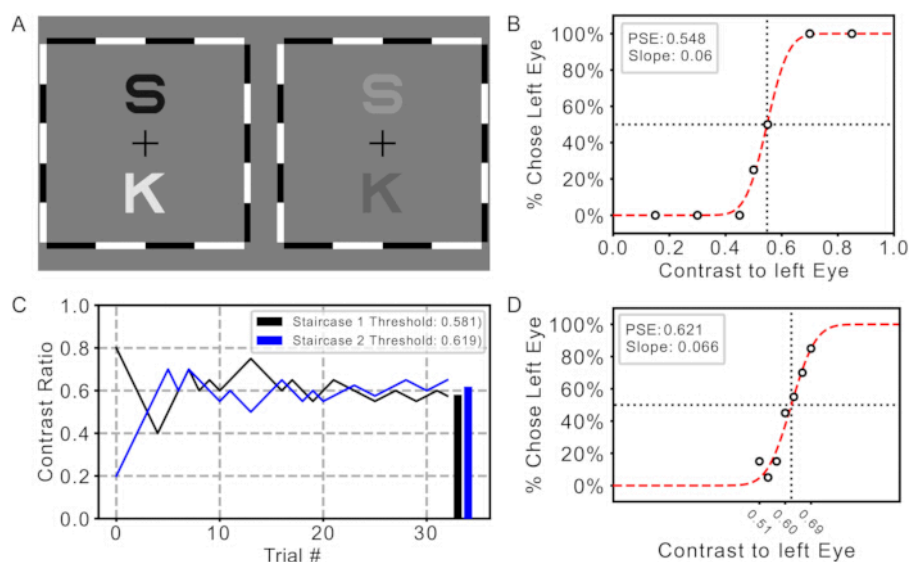


Figure 2: Letter ocular dominance task and results. (A) Test stimulus. (B) Results from a practice test using the method of constant stimuli. (C) Results from two staircases. Black and blue lines represent contrasts at each step of the two staircases. Colored bars represent thresholds obtained from respective staircases. (D) Psychometric function from the method of constant stimuli. Dots indicate percentages of trials where the participant perceived a letter presented to the left eye as brighter at each contrast tested. The red curve represents a fitted psychometric curve. The intersection of the dotted lines depicts the estimated point of subjective equality (PSE). [Please click here to view a larger version of this figure.](#)

4. Run plaid motion integration

NOTE: Use the initial demonstration to familiarize the participant, then press Enter to start a practice trial.

1. Present the moving grating stimulus as shown in [Figure 3A](#). Instruct the participant to look at the moving gratings, which can move in 1 of 5 directions, as indicated on the screen, or in both left and right directions simultaneously (**split**).
2. Ask the participant to verbally report the perceived motion direction and any change in the perceived motion while viewing the stimulus.
3. Press and hold the corresponding number (1–5 for each direction as labeled or 0 for split motion) until the participant reports a different number.

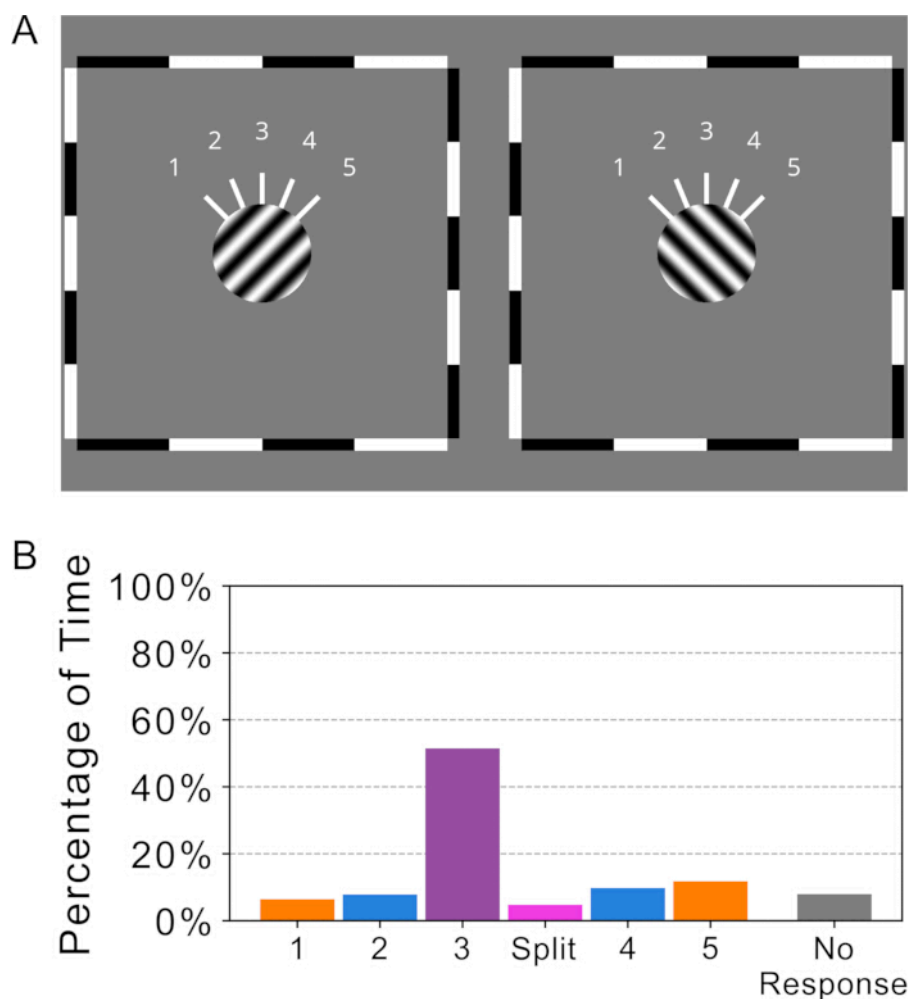


Figure 3: Plaid motion integration task and results. (A) Test stimulus. (B) Representative results. Colored bars represent the percentage of time when the participant reported each perceived motion direction as labeled, including **split** when both left and right directions are seen simultaneously. [Please click here to view a larger version of this figure.](#)

