ORIGINAL RESEARCH

Color vision devices for color vision deficiency patients: A systematic review and meta-analysis

Shiva Ram Male[1] | Bindiganavale R Shamanna[1] | Rishi Bhardwaj[1] | Chakravarthy Bhagvati[2] | Baskar Theagarayan[3]

[1]School of Medical Sciences, University of Hyderabad, Gachibowli, India

[2]School of Computer and Information Sciences, University of Hyderabad, Gachibowli, India

[3]Department of Optometry and Vision Sciences, Centre for Vision across the Life Span, School of Applied Sciences, University of Huddersfield, Huddersfield, UK

Correspondence
Baskar Theagarayan, Department of Optometry and Vision Sciences, Centre for Vision across the Life Span, School of Applied Sciences, University of Huddersfield, Huddersfield, UK.
Email: b.b.pittytheagarayan@hud.ac.uk

Abstract

Background and Aims: There is insufficient evidence to support that using electronic or optical color vision devices improve color perception with current advanced technology. The purpose of this study is to compare and analyze the different color vision devices available for patients with color vision deficiency (CVD) and evaluate whether these devices improved their color perception.

Methods: This review included randomized, experimental, comparative studies, as well as narrative reviews, prototype and innovation studies, and translational studies, followed by case-control and clinical trials with nonsurgical interventions studies, that is, electronic color vision devices, optical devices, and contact lens-based studies, with standardized inclusion and exclusion criteria.

Results: The primary outcome studied was the performance of color vision devices, both objective and subjective. Secondary outcomes included the ease of use and accessibility of color vision devices and technology. The grading of recommendation, assessment, development, and evaluation framework was used to develop a systematic approach for consideration and clinical practice recommendation for CVD devices for color-deficient populations. We incorporated meta-analysis reports from a total of $n = 16$ studies that met the criteria which consisted of case-control studies, prototype and innovation studies, comparative studies, pre- and post-clinical trial studies, case studies, and narrative reviews. Proportion and standard errors, as well as correlations, were calculated from the meta-analysis for various available color vision devices.

Conclusion: This review concludes that commercially available color vision devices, such as EnChroma Glasses, Chromagen filters, and EnChroma Cx-14 do not provide clinically significant evidence that subjective color perception has improved. As a result, recommending these color vision devices to the CVD population may not prove high beneficial/be counterproductive. However, only a few color shades can be perceived differently. This systematic review and analysis will aid future research and development in color vision devices.

1 | INTRODUCTION

The term "color vision" refers to an animal's capacity to distinguish between lights of varying wavelengths (or spectral power distributions). Cone pigments, which serve as photoreceptors in the retina, are principally responsible for color vision.[1] Deficiency in the ability to see colors, often known as color vision deficiency (CVD) or color vision impairment, may occur if there is a problem with the cone pigments. CVD is when a person has trouble separating between various hues. Most patients with color vision insufficiency have trouble distinguishing among certain hues (often red, green, and blue, with yellow being less prevalent).[2] Since most individuals have adjusted to their new environments, they are often unaware of the illness. Those who inherit the X-linked recessive gene that causes CVD from their mothers will likely have impaired color vision. CVD could also be caused by damage to the retina or optic nerve.[3]

1.1 | Types of CVD

Trichromacy: It describes as normal color vision. Where three cone cells (red, green, and blue) function normally, and people with normal color vision are also called trichromats.[4]

The population who are unable to see or distinguish are considered to have CVD, and it includes as shown in Figure 1.

Protanopia: In this red cone photoreceptor, longer wavelength photopigment is absent.

Protanomaly: In this red cone photoreceptor is present but improper or deficiency is observed

Deuteranopia: In this green cone photoreceptor, the middle wavelength photopigment is absent.

Deuteranomaly: In this green cone photoreceptor is present but improper or deficiency is observed.

Tritanopia: In this blue cone photoreceptor, short wavelength photopigment is absent.

Tritanomaly: In this blue cone photoreceptor is present but improper or deficiency is observed.

Achromatopsia: It is a condition with cone photoreceptor malfunction or the absence of cone receptors responsible for color vision. The majority of cases are congenital in nature.[5]

Blue cone monochromacy: In this condition, color-sensitive cones in the eye are compromised. Cone cell receptors respond to red, green, and blue. Blue cone monochromatism affects the red and green cones but not the blue cones.[6]

The rationale for the current study is that there is currently no treatment or medication available that has the potential to permanently repair color vision deficits. The only way to deal with it is to establish a psychological plan to deal with it and make use of color vision devices. However, there are color vision devices commercially available in the market that claim to increase color vision perception. This is the only method that can be used. But how effective are these devices in developing countries and elsewhere? Do these tools or devices alleviate the issue and lead to an improvement in color perception?

1.2 | Objectives

To identify the various color vision devices available for a population with CVD from 1976 to June 2022.

To compare and recognize whether the above available devices achieve a better objective and subjective color perception.

To investigate the quality and evidence about how the available CVD devices are used in clinical practice, as well as whether any interventional or clinical studies have been conducted to solve the challenges.

2 | METHODS

In the current review, we conducted a systematic review and meta-analysis using PROSPERO, PRISMA guidance, and the guidelines developed by the Cochrane Collaboration.[7–9]

2.1 | Eligibility criteria

We included randomized and quasi-randomized trials, case-control studies, prototype and innovation studies, comparative studies, pre- and post-clinical trial studies, case studies, and narrative reviews, as well as any other relevant studies in which color vision exposure or outcome is measured using CVD devices. In addition, we included other studies that met the inclusion criteria for measuring outcomes.

