Heavy and light smokers have slight differences in chromatic

Natalia L. Almeida, Thiago P. Fernandes, Fatima M. Felisberti, Milena E. Oliveira, Gabriella M. Silva, Jandirlly J. Souto and Natanael A. Santos

Abstract

Objectives: The effects of smoking on color vision have been scarcely studied. To bridge such gap, this study examined if there were differences in chromatic discrimination between heavy and light smokers. **Methods**: The psychophysical Trivector test was used to evaluate chromatic discrimination in healthy controls (n = 36), heavy smokers (n = 29), and light smokers (n = 32). The subject's task was to identify the orientation of the Landolt C ring gap presented and randomized in one of the four positions (e.g., up, down, right, and left). **Results**: The thresholds for Protan (red), Deutan (green) and Tritan (blue) were lower in heavy smokers compared to nonsmokers but not to light smokers. **Conclusions**: The results confirm that heavy smoking and chronic exposure to its harmful compounds affect color discrimination when compared to light smoking; this is more pronounced in heavy smokers than light smokers. This is particularly important to understand the differences among smokers on visual and multisensory processing.

Keywords: Cigarette smoking; color discrimination; chromatic discrimination; substance misuse; Cambridge Color Test.

1. Introduction

Tobacco smoke has several active compounds, some of which toxic after acute or long-term exposure.[1] Those tobacco compounds interact with presynaptic nAchRs in the central nervous system leading to an increased release of several neurotransmitters such as dopamine and glutamate, which in turn can affect the retina and the optic nerve (Picciotto et al. 2000).[2,3] There are known associations between smoking and ophthalmological conditions such as cataracts, macular degeneration, ischemic or oxidative mechanisms, reduction in the thickness of the medial and lateral frontal cortex and decreased activity of the occipital cortex.[4,5] There is also evidence that long-term heavy smokers have lower contrast sensitivity and lower performance in color discrimination than healthy controls, suggesting that smoking and chronic exposure to its compounds affect visual processing.[2,6,7] Furthermore, a few studies showed that cigarette compounds are harmful and affect visual processing as a whole (i.e., involving bothred-green and blue-yellow defects). Previous studies did not evaluate the differences among heavy and light smokers, which highlightsthe need for rigorous testing procedures to measure color vision, such as the Cambridge Color Test (CCT[8]) Moreover, we need to understand the ways in which smoking alters chromatic discrimination in both heavy and light smokers, to identify possible mechanisms underlying the neurotoxic effects of smoking on multisensory integration.

To our knowledge, no study to date assessed whether there is a difference between heavy smokers and light smokers in terms of damages in color processing ability (i.e. sporadic smokers would show lower acetylcholine activity and lower visual damage). The purpose of this study was to assess the differences between smokers on a psychophysical test (Trivector). We expected to find significant impairments in smokers for Protan (red), Deutan (green) and Tritan (blue). Since those losses may be diffuse,[9–11] we predict the differences will be global and involve both systems (red-green and blue-yellow).

2. Methods

2.1. Participants

Participation in the study was voluntary and informed consent was obtained prior testing. Recruitment was carried out through social media announcements. The participants were 97 participants in the 25–45 years-old range: 36 healthy controls (mean age = 33.7 years; *SD* = 8.9 years), 29 heavy smokers (mean age = 35.4 years; *SD* = 7.5 years), and 32 light smokers (mean age = 36.6 years; *SD* = 8.4 years). All participants were screened for color blindness using the test of[12] for color deficiency, and had normal or corrected-to-normal vision as determined by visual acuity of at least 20/20. The Fagerstrom Test for Nicotine Dependence (FTND) was used to classify the participants.[13] Those who scored >7 on the test were considered heavy smokers, and those scoring <5 were considered light smokers. According to FTND, the light smokers' group were constituted of participants that were not diagnosed with Tobacco Use Disorder.