5. Run fine peripheral stereopsis

1. Present the peripheral and central stereopsis stimuli as shown in **Figure 4A,B**. Use the **Stationary** task to familiarize the participant.
 1. Instruct the participant to fixate the cross, wherever it is presented on the screen.
 2. **NOTE:** Watch the participant's eye movement to ensure that their gaze follows the fixation cross.
 3. Ask the participant whether the black square appears behind or in front of the white frame or appears on the same plane.
4. Press 1 if the black square has depth, or 2 if not.
2. Use the **Regular** task to practice with the 2-interval forced-choice task.
 1. Inform the participant that the stimulus will flash twice, and the depth will appear in one of the two flashes.
 2. Instruct the participant to report in which of the two flashes they see the depth.
 3. Press 1 or 2 based on the participant's choice.
3. Run a formal test with the same instructions as the **Regular** practice.

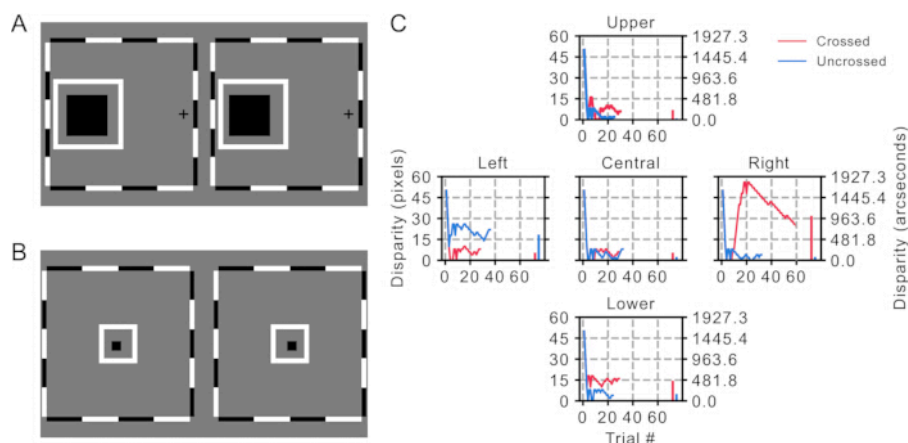


Figure 4: Fine peripheral stereopsis task and results. (A) Test stimulus for the peripheral task. (B) Test stimulus for the central task. (C) Representative results. Red and blue curves represent staircase data for crossed and uncrossed disparities, respectively, at each location (0° and 10° eccentricity). Colored bars on the right side of each graph indicate thresholds obtained from respective staircases. [Please click here to view a larger version of this figure.](#)

6. Run coarse peripheral stereopsis

NOTE: Press the space bar to start a trial.

1. Present the coarse stereopsis stimulus as shown in **Figure 5A**. Instruct the participant to maintain fixation on the cross.
2. When the stars have disappeared, ask the participant the following questions: **did you see depth?** if **yes**, **'were the star(s) appearing behind or in front of the moons?'** and **'how many stars were presented?'**
3. Use the up and down arrow keys to select a response and use the left and right keys to navigate between questions.

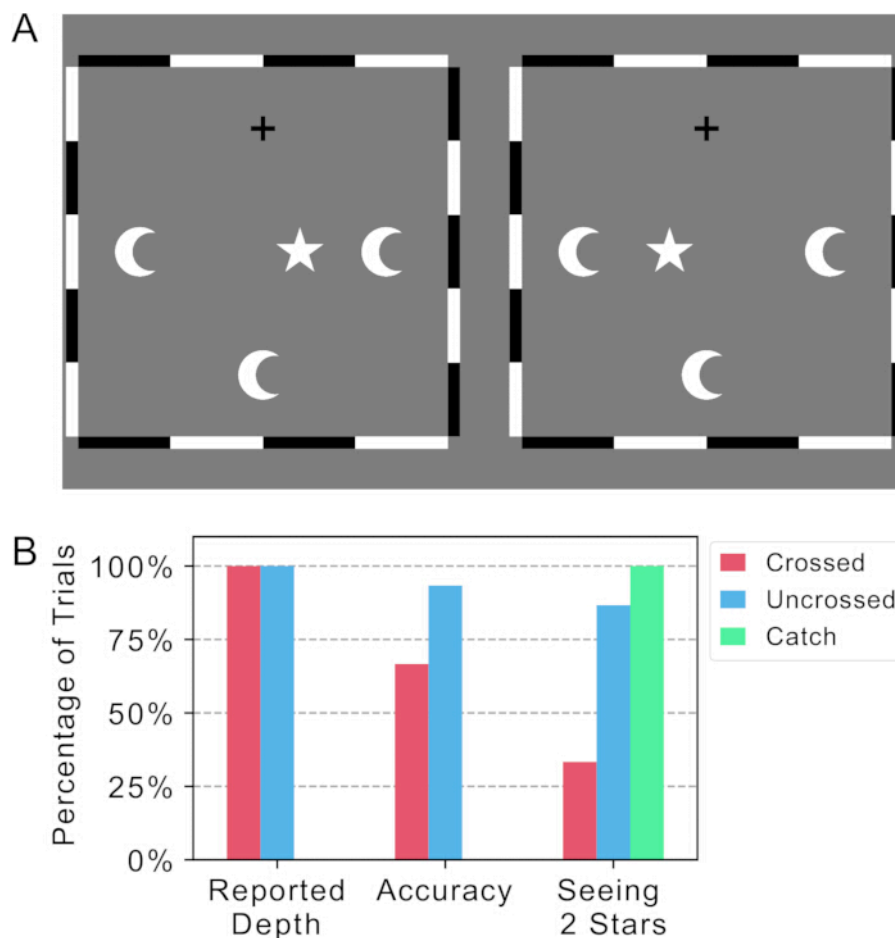


Figure 5: Coarse peripheral stereopsis task and results. (A) Test stimulus. (B) Representative results. Red, blue, and green colors represent data from crossed, uncrossed, and catch trials, respectively. Left bars represent the percentage of trials in which depth was reported. Middle bars represent the proportion of correct depth direction responses from trials where depth was reported. The right bars show the percentage of trials in which two stars were reported. [Please click here to view a larger version of this figure.](#)

7. Run dynamic local stereopsis

NOTE: This test contains four practice trials designed to provide step-by-step guidance to help readers become familiar with the task.