2.2 | Participants or the population being studied

In this review, we focused specifically on the CVD population, and before searching for articles and materials, we used the following inclusion and exclusion criteria.
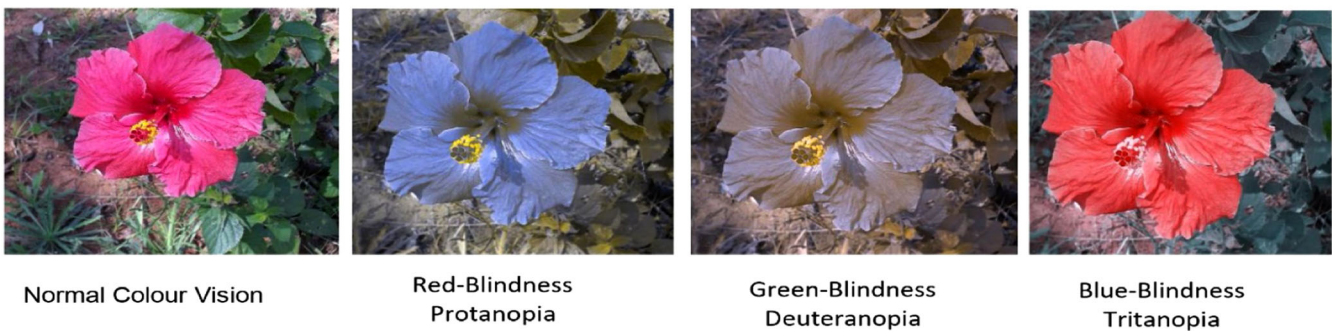
2.3 | Inclusion criteria

Patients with CVDs caused by congenital or acquired conditions who use CVD devices were included. Before shortlisting the studies,
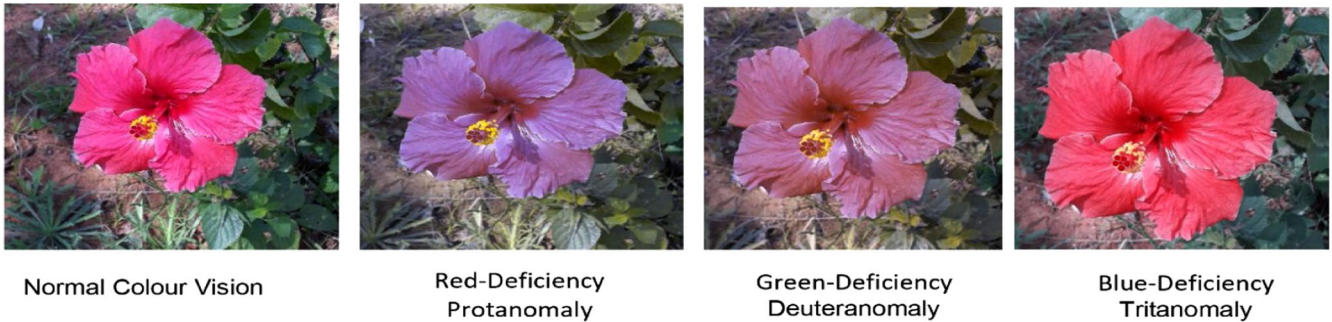
FIGURE 1 The color blinder software was used to generate color vision deficiency models of various types of illustrations using a *Hibiscus* flower as an image.

participants with CVD and impairment were evaluated for retinal abnormalities. These include macular diseases, diabetic retinopathy, hypertensive retinopathy, accelerated macular degeneration, cone dystrophy, and optic nerve-related problems.

2.4 | Exclusion criteria

Patients with retinitis pigmentosa, acquired chemical injuries, patients with developmental delay, and participants who were mentally retarded were not be enrolled in the study. Additionally, articles pertaining to participants who fall into this group were not considered for additional review.

2.5 | Information sources

We searched for information for this review in databases such as PROSPERO, PRISMA, and the Cochrane Central Register of Controlled Trials (which includes the Cochrane Eyes and Vision Trials Register) from 1976 to 2022. Followed by searches were also made in PubMed, MEDLINE Ovid, Embase Ovid, BIREME LILACS, Open Grey, the ISRCTN registry, ClinicalTrials.gov and the World Health Organization International Clinical Trials Registry Platform, and the US National Institutes of Health Ongoing Trials Register Clinical trials. From 1967 to 1987, the National Institute for Rehabilitation Engineering (NIRE) database has a registry of devices registered and manufactured

in the nineteenth century, as well as a Google patents search portal on CVD devices and devices.

We also used journal website sources that specifically published on rehabilitation devices, such as the British Journal of Visual Impairment from 1983 to June 2022, the *Journal of Visual Impairment and Blindness* from 1976 to 2022, color research and applications from 1990 to 2019, and translational vision science and technology from 2000 to 2022 for relevant trials, and any other high impact journals.

