DIVERSITY ON DRIVER INFORMATION SYSTEMS: A SWOT ANALYSIS OF VISION AID R&D FOR DRIVERS WITH ABNORMAL COLOR VISION

Henrique Novais Nunes de Oliveira
Ford South America

Fabrício Ferreira
Thiago Murari
Rafael Vieira
Roberto Costa
Ford South America

ABSTRACT

This paper presents a SWOT analysis of the vision aid R&D projects that can help abnormal color vision drivers while suggesting a prototype. Creating unique and satisfying user experiences are becoming the focus of products and digital user interfaces are a big part of this deliver. Digital interfaces grow in complexity, quantity and customization: Graphical User Interfaces (GUI) will become standard features for cars all over the world while about 200 million individuals are born as Color Vision Deficient (CVD). An introduction to critical concepts for understanding the Abnormal Color Vision (ACV) condition is done while six R&D projects aimed at helping CVD individuals are analyzed as to better understand how to bring these innovations to the automotive industry for applications on improving a Abnormal Color Deficient (ACD) driver's UX. Thus, to provide freedom of movement and comfort to the CVD driver, an optimal prototype concept is suggested in order to access these UX challenges.

INTRODUCTION

User experience (UX) has become an important topic in the automotive industry and its meaning may be shunned by how often the term is used.

Thankfully, Hassenzahl and Tractinsky (2006) brought to light that UX is related to three major fronts: addressing human needs beyond the instrumental, providing aid to the user's emotional state and the combination of the time and the situation in which the experience happens.
Research Kun, Boll and Schmidt (2016) indicate that further developments in Advanced Driver-Assistance Systems (ADAS) directly affects drivers' behavior inside the system, more actions are available to the driver as automation levels up (Table 1).

Table 1. Levels of automation and expected secondary tasks. Adaptation of table from Kun et al. (2016).

Level	Description	Example of expected secondary task
0	Car has no automation	Radio listening
1	Driver in pedal or steering wheel	Same as level 0
2	Driver away from pedal or steering wheel	Time-limited reading
3	Fully autonomous driving for time periods	Watching movies
4	Fully autonomous driving	Sleeping

Thus, Human-Machine Interfaces (HMI) must increase in quantity and quality in order to take full advantage of these secondary actions in a world going through a digital transformation process, a transformation in a scale described by Vial (2019).
We are beyond passing a time in which automotive HMIs are restricted to infotainment systems, HMIs will be needed to interact with most of, if not all, functions of any means of transportation.
However, HMIs, such as **Graphical User Interfaces (GUI), assume certain levels of contrast and range of colors for user usability when about 200 million individuals (MACHADO, OLIVEIRA AND FERNANDES, 2009) have difficulties processing information through color: these are Color Vision Deficient (CVD) individuals.**
About 8% of caucasian males (SHARPE, STOCKMAN, AGLE, AND NATHANS, 1999) are afflicted by Abnormal Color Vision (ACV) along with other ethnicities as shown in Table 2 and a recent research pipeline with participation of middle-aged individuals (JAFARZADEHPUR ET AL., 2014) indicates that CVD may be acquired with age.

Table 2. Red-green ACV among different ethnic groups from [5]

Ethnic Groups	Incidence of red-green CVD (%)	
	Male	Female
Caucasians	7.9	0.42
Asians	4.2	0.48
Africans	2.6	0.54

These 200 million individuals, that have always presented restraints (COLE, 2004) due to their physical conditions, could be more inhibited than ever when their daily commute experiences become bound to the usage of colorful and yet not empathetic designs of automotive GUIs.
Finally, this paper focus on answering two questions in the presented context:

Question 1: How a research and development has contributed to better UX journeys for CVD drivers?
Question 2: What Minimal Viable Product (MVP) prototype could further contribute to CVD drivers?