1. Present the dynamic stereopsis stimulus and task interface as shown in **Figure 6A,B**. Start by running practice Task 1 (single location, single interval).

1. Instruct the participants to look at the center, while paying attention to the target location as specified.

NOTE: To help the participant understand the stimulus, allow them to look directly at the target location only during practice.

2. Ask the participant whether the square moved closer to or farther away from them.
3. Press **1** if the participant saw motion in depth, or **2** if not.

NOTE: Horizontal motion does not count as motion in depth.

4. For patients with better vision in the periphery than in the center, advise the patient to use their peripheral vision to look at the target location.
5. If the participant is able to see motion-in-depth, proceed to the next practice task.
2. Run practice Task 2 (single location, two-interval forced-choice).
 1. Inform the participant that the stimulus will now flash twice.
 2. Ask the participant which of the two flashes contains motion in depth at the target location as specified.
 3. Press **1** or **2** based on the participant's choice.

4. If the participant fails to see motion-in-depth reliably, reinstruct them and allow them to look directly at the target location.
5. If the participant is able to see motion-in-depth, proceed to the next practice task.
3. Run practice Task 3 (two locations, two-interval forced-choice).
1. Provide the same instructions as Task 2, except that the target may now be at either of two locations.
4. Run practice Task 4 (Full Practice).
1. Provide the same instructions as Task 3, except that the target may now be at any of the four peripheral locations.
5. When ready, run **Dynamic Periphery** and **Dynamic Center** for a formal test.

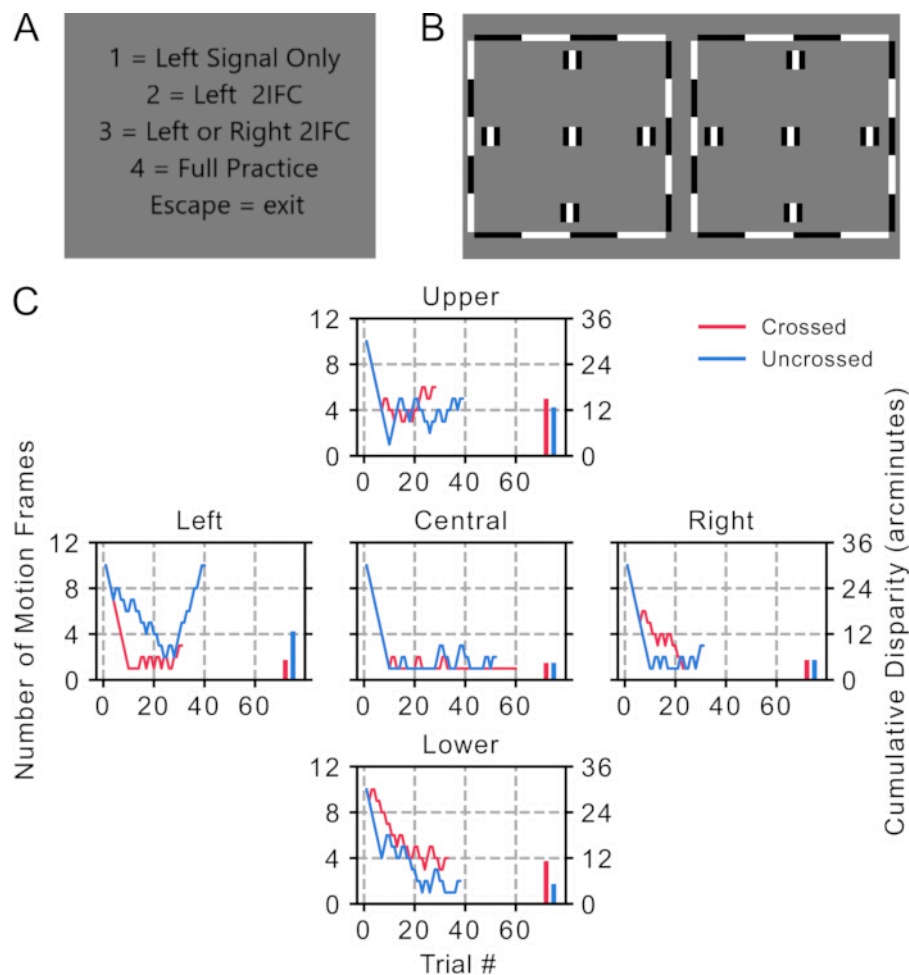


Figure 6: Dynamic local stereopsis task and results. (A) Menu for step-by-step practice. (B) Test stimulus. (C) Representative results. Red and blue curves represent staircase data for crossed and uncrossed disparities, respectively, at each retinal location (0° and 5° eccentricity). Colored bars on the right of each graph indicate thresholds obtained from respective staircases. [Please click here to view a larger version of this figure.](#)

8. Run the Pulfrich task

NOTE: Luminance on one half of the screen is reduced (**Figure 7A**) to mimic neutral density (ND) filters.

1. Present the Pulfrich task stimulus as shown in **Figure 7A**. Confirm whether the participant can see depth and whether the moons are moving in front of or behind the stars.
2. Ask the participant to use the / or * key to move the stationary moon at the bottom of the screen forward or backward, until it appears to be at the same depth as the moving moons.
3. Optional: ask the participant to indicate the amount to depth perceived using the response box (**Figure 7B**).
 1. Present the response box to the participant, facing the participant, with the center of the box approximately 40 cm away from their eyes.

2. Ask the participant to move the slider on both sides of the box until the moons inside the box appear to be at the same depth as the moving moons on the computer screen.
 3. Type the reading on the slider onto the computer screen.
Press **+** to move on.
- NOTE:** The physical response box is described in **Supplementary File 2**.