Nonsmokers had never smoked a cigarette (or less than 15 cigarretes during their lifetime). Smokers were allowed to smoke until the beginning of the experiment, similar to our previous studies.[7]

The exclusion criteria included: presence of cardiovascular disease, current history of neurological disorder, history of head trauma, current or previous use of other drugs, history of contact with substances (such as solvents), current or previous use of other drugs, or use of medications that can affect visual processing.[14]

This study followed the ethical principles of the Declaration of Helsinki and was approved by the Committee of Ethics in Research of the Health Sciences Center of Federal University da Paraiba (CAAE: 60944816.3.0000.5188).

2.2. Stimuli and apparatus

The chromatic discrimination was investigated u sing the subtest Trivector from the Cambridge Color Test (CCT). It is considered a psychophysical method capable of estimating discrimination thresholds quickly and with reliable results. It is sensitive to individual differences between normal trichromats, and to distinguishing them from people with color vision impairment.[15]
The CCT stimulus is a colored Landolt ring displayed within a differently colored background. The position of the opening in the ring is presented randomly in one of four positions in the test screen; up, down, left and right. The chromatic contrast of the ring is varied until a threshold is obtained. In our setting, the "ring" will have an opening of 1.25° of visual angle at 3-meter viewing distance. To ensure that the break in the ring is identified based only chromatic information, luminance noise is added by subdividing the background and stimulus into small circles randomly varying in size (between 2.8° arcmin and 5.7° arcmin in diameter), and randomly varying in luminance (between 8 and 18 cd/m2 in 2 cd/m2 increments). Three different stimuli were used to measure thresholds along the Protan, Deutan, and Tritan lines of confusion through the background (red, green and blue, respectively). A lower threshold is associated with better chromatic discrimination.

2.3. Procedure

Instructions were presented for participants before starting the test. The method a four-alternative forced-choice (4-AFC) was used. The stimulus Landolt "C" was presented with its gaps randomized in one of four positions (left, right, up, or bottom).[15] The subjects' task was to identify, using a remote-control response box, in which position the presented stimulus gap was. The participants were also instructed to respond whether they could not identify the stimulus gap.[16] Each CCT session lasted from five to 15 minutes. For each of the three confusion lines, the CCT algorithm implemented two interleaved staircases presented in a random order using a weighted a one up/one down staircase rule, with a ratio of 1/3 to converge on the 75% threshold. Accuracy over speed was emphasized in the instruction.

2.4. Statistical analysis

Both groups presented a non-normal distribution (Monte Carlo method for skewness and kurtosis). For group comparisons, a univariate analysis of variance (ANOVA) was used, with pairwise comparisons using the post-hoc of Games-Howell (different sample sizes). Omega squared (ω_2) was used to assess effect sizes (for small sample sizes, ω_2 reduces bias).

3. Results

3.1. Sample characteristics

The three groups did not differ in age [F (2, 95) = 1.01, p = .360], level of education [F (2, 95) = 1.03, p = .300] or the ratio of males to females [χ (2) = 0.68, p = .709). No differences were found in years of cigarette use [t (59) = 0.56, p = .577] between the two groups of smokers (Table 1).

3.2. Trivector

The results of the Trivector are summarized in Figure 1. There were significant differences in thresholds for the Protan [F (2,95) = 11.58, p < .001, ω_2 = 0.45 (95% CIs: 0.32 – 0.67)], Deutan [F (2, 95) = 8.02, p = .001, ω_2 = 0.37 (95% CIs: 0.21 – 0.55)] and Tritan [F (2, 95) = 11.58, p < .001, ω_2 = 0.43 (95% CIs: 0.27 – 0.62)]. Post-hoc analysis showed differences between groups; healthy controls had better color discrimination for Protan that than heavy smokers for Protan (p < .001), Deutan (p < .001) and Tritan (p < .001). Healthy controls had also better discrimination
than light smokers for Protan (p < .001), Deutan (p = .002) and Tritan (p = .037). When comparing heavy and light smokers, there were no differences for Protan (p = .679), Deutan (p = 867) and Tritan (p = .066).

4. Discussion

The data indicated that smokers as a whole had impaired color vision compared with nonsmokers. Overall, our findings showed impairments in the red-green and blue-yellow color systems and the CCT are was sufficiently sensitive to detect these losses.