This paper is organized as follows: Key Color Vision Concepts Section describes key concepts for understanding a CVD condition, **Methodology and Results Sections answer the Question 1 while the Conclusion Section presents a prototype suggestion and a conclusion to answer Question 2.**

KEY COLOR VISION CONCEPTS

Normal human color vision is due to three different types of photoreceptor cells called *cones*: *L*, *M* and *S*. Each cone covers a part of the visible spectrum whereas L is for larger, M for medium and S for shorter wavelength (GEGENFURTNER, KARL, AND KIPER, 2003).

Each cone is defined by the type of photopigment it contains and three photopigments constitute the human vision. Thus, normally, we have *trichromatic color vision*.

However, natural variations of proteins in a photopigment may cause a shift in sensitivity to light: individuals with such conditions are bearers *anomalous trichromacy*.

In this case, color perception varies greatly and can be further classified in three subcases of *anomalous trichromacy* (Figure 1):

- *Protanomaly*: red-weak anomalous trichromacy.
- *Deuteranomaly:* green-weak anomalous trichromacy.
- *Tritanomaly:* blue-weak anomalous trichromacy.

There are cases in which Machado et al. (2009) a photopigment is missing. Individuals in such condition have *dichromacy*, capable of recognizing only two photopigments. *Dichromacy*, just like *trichromacy*, is further classified as (Figure 2):

- *Protanomaly*: dichromacy in which there are no red cones.
- *Deuteranomaly:* dichromacy in which there are no green cones.
- *Tritanomaly:* dichromacy in which there are no blue cones.

There are severe cases of ACV in which only one photopigment exists or there are no photopigments. These cases are classified as *monochromacy*. Bearers of such condition may have symptoms such as abnormal sensitivity to light and abnormal eye movement (YEE ET AL., 1981).

ACV simulation (Figure 2) was done through the usage of the *colorspacious* library (SMITH, 2020) which applies the physiologically-based color simulation model developed by Machado et al. (2009).

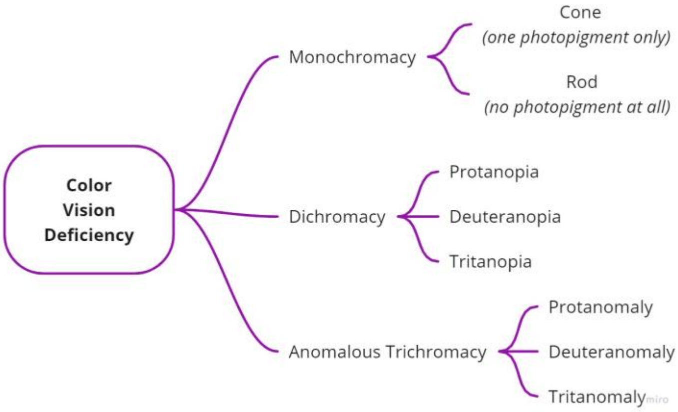

Figure 1. Mental map of ACV types.