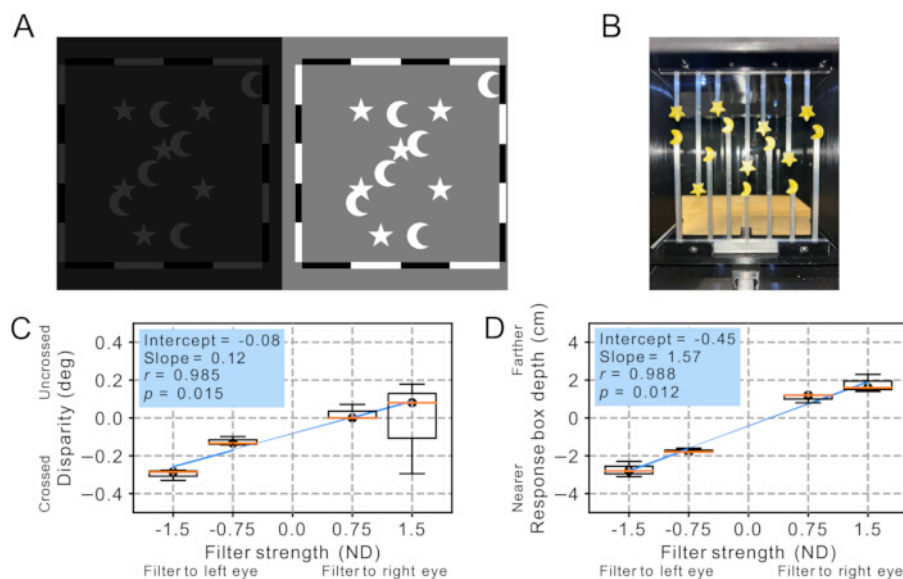


Figure 7: Pulfrich task and results. (A) Test stimulus. All moons are in motion except the one at the bottom. (B) Inside view of the response box, showing stars affixed to the ceiling and moons on a rail. (C) Results from the disparity-matching task. Medians are indicated by black dots and orange lines. Boxplots represent the range (minimum and maximum) and the interquartile range. Note that because only three trials were tested per filter strength, the medians and extremes reflect all data for each condition. Blue lines represent linear regressions performed using median data across all filter strengths. (D) Results from the physical depth-matching task. Medians are indicated by black dots and orange lines. Boxplots represent the range (minimum and maximum) and the interquartile range. Note that because only three trials were tested per filter strength, the medians and extremes reflect all data for each condition. Blue lines represent linear regressions performed using median data across all filter strengths. [Please click here to view a larger version of this figure.](#)

9. Run motion parallax

1. Present the motion parallax stimuli as shown in **Figure 8A,B**. Instruct the participant to fixate on the central cross.
2. Press Enter to start a trial.
3. Instruct the participant to report the square that appeared elevated in depth during the rotation, while fixating the central cross.
4. Press the corresponding number for that square.

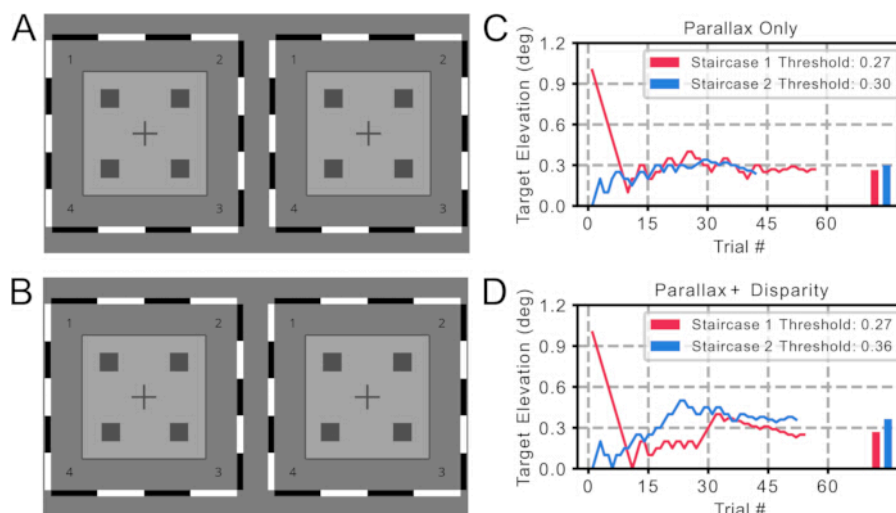


Figure 8: Motion parallax task and results. (A) Test stimulus for the “parallax” task. (B) Test stimulus for the “parallax + disparity” task. Note that the bottom left square in this example (number “4”) contains a binocular disparity cue. (C) Representative results from the “parallax” task. Red and blue lines represent raw data from two staircases. Colored bars represent thresholds obtained from respective staircases. (D) Representative results from the “parallax + disparity” task. Red and blue lines represent raw data from two staircases. Colored bars represent thresholds obtained from respective staircases. [Please click here to view a larger version of this figure.](#)

10. Run da Vinci stereopsis

1. Present the dichoptic stimulus configuration as shown in **Figure 9A**. Instruct the participant to compare the depth of the two bars relative to the large box and report which bar appears to be in front of the box.
2. Press **8** or **5** for the top or bottom bar, or press **Enter** if they all appear on the same plane.
3. During practice, if the participant sees depth in a catch trial, reinstruct them to ensure that they understand the task.

