Video Article

How to Build a Dichoptic Presentation System That Includes an Eye Tracker

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Abstract

The presentation of different stimuli to the two eyes, dichoptic presentation, is essential for studies involving 3D vision and interocular suppression. There is a growing literature on the unique experimental value of pupillary and oculomotor measures, especially for research on interocular suppression. Although obtaining eye-tracking measures would thus benefit studies that use dichoptic presentation, the hardware essential for dichoptic presentation (e.g. mirrors) often interferes with high-quality eye tracking, especially when using a video-based eye tracker. We recently described an experimental setup that combines a standard dichoptic presentation system with an infrared eye tracker by using infrared-transparent mirrors[1]. The setup is compatible with standard monitors and eye trackers, easy to implement, and affordable (on the order of US$1,000). Relative to existing methods it has the benefits of not requiring special equipment and posing few limits on the nature and quality of the visual stimulus. Here we provide a visual guide to the construction and use of our setup.

Video Link

The video component of this article can be found at https://www.jove.com/video/56033/

Introduction

Under normal viewing conditions each of our eyes receives a slightly different visual input. This input is then processed to produce one coherent, three-dimensional representation of the world. Dichoptic presentation, the practice of independently controlling the input presented to each of the two eyes, thus enables researchers to study how humans reconstruct a three-dimensional representation from two two-dimensional retinal images[2,3,4]. In addition, if the two eyes' images are too dissimilar, this interocular combination fails, and observers instead report perception of only one of the images at a time while the other remains suppressed, in phenomena such as binocular rivalry[5] and continuous flash suppression[6]. Researchers of such interocular suppression, too, use dichoptic presentation, in this case to examine questions related to topics like the neural locus of awareness[7], perceptual selection[8,9], and unconscious processing[10].

Gaze and pupil dynamics are recorded for multiple purposes in research on human behavior and perception. Gaze direction can inform about, for instance, attention allocation[11,10,13] and decision making[14], while pupil size can reveal aspects of visual processing[15,16], task engagement[17], or fluid intelligence[18].

Combining eye tracking with dichoptic presentation is useful in research into, for instance, three dimensional (3D) perception[19,20,21,22] or ocular responses to visual input during interocular suppression[23,24,25]. For example, eye movements have been found to reveal unconscious processing without subjective perception during continuous flash suppression[23]. Clinical visual researchers can use the ability to track both eyes during dichoptic presentation to investigate ocular diseases that affect the two eyes asymmetrically, for example, to monitor the monocular and binocular visual distortions occurring in amblyopia[26] and maculopathy[27].

We recently described a setup[1] that allows for the combination of high quality video-based eye tracking and dichoptic stimulation with little limitation on the size or color of the stimuli, and we evaluated its performance. Below we will summarize the construction and use of this setup.

Protocol

This protocol has been approved by the Institutional Review Boards of Michigan State University.

1. Building the system

1. **Rationale**

1. Prepare the mirror setup, a variant of the classic Wheatstone stereoscope[28] illustrated in **Figure 1**, consisting of two mirrors positioned at a 45° angle relative to the participant's midline. The mirrors reflect stimuli from two screens that are positioned at opposite ends of a table, facing each other.
2. Seat a participant in front of the mirrors and have them view a different screen, reflected via a different mirror, with each eye. For best results, use a head rest for stabilizing the participant's head.
3. Position an infrared-sensitive video-based eye tracker, including a camera and an illuminator, in front of the participant but behind the mirrors. The eye tracker is represented by a box in **Figure 1**.
   NOTE: One challenge when trying to track the eyes in normal setups of this type, is that the eyes are blocked by the mirrors.
4. Use two front-surface mirrors, often advertised as "cold mirrors" (incident angle: 45°), that feature near-complete reflectance of visible wavelengths and near-complete transmission of near-infrared wavelengths (see Table 1 for detailed information about the mirrors).
   NOTE: Such mirrors can be obtained via companies supplying optical equipment for scientific and industrial purposes, which usually list components like these as 'cold mirrors' or as a type of 'dichroic mirrors' (see more detail in Materials/Equipment Table).

		Setup 1	Setup 2
Mirrors	Dimensions	10.10 × 12.70 cm	10.10 × 12.70 cm
	Reflectance	400 ~ 690 nm	425 ~ 650 nm
	Transmission	750 ~ 1200 nm	800 ~ 1200 nm
Eye Tracker	Brand	Research-end Eye Tracker	Customer-grade Eye Tracker
	Transmission	890 ~ 940 nm	Around 850 nm

Table 1. Details of two versions of the setup with which we have worked.
The eye tracker's transmission wave length range is covered by the mirrors' transmission range at a 45° incidence angle, but outside their reflectance range.