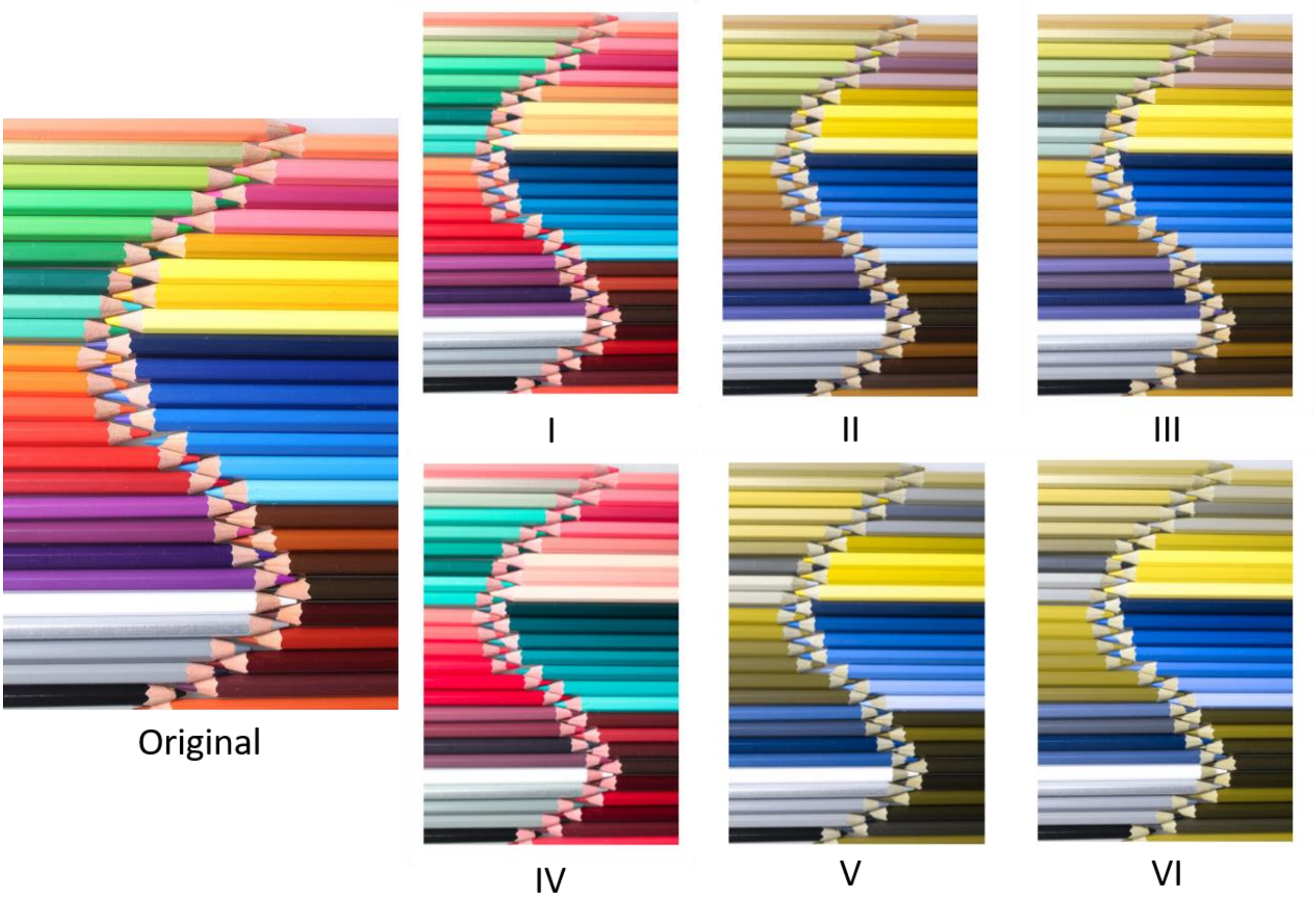

Figure 2. Color comparison between original image and CVD view simulation through colorspacious (SMITH, 2020) using the physiologically-based model from Machado et al. (2009). Numbers I to III are anomalous trichromacy cases while IV to VI are dichromacy cases. Up from left to right: tritanomaly, protanomaly and deuteranomaly. Down from left to right: tritanopia, protanopia and deuteranopia.

METHODOLOGY

The first step of the work consisted in bibliographic research focused on basic concepts of ACV in order to further understand the phenomena.

Thereafter, six concepts have been chosen by the authors in order to analyze the Research & Development (R&D) ecosystem for solutions focused on providing direct or indirect benefits to CVD drivers.

Finally, a Strength, Weakness, Opportunities and Threats (SWOT) analysis was done in order to guide the analysis towards a prototype concept that could take advantage of strengths and opportunities while avoiding threats and weaknesses.

RESULTS

Among the six concepts chosen for evaluation as to answers for Question 1, we found that: Nuñez, J. R., Anderton, C. R., and Renslow (2018) developed a code library which uses physiologically-based models developed by Sharpe et al. (1999) to convert colormaps, matrix structures used for converting the color range of an image, to a safe spectrum of light determined by the type of CVD being input, colormap conversion is available for deuteranomaly, protanomaly and tritanomaly.

Jenny and Kelso (2007) developed another software application. However, this one is focused on Computer Aided Design (CAD). Color Oracle, as named in the article, is a software solution that gives the designer an instant feedback on CVDs interpretation of the work at hand through snapshot images, these project images are processed to simulate a CVD perspective and then the processed image is displayed to the user. Still in the software domain, Iqbal et al. (2018) bring an application to the mobile platform: an operational system friendly to color vision deficient users of different types.