We likewise utilized search and information databases to find additional trials, such as Scopus, Science Citation Index, Web of Science, and Thomson Reuters index, to find articles that cited relevant articles in Q1 and Q2 ranking journals based on SCI index ranking and lists.
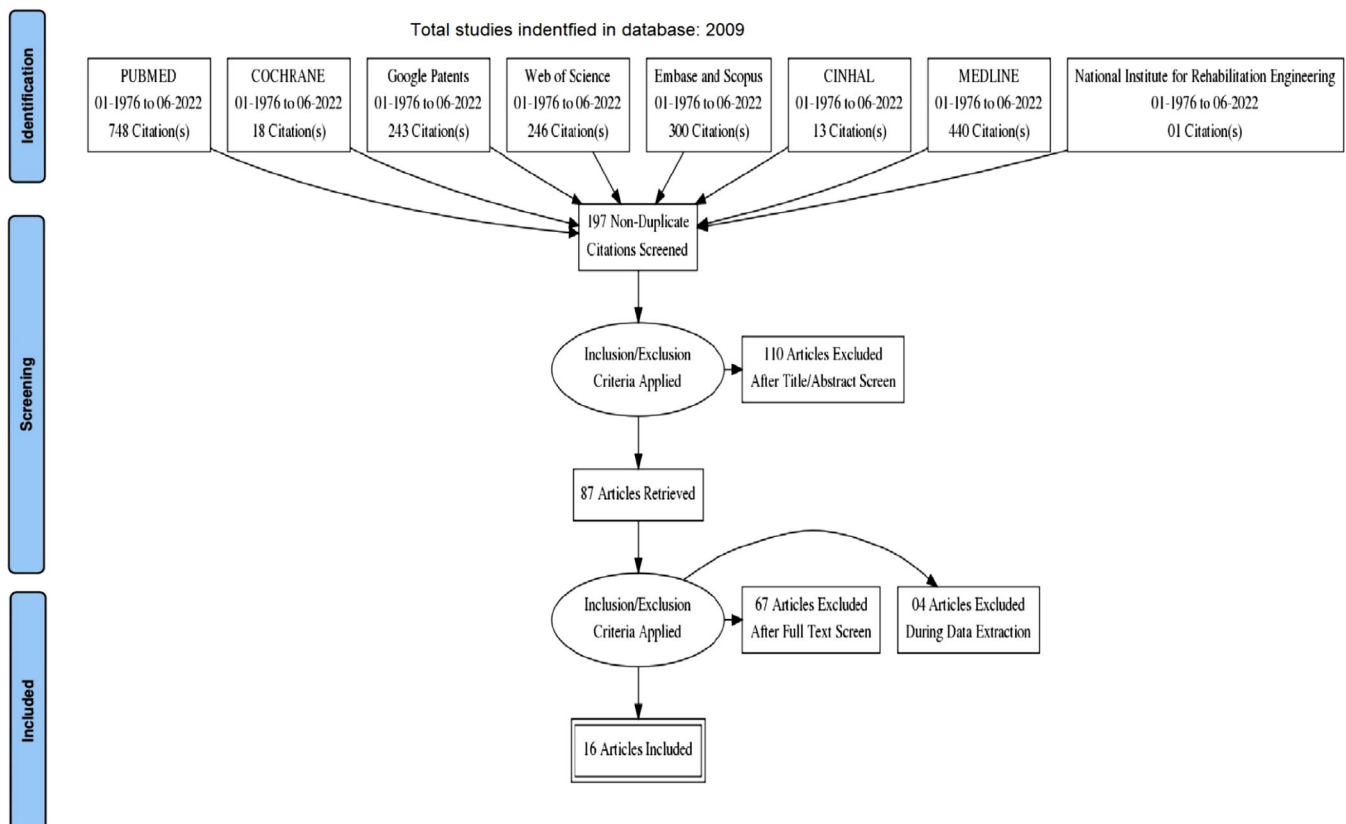
2.6 | Search strategy

In response to this, we used search strategies from databases available in the period between 1976 and 2022. We approached and contacted investigators and manufacturers of color vision devices for their assistance in other scientific reports and papers. We have used PROSPERO and PRISMA criteria to develop the

SEARCH strategy flowchart. No limitations were placed on the review's scope regarding the languages or publication years considered acceptable for inclusion. On the other hand, we did not take into consideration any articles that were written in any other language but English. As shown in the SEARCH strategy Prisma Flowchart[10] (Figure 2).

2.7 | Data collection and analysis

Initially, Two authors (Shiva Ram Male and Rishi Bhardwaj) analyzed electronic search titles, abstracts, and full-text items. We collected full copies of all relevant or possibly relevant trials and evaluated them using the review's inclusion criteria. Only those that match our inclusion criteria, study objective, and methodological quality were evaluated. The authors did not hide trial or research details when assessing. We used discussions and consensus to address differences about whether a trial or study should be included, and we tried to gather additional material whenever relevant and required. The risk of bias and quality was assessed by the journal's Q1 and Q2 quality indexes and citations are used to assess the quality of articles chosen by the authors, using the checklist criteria and critical appraisal of published literature.[11]

PRISMA-Flowchart SEARCH Strategy for: Colour Vision aids for Colour vision deficiency patients: A Systematic Review

FIGURE 2 According to the PRISMA criteria, a flowchart description of the search approach is presented. *N*= 16 research reports were included in the final meta-analysis. PRISMA-flowchart search strategy for: Color vision aids for color vision deficiency patients: A systematic review. PRISMA, preferred reporting items for systematic review and meta-analysis.

2.8 | Data synthesis

We described the study characteristics such as color vision device name, year of development, country, study design, sample size, objective and subjective color vision score improvement, and certainty of evidence. The extracted data from each study was used to measure independently for grading of recommendation, assessment, development, and evaluations (GRADE) analysis.[12]

2.9 | Statistical analysis

The extracted data were analyzed using the statistical software MedCalc-Version 20.11.[13] The following tests and measurements were included due to statistical heterogeneity. The Q-test was evaluated and measured in all the studies included in the meta-analysis. Random effect models were used to determine the proportion of data and likelihood estimates I^2 that were included in the studies. We reported the proportions and calculated the significance and 95% confidence intervals (CIs) between the studies. The GRADE framework was used to develop a systematic approach and clinical recommendations for the primary outcome of color vision objective and subjective score.

The Eggers and Kendalis τ tests were used to assess study and publication bias. Significant levels of standard errors (SEs) and 95% CI were reported, and the data was plotted on a funnel plot. The correlation coefficient and sample size between the studies reported were included in nine studies, and the data were plotted using a linear regression model. However, seven studies were excluded from this correlational analysis due to a small sample size, insufficient parameters, and data scarcity.

2.10 | Comparison

We considered publications and research that compared color perception in CVD patients using normal color vision with best corrected visual acuity and healthy emmetropes as controls.

2.11 | Outcome

Objective color vision score after using color vision devices was measured and considered as the primary outcome, with subjective color perception used as the secondary outcome, followed by the standardized color vision test.