2. **Structure of the Setup**
   1. Build the setup on top of a desk. Besides the mirrors and eye tracker, it consists only of three custom-built elements made of fiberboard (see **Figure 2** for an assembly guide) and two flat-screen monitors on monitor-arms available from normal office supply stores.
   2. **Fiberboard elements**
      1. Build the framework of the setup from three components of fiberboards: one central component and two reference boards on each side (see **Figure 1** for general positioning, Table 2 for detailed dimensions, and **Figure 2** for an assembly guide of each component). Paint all these pieces in matte black to reduce light scatter.
         NOTE: The central component (see **Figure 2B** and **2D**) holds the mirrors and eye tracker. Both are on the same plateau, thus keeping the eye tracker at participants' eye level.
      2. Place the top element of this component such that it leaves 8 cm in depth in the front of the desk. Such an arrangement allows enough room for the participant's face when stabilized on the head rest and avoids condensation on the mirrors during expiration, while minimizing the distance between the participant's eyes and the mirrors to maximize the possible use of the participant's visual field.
      3. Position the two reference boards straight below the monitors (see **Figure 1** for positioning and **Figure 2** panels A and C for an assembly guide) for easy manual calibration of the screens. Note that the apparent offset in **Figure 1** between screen and board is due to limited depth cues in the image; the boards are straight below the monitors on both sides.
      4. Exactly align the long horizontals with the edges of the desk, while the long verticals leave 4 cm beyond the front of the desk for ease of stabilizing a calibration board (see below) to these boards. The two small verticals will ensure the long vertical staying vertical as the reference for the monitors.
      5. Optionally, use a separate piece of fiberboard as a calibration board (see **Figure 3**). In this case, after obtaining an optimal position of a monitor, position the calibration board against the reference board and indicate the positions of both the reference board and the monitor on the calibration board while it is in place (in the example of **Figure 3**, wooden slats provide these indications).
      6. Whenever this desired monitor position is lost (accidentally or because other experiments require a different position), retrieve this position by using the markings on the calibration board to put the calibration board back in the same place relative to the reference board that has a fixed position on the desk. Move the monitor again to line up with the appropriate markings (see step 2.1.1. for details).

Component	Dimensions (cm)	Number	Remark
Central Component	80 × 25 × 2	1	Horizontal top
	23 × 25 × 2	1	Horizontal bottom
	21 × 32 × 2	1	Central vertical
	32 × 25 × 2	1	Front-facing vertical
Reference Boards	61 × 11 × 2	2	Long horizontal
	66 × 29 × 2	2	Long vertical
	11 × 15 × 2	4	Small vertical

Table 2. Details of the fiberboard components.

3. **Monitors and Mirrors**
    1. Position the setup on top of a standard office desk.
    2. Mount two flat-screen monitors on standard monitor arms clamped to the side of the desk (clamping both the reference board and the desk). These arms allow translation in three dimensions as well as rotation in the plane of the screen. Conventional CRT-monitors are clearly also compatible with the setup, but would not afford the same flexibility in terms of positioning and repositioning.
    3. Mount the mirrors on mirror mounts that are sold for the purpose by the same suppliers that stock cold mirrors. Connect these mounts to the fiber board holding the mirror at participants' eye level. Position the mirrors to touch at a 90° angle in the center, right before the participant's nose.

4. **Remaining elements**
    NOTE: Some experiments require participants not seeing the screens from the corner of their eyes, so that a direct line of sight to the screens (dashed lines in **Figure 4A**) should be avoided.
    1. In that case, create "blinders" made of black cardboard and foam-padded hole straps painted in black, and attach them to the posts of the head rest (see **Figure 4B**). Adjust the blinders in height and angle to accommodate individual participants. If the wall in front of the participant has high reflectance, hanging a piece of black fabric will help remedy this.

2. Using the system

1. **Hardware calibration**
    NOTE: The purpose of calibration is to achieve satisfactory alignment of the two monitors for ease of fusion of the two monitors' images for each participant. This can be achieved in two steps: hardware calibration (described here) and software calibration (described below).
    1. When using a calibration board, as described above, align it with one of the reference boards, holding it in place with a C-clamp if needed, and then move the corresponding monitor to line up with the desired reference lines on the calibration board. The monitors should be parallel to each other, and each should be straight above its reference board.
    2. When using blinders, move them to the participant's eye level and rotate them slightly toward the midline, i.e. more inward, compared to the orientation of the monitors. Make sure that each eye can see the whole visual stimulus in the mirror without seeing any of it directly. Turning the blinders toward rather than away from the midline will minimize participants' exposure to other visual input.