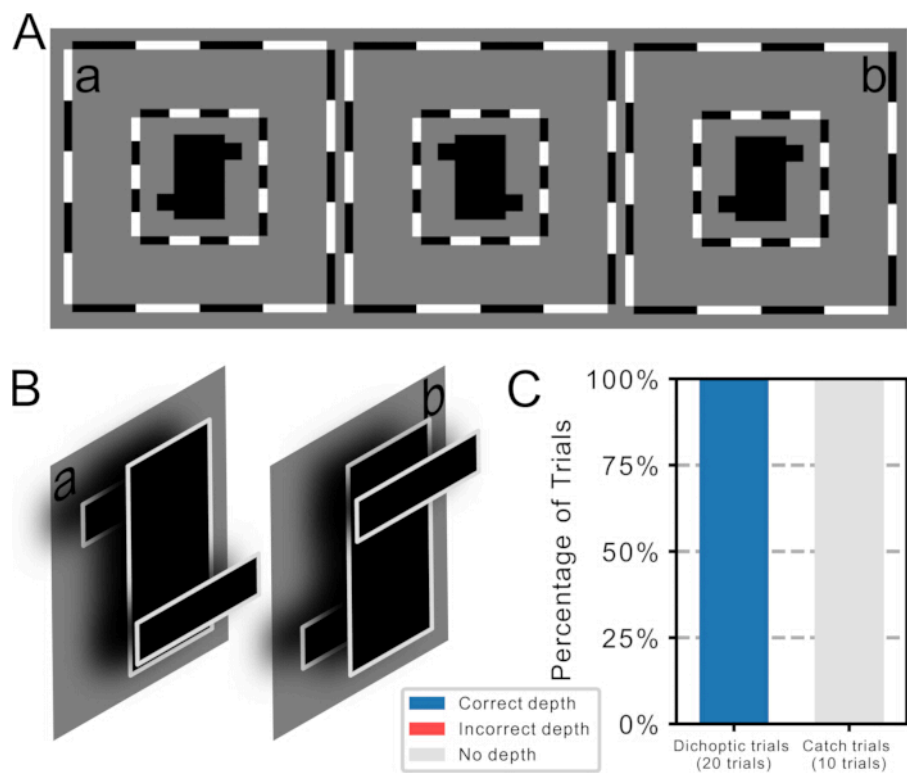


Figure 9: Da Vinci stereopsis task and results (A) Illustration of the test stimulus, showing two pairs of dichoptic stimuli. (B) Perceptual outcomes after fusion. By crossing the eyes, fusing the left and middle stimuli produces the illusion shown in (a), and fusing the middle and right stimuli produces the illusion shown in (b). Note that during each trial, only one stimulus pair is shown. (C) Representative results. Blue, red, and gray bars indicate the percentage of trials in which participants reported correct depth, incorrect depth, or no depth. Note that all responses were correct in this example; hence, no red bar is presented. [Please click here to view a larger version of this figure.](#)

Results

Representative data were collected from a 20-year-old participant with normal vision (visual acuity 0.0 logMAR for each eye; stereoacuity 40 arcsec).

Letter ocular dominance

Results from two staircases and the method of constant stimuli (Figure 2C,D) indicate slightly stronger right-eye dominance for this participant.

Expected results: Each staircase should progressively approach its threshold, with the final few reversals clustering near that point. Ideally, both staircases should converge to a similar threshold.

The psychometric curve should appear S-shaped, with data points ideally located on or around the curve. An inverse S shape likely indicates a wrong response, as it reports the darker rather than the brighter letter. For a participant with normal vision, the staircase thresholds and PSE are typically near 0.5. In addition, the PSE should fall within the range of contrasts tested and align with staircase results; if not, it may indicate poor or intermittent adherence to instructions or an unstable ocular dominance.

Clinical relevance: This task, originally created by Bossi et al.^{23,24} provides an evaluation of participants’ ocular dominance and the strength of interocular suppression. Patients with strong suppression will show a PSE closer to either end (0 or 1). Results of this test go beyond a binary determination of ocular dominance by enabling a more detailed classification, as illustrated in Table 2.

Classification	PSE range	Eye dominance
Dichotomous	< 0.5	Left eye dominance
	> 0.5	Right eye dominance

Detailed	< 0.4	Strong left eye dominance
	0.4 - 0.48	Weak left eye dominance
	0.48 - 0.52	Balanced
	0.52 – 0.6	Weak right eye dominance
	> 0.6	Strong right eye dominance

Table 2: Interpretation of ocular dominance results. Interpretation of letter ocular dominance test results. Note that the detailed classification was determined based on prior work of the authors^{36,37} and can be adjusted as needed.

Plaid motion integration

Results indicate predominantly fused motion perception (response 3), with slightly longer dominance by the right eye (responses 4 and 5) (Figure 3B).

Expected results: Participants with normal vision are expected to show a range of responses indicating fusion (3), partial fusion (2, 4, or Split), and non-fusion (1 and 5). Their responses should appear broadly symmetrical for both eyes, indicating weak or balanced ocular dominance.

Clinical relevance: This task provides an evaluation of the participant’s ocular dominance and the contribution of both eyes over time. Patients with strong suppression will perceive the motion presented to the dominant eye for a longer duration, resulting in a skewed distribution toward that eye. Percepts of fused motion can indicate binocularity that might not be detected through other tasks.

Fine peripheral stereopsis

Results show fine stereopsis thresholds at central and four peripheral locations at 10° eccentricity, with lower thresholds at the center compared to the periphery (Figure 4C).

Expected results: Each staircase should approach its threshold progressively, with the final few reversals oscillating around it. In Figure 4C, most staircases follow this pattern. However, the staircase for crossed disparity in the right visual field failed to converge onto a threshold and should be interpreted with caution. Ideally, this condition should be retested. Note that the thresholds here are higher than the clinically-normal threshold (60 arcseconds²⁵) due to the brief presentation time of stimuli and testing in the periphery.

Clinical relevance: This task evaluates stereopsis thresholds at central and peripheral locations using psychophysical staircases. Patients with clinically non-measurable central stereo vision may still exhibit relatively preserved peripheral stereo vision.

Coarse peripheral stereopsis

Results show that depth was perceived in all trials, with the direction of depth correctly identified in most cases (Figure 5B). Fusion of the stars into a single object occurred in two-thirds of crossed trials, suggesting that a larger disparity may be required to assess coarse stereopsis for this individual.

Expected results: Participants capable of perceiving coarse stereopsis are expected to consistently report depth (100% of trials), accurately identify the type of depth (100% of trials), and reliably report seeing two stars (100% of trials). If a participant correctly reports depth but perceives only one star, this indicates successful fusion of the stimulus and would not qualify as coarse stereopsis, suggesting that larger disparities may be required to test their coarse stereo.