3 | RESULTS

The search was carried out in the electronic database using the parameters shown in Figure 2. A total of 2009 different titles and abstracts were generated from eight different data sources, but only 87 (3.98%) different articles were retrieved after the title and abstract screen, and of those 87 articles, 67 (3.33%) were disqualified after the full-text article screening because they did not fulfill the review question, did not have clinical data available, had poor methodologies, or used low-quality methodology. In the end, 20 (1%) papers were considered for inclusion, but 4 papers were rejected due to the data needed for color vision devices was not readily available. As a result, the meta-analysis of the research included $n = 16$ articles.

3.1 | Color vision scores

Color vision defects were observed in 13 studies, and these studies reported the color vision score objective and subjective parameters with the Ishihara color vision test in 9 (56%) and 6 (46%) studies with the D-15 color vision test, respectively, and 2 (15.34%) studies with Farnsworth–Munsel (FM)-100 color vision test, followed by 1 (7%) study with red, green, and blue (RGB) color space tests. Each study's color vision scores were extracted as a percentage distribution, and subjective responses were represented by the outcome after using the color vision aid.

Six of the aforementioned studies had small sample sizes. As a result, the other 10 studies were used to better understand the color vision score improvement in the sample reported with the heterogeneity tests ($Q = 4.5$, $df = 9$, $p = 0.86$, 95% for $I^2 = 0.00$–26.6), as shown in Table 1 and Figure 3.

In addition to this, the evidence was compiled from the following studies using GRADE analysis, as shown in Table 2. Each of the 16 investigations has provided a metric for determining how certain the evidence is, and this information was reported in a table. Publication bias was measured using Egger's test ($I = -1.3$, 95% CI = -3.3 to 0.6, $p = 0.14$) and Begg's test Kendall's $\tau = -0.4226$, $p = 0.11$, after which corelation coefficients were plotted and the distributed data was plotted in Forest plots using the Heterogeneity $Q = 8.6$, $df = 8$, $I^2 = 7.7\%$, $p = 0.37$, and as may be seen in Figure 4.

A significant association between the color vision devices and the sample size was reported in 13 studies, whereas 3 studies were excluded due to a lack of clinical data. From these eligible studies, we measured the proportion ratios and tested for heterogeneity ($Q = 51.9$, $df = 12$, $p = 0.001$, $I^2 = 76.9$, 95% CI for $I^2 = 60.7$–86.4), and this data was represented with a forest plot and SE was measured including the publication bias with Eggers and represented with Funnel plot, as illustrated in Figure 5.

3.2 | Risk of bias assessment

We reported and summarized the results of the risk of bias assessment in the characteristics of included studies. Selection bias (allocation method), exclusion and follow-up process outcome bias (selective reporting of outcomes), performance and detection bias with color vision devices used, as well as period effect (whether the condition can change during subsequent phases of testing of each

TABLE 1 Shows the CVD population's score on various types of color vision (cv) tests, both objective and subjective, taken from a variety of studies involving the use of cv aids (n = 16)

Author and year	Country	Sample	cv aid/device	cv test	cv score	Subjective color perception
Schiefer, U et al. (1985)	Germany	N = 1	Hydroflex central tinted contact lens by Wöhlk Company	Ishihara cv test	80%	Yes
Zeltzer, HI et al. (1991)	USA	N = 1	Long wavelength pass filters	Ishihara cv test	20%	No
Hovis, JK et al. (1997)	Canada	N = 10	The contact lens for correction of color blindness	Ishihara and D-15 cv tests	33%	No
Swarbrick, HA et al. (2001)	Australia	N = 14	ChromaGen	Ishihara and D-15 cv tests	70%	Yes
Dain, SJ (2009)	Australia	N = 49	Sunglass tints	D-15 cv tests	59%	No
Matthew, OM et al. (2011)	UAE	N = 13	Chromagen Lenses	Ishihara cv test	85%	Yes
Bruce, J et al. (2014)	UK	N = 33	Colored overlays	Ishihara cv test	20%	No
Masstey, R et al.(2016)	USA	N = 27	O2 Amp and the EnChroma glasses	D-15 and cv test	11%	No
Veselý, P et al.(2017)	Czech Republic	N = 39	Red and green chromagen Filters	D-15 and cv test	45%	Yes
Almutairi et al. (2017)	USA	N = 9	EnChroma Cx-14 filters	Ishihara and FM-100 cv tests	20%	No
Gómez-Robledo, L et al. (2018)	Spain	N = 48	EnChroma glasses	FM-100 cv test	10%	No
Abdel-Rahman et al. (2018)	UK	N = 0	Bragg filters based on color dye contact lenses	Not reported	No	No
Salih, AE et al. (2020)	UAE	Review	VINO, EnChroma CVD glasses, and contact lens for CB	Reported and compared between aids	45%	Yes
Ahmed et al. (2021)	UAE	N = 0	Gold nanoparticle-induced contact lenses	Not reported	No	No
Jonathan Sutton, J et al. (2022)	New Zealand	N = 19	Augmentation of reality-based computational CVD glasses	Ishihara cv test and RGB ColorSpaces	80%	Yes
Roostaei, N et al. (2022)	Iran	N = 1	Flexible plasmonic contact lenses for color deficiency	Not reported	No	No