2. **Software calibration**
    1. Since participants may vary in their eye position relative to the mirrors despite the use of a head rest, calibrate further before doing experiments. This part is most easily done in the software, i.e. without moving the setup's parts any further. There are two possible methods.
        1. For the first, present a dot on each of the two screens in alternation, and instruct the participant to eliminate the perceived position change by moving the dot on one of the screens (or both in opposite directions).
        2. For the second method, instruct the participant to align the frames of experimental stimuli instead of two dots so that both eyes' visual fields critical to the particular experiment are aligned.

    2. After applying either method, center the stimuli in the experiment on the resulting on-screen positions. Other aspects of setting up displays and stimuli for dichoptic presentation in general can be found elsewhere[5].

Representative Results

After the calibration described in the protocol, we performed a calibration-validation procedure without problems with the mirrors in place. The effectiveness of the method is clearly illustrated by **Figure 5**, which shows the camera's image (using a research end eye tracking system) with the mirrors in place. The two sets of parallel lines along participants' nose and the lines above the eye brows are the edges of the mirrors but, nevertheless, the face is as clear inside of that frame as it is outside. This highlights the lack of signal loss at the wavelengths recorded by the camera. A formal evaluation previously showed pupil size, saccade, and smooth pursuit results to be equivalent with mirrors and without mirrors[1]. We describe a representative part of that evaluation.

A short experiment was conducted with only one mirror in place to compare the results with and without the mirror. The participant made saccades to different locations on the screen. The eye tracker did not miss any samples for either eye. The average correlations in the horizontal gaze angle and vertical gaze angle were 0.99 (see **Figure 6**).

How much does it cost?

In a laboratory that already has standard eye-tracking materials such as an eye tracker, a head rest, and monitors, the approximate price of the additional components would approach US$1,000. This price compares favorably to some alternatives such as goggle systems[29] at the time of publication (2017). Mirrors: $400; mirror holders: $150; fiberboard, glue, *etc.*: $100; monitor arms: $300. The cost of an eye tracker may range from $100 to over $25,000 depending on factors like the precision and sampling rate (see more options in [30]).

How well does it work for different eye trackers?

Two types of infrared eye trackers were previously evaluated in terms of the quality of the eye data[1]. They are a desktop-mounted research-end eye tracker and a consumer-grade eye tracker, each in combination with a slightly different mirror pair (see Table 1 for details). The product specifications suggest that both trackers should work well with this setup, and this is corroborated by the published evaluation[1]. More options for eye trackers can be found in [30].

How to avoid interference of the eye tracker's infrared illuminator?

The wavelength of light transmitted by the eye tracker's infrared illuminator extends into the visible range. Participants can therefore sometimes see the red array or dots through the mirrors, especially during the calibration-validation procedure when the screen is mostly black. The severity of the concern depends on the particular experimental design, e.g. avoidance of using the color red in the stimulus will decrease the possibility of potential confusion. In addition, experimenters can increase the background luminance so that the red dots are hardly visible, and some eye trackers allow the illuminator power to be turned down. Moreover, in cases where the stimulus of interest covers a relatively small part of the screen, the illuminator can be moved not to overlap with this part.

What is the maximum size of the field of view?

The current setup could cover more than 30 degrees in visual angle both vertically and horizontally.

How long does it take to build the setup and calibrate each participant?

Building the system takes about a day if all the materials and equipment are available. It takes less than 10 min to calibrate each participant on both the dichoptic presentation and eye tracking system.

