

Original Research Article

Colour vision deficiency and driving: impact on safety, performance and everyday challenges

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ABSTRACT

Background: This study aimed to assess the impact of colour vision deficiency (CVD) on driving performance, challenges and related factors among licensed male drivers.

Methods: This prospective observational study recruited drivers with normal and colour vision deficiency. Initial screening used the Ishihara plates, followed by AO-HRR plates to confirm the type of congenital CVD, and the Farnsworth Lantern signal test to assess signal perception. Drivers with best-corrected visual acuity less than 6/12 or acquired CVD were excluded. Detailed eye examinations and occupational/driving histories were also collected.

Results: The study included 63 male drivers: 30 with normal colour vision (mean age 41.1±6.6 years) and 33 with congenital CVD (mean age 38.7±8.9 years). Drivers with CVD were eight times more likely to experience difficulties compared to the normal vision group (OR: 7.80, 95% CI: 2.22-27.39, p=0.001), and nearly five times more likely to report difficulties under adverse conditions such as rain, fog, bright sunlight, (OR: 4.79, 95% CI: 1.36-16.87, p=0.015). No statistically significant association was found between CVD and road traffic accidents (RTA) in current study (p=0.07). However, CVD did affect the driving performance and self-reported difficulties.

Conclusions: No statistically significant association was found between CVD and RTA in current study; however, it significantly affects driving performance, with protans experiencing delayed signal recognition and deutans experiencing more colour confusions, especially under adverse weather conditions when secondary cues were absent.

Keywords: Colour vision deficiency, Deutan, Driving performance, Protan, Traffic signal perception

INTRODUCTION

Driving relies heavily on visual input, including colour discrimination, which plays a key role in identifying road cues such as traffic signal lights, brake lights, and retro-reflectors. However, these advantages may not fully extend to drivers with colour vision deficiency (CVD) particularly congenital red-green deficiency.¹ This can affect how they detect and interpret traffic signals, especially in urban environments with multiple signal sources.² Although many individuals with CVD develop compensatory strategies, their performance may still be

challenged on unfamiliar routes, glare, fog, rain, or night-time driving.³

Reported prevalence of congenital CVD among Indian driver ranged between 1.34% to 14%, screened predominantly using Ishihara plates, across various states in India, indicating that a meaning proportion of driving population may be affected.⁴⁻⁷ Previously, Indian licensing did not permit individual with CVD to obtain a driving license; this was recently amended by the Ministry of Road Transport and Highways (MoRTH), allowing those with mild-to-moderate CVD to obtain a licence.⁸ This makes it important to understand not only

whether CVD is associated with crashes, but also whether it affects day-to-day driving performance and visual perception in real-world situations. This study therefore aimed to evaluate the driving-related challenges in drivers with congenital CVD using clinical colour vision tests, signal perception test and detailed occupational driving history.

METHODS

The prospective observational study was conducted between September 2021-March 2022, at the department of occupational optometry services of a tertiary eye care hospital, in Chennai. The study adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board and ethics committee.

The sample size was estimated for a single sample proportion using Cochran's formula $n = Z^2 p(1-p)/e^2$, where $Z=1.96$ (5% type I error), $e=5\%$ margin of error, and $p=2.02\%$. The estimated proportion of the population, that is, the prevalence of CVD was obtained from a study conducted among truck drivers frequenting a truck parking area located in the NH 4 (Chennai-Bengaluru highway).⁶ This yielded a minimum requirement of 31 participants.

Inclusion and exclusion criteria

Drivers visiting occupational optometry clinic of a tertiary eye hospital for routine eye examinations were recruited for the study. Following the comprehensive eye examination, all the eligible drivers identified with congenital color vision deficiency were recruited with informed consent. Drivers with normal color vision were recruited as controls, selected at random from eligible attendees. No participant who was approached declined to participate.

Participants were light motor vehicle (LMV) or heavy motor vehicle (HMV) drivers, aged between 18 and 55 years, with a best corrected visual acuity (BCVA) of 6/12 or better in both eyes. Drivers with systemic diseases or ocular pathologies known to affect the colour vision defects excluded. A detailed occupational history (Appendix 1) relevant to driving was recorded, and responses were documented. The occupational history was categorized into four components: 1) driving experience, (2) colour vision awareness and licensing history, (3) self-reported difficulties and (4) traffic offences and road traffic accidents.