Clinical relevance: This task evaluates coarse stereopsis thresholds at a peripheral location. Patients with clinically non-measurable central stereo vision may still form depth perception using diplopia cues at peripheral locations.

Dynamic Local Stereopsis

Results show thresholds for crossed (looming) and uncrossed (receding) disparities at central and four peripheral locations, with slightly lower thresholds observed at the center compared to the periphery (Figure 6C).

Expected results: Each staircase should approach its threshold progressively, with the final few reversals oscillating around it. In Figure 6C, most staircases follow this pattern. However, the staircase for uncrossed disparity in the left visual field failed to converge onto a threshold and should be interpreted with caution. Ideally, this condition should be retested.

Clinical relevance: This task assesses the ability to perceive depth from accumulated disparity cues over time, at both the center and 5° eccentricity. This motion-in-depth is not being assessed in current clinical assessments. This task will help gain an understanding of patients’ depth perception and motion processing. Patients with clinically non-measurable static stereo vision may still exhibit depth perception for moving objects.

The Pulfrich task

Results show a linear relationship between filter strength and perceived depth using both measures, with intercepts close to 0, indicating no spontaneous Pulfrich perception (**Figure 7C,D**).

Expected results: Ideally, trials at each filter strength should yield minimal variance (narrow and symmetrical boxplots). The fitted linear regression line is expected to pass through the median response at each filter strength. For participants with equal vision in both eyes, a filter placed over the left eye (denoted as negative) should induce depth in front of the screen, reflected by crossed disparity and nearer moons. Conversely, a filter placed over the right eye (denoted as positive) should induce depth behind the screen, reflected by uncrossed disparity and farther moons. No spontaneous Pulfrich perception (an intercept of 0) is expected for participants with normal binocular vision.

Clinical relevance: This task assesses the ability to perceive depth based on temporal disparity induced by reduced illumination in one eye^{26,27,28}. The slope can indicate patients' sensitivity to changes in filter strength. A non-zero intercept indicates spontaneous Pulfrich perception, as has been reported in patients with amblyopia^{29,30}.

Motion Parallax

Results show similar thresholds for both the "parallax" and "parallax + disparity" tasks (**Figure 8C,D**).

Expected results: Each staircase should approach its threshold progressively, with the final few reversals oscillating around it. Ideally, both staircases in a single task should converge on a similar threshold.

Clinical relevance: While motion parallax is a monocular depth cue, it shares similarities with binocular disparity^{31,32}. Both cues arise from differences in projected retinal locations, either by viewing with both eyes (in the case of binocular disparity), or viewing from different vantage points (in the case of motion parallax)^{31,32}. It is therefore important to understand how individuals, particularly those unable to appreciate binocular cues, utilize motion parallax cues.

Da Vinci stereopsis

Results indicate that this participant reliably perceived da Vinci stereopsis (**Figure 9C**).

Expected results: Participants are expected to report the correct depth type on all dichoptic trials and no depth on catch trials. The opposite, incorrect type of depth is generally not expected, given the geometry mechanisms for occlusion and camouflage^{33,34,35}. Participants lacking binocular integration are expected to report no depth on all trial types.

Clinical relevance: This task assesses the ability to perceive depth based on occlusion cues. Although depth perception derived from da Vinci stereopsis is generally imprecise³⁴, the extraction of monocular occlusion cues relies on detecting areas presented

exclusively to each eye³³. This binocular integration makes da Vinci stereopsis a potential indicator of residual binocularity for patients with binocular vision deficits.

Supplementary File 1: Detailed description of test stimuli and psychophysical procedures.

This file provides comprehensive specifications for each task in the binocular vision battery, including stimulus design (size, contrast, eccentricity, and motion parameters), experimental procedures, and psychophysical methods used to estimate thresholds (e.g., staircase procedures and method of constant stimuli). [Please click here to download this file.](#)

Supplementary File 2: Design and specifications of the Pulfrich response box. This file describes the construction and dimensions of the custom-built response box used for the physical depth-matching task, including the arrangement of movable moons, stationary stars, and structural components. [Please click here to download this file.](#)

Discussion

This novel battery of tests was developed to assess multiple facets of binocular vision, ranging from simultaneous perception and fusion to distinct mechanisms underlying stereopsis. The entire protocol takes at least 85 minutes to complete, providing a comprehensive evaluation of depth perception. Tests may be administered individually or in combination, depending on research or clinical needs. The full test battery is best suited to research environments where longer testing durations are feasible. Nevertheless, subsets of these tests can yield quick and valuable insights into specific aspects of binocular vision (**Table 1**).

The protocol described herein offers a potential framework for evaluating aspects of stereopsis that are currently not assessed in clinical and research settings. For example, patients with monocular amblyopia ("lazy eye") often experience suppression³⁸ and exhibit an absence of clinically measurable stereopsis. Nevertheless, research suggests that residual binocular interactions may still occur^{16,39}. A comprehensive assessment of binocular vision in these patients will not only enhance our understanding of their everyday visual performance and quality of life but also provide insight into visual development and potential for rehabilitation. Similarly, patients with macular degeneration experience significant central vision loss and rely heavily on peripheral vision¹⁶. Evaluating the capacity of peripheral stereopsis in this population is therefore essential, both for understanding their quality of life and for designing visual training techniques that enhance their use of peripheral vision. The battery of tests may also be extended to pediatric populations, which could provide insight into binocular visual development, potential links to school performance, and early detection of binocular disorders^{40,41}.

To facilitate testing in children and ensure compliance, this protocol can be adapted by incorporating gaming elements and/or immersive displays (e.g., virtual reality headsets)^{42,43}.