Meanwhile, Tanuwidjaja et al. (2014) develop a software platform based on Google Glasses for adapting the scene-view based on the type of ACV of the user. Kim et al. (2007) too takes advantage of portability to create a system capable of identifying traffic signals and alerting a CVD driver about the current traffic signal state.

Rigden (1999) focuses on giving web-designers advice on how contemplate bearers of ACV in their works through the color pallet files for each case of the deficiency while providing advice on how to use text and contrast to reduce any noise in the visual communication. **These were six examples of how R&D is a catalyst for technologies innovating for CVD individuals (six answers to Question 1).**

At last, a SWOT analysis worked through categorizing positive and negative sides of the R&D ecosystem focused on solutions for abnormal color vision users:

- Strengths
  - ACV is a widely researched phenomenon in medical literature (S1).
  - ACV research data is widely available on the internet (S2).
  - Code libraries from ACV applications are available in open source licenses, probably due to the potential health breakthroughs that may be achieved from such projects (S3).
  - Augmented reality technologies will bring great solutions for CVD (S4).
- Weaknesses
  - Solutions to individuals with ACV do not seem to be widely funded by private corporations (W1).
  - Lack of product development requirements for AVC users (W2).
  - Hardware for physical prototypes is very expensive and it does not have adequate specifications for real-time applications (W3).

- Opportunities
  - Development of models for simulation and interpretation of ACV with likelihood to real life information processing through colors (O1).
  - Assessing appropriate user experience journeys for CVD customers using UX concepts (O2).
  - CVD-focused concepts and prototypes create new business opportunities in the automotive sector, including patents. (O3).
  - ACV individuals range from all kinds of ethnicity, social status and other characteristics due to its genetic origin (O4).
- Threats
  - None of the R&D projects in this research were origin to a profitable product for CVD clients in the automotive business (T1).
  - Government regulations may restrict the commercial use of some solutions (T2).
  - To provide a cost-efficient solution for such a niche market becomes a challenge due to the highly competitive environment of the automotive business (T3).

S1 and S2 allows for proper data gathering when it comes to understanding how CVD occurs in the majority of cases while S3 and S4 combined appear to be the future permanent solution for issues caused by being unable to properly get information from color.

Unfortunately, S4 or S3 alone won't solve the problem and in order for both conditions to be in place W2 and W3 must already be solved.

In other words, algorithms for image processing require a lot of processing power(S3) and practical wearable devices capable of augmented reality(S4) with such capabilities are still a thing of the future (W2 and W3).

Even with ACV being a widely known permanent condition that affects and will affect a big and diverse number of individuals from different races, social and economic backgrounds (O4), oddly enough, no privately funded prototypes were found by this research (W1).

While severe cases dichromatic color vision simulation are well covered other types of ACV color vision simulation do not get the same attention (O1) and any development in concepts that dampen CVDs issues could be applied for companies' employees or to its clients (O2).

Instead of thinking only about solving color issues that might arise on the whole client UX journey, an example would be to focus on creating empathetic design and engineer practices concerning CVD drivers in the automotive business.

As to W1 and W2, these make innovation in the discussed context quite easier since there is a lack of competition (O3).

Finally, such a highly competitive and regulated industry such as the automotive one (W2 and W3) require a scalable solution with low-cost prototyping in order to be as cost-effective as possible due to T1.

A scalable, low-cost prototyping solution that is capable of being developed without being buried by regulation and expensive hardware while benefitting from open source technology available is certainly a pure software solution.

Pure software solutions can be malleable in magnitude and be targeted at a diverse audience that could even go further then only CVDs that have a driver's license.