Following the comprehensive eye examination, subjects were screened for colour vision deficiency using the 38-plate edition of Ishihara pseudoisochromatic plates (PIP). The plates were held at a distance of 75 cm and tilted perpendicular to the line of vision. Plates 1-17 were presented sequentially, with three seconds allowed for each response. Failure to correctly identify one digit (in single-digit plates) or both digits (in two-digit plates) was

considered an error. Subjects with more than three typical errors in transformation and vanishing plates were classified as colour vision deficient.⁹

Participants who failed the screening test underwent further testing with the fourth edition of Hardy-Rand-Rittler (AO H-R-R) pseudoisochromatic plates (Good-Lite Co., USA) to confirm and classify the type of congenital color vision defect. The plates 11-20 were used to diagnose red-green (protan/deutan defects, and plates 21-24 for blue-yellow (tritan/tetartan) defects. With the use of scoring sheet, for each plate, a check marks were recorded when the patient correctly named and located symbol. The checks were summed separately by columns between 11 to 20, excluding 21-24. An individual is classified as protan if the total number of checks in the protan column exceeds the deutan column, and vice versa. Severity was graded according to the maximum number of errors recorded across the mild, moderate, and strong diagnostic plates.¹⁰

Both participants with normal and deficient colour vision underwent the Farnsworth Lantern Signal test. At the test was conducted at a distance of three meters, nine combinations of red, green, and yellow lights were presented vertically in pairs at eye level in random order, with two seconds allowed per response. If a participant changed their response before the next presentation, the final response was recorded. The test was repeated if the subject did not comprehend it on the first attempt. An error was recorded when one or both lights in a pair were misnamed, and more than one error was considered a failure. All the color vision testing was performed under standard clinical room fluorescent lighting, with illuminance maintained at 350 lux, meeting the recommended illumination levels.¹¹

Data were entered and coded in Microsoft Excel 2019, screened for missing data and outliers: no missing data were identified and all 63 participants were included. Data were analyzed using SPSS version 20.0 (IBM Statistics). The association between colour vision-related driving difficulties, road traffic accidents (RTA), and traffic offences among colour vision normal and colour vision deficient subjects was analyzed using Pearson's Chi-Square test. A p value of ≤ 0.05 was considered statistically significant. Since data were not normally distributed, as determined by the Shapiro-Wilk normality test ($p > 0.05$), the Mann-Whitney U test was used to compare years of driving experience and average kilometres driven per day between colour vision normal and colour vision deficient subjects. Binary logistic regression was used to estimate odds ratio for colour vision-related driving difficulties. The primary outcome was a composite variable representing any reported difficulty across four domains: signal perception, adverse conditions (rain, fog, bright sunlight, and night driving), unfamiliar routes, and fatigue. A second outcome specifically isolated difficulty under adverse conditions. For both outcomes, colour vision status was entered as the sole predictor (univariate/crude odds ratio), consistent

with the study's primary comparative objective. For the RTA outcomes, seven variables (age, presenting visual acuity, colour vision status, driving experience, driving extent, presence of glare, and refractive error) were accounted based on clinical plausibility as risk factors for RTA.

RESULTS

A total of 63 male drivers were recruited, 30 with normal colour vision and 33 with colour vision deficiency (CVD). The mean age of drivers with normal colour vision was 41.1 ± 6.6 years, while the mean age of drivers with CVD was 38.7 ± 8.9 years. Among them, 61 (98.4%) were light motor vehicle (LMV) drivers, operating auto rickshaws, van, and mini trucks, while 2 (3.2%) were heavy motor vehicle (HMT) drivers, operating buses and trucks. Presenting visual acuity was less than 6/12 in one or both eyes in 17(27%) drivers, improving to 6/6 following refractive correction meeting the eligibility criteria. Glare symptoms were reported by 6 (9.5%) drivers. Rest of the ocular finding were observed to be normal among the participants.