To ensure valid and reliable results, the protocol must be administered correctly. Critical procedural steps include: (1) aligning the monitor, the mirror stereoscope and the chinrest; (2) measuring the viewing distance and entering it into **PsychoPy Monitor Center**; (3) performing gamma calibration for the monitor; (4) providing clear instructions to ensure that participants understand each task; (5) reminding participants to maintain fixation when a fixation cross is present; (6) completing practice trials and confirming that performance is reliable before proceeding to formal tests.

Importantly, the custom code developed to administer the tests (provided in the **Table of Materials**) can be adapted to meet the various needs of individual studies. Possible adaptations include, but are not limited to: (1) stimulus parameters such as shape, size, eccentricity, location, and presentation time; and (2) psychophysical parameters such as step size, number of trials, or the use of alternative adaptive procedures, including weighted up-down methods and Bayesian adaptive procedures^{44,45}. The eccentricities and locations in this battery were chosen for illustration and can be changed in the code based on readers' research interests, provided appropriate hardware is available. In the context of clinical application, for patients with interocular suppression, the extent of the suppression scotoma can be assessed using clinical measures such as the Worth 4-Dot test, and the eccentricity of test stimuli can be adjusted in the code accordingly to avoid the scotoma. For patients with strong interocular suppression, monocular contrast can be lowered to relieve suppression. The code can also be adapted to allow vertical separation between the stimuli presented to each eye to accommodate individuals with vertical strabismus.

The novel battery has the potential to innovate the assessment of binocular vision, offering insights into distinct mechanisms underlying stereopsis; however, it is important to acknowledge a few limitations. First, the primary device required for testing was the mirror stereoscope, which in the present study offered limited adjustability. Patients with significant ocular misalignment (i.e., strabismus) cannot be assessed using the current stereoscope configuration. Using more flexible hardware—such as one that allows adjustment of all mirrors or uses 3-D shutter goggles⁴⁶ or virtual reality devices^{47,48}—may help overcome this limitation.

Another limitation of this setup is the inability to incorporate eye tracking. It is therefore critical to instruct participants to maintain gaze on the fixation cross and monitor fixation by observing the participant's eyes. The testing protocol could be improved by adding eye tracking to monitor fixation. Alternatively, the task stimulus can be adapted, for example, by briefly presenting a small

letter at the fixation point and asking participants to report it while simultaneously performing the peripheral task. Accurate reporting of the letter will indicate fixation at that location.

Finally, testing peripheral stereopsis in this protocol was confined to 10 degrees due to the hardware limitations. Specifically, the viewing distance was constrained by the monitor's dimensions and resolution, reflecting a trade-off between achieving large eccentricities and maintaining sufficiently small pixel size. Reducing the viewing distance would allow testing at larger eccentricities, but each pixel would subtend a larger visual angle, limiting the minimum disparity that can be presented. Conversely, increasing the viewing distance would improve pixel resolution but would substantially restrict the range of eccentricities. Within the current setup, testing at 10 degrees was only feasible by presenting the fixation cross eccentrically, requiring participants to shift their eyes away from the primary position. A larger monitor or a wearable virtual reality headset^{49,50} with high-resolution may be adopted to address this limitation.

In summary, the test battery offers a multifaceted approach to evaluating binocular integration and stereopsis, providing a rigorous and comprehensive assessment of depth perception extending current clinical approaches. When necessary, these tests can be tailored to specific needs, supporting applications in broader populations under diagnostic, research, and rehabilitative contexts.

Disclosures

All authors declare no conflicts of interest.

Acknowledgments

This work was supported by the Canadian Institutes of Health Research (CIHR) grant (PJT 183761) to EN, XG, DM, DIS, and BT. We thank the REWIRE-D Study Group (rewire-d.ca) for their contributions to the development of this work.

References

1. Ali RS. Relationship between ocular sensory dominance and stereopsis [dissertation]. Florida: Nova Southeastern University; 2016.
2. Cibis GW, Ing MR. Binocular vision. In: Duane's Ophthalmology. Philadelphia: Lippincott Williams & Wilkins; 2013.
3. Barrett BT. Assessment of binocular vision and accommodation. In: Clinical procedures in primary eye care. Oxford: Saunders; 2014.
4. Lee J, McIntyre A. Clinical tests for binocular vision. *Eye*. 1996;10(2):282-5.
5. von Noorden GK, Campos EC. Binocular vision and ocular motility: theory and management of strabismus. 6th ed. St. Louis: Mosby; 2002.