Abbreviations: CVD, color vision deficiency; FM, Farnsworth–Munsel; RGB, red, green, and blue.
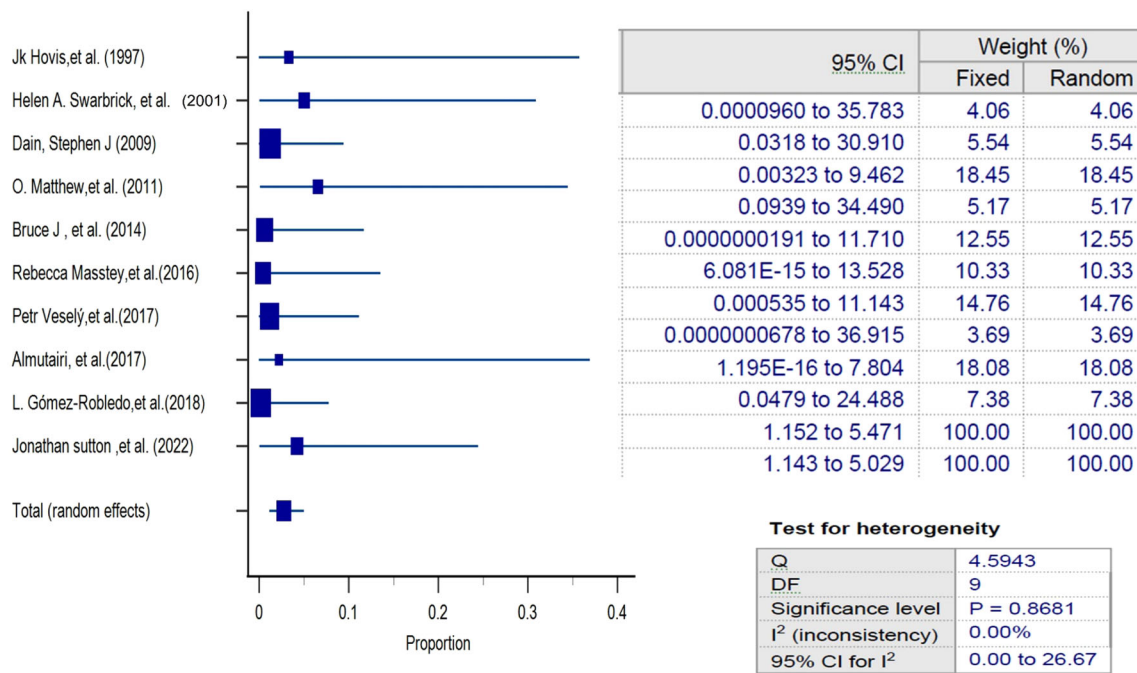
FIGURE 3 A forest plot illustration of ten studies demonstrates low variability and no significant correlation in color vision scores. This may be due to the small sample in research involving various color vision devices available in the market. CI, confidence interval; DF, degree of freedom.

color vision aid or device), and carryover effect (whether the effect on the performance of using a specific device affects the color vision outcomes of various device), were included as parameters in evaluating and reporting the risk of bias from $n = 16$ studies. To represent the data on the risk of bias, a generic traffic plot was illustrated and constructed using the robvis tool,[30] as shown in Figure 6.

4 | DISCUSSION

This systematic review and meta-analysis emphasize that technological advancements occurred between 1967 and 2022, as well as an increase in the development of color vision devices, with the most cutting-edge prototypes and models now available commercially in the market. Nonetheless, the NIRE study emphasized a 20-year database on effective color vision impairment rehabilitation devices and gadgets for CVD patients.[31] The database spanned the years 1967 to 1987. In the current situation, neither of these were applicable or functional, and the devices in question were only used as a stopgap measure; no clinical trials or evidence-based practices were conducted with their use.

The results showed key findings that after the usage of devices the color perception scores were not relatively significant, and commercially available devices such as EnChroma color vision glasses also could not show the results as they claim from their advertisements and marketings. The studies that were included in the current review showed low color vision scores and a minimal outcome of

color perception. In addition, neither a clinical trial nor an evidence-based study has been carried out on these devices, and developing a clinical recommendation for the utilization of these devices would be extremely difficult and expensive. These findings are also supported by the variation in perceived color perception with EnChroma glasses which did not improve diagnostic test results or normalize color vision in CVD patients.[23,24]

Furthermore, tests for evaluating color vision scores are crucial, most of the studies reported in the review and meta-analysis concluded that the Ishihara pseudo isochromatic test is primarily for color discrimination and may not provide a complete diagnosis of CVD, whereas the D-15 and FM-100 color vision tests reveal the full diagnosis and color perception outcomes effectively and with a high sensitivity rate. RGB color space evaluation and other color science tools will help to accurately identify the color in higher-end technology prototypes. These findings support the notion that the Ishihara color blindness tests can be passed using computational stimulation and digital color filters, and that using standard colorimetry tools and methodologies has no effect on CVDs' perception of advanced color vision tests.[32]

The speed and accuracy with which color vision insufficiency can now be diagnosed and treated because of technological advancements are critical factors to consider. Future researchers and manufacturers of rehabilitation devices should focus on these advancements, and predictions are made about how the tests will progress with increasingly advanced computer technology, with the goal of producing consistent and rigorous assessments of color vision that will be widely used in clinical practice.[33]

TABLE 2 Color vision aid and its effectiveness on color vision improvement were measured for the evidence, which was compiled using GRADE analysis[12] from the following studies n = 16