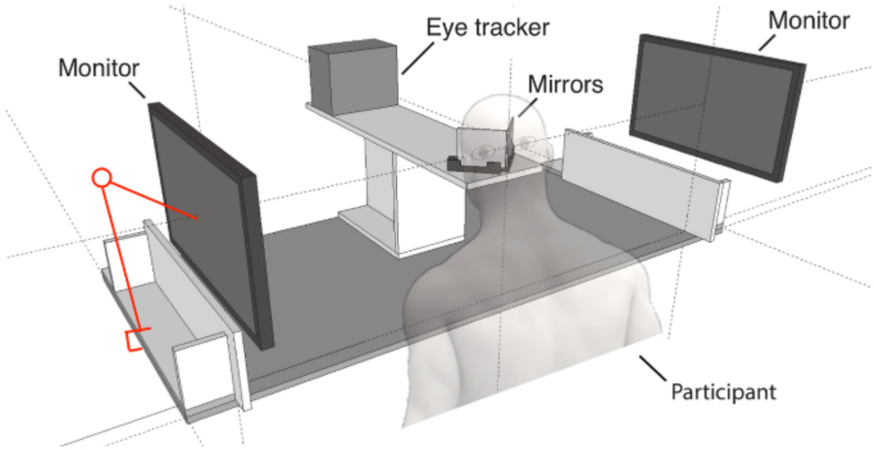

Figure 1. Schematic illustration of the setup.
The setup is on an office desk, and the participant is seated at the desk and looking into a different mirror with each eye. Although not strictly necessary, best results are obtained by supporting the participant's head with a head rest mounted on the side of the table. (Note that the apparent offset between screen and board on the right side is due to limited depth cues in the image). The figure has been adapted from [1]. Please click here to view a larger version of this figure.

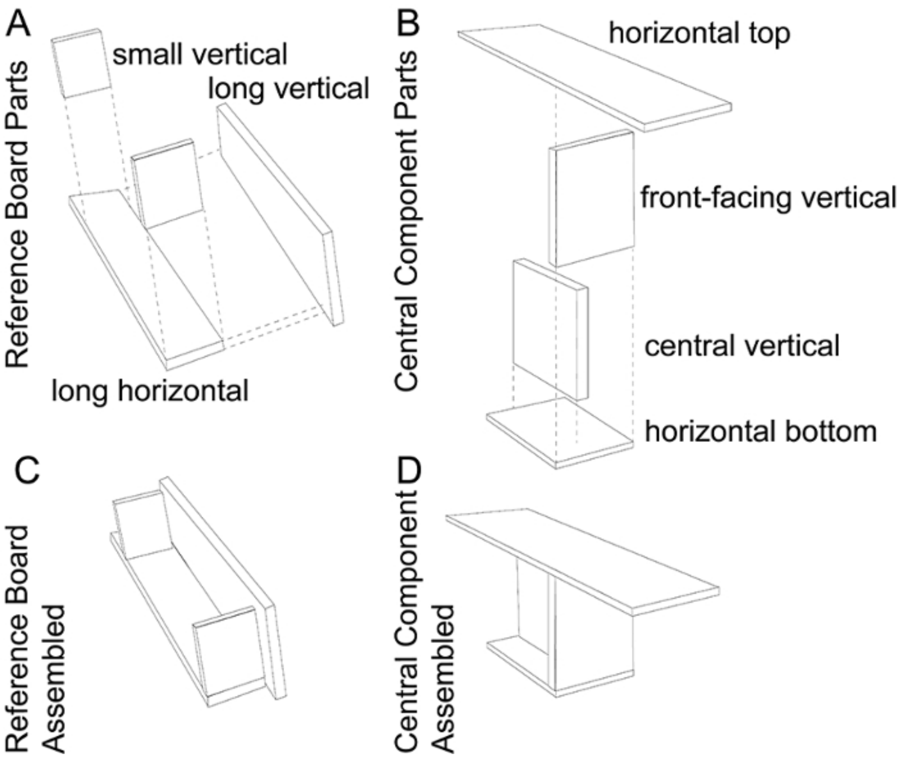

Figure 2. An assembly guide of the reference boards (panels A and C) and the central component (panels B and D). Panels A and C only show the reference board that is on the left side of the setup; the reference board on the right side is the mirror image of the left one, i.e. with the small vertical boards pointing away from the midline. Please click here to view a larger version of this figure.