6. de Belsunce S, Sireteanu R. The time course of interocular suppression in normal and amblyopic subjects. *Invest Ophthalmol Vis Sci.* 1991;32(9):2645-52.
7. Hupé JM, Signorelli CM, Alais D. Two paradigms of bistable plaid motion reveal independent mutual inhibition processes. *J Vis.* 2019;19(4):5.
8. Riesen G, Norcia AM, Gardner JL. Humans perceive binocular rivalry and fusion in a tristable dynamic state. *J Neurosci.* 2019;39(43):8527-37.
9. Dieter KC, Sy JL, Blake R. Individual differences in sensory eye dominance reflected in the dynamics of binocular rivalry. *Vision Res.* 2017;141:40-50.
10. O'Connor AR, Tidbury LP. Stereopsis: are we assessing it in enough depth? *Clin Exp Optom.* 2018;101(4):485-94.
11. Tittes J, et al. Assessment of stereovision with digital testing in adults and children with normal and impaired binocularity. *Vision Res.* 2019;164:69-82.
12. Hubel DH, Wiesel TN. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *J Physiol.* 1962;160:106-54.
13. Rovamo J, Virsu V. An estimation and application of the human cortical magnification factor. *Exp Brain Res.* 1979;37(3).
14. Spillmann L, Ransom-Hogg A, Oehler R. A comparison of perceptive and receptive fields in man and monkey. *Hum Neurobiol.* 1987;6(1):51-62.
15. Nadler JW, Barbash D, Kim HR, Shimpi S, Angelaki DE, DeAngelis GC. Joint representation of depth from motion parallax and binocular disparity cues in macaque area MT. *J Neurosci.* 2013;33(35):14061-74.
16. Verghese P. The utility of peripheral stereopsis. *Front Neurosci.* 2023;17:1217993.
17. Witz N, Hess RF. Mechanisms underlying global stereopsis in fovea and periphery. *Vision Res.* 2013;87:10-21.
18. Yildirim C, Mehmet Mutlu F, Chen Y, Altinsoy HI. Assessment of central and peripheral fusion and near and distance stereoacuity in intermittent exotropic patients before and after strabismus surgery. *Am J Ophthalmol.* 1999;128(2):222-30.
19. Hess RF, Mansouri B, Thompson B, Gheorghiu E. Latent stereopsis for motion in depth in strabismic amblyopia. *Invest Ophthalmol Vis Sci.* 2009;50(10):5006.
20. Mollenhauer KA, Haase W. Dynamic stereopsis in patients with impaired binocular function. *Strabismus.* 2000;8(4):275-81.
21. Watanabe Y, Kezuka T, Harasawa K, Usui M, Yaguchi H, Shioiri S. A new method for assessing motion-in-depth perception in strabismic patients. *Br J Ophthalmol.* 2008;92(1):47-50.
22. Tredici TD, von Noorden GK. The Pulfrich effect in anisometropic amblyopia and strabismus. *Am J Ophthalmol.* 1984;98(4):499-503.
23. Bossi M, Hamm LM, Dahlmann-Noor A, Dakin SC. A comparison of tests for quantifying sensory eye dominance. *Vision Res.* 2018;153:60-69.
24. Bossi M, et al. Binocular therapy for childhood amblyopia improves vision without breaking interocular suppression. *Invest Ophthalmol Vis Sci.* 2017;58(7):3031-41.
25. Elliott DB. *Clinical procedures in primary eye care.* 4th ed. Oxford: Saunders; 2014.
26. Lanska DJ, Lanska JM, Remler BF. Description and clinical application of the Pulfrich effect. *Neurology.* 2015;84(22):2274-78.
27. Read JCA, Cumming BG. Effect of interocular delay on disparity-selective V1 neurons: relationship to stereoacuity and the Pulfrich effect. *J Neurophysiol.* 2005;94(2):1541-53.
28. Carney T, Paradiso MA, Freeman RD. A physiological correlate of the Pulfrich effect in cortical neurons of the cat. *Vision Res.* 1989;29(2):155-65.
29. Wu Y, et al. Two patterns of interocular delay revealed by spontaneous motion-in-depth Pulfrich phenomenon in amblyopes with stereopsis. *Invest Ophthalmol Vis Sci.* 2020;61(3):22.
30. Reynaud A, Hess RF. An unexpected spontaneous motion-in-depth Pulfrich phenomenon in amblyopia. *Vision.* 2019;3(4):54.
31. Kim HR, Angelaki DE, DeAngelis GC. The neural basis of depth perception from motion parallax. *Philos Trans R Soc B Biol Sci.* 2016;371(1697):20150256.
32. Rogers B. Revisiting motion parallax as a source of 3-D information. *Perception.* 2016;45(11):1267-78.
33. Tsirlin I, Wilcox LM, Allison RS. da Vinci decoded: does da Vinci stereopsis rely on disparity? *J Vis.* 2012;12(12):2.
34. Blake R, Wilson H. Binocular vision. *Vision Res.* 2011;51(7):754-70.
35. Tsirlin I, Wilcox LM, Allison RS. A computational theory of da Vinci stereopsis. *J Vis.* 2014;14(7):5.
36. Chen X, Hall K, Bobier WR, Thompson B, Chakraborty A. Transcranial random noise stimulation and exercise do not modulate ocular dominance plasticity in adults with normal vision. *J Vis.* 2022;22(10):14.
37. Chen X, Bobier W, Thompson B. Short-term ocular dominance plasticity is not modulated by visual cortex tDCS but increases with length of monocular deprivation. *Sci Rep.* 2023;13(1):6666.
38. Li J, et al. The role of suppression in amblyopia. *Invest Ophthalmol Vis Sci.* 2011;52(7):4169.
39. Hess RF, Thompson B, Baker DH. Binocular vision in amblyopia: structure, suppression and plasticity. *Ophthalmic Physiol Opt.* 2014;34(2):146-62.
40. Christian LW, Nandakumar K, Hrynychak PK, Irving EL. Visual and binocular status in elementary school children with a reading problem. *J Optom.* 2018;11(3):160-66.
41. Grisham D, Powers M, Riles P. Visual skills of poor readers in high school. *Optometry.* 2007;78(10):542-49.
42. Mesfin Y, Kong A, Backus BT, Deiner M, Ou Y, Oatts JT. Pilot study comparing a virtual reality-based visual field test to standard perimetry in children. *J AAPOS.* 2024;28(3):103933.
43. Denking S, et al. The eRDS v6 stereotest and the vivid vision stereo test: two new tests of stereoscopic vision. *Transl Vis Sci Technol.* 2023;12(3):1.
44. Kaernbach C. Simple adaptive testing with the weighted up-down method. *Percept Psychophys.* 1991;49(3):227-29.
45. García-Pérez MA. A cautionary note on the use of the adaptive up-down method. *J Acoust Soc Am.* 2011;130(4):2098-2107.
46. I-BIT study group, et al. Interactive binocular treatment (I-BIT) for amblyopia: pilot study of a 3D shutter glasses system. *Eye.* 2013;27(9):1077-83.
47. Saraiva AA, Nogueira AT, Ferreira NMF, Valente A. Application of virtual reality for treatment of strabismus and amblyopia [conference presentation]. *IEEE International Conference on Serious Games and Applications for Health;* 2018.
48. Chan HS, Tang YM, Do CW, Wong HHY, Chan LY, To S. Design and assessment of vision training using virtual reality. *Digit Health.* 2023;9:20552076231176638.

49. Sun X, Varshney A. Investigating perception time in far peripheral vision [conference presentation]. ACM Symposium on Applied Perception; 2018.
50. Vera J, Glazier AN, Dunbar MT, Ripkin D, Nafey M. Evaluating validity of virtual reality headsets for visual field testing. *Vision*. 2025;9(4):80.