Author	Color Vision aids/Device	Year	Study design	Sample	Color Vision score	Subjective Color perception outcome	Certainty of the evidence (GRADE)
Schiefer, U et al.[14]	Hydroflex central tinted contact lens by Wöhlk Company, Kiel.	1985	Case study	N = 1	Improved	Yes	Low certainty
Hovis, JK et al.[15]	Long wavelength pass filters	1997	Case study and comparative study design	N = 10	Partially improved	No	Low certainty
Zeltzer, HI et al.[16]	Contact lens for correction of color blindness	1991	Innovation and Prototype and case study	N = 1	Partially improved	No	Low certainty
Swarbrick, HA, et al.[17]	ChromaGen filter	2001	Case control comparative	N = 14	Improved	Yes	Moderate certainty
Dain, SJ et al.[18]	Sunglass tints	2009	Case control	N = 49	Partially improved	No	Low certainty
Oriowo, OM et al.[19]	Chromagen Lenses	2011	Comparative study design	N = 13	Partially improved	No	Low certainty
Bruce, J et al.[20]	Colored overlays-Society for Colored Lens Prescribers	2014	Randomized control trial	N = 33	Partially improved	No	Low certainty
Masstey, R et al.[21]	O2 Amp and the EnChroma glasses	2016	Comparative experimental pre and poststudy design	N = 27	Partially improved	No	Low certainty
Veselý, P et al.[22]	Red and green chromagen filters	2017	Case-control study design	N = 39	Improved	Yes	Moderate certainty
Almutairi, N et al.[23]	EnChroma Cx-14 filters	2017	Comparative study design	N = 9	Partially improved	No	Low certainty
Gómez-Robledo, L et al.[24]	EnChroma Glasses	2018	Pre- and poststudy design	N = 48	Improved	No	Low certainty
Badawy, A-R, et al.[25]	Bragg filters based Color dye contact lenses	2018	Innovation and prototype design	N = 0	Not reported	Not reported	Low certainty
Salih, AE et al.[26]	VINO, EnChroma CVD glasses, and Contact lens for CB	2020	Comparative study design	Review	Improved	Yes	Moderate certainty
Salih, AE et al.[27]	Gold nanoparticle induced Contact lenses	2021	Prototype and innovation	N = 0	Not reported	Not reported	Low certainty
Roostaei, N et al.[28]	Flexible plasmonic contact lenses	2022	Prototype and innovation	N = 1	Not reported	Not reported	Low certainty
Sutton, J et al.[29]	Augmentation of reality-based computational CVD glasses	2022	Prototype, innovation, and exploratory study	N = 19	Improved	Yes	Moderate certainty

Note: Very low certainty: The true effect is probably markedly different from the estimated effect.

Abbreviations: CVD, color vision deficiency; GRADE, grading of recommendation, assessment, development, and evaluations.

Low certainty: The true effect might be markedly different from the estimated effect.

Moderate certainty: The authors believe that the true effect is probably close to the estimated effect.