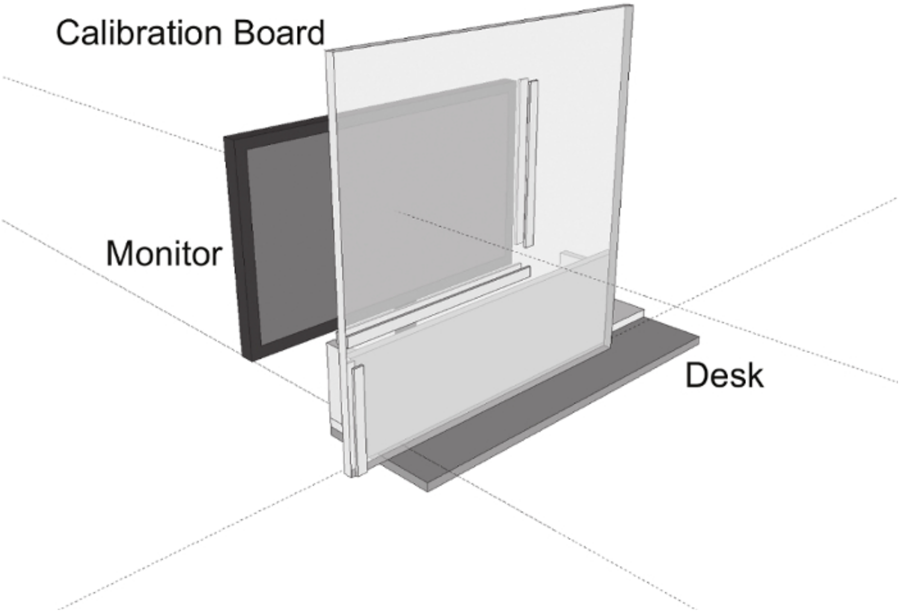

Figure 3. Calibration board. In this example, wooden slats take a role that can also be performed by drawn lines. A vertical slat and a horizontal slat trace around the corner of the monitor when it is in the correct position. Another vertical slat near the bottom of the board aligns with the short side of the reference board (long vertical board) when it is in the correct position. Please click here to view a larger version of this figure.

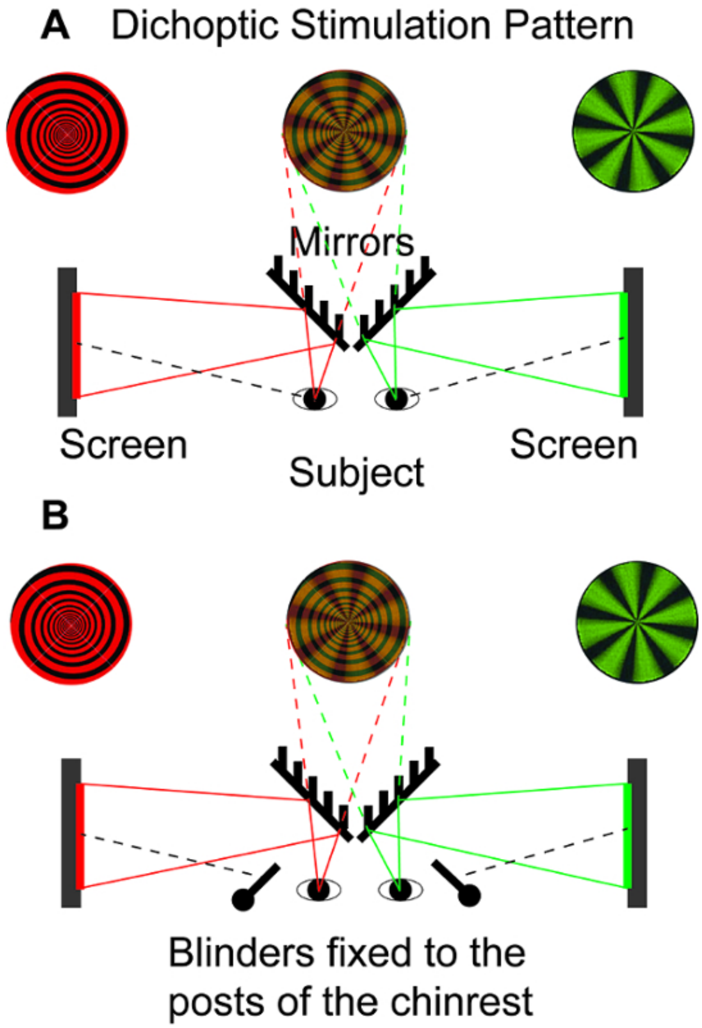

Figure 4. Demonstration of the blinders.
The blinders prevent a direct line of sight to the screens (dashed lines). Please click here to view a larger version of this figure.

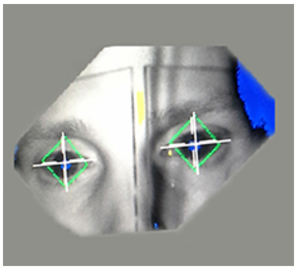

Figure 5. Frame of the camera's view during dichoptic presentation, faintly showing the edges of the mirrors but otherwise showing no obstruction due to the mirrors.