The parvocellular pathway in the early visual system carries both luminous contrast information for fine detail along with chromatic information based on the long and middle-wavelength sensitive cones. Conversely, the magnocellular pathway relays luminous contrast information for low contrast in their cells. The koniocellular pathway carries chromatic information based on the short (S) wavelength sensitive cone and both the M- and L-cone responses.[17] These results do not support the notion of pathway selectivity deficits, despite the existence of nicotinic acetylcholine receptors (nAChRs) in the primary visual cortex (i.e., there are more nAChRs in the parvocellular pathway).[17] It is difficult to segregate the signals in visual pathways[18] because it contains a combination of additive and opponent cone signals (L + M, L − M, and S − [L + M]) and it is not clear which of the parvo-, magno-, and koniocellular pathways are affected by smoking. We can only speculate that diffuse impairment may involve one, two, or all three pathways and hypothesize the existence of a diffuse deficit in color processing for both heavy and light smokers. Although the results did not show significant differences for the confusion axes between the group of heavy smokers and light smokers, it is important to emphasize the small difference for the Tritan axis. Further studies may help to better understand how these conditions behave in the blue-yellow color systems.

It is important to emphasize the reliability of the CCT for color vision assessment, even when used alone.[8] Nonetheless, this study had some limitations. Because we did not measure cotinine use, we cannot provide a more accurate physiological explanation of the results. In future studies we will seek to analyze these markers. Although our results indicate that the visual damage was global, we did not carried out electrophysiological measurements to verify whether the damage occurred at the photoreceptors, subcortical, or cortical level. Also the use of FTND to classify smokers as heavy and light smokers should be better studied in further studies (e.g., classify according to the DSM-V or to physiological markers).

This study points to a significant link between smoking and chromatic discrimination, which calls attention to examine which cigarette compounds are involved in the impairments highlighted here, as well as confirm the consequences of long-term tobacco use in visual processing in general.

Authors' contributions

NA performed the experiments, participated in the design of the study and performed the statistical analysis. TF conceived and designed the experiments, participated in its coordination and helped to draft the manuscript. FF, GS, JS and MO helped to draft the manuscript and helped with data interpretation. NS conceived and designed the experiments,
helped to draft the manuscript and helped with data interpretation. All authors read and approved the final manuscript.

Disclosure statement

The authors declare that they have no competing interests.