High certainty: The authors have a lot of confidence that the true effect is similar to the estimated effect.
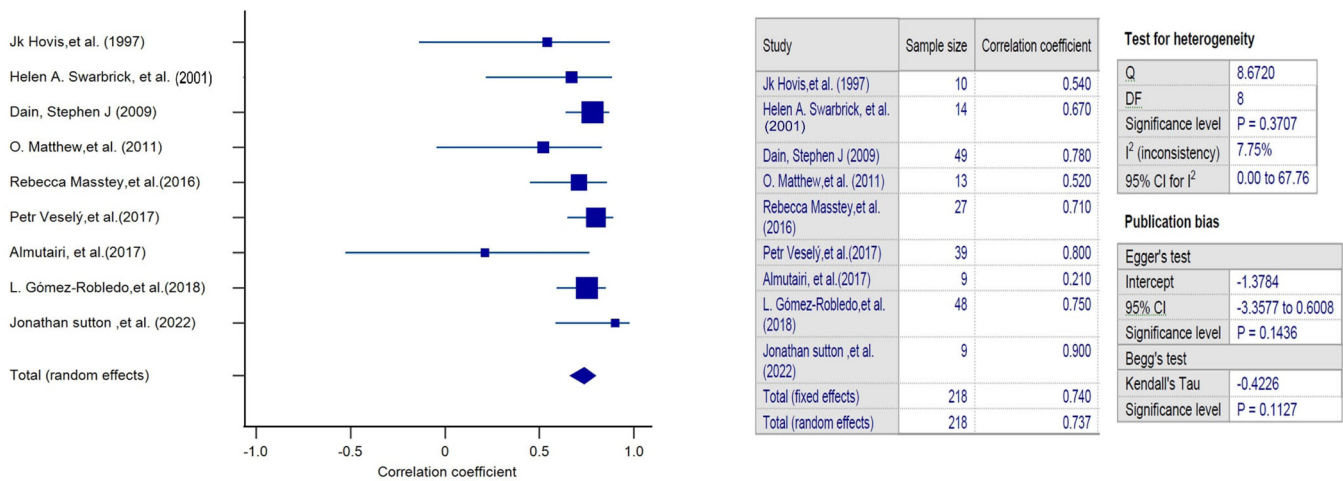
FIGURE 4 Illustration of a forest plot using the color vision score and correlation coefficients from $n = 9$ studies. The heterogeneity is modest, but the correlation is substantial. CI, confidence interval; DF, degree of freedom.
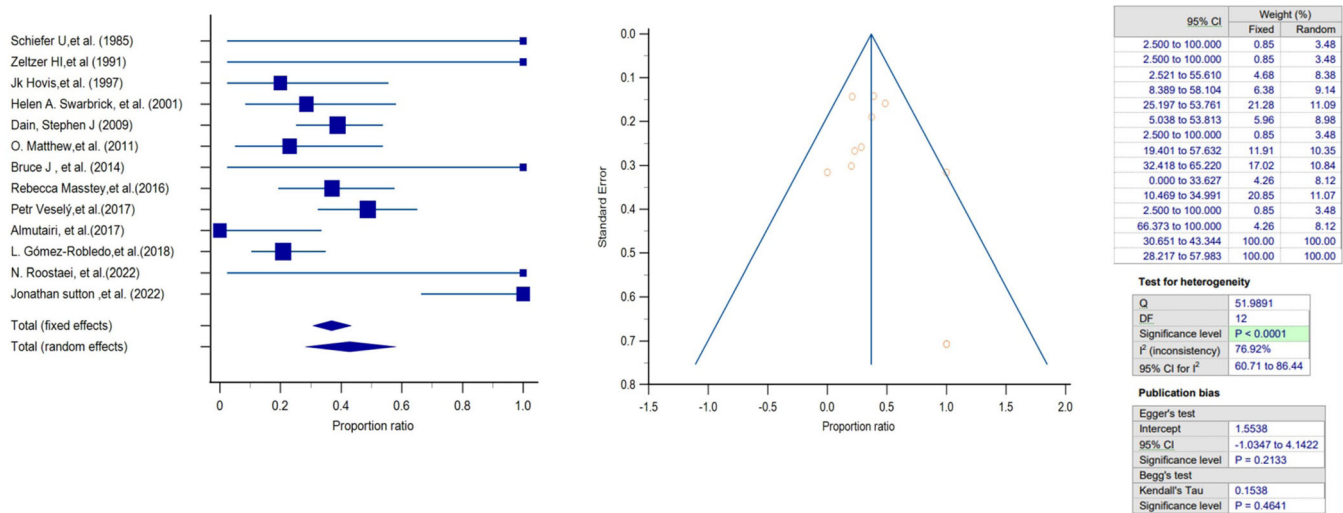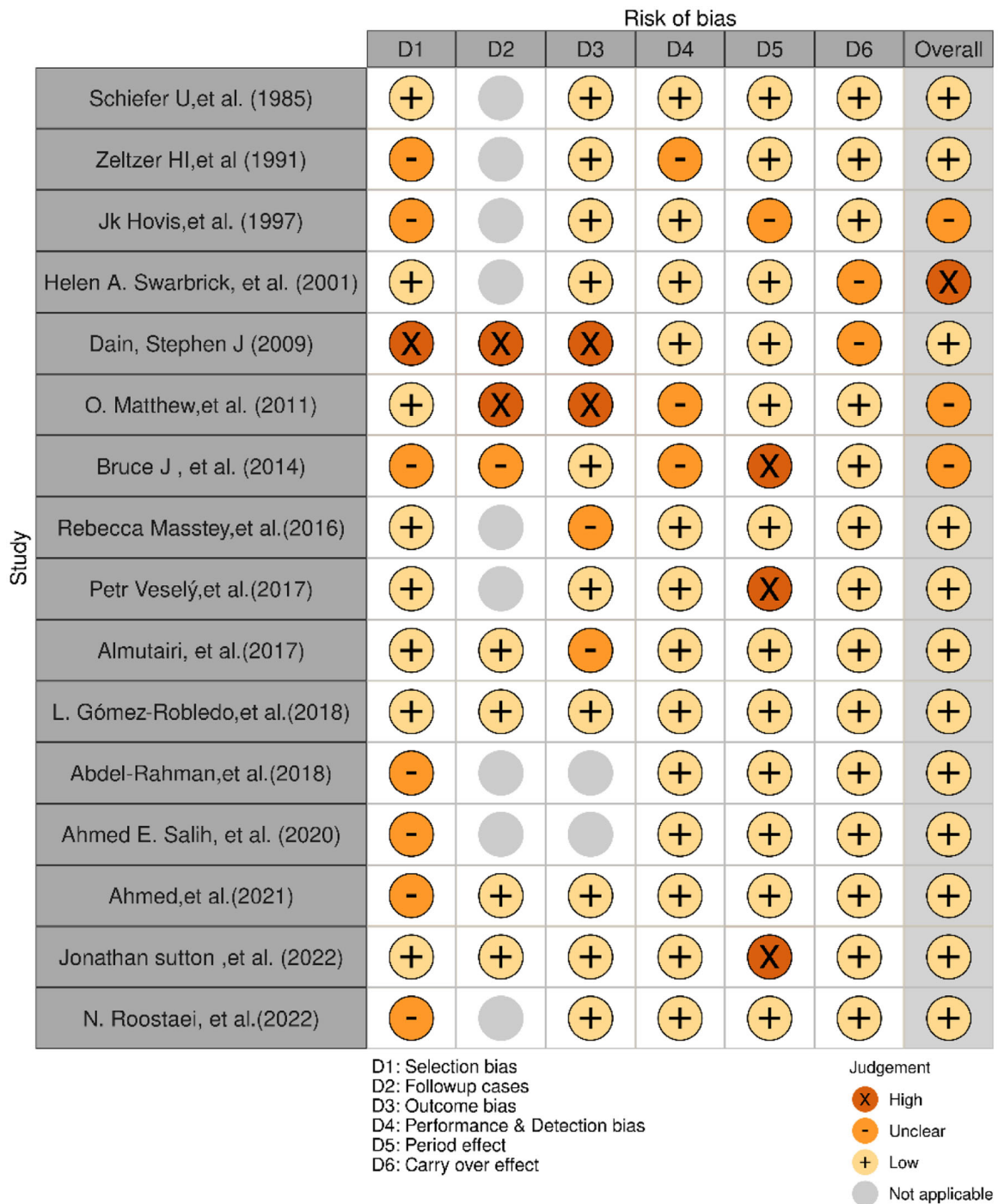

FIGURE 5 A forest plot and a funnel plot displaying color vision aids and sample size, followed by proportion ratios and standard error for the evaluation of publication bias. CI, confidence interval; DF, degree of freedom.