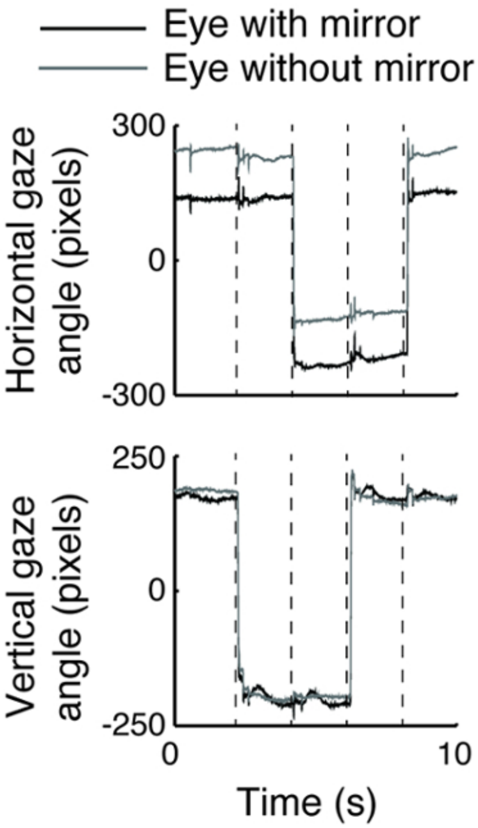

Figure 6. Data collected from representative participants using the research-end eye tracker during a saccade task. The vertical dashed lines indicate changes in target position. The figure has been adapted from [1].

Discussion

We present a step-by-step guide for the construction and use of an experimental setup that allows simultaneous tracking of the both eyes and dichoptic presentation of visual stimuli. In many situations where dichoptic stimulation is used, the critical issue preventing effective eye tracking is that the mirrors for dichoptic presentation block the sight of video-based eye trackers. This is resolved here by using infrared-transparent mirrors and an infrared-sensitive eye tracker. This setup allows researchers of 3D vision, interocular suppression or clinical research to collect high quality eye tracking data while using large, arbitrarily colored stimuli.

This setup can be modified based on the experimental needs. If the stimuli from both eyes are small enough[5] to fit onto a single screen, four mirrors with one screen might be enough to achieve eye tracking with dichoptic presentation. In that case, two more front-surface mirrors (infrared-transparency not required) would be placed peripheral and parallel to the current mirrors, reflecting visual stimuli on the screen to the current mirrors (see reference [5] for placement of mirrors in a standard mirror stereoscope).

There are a few limitations of this experimental setup. One is the potential visual contamination of the illuminator of the eye tracker mentioned in the representative results. Secondly, if the color of the visual stimuli is irrelevant, anaglyph glasses might be a better choice in terms of the cost, especially if it is not critical that separation of the two eyes' images is not always complete when using anaglyph glasses.

Compared to techniques that rely on non-optical recording directly from the eyes, for instance electro-oculography[31,32,33] and the scleral coil technique[19,34,35], the proposed method is less invasive and allows pupillometry. On the other hand, some participants have eyes that are difficult to capture using video-based eye recording, so in those cases direct recording methods are preferred. Our method should also be compared to other methods that do rely on a visual signal. For example, eye tracking can be achieved with goggle systems that have cameras integrated in the eye pieces[36] or the head mounted displays[37]. Goggle systems have the benefit that they do not require participants to stay still but the spatial and temporal resolution of such systems can be low compared to the proposed method. It is also possible to do video-based eye recording through the lenses of anaglyph glasses (e.g. red-green or red-blue goggles)[20,38,39], which has the drawback of limiting the colors that can be used in the visual stimuli shown to the participant. Separation of the eyes' images can also be achieved using polarized stereo glasses[30] or active stereo shutter glasses[22,40,41]. Such methods are easier to implement than the proposed one but the visual stimulation quality may suffer from stereoscopic crosstalk.

One group successfully used a setup combining a standard 4-mirror stereoscope with an eye tracker[24,25] by tracking one eye through a gap between the mirrors. Aside from allowing only monocular eye tracking, this method has the drawback that recording through this gap limits the size of the mirrors used and, therefore, the field of view, and that it requires very specific positioning of the eye tracker. As a result, the setup routine can take up to 20 min (Miriam Spering, personal communication, May 7, 2017). In comparison, the proposed method allows a field of view of more than 40 degrees, tracking of both eyes, and it takes around 10 min to finish the whole calibration process.

There is a trend in research involving interocular suppression to use pupillary and oculomotor responses in addition to, or in replacement of, the traditional button press responses[36,42,43]. For one thing, eye dynamics might reveal unconscious processing, while button presses typically signal subjective awareness[24,25]. Moreover, relying on eye responses can prevent potential confounds associated with manual responses in experiments[26,33]. Our setup provides an ideal solution for those wishing to pursue this combination of interocular suppression and eye tracking.