Among the 33 drivers with CVD, color vision deficiency was diagnosed using Ishihara pseudoisochromatic plates (PIP) and classified as 22 (66.6%) as deuterans and 11 (33.3%) as protans using AO Hardy-Rand-Rittler (H-R-R) test. Severity, also graded using the AO H-R-R test as

follows: 6 (18.2%) had mild deutan, 3 (9.1%) had moderate deutan, 13 (39.4%) had strong deutan, 1 (3%) had moderate protan, and 10 (30.3%) had strong protan. Difficulties related to colour vision were reported by 13 (20.6%) drivers.

Only 3(9%) out of 33 CVD passed the Farnsworth Lantern test. Error score increased with increasing CVD severity, showing a strong positive correlation between HRR severity and lantern scores ($r=0.73$, $p=0.00017$). Deuterans in mild-severity group were more likely to pass the lantern test, while both moderate and strong deuterans CVD failed the lantern test. Among protans, no significant association was observed between HRR severity and lantern scores ($r=0.205$, $p=0.545$). No significant difference in lantern scores observed between protans and deuterans ($U=109.60$, $p=0.808$).

Average driving experience and daily mileage by colour vision status

Drivers with normal colour vision observed to have slightly higher average driving experience 16 ± 8.02 years, compared with drivers with CVD 13.85 ± 9.57 years, however the difference was not statistically significant ($p=0.178$). Conversely, statistically significant difference in average kilometres driven per day among drivers with CVD (62.70 ± 99.56 km) compared to drivers with normal colour vision (161.67 ± 155.28 km) ($p=0.01$).

Table 1: Colour perception, driving performance, and history of traffic offences and RTA.

Questions	Colour vision normal (n=30)		Colour vision deficiency (n=33)		Chi-square P value
	Yes (%)	No (%)	Yes (%)	No (%)	
1. CV need: Is normal colour perception important for driving?	29 (96.6)	1 (3)	27 (81.8)	6 (18.1)	0.061
2. CV adequacy: Do you think your colour vision is good enough to drive?	30 (100)	0 (0)	29 (87.8)	4 (12.1)	0.049
3. CV difficulty: Do you have any difficulties (delay/confusion/ inability) in perceiving traffic signals, or rear lighting: tail/brake lights in vehicles, retro-reflectors in roads/vehicles?	2 (6.6)	28 (93.3)	11 (33.3)	22 (66.6)	0.009
4. CV difficulty on unfamiliar places: When driving on unfamiliar places, have you ever experienced difficulty in appreciating colour codes/signals?	0 (0)	30 (100)	6 (18.2)	27 (81.8)	0.014
5. CV difficulty under adverse conditions: Do you find it challenging to perceive colour signals under bright sunlight/at night-time/during rain/fog/when tired/sleepy?	4 (13.3)	26 (86.7)	14 (42.4)	19 (57.6)	0.011
6. Traffic offense: Have you committed a traffic offense by jumping stop lights?	9 (30)	21 (70)	6 (18.2)	27 (81.8)	0.271
7. RTA: Have you caused any road accidents?	7 (23.3)	23 (76.8)	2 (6)	31 (93.9)	0.070

* CV: Colour Vision, RTA: road traffic accident.

Self-awareness on colour vision deficiency and obtaining a driving license

Of the 33 drivers diagnosed with CVD, only 18 (54.5%) were aware of their condition while applying for a driving

license. Only one HMT driver underwent a comprehensive ophthalmic examination, including a colour vision test and eight drivers (12.7%) underwent a signal test at the regional transport office (RTO). Although 12 out of 18 drivers who were aware of their

CVD believed that good colour vision is essential for driving, none self-reported their colour vision status to the RTO before obtaining their license. The outcomes of questions related to colour perception and driving performance are summarized in Table 1.

Fifty-six drivers (88.9%) perceived that having normal colour vision is crucial for driving on Indian roads, particularly in cities with numerous traffic signals. This perception was more pronounced among those with greater driving experience in terms of both years ($U=99.5$, $p=0.033$) and distance driven ($U=71.5$, $p=0.005$). Among drivers with CVD, four (12.1%) - three protans and one deutan - reported that their colour vision was not adequate for driving, despite having significant

experience. Six drivers with CVD (18.2%) - four protans and two deutans - reported difficulty recognizing colour-coded signals while driving on unfamiliar areas, attributed to the absence of positional cues.