A few color vision filters, such as chromagen filters, tinted lenses, and colored overlays, report an improvement in color vision scores. However, subjective color perception is ineffective, and CVD patients benefit from mild color enhancement. These devices are beneficial for people with protanomaly – red CVD. However, it does not display advanced color changes.[17,22] Similarly, in the current review, the chromagen filters demonstrated moderate certainty for clinical evidence, which should be investigated further with larger sample size and more advanced clinical color vision tests. Previous investigations on clinical practice demonstrated no substantial impact on CVD individuals. However, the red filter improved color vision performance and can benefit protanomaly patients.[34]

Contact lens technology made more advances and created further prototypes for patients with color blindness. Unfortunately, there have been very few clinical evaluations and no interventional phase studies to assess efficacy and color vision outcomes. The hydro flex central tinted lens improved color vision score and subjective perception but was limited to a case study and further investigation was halted,[14] followed by some cases of red-green color vision impairments may be improved using Chromagen lenses.[19] Colored dye contact lenses based on Bragg Filters are a recent innovation.[25] However, this prototype lacks any clinical data or efficacy demonstrated in human participants that color vision scores have improved. Similarly, gold nanoparticle-induced contact lenses innovation developed but not yet implemented for clinical trials on the human population to conclude that it may be beneficial for the CVD population, as this technology reveals no toxicity in human corneal fibroblasts and epithelial cells, indicating their promise in wavelength filtering and CVD management.[27]

Risk of bias

Study	D1	D2	D3	D4	D5	D6	Overall
Schiefer U,et al. (1985)	+	(na)	+	+	+	+	+
Zeltzer HI,et al (1991)	−	(na)	+	−	+	+	+
Jk Hovis,et al. (1997)	−	(na)	+	+	−	+	−
Helen A. Swarbrick, et al. (2001)	+	(na)	+	+	+	−	X
Dain, Stephen J (2009)	X	X	X	+	+	−	+
O. Matthew,et al. (2011)	+	X	X	−	+	+	−
Bruce J , et al. (2014)	−	−	+	−	X	+	−
Rebecca Masstey,et al.(2016)	+	(na)	−	+	+	+	+
Petr Veselý,et al.(2017)	+	(na)	+	+	X	+	+
Almutairi, et al.(2017)	+	+	−	+	+	+	+
L. Gómez-Robledo,et al.(2018)	+	+	+	+	+	+	+
Abdel-Rahman,et al.(2018)	−	(na)	(na)	+	+	+	+
Ahmed E. Salih, et al. (2020)	−	(na)	(na)	+	+	+	+
Ahmed,et al.(2021)	−	+	+	+	+	+	+
Jonathan sutton ,et al. (2022)	+	+	+	+	X	+	+
N. Roostaei, et al.(2022)	−	(na)	+	+	+	+	+

D1: Selection bias
D2: Followup cases
D3: Outcome bias
D4: Performance & Detection bias
D5: Period effect
D6: Carry over effect

Judgement
X High
− Unclear
+ Low
(na) Not applicable

FIGURE 6 A generic traffic plot was presented and built utilizing the data on the risk of bias using the robvis tool.

In the latest days, flexible plasmonic contact lenses with color enhancement have been developed for the management of CVD patients. However, clinical trials and data are still pending. Flexible plasmonic contact lenses were created using polydimethylsiloxane and soft nanolithography for red–green deficiency and color blindness. Plasmonic contact lenses have a good color filter for correcting color blindness. Color blindness can be corrected thanks to biocompatibility, low cost, stability, and ease of fabrication.[28] By considering the above novel technologies, more clinical trials and case-control studies will offer insights into color vision devices and management.[26]

Recent research using a computational color vision device, an augmented reality prototype, and an exploratory study approach showed improved clinical outcomes with small sample size. This study revealed that using augmented reality to develop computational glasses that can correct for a loss in color vision provides exciting insights into this technology. This study demonstrated that augmented reality glasses could compensate for this disadvantage[29]

Color lite filters will not increase the CVD gamut. Because the cone sensitivity calculation requires various assumptions, the CIELAB color space may not be appropriate. There is no data on CVD observers' adaptation to long, medium and short color blindness.[35] With advanced computing technology and advances, implementing Computational CVD devices might be beneficial. However, clinical trials and intervention studies are required for testing and validating these devices to have a better knowledge of CVD and treatment. Only one computational model was included in the current review, which has modest confidence in improving color vision outcomes and can show improved findings in the future by implementing and testing in a more enormous CVD population.

Finally, the present study underlines that because of the scarcity and paucity of clinical trials and other interventional research, very little information on the impact of commercially available color vision devices on CVD patients was analyzed. From the reported studies few color vision devices are considered for rehabilitation devices, red and green chroma gen filters, O2 amp oxy- color vision glasses, and augmentation reality-based computational CVD glasses.

A few limitations were also mentioned, such as the smaller sample size, the lack of clinical data, and the absence of more color vision approaches for gathering primary data. Especially with respect to CVD devices based on contact lens technology. Clinical data were presented in only a few papers and research. To solve these constraints, future research can investigate this gap to learn more about contact lens technologies that can help with CVD. The evolution of color vision devices over a period with no concurrent validation of their utility may be another limitation.

5 | IMPLICATIONS FOR FUTURE RESEARCH, POLICY, AND CLINICAL PRACTICE

The reported study limitation was also considered in the Risk and Bias evaluation to focus more on future studies, how technology is evolving in producing novel color vision devices, and according to the findings, most CVD devices were produced by developed countries. Given this, the most densely populated country with a rising prevalence of CVD such as India, should focus on developing revolutionary technology devices for the CVD population. From the current review, the authors identified the future scope for low-cost prototypes with customized color vision devices by assessing individual CVD patients' cone sensitivity measurements.

AUTHOR CONTRIBUTIONS

ACKNOWLEDGMENT

CONFLICT OF INTEREST
The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT
All datasets generated and analyzed are available in the article.

ETHICS STATEMENT
This study protocol has been assessed and approved by the institutional ethics committee at the University of Hyderabad Reg. No.: UH/IEC/2019/215.

TRANSPARENCY STATEMENT
Shiva Ram Male affirms that this systematic review based on his PhD thesis work is an honest, accurate, and transparent description of the research being described, that no critical components of the investigation have been omitted, and that any discrepancies from the planned study have been explained. The initial findings of the systematic review was presented at 43rd ECVP, 2021.

ORCID
Shiva Ram Male http://orcid.org/0000-0001-5872-4990
Bindiganavale R Shamanna https://orcid.org/0000-0001-9270-837X
Baskar Theagarayan http://orcid.org/0000-0002-5788-3735

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