Disclosures

The authors have nothing to disclose.

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References

1. Brascamp, J. W., & Naber, M. Eye tracking under dichoptic viewing conditions: a practical solution. *Behav. Res. Methods.* , 1-7 (2016).
2. Barendregt, M., Harvey, B. M., Rokers, B., & Dumoulin, S. O. Transformation from a Retinal to a Cyclopean Representation in Human Visual Cortex. *Curr. Biol.* **25** (15), 1982-1987 (2015).
3. Held, R. T., Cooper, E. A., & Banks, M. S. Blur and Disparity Are Complementary Cues to Depth. *Curr. Biol.* **22** (5), 426-431 (2012).
4. Julesz, B. *Foundations of cyclopean perception.* **xiv** U. Chicago Press: Oxford, England, (1971).
5. Carmel, D., Arcaro, M., Kastner, S., & Hasson, U. How to Create and Use Binocular Rivalry. *J. Vis. Exp.* (45), (2010).
6. Tsuchiya, N., & Koch, C. Continuous flash suppression reduces negative afterimages. *Nat. Neurosci.* **8** (8), 1096-1101 (2005).
7. Crick, F., & Koch, C. Consciousness and neuroscience. *Cereb. Cortex.* **8** (2), 97-107 (1998).
8. Jiang, Y., Costello, P., Fang, F., Huang, M., & He, S. A gender- and sexual orientation-dependent spatial attentional effect of invisible images. *Proc. Natl. Acad. Sci.* **103** (45), 17048-17052 (2006).
9. Jiang, Y., Costello, P., & He, S. Processing of Invisible Stimuli: Advantage of Upright Faces and Recognizable Words in Overcoming Interocular Suppression. *Psychol. Sci.* **18** (4), 349-355 (2007).
10. Bahrami, B., Carmel, D., Walsh, V., Rees, G., & Lavie, N. Spatial attention can modulate unconscious orientation processing. *Perception.* **37** (10), 1520-1528 (2008).
11. Smith, D. T., Ball, K., Ellison, A., & Schenk, T. Deficits of reflexive attention induced by abduction of the eye. *Neuropsychologia.* **48** (5), 1269-1276 (2010).
12. Deubel, H., & Schneider, W. X. Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Res.* **36** (12), 1827-1837 (1996).
13. Pastukhov, A., & Braun, J. Rare but precious: Microsaccades are highly informative about attentional allocation. *Vision Res.* **50** (12), 1173-1184 (2010).
14. Reddi, B. a. J., & Carpenter, R. H. S. The influence of urgency on decision time. *Nat. Neurosci.* **3** (8), 827-830 (2000).
15. Barbur, J. L. Learning from the pupil-studies of basic mechanisms and clinical applications. *Vis. Neurosci.* **1**, 641-656 (2004).
16. Naber, M., & Nakayama, K. Pupil responses to high-level image content. *J. Vis.* **13** (6), 7-7 (2013).
17. Gilzenrat, M. S., Nieuwenhuis, S., Jepma, M., & Cohen, J. D. Pupil diameter tracks changes in control state predicted by the adaptive gain theory of locus coeruleus function. *Cogn. Affect. Behav. Neurosci.* **10** (2), 252-269 (2010).
18. Van Der Meer, E. *et al.* Resource allocation and fluid intelligence: Insights from pupillometry. *Psychophysiology.* **47** (1), 158-169 (2010).
19. Erkelens, C. J., & Regan, D. Human ocular vergence movements induced by changing size and disparity. *J. Physiol.* **379**, 145-169 (1986).
20. Wismeijer, D. A., Erkelens, C. J., Ee, R. van & Wexler, M. Depth cue combination in spontaneous eye movements. *J. Vis.* **10** (6), 25-25 (2010).
21. Takagi, M. *et al.* Adaptive Changes in Dynamic Properties of Human Disparity-Induced Vergence. *Invest. Ophthalmol. Vis. Sci.* **42** (7), 1479-1486 (2001).
22. Maiello, G., Harrison, W. J., & Bex, P. J. Monocular and Binocular Contributions to Oculomotor Plasticity. *Sci. Rep.* **6** (2016).
23. Rothkirch, M., Stein, T., Sekutowicz, M., & Sterzer, P. A direct oculomotor correlate of unconscious visual processing. *Curr. Biol.* **22** (13), R514-R515 (2012).
24. Spering, M., Pomplun, M., & Carrasco, M. Tracking Without Perceiving A Dissociation Between Eye Movements and Motion Perception. *Psychol. Sci.* **22** (2), 216-225 (2011).
25. Spering, M., & Carrasco, M. Acting without seeing: eye movements reveal visual processing without awareness. *Trends Neurosci.* **38** (4), 247-258 (2015).
26. Piano, M. E. F., Bex, P. J., & Simmers, A. J. Perceptual Visual Distortions in Adult Amblyopia and Their Relationship to Clinical FeaturesPerceptual Visual Distortions in Adult Amblyopia. *Invest. Ophthalmol. Vis. Sci.* **56** (9), 5533-5542 (2015).
27. Wiecek, E., Lashkari, K., Dakin, S. C., & Bex, P. Novel Quantitative Assessment of Metamorphopsia in MaculopathyQuantitative Assessment of Metamorphopsia. *Invest. Ophthalmol. Vis. Sci.* **56** (1), 494-504 (2015).
28. Wheatstone, C. Contributions to the Physiology of Vision.--Part the First. On Some Remarkable, and Hitherto Unobserved, Phenomena of Binocular Vision. *Philos. Trans. R. Soc. Lond.* **128**, 371-394 (1838).
29. Beach, G., Cohen, C. J., Braun, J., & Moody, G. Eye tracker system for use with head mounted displays. *1998 IEEE Int. Conf. Syst. Man Cybern. 1998.* **5**, 4348-4352 vol.5 (1998).
30. Gibaldi, A., Vanegas, M., Bex, P. J., & Maiello, G. Evaluation of the Tobii EyeX Eye tracking controller and Matlab toolkit for research. *Behav. Res. Methods.* , 1-24 (2016).
31. Fox, R., Todd, S., & Bettinger, L. A. Optokinetic nystagmus as an objective indicator of binocular rivalry. *Vision Res.* **15** (7), 849-853 (1975).