Eighteen drivers (28.6%) reported difficulties while driving under adverse conditions - four drivers with normal colour vision (13.3%) versus 14 drivers with CVD (42.4%), including five protans and nine deutans. While drivers with normal colour vision were expected to have better signal perception, four (13.3%) reported difficulties in recognizing signals when the lights were dim, damaged, or in adverse weather conditions such as heavy rain or fog. The percentage of drivers reporting difficulties by type of defect is presented in Table 2.

Table 2: Percentage of drivers reporting difficulties by type of defect.

Type of difficulty	Number and percentage of drivers with CVD	
	Protan n=11 (%)	Deutan n=22 (%)
Delay in seeing signal lights	4 (36.36)	4 (18.18)
Confusion in signal lights	1 (9.09)	2 (9.09)
Difficulty in driving on unfamiliar places	4 (36.36)	2 (9.09)
Difficulty under sunlight	3 (27.27)	3 (13.64)
Difficulty at night-time driving	2 (18.18)	2 (9.09)
Difficulty during rain and fog	3 (27.27)	7 (31.82)
Difficulty when fatigued/tired/sleepy	2 (18.18)	1 (4.55)

Table 3: Possible risk factors for road traffic accidents.

Risk factors for RTA	N	Odds ratio	95% CI	P value
Age	63	1.04	0.95-1.13	0.39
Presenting visual acuity	63	0.08	0.001-6.02	0.25
Spherical equivalent Refractive Error	63	0.95	0.54-1.68	0.87
Driving experience (in years)	63	1.03	0.95-1.11	0.54
Driving extent (kilometres /per day)	63	1.00	0.99-1.01	0.95
Colour vision status				
Colour vision normal	30	1.00		
Colour vision deficient	33	0.212	0.04-1.12	0.07
Glare				
Absent	51	1.00		
Present	12	1.26	0.23-6.99	0.79

*RTA: Road traffic accident, CI: Confidence interval.

Drivers with colour vision deficiency were approximately eight times (OR: 7.80, 95% CI: 2.22-27.39, $p=0.001$) more likely to experience colour vision-related difficulties while driving than those with normal colour vision. Reported colour vision-related driving difficulties varied with driving experience, decreasing as years of experience increased ($p=0.018$). Drivers with colour vision-deficiency were nearly five times more likely to face challenges under adverse conditions compared to drivers with normal colour vision (OR: 4.79, 95% CI: 1.36-16.87, $p=0.015$).

Traffic offence committed: Nine drivers with normal colour vision (30%) and six drivers with CVD (18.18%) committed traffic offenses by jumping stop lights. Among the colour vision-deficient drivers, two were protans and four were deutans. However, both protans attributed their offense to an unintentional cause - misinterpretation of signal lights. There was no statistically significant association between colour vision status and traffic offenses ($\chi^2=1.21$, $p=0.27$).

Road traffic accidents (RTA) caused: seven drivers with normal colour vision (23.33%) and two drivers with CVD

(6.06%) were involved in road traffic accidents (RTAs)-six minor crashes and three major collisions. The attributed causes included glare, poor road maintenance, improper driving techniques, foggy conditions, and careless driving. Both CVD drivers involved in RTAs were protans; however, their accidents were reported to be due to glare and improper driving techniques, rather than colour vision deficiencies. There was no statistically significant association between CVD and RTAs ($\chi^2=3.82$, $p = 0.07$); however, with only nine reported RTAs across the groups, this analysis was likely underpowered to detect a true association.

The following driver characteristics were entered into a multivariable model: age, presenting visual acuity, refractive error, driving experience, daily driving distance, presence of CVD, and glare complaints. None of these factors had a statistically significant influence on RTAs ($p>0.05$); odds ratio for each potential risk factor is presented in Table 3.