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References

1. Solberg Y, Rosner M, Belkin M. A associacao entre o tabagismo e doencas oculares. Surv Ophthalmol. 1998;42(6):535–47. doi:10.1016/S0039-6257(98)00002-2.
2. Bimler D, Kirkland J. Multidimensional scaling of D15 caps: color-vision defects among tobacco smokers?Vis Neurosci. 2004;21(3):445–58. doi:10.1017/s0952523804213116.
3. Karama S, Ducharme S, Corley J, Chouinard-Decorte F, Starr JM, Wardlaw JM, Bastin ME, Deary IJ. Cigarette smoking and thinning of the brain's cortex. Mol Psychiatry. 2015;20(6):778–85. doi:10.1038/mp.2014.187.
4. Goriounova NA, Mansvelder HD. Short- and long-term consequences of nicotine exposure during adolescence for prefrontal cortex neuronal network function. Cold Spring Harb Perspect Med. 2012;2(12):a012120. doi:10.1101/cshperspect.a012120.
5. Mazzone P, Tierney W, Hossain M, Puvenna V, Janigro D, Cucullo L. Pathophysiological impact of cigarette smoke exposure on the cerebrovascular system with a focus on the blood-brain barrier: expanding the awareness of smoking toxicity in an underappreciated area. Int J Environ Res Public Health. 2010;7(12):4111–26. doi:10.3390/ijerph7124111.
6. Fernandes TP, Almeida N, Santos N. Comparison of color discrimination in chronic heavy smokers and healthy subjects. F1000Res. 2017;6:85. doi:10.12688/f1000research.10714.3.
7. Fernandes TP, Silverstein SM, Almeida NL, Santos NA. Psychophysical evaluation of contrast sensitivity using Gabor patches in tobacco addiction. J Clin Neurosci. 2018;57:68–73. doi:10.1016/j.jocn.2018.08.034.
8. Fernandes TP, Santos NA, Paramei GV. Cambridge colour test: Reproducibility in normal trichromats. J Opt Soc Am A Opt Image Sci Vis. 2020;37(4):A70–A80. doi:10.1364/JOSAA.380306.
9. Arda H, Mirza GE, Polat OA, Karakucuk S, Oner A, Gumus K. Effects of chronic smoking on color vision in young subjects. Int J Ophthalmol. 2015;8(1):77–80. 10.3980/j.issn.2222-3959.2015.01.14.
10. Fernandes TP, Almeida NL, Dias ALA, Nogueira RMTBL, Santos NA. Use of the MacAdam ellipses for psychophysical evaluation of color discrimination in chronic heavy smokers. *Psychol Neurosci*. 2017;10(4):437–48. doi:10.1037/pne0000096.
11. Fernandes TP, Silverstein SM, Almeida NL, Santos NA. Visual impairments in tobacco use disorder. Psychiatry Res. 2019;271:60–7. doi:10.1016/j.psychres.2018.11.024.
12. Ishihara S. 1972. The series of plates designed as a test for colour-blindness.
13. Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerstrom test for nicotine dependence: A revision of the Fagerstrom Tolerance Questionnaire. Br J Addict. 1991;86(9):1119–27. doi:10.1111/j.1360-0443.1991.tb01879.x.
14. Lalanne L, Ferrand-Devouge E, Kirchherr S, Rauch L, Koning E, Speeg C, Laprevote V, Giersch A. Impaired contrast sensitivity at low spatial frequency in cannabis users with early onset. Eur Neuropsychopharmacol. 2017;27(12):1289–97. doi:10.1016/j.euroneuro.2017.09.006.
15. Paramei GV, Oakley B. Variation of color discrimination across the life span. J Opt Soc Am A Opt Image Sci Vis. 2014;31(4):A375–A384. doi :10.1364/JOSAA.31.00A375.
16. Mollon JD, Regan BC. 2000. Cambridge Colour Test Handbook. https://sites.oxy.edu/clint/physio/article/CAMBRIDGECOLOURTESTHandbook.pdf
17. Fernandes TP, Hovis JK, Almeida N, Souto JJ, Bonifacio TA, Rodrigues S, Silva GM, Andrade MO, Silva JB, Gomes G, et al . Effects of nicotine gum administration on vision (ENIGMA-Vis): Study protocol of a double-blind, randomized, and controlled clinical trial. Front Hum Neurosci. 2020;14:314. doi:10.3389/fnhum.2020.00314.
18. Klistorner A, Crewther DP, Crewther SG. Separate magnocellular and parvocellular contributions from temporal analysis of the multifocal VEP. Vision Res. 1997;37(15):2161–9. doi:10.1016/S0042-6989(97)00003-5.
19. Erb C, Nicaeus T, Adler M, Isensee J, Zrenner E, Thiel HJ. Colour vision disturbances in chronic smokers. Graefes Arch Clin Exp Ophthalmol. 1999;237(5):377–80. doi:10.1007/s004170050247

Table 1. Demographics and cigarette use in healthy controls, heavy smokers and light smokers (*n* = 97).

Sample characteristics	Healthy controls (n = 32)	Heavy smokers (n = 29)	Light smokers (n = 32)
Gender (%)			
Male	29 (60.4%)	18 (52.9%)	
Female	19 (39.6%)	16 (47.1%)	
Age, years (SD)	33.7 (8.9)	35.4 (7.6)	36.6 (8.4)
Level of education, years (SD)	11.4 (2.8)	9.7 (2.2)	9.1 (2.2)
Smoking years (SD)	0	9.8 (4.6)	10.4 (3.4)
Trivector – Mean			
Protan (SD)	45.1 (11.8)	61.9 (20.7)	66.9 (24.4)
Deutan (SD)	47.5 (18.8)	66.3 (25.1)	66.5 (23.0)
Tritan (SD)	74.6 (21.6)	96.2 (19.0)	86.0 (14.3)

Figure 1. Results for the Trivector subtest for Protan (A), Deutan (B) and Tritan (C). Solid lines represent the mean, boxes represent the quartiles and the whiskers represent the range.