32. Leopold, D. A., Fitzgibbons, J. C., & Logothetis, N. K. *The Role of Attention in Binocular Rivalry as Revealed through Optokinetic Nystagmus.* (1995).
33. Zaretskaya, N., Thielscher, A., Logothetis, N. K., & Bartels, A. Disrupting Parietal Function Prolongs Dominance Durations in Binocular Rivalry. *Curr. Biol.* **20** (23), 2106-2111 (2010).
34. Robinson, D. A. A Method of Measuring Eye Movemnent Using a Scieral Search Coil in a Magnetic Field. *IEEE Trans. Bio-Med. Electron.* **10** (4), 137-145 (1963).
35. Kalisvaart, J. P., & Goossens, J. Influence of Retinal Image Shifts and Extra-Retinal Eye Movement Signals on Binocular Rivalry Alternations. *PLOS ONE.* **8** (4), e61702 (2013).
36. Frässle, S., Sommer, J., Jansen, A., Naber, M., & Einhäuser, W. Binocular rivalry: frontal activity relates to introspection and action but not to perception. *J. Neurosci.* **34** (5), 1738-1747 (2014).
37. Duchowski, A. T. *et al.* Binocular Eye Tracking in Virtual Reality for Inspection Training. *Proc. 2000 Symp. Eye Track. Res. Appl.* , 89-96 (2000).
38. Hayashi, R., & Tanifuji, M. Which image is in awareness during binocular rivalry? Reading perceptual status from eye movements. *J. Vis.* **12** (3), 5-5 (2012).
39. Dam, L. C. J. van & Ee, R. van Retinal image shifts, but not eye movements per se, cause alternations in awareness during binocular rivalry. *J. Vis.* **6** (11), 3-3 (2006).
40. Maiello, G., Chessa, M., Solari, F., & Bex, P. J. Simulated disparity and peripheral blur interact during binocular fusionShort Title?? *J. Vis.* **14** (8), 13-13 (2014).
41. Vinnikov, M., Allison, R. S., & Fernandes, S. Impact of depth of field simulation on visual fatigue: Who are impacted? and how? *Int. J. Hum.-Comput. Stud.* **91**, 37-51 (2016).
42. Tsuchiya, N., Wilke, M., Frässle, S., & Lamme, V. A. F. No-Report Paradigms: Extracting the True Neural Correlates of Consciousness. *Trends Cogn. Sci.* **19** (12), 757-770 (2015).
43. Naber, M., Frässle, S., & Einhäuser, W. Perceptual Rivalry: Reflexes Reveal the Gradual Nature of Visual Awareness. *PLOS ONE.* **6** (6), e20910 (2011).