DISCUSSION

The present study assessed the impact of colour vision deficiency (CVD) on driving performance, challenges, and related factors among licensed male drivers. Among the drivers with CVD, most were deutan, and 13 (39.3%) had strong defects. The mean age and years of driving experience were comparable between the two groups, but drivers with CVD reported driving fewer kilometres per day, suggesting either driving restrictions or behavioral adaptations in response to their limitations in colour perception. Overall, 89% of drivers agreed that normal colour vision is necessary for safe and efficient driving on Indian roads. Nearly all drivers with normal colour vision and the majority with CVD perceived their colour vision as adequate for driving, underscoring the need for awareness so they do not underestimate its potential implications.

Drivers with CVD were about eight times more likely to struggle with perceiving colour codes used on the road and about five times more likely to face difficulties under adverse environmental conditions such as rain, fog, bright sunlight, and night-time when compared to drivers with normal colour vision. These findings support previous studies suggesting that CVD may increase the risk of driving errors, particularly in adverse weather conditions and at night-time. This risk is heightened when secondary cues such as signal position or vehicular movement are absent or when drivers with CVD are tired, as signal lights may be confused with street lights.^{3,12-14} Unlike in the study by Tagerelli et al, where drivers with CVD preferred day driving, in the current study, more drivers with CVD reported difficulty under sunlight than at night.¹⁴

Six drivers with CVD reported difficulty appreciating colour signals, compared to none among those with normal colour vision. This finding suggests that CVD-

related challenges become more evident in new or unaccustomed environments where positional cues are not well learned. Under adverse conditions such as rain, fog, bright sunlight, or night-time driving, 42.4% of CVD drivers reported challenges, highlighting the influence of environmental factors on visual signal perception. These findings highlight the need to counsel drivers with CVD about potential difficulties they may experience while driving, even when they are not yet aware of them.

Seven of eleven drivers with protan defects (63.6%) faced more difficulties than ten of twenty-two drivers with deutan defects, especially in recognising signal lights on unfamiliar routes and during adverse weather conditions. All protans who committed traffic offences attributed them to colour perception and these align with observations made by previous authors.^{12,15,16} Drivers with protan defect reported that they were only able to recognize signal lights at closer distances, which is attributable to their reduced visual range.^{3,15} Drivers with deutan defects reported more confusion between signal light colours, which is attributable to the absence of brightness cues seen in protans. This finding is consistent with previous experimental studies, where deutan showed a significantly reduced ability to detect coloured road signs and signals in complex visual environments and performed worse in naming colours when lights were projected randomly without positional cues.^{2,15,17} This difference highlights the need to classify CVD subtypes and counsel accordingly rather than treating them simply as individuals with colour vision deficiency.

Although we did not find a statistically significant association between colour vision status and road traffic accidents or traffic offences ($p>0.05$), the absence of significance does not negate the practical difficulties reported by drivers with CVD. These results are consistent with studies among commercial drivers in various other countries, in which many drivers with CVD often compensate effectively and drive as safely as those with normal colour vision.^{12,18-21} A meta-analysis reported a 36% increased risk of RTAs among drivers with CVD (RR 1.36, 95% CI 1.01-1.82), a considerably larger evidence base than the current study could draw on for its own null result.²²

Compensatory strategies and self-regulations may reduce real-world crash rates, consistent with our finding that drivers with CVD relied on positional or contextual cues rather than colour alone. For instance, all drivers in current study were able to identify signal lights by moving closer to the post, and none reported difficulty recognizing rear lighting, retro-reflectors, or signboards. Drivers with CVD also drove significantly fewer kilometres per day than those with normal colour vision ($p=0.01$), despite comparable years of driving experience. Nearly half of drivers with CVD (45.45%) were unaware of their deficient status and its driving implications and none had undergone detailed colour vision evaluation yet they had adopted the compensatory behaviours

unprompted. This highlights the need for increasing screening and education so individuals with CVD can be counselled appropriately to adopt compensatory strategies.⁸