CONCLUSION

Even though CVD is a widely researched phenomenon, CVD drivers still have their best moments to come since no major concepts focused on their necessities seem to be getting to them any sooner. **However, pure software prototypes have the edge when it comes to adding new features on an already existing platform at a low-cost prototyping with diverse project scope and, thus, are the answer of Question 2.**

Prototypes using pure software seem to be ideal when it comes to starting a trend providing a user with AVC a UX journey that contemplates their deficiencies and such pure software prototype could either be targeted at engineers and designers, craftsman of this journey, or at the end CVDs themselves.

Developing products designed for people with disabilities is important to achieve a more just and equal society. This is also part of the United Nations Sustainable Development Goals, being represented by the goals Reduce Inequalities (#10) and Sustainable Cities and Communities (#11).

Future research must consider the feasibility of including different color palette configurations inside HMIs developed or used in the product cycle plan of automotive businesses.

REFERENCES

1. M. Hassenzahl and N. Tractinsky, "User experience - a research agenda", Behaviour & Information Technology (2006), 25:2, 91-97.
2. A. L. Kun, S. Boll and A. Schmidt, "Shifting Gears: User Interfaces in the Age of Autonomous Driving," in IEEE Pervasive Computing, vol. 15, no. 1, pp. 32-38, Jan.-Mar. 2016.
3. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems, 28(2), 118-144.
4. Gustavo M. Machado, Manuel M. Oliveira, and Leandro A. F. Fernandes "A Physiologically-based Model for Simulation of Color Vision Deficiency". IEEE Transactions on Visualization and Computer Graphics. Volume 15 (2009), Number 6, November/December 2009. pp. 1291-1298.
5. L. T. Sharpe, A. Stockman, H. J¨ agle, and J. Nathans. Color Vision: From Genes to Perception, chapter Opsin genes, cone photopigments, color vision, and color blindness, pages 3–51. Cambridge University Press, 1999.
6. Jafarzadehpur E, Hashemi H, Emamian MH, Khabazkhoob M, Mehravaran S, Shariati M, Fotouhi A. Color vision deficiency in a middle-aged population: the Shahroud Eye Study. Int Ophthalmol. 2014 Oct;34(5):1067-74. doi: 10.1007/s10792-014-9911-2. Epub 2014 Feb 14. PMID: 24526316.
7. Cole, B. L. (2004). The handicap of abnormal colour vision. Clinical and Experimental Optometry, 87(4-5), 258–275. doi:10.1111/j.1444-0938.2004.tb05056.x
8. Gegenfurtner, Karl R., and Daniel C. Kiper. "Color vision." Annual review of neuroscience 26.1 (2003): 181-206.
9. Yee, R. D., Baloh, R. W., & Honrubia, V. (1981). Eye Movement Abnormalities in Rod Monochromacy. Ophthalmology, 88(10), 1010–1018. doi:10.1016/s0161-6420(81)80029-2
10. Nathaniel J. Smith (2020). Colorspacious. Available at <https://github.com/njsmith/colorspacious>.
11. Nuñez, J. R., Anderton, C. R., & Renslow, R. S. (2018). Optimizing colormaps with consideration for color vision deficiency to enable accurate interpretation of scientific data. PloS one, 13(7), e0199239.
12. Jenny, B., & Kelso, N. V. (2007). Color design for the color vision impaired. Cartographic perspectives, (58), 61-67.
13. Tanuwidjaja, E., Huynh, D., Koa, K., Nguyen, C., Shao, C., Torbett, P., ... & Weibel, N. (2014, September). Chroma: a wearable augmented-reality solution for color blindness. In Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing (pp. 799-810).
14. Rigden, C. (1999). 'The Eye of the Beholder'- Designing for Colour-Blind Users. British Telecommunications Engineering, 17, 291-295.
15. Iqbal, M. W., Shahzad, S. K., Ahmad, N., Amelio, A., & Brodic, D. (2018, February). Adaptive interface for color-blind people in mobile-phones. In 2018 International Conference on Advancements in Computational Sciences (ICACS) (pp. 1-8). IEEE.
16. Kim, Y. K., Kim, K. W., & Yang, X. (2007, August). Real time traffic light recognition system for color vision deficiencies. In 2007 International Conference on Mechatronics and Automation (pp. 76-81). IEEE.