The Farnsworth flashlight lantern findings provided an objective functional perspective that complemented the self-reported driving difficulties. Only 3(9%) of 33 drivers with CVD passed the lantern test, and scores strongly correlated with HRR severity among deuterans ($r=0.73$, $p=0.00017$), with only mild-severity deuterans predominantly passing; and both moderate and strong deuterans failed. This observation is consistent with the Farnsworth lantern's known design, which is intended to fail individuals with moderate-to-severe CVD.²³ Among protans, no significant correlation was observed between HRR severity and lantern performance ($r=0.205$, $p=0.545$), likely reflecting the absence of mild-severity protans in this sample rather than a true absence of a severity relationship. There was no significant overall difference in lantern scores between protans and deuterans ($U=109.60$, $p=0.808$). This supports the need for subtype-specific counselling. Common colour confusion on the lantern included yellow and green, and are often misperceived as orange/red and yellow/red respectively. Protans identified red more accurately than the other two colors. These findings support the need for subtype-specific counselling: protans may need advice regarding reduced signal recognition at a distance, and deuterans may benefit from guidance on hue confusion and the limitations of relying on colour alone.

Practice-based counselling should be provided to drivers with CVD to help them make better judgements while driving, such as reducing speed, avoiding driving when tired, maintaining a longer distance from vehicles ahead, and relying on secondary cues like signal position or vehicular movements.⁸ Drivers with CVD should also be cautioned about unfamiliar routes and adverse environmental conditions. Driving regulations for CVD vary considerably worldwide, with several jurisdictions moving away from categorical colour vision screening toward functional assessment and compensatory strategies; the present findings support this broader shift toward evaluating real-world driving performance rather than colour vision status alone.⁸

Limitations

The lack of detailed information on other contributory factors such as educational level and smoking or alcohol use, possible recall and response bias, and limited generalizability due to the single-center design, the predominance of light motor vehicle drivers, and the exclusively male sample- reflecting the higher prevalence of congenital CVD among males, though findings may not extend to the smaller population of affected female drivers. Self-reported crash history may not fully capture the impact of CVD on driving performance. Larger multicentre studies, including more heavy vehicle drivers

and objective simulation-based assessment of driving performance, are warranted.

CONCLUSION

This study reports the difficulties experienced by drivers with congenital CVD in driving performance and signal perception. Drivers with CVD were up to eight times more likely to report difficulties overall and five times more likely under adverse conditions than those with normal colour vision, with protans and deuterans showing distinct patterns of difficulty. With the Ministry of Road Transport and Highways (MoRTH) now permitting individual with mild-to-moderate colour blindness to obtain commercial driving licence, incorporating colour vision deficiency subtype, functional colour vision testing, and detailed occupational driving history can make patient counselling more targeted and relevant.⁸

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APPENDIX 1

Detailed occupational history relating to color vision in driving and RTA

Driving history

Driving experience related questions:

1. How many years have you been driving?
2. How regularly do you drive? (No. of days/ week; No. of hours/day)
3. How many kilometres do you drive in a week?

Color vision deficiency awareness and Driving license related questions:

1. What type of license do you hold? (Transport/ non-transport)
2. When did you obtain your license?
3. When did you renew your license last?
4. Was your color vision checked before obtaining license or before renewal of license?
5. If color vision was checked, who checked it? (By self/ ophthalmologist/ optometrist/ general medical practitioner/ road traffic officer)
6. If color vision was defective: are you aware of your color vision deficiency?
7. If color vision defective: if you're aware of your color vision deficiency, did you self-declare your color vision status before obtaining your driving license?

Accident history

Color vision related perceptions:

1. How important is color vision to driving?
2. Do you think your color vision is good enough to drive?
3. Do you have any difficulties (delay/ confusion/ inability) in perceiving traffic signals, rear lighting: tail/ brake lights in vehicles, retro-reflectors in roads/ vehicles?
4. Do you find it challenging to perceive color signals under bright sunlight/ at night-time/ during rain/ fog/ when fatigued/ sleepy?
5. When driving on unfamiliar routes, have you ever experienced difficulty in appreciating color codes/signals?

Traffic offences and RTA related questions:

1. Have you committed traffic offence by jumping stop lights?
2. If yes, what was the reason? (Probe: Was it a deliberate violation/ in deliberate error due to not perceiving the signal because of CVD?)
3. Have you been involved in any road traffic accidents? (human/ material damage)
4. If you've caused any accidents, was it a near-miss/ minor crash/ major collision?
5. If you've caused any accidents, do you attribute it to difficulty in color perception