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Visual impairments in tobacco use disorder

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ABSTRACT

Prior studies found small effects of chronic smoking on spatial and color vision, but they were inconclusive. This study tries to: (1) replicate and extend these previous findings, and (2) rule in that this relationship is pronounced by tobacco addiction. Data were recorded in 71 healthy controls (M = 33.5 years; *SD* = 5.4 years) and 63 individuals with tobacco addiction (M = 34.7 years; *SD* = 4.8 years). Visual processing was assessed in the forms of contrast sensitivity for linear sine-wave gratings (spatial frequencies ranging between 0.2 and 16 cycles per degree) and color discrimination (using the Ellipse and Trivector subtests). The groups were matched for age, gender and level of education. The group with heavy smokers had reduced sensitivity for all spatial frequencies ($p < .001$), and impairments in color discrimination for both Trivector (all *p*-values < .001 for Protan, Deutan and Tritan) and Ellipse (all *p*-values < .001). This study consistently replicates and extended previous findings, and showed that visual processing can be strongly associated with tobacco addiction. These results indicate that excessive use of cigarettes, or chronic exposure to their compounds, affects visual discrimination, supporting the existence of overall deficits in visual processing in tobacco addiction.

1. Introduction

Tobacco addiction is one behavior strongly linked to cigarette consumption. Cigarette smoke consists of numerous compounds that are harmful to health and has been linked to a reduction of cortical thickness, involving such areas as the medial and lateral frontal cortex and a decrease in activity of the occipital cortex (Goriounova and Mansvelder, 2012; Govind et al., 2009). Some studies investigated the effects of cigarette smoking on cognitive function, but few have evaluated the effects of cigarette smoking on spatial and color vision. In general, heavy smokers performed worse than healthy controls for contrast sensitivity (Fernandes et al., 2017a; Fernandes et al., 2018a), backward masking (Kunchulia et al., 2014) and color vision (Fernandes et al., 2017b). However, the sample sizes of these studies were relatively small, and some variables were not controlled. In particular, this field of study still has gaps in the literature with regard to the ways in which heavy smoking affects the perception of form and the ability to discriminate colors.

Here, we used some psychophysical paradigms to (1) extend and replicate previous findings about smoking and visual processing and (2) investigate whether tobacco addiction deteriorates performance compared to healthy controls. We investigated contrast sensitivity to sine-wave gratings and assessed color discrimination using the Cambridge Colour Test through Trivector (three vectors corresponding to Protan, Deutan and Tritan confusion lines) and Ellipse (the use of MacAdam's Ellipses corresponding to regions on a chromaticity diagram). Both of these paradigms were widely reported in the literature and has demonstrated validity in populations with retinal, subcortical and cortical dysfunction (Feitosa-Santana et al., 2008; Fernandes et al., 2018d; Fernandes et al., 2018a; Fernandes et al., 2017b; Regan et al., 1998; Zachi et al., 2017a).

2. Materials and methods

2.1. Ethics statement

The present study followed the ethical principles of the Declaration of Helsinki and was approved by the Committee of Ethics (registration no. CAAE: 60944816.3.0000.5188) from the Federal University of Paraiba. Written informed consent was obtained from all of the participants.

2.2. Participants

Seventy-one healthy controls (HCs; mean age = 33.5 years; *SD* = 5.4 years; 45 males) and 63 participants diagnosed with tobacco

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use disorder (mean age = 34.7 years; *SD* = 4.8 years; 42 males) who had no previous experience in perceptual tasks participated in this study, conducted between 2015 and 2017. The participants were 25–45 years old. Data of 38 observers were excluded if they met any of the following exclusion criteria: current history of neurological disorder, cardiovascular disease, and history of head trauma, history of contact with such substances as solvents, current or previous drug abuse (Lalanne et al., 2017) beyond tobacco addiction (for smokers) according to the *Diagnostic and Statistical Manual of Mental Disorders*, 5th edition (DSM-5) (American Psychiatric Association, 2013), and current use of medications that may affect visual processing (e.g. benzodiazepines).

Participants had no retinal abnormalities on fundoscopic examination or optical coherence tomography. All of the participants were screened for color blindness using the Ishihara test for color deficiency (Ishihara, 1972) and had normal or corrected-to-normal vision (at least 20/20) as assessed by a Snellen chart. Both groups were matched for gender, age, and level of education. The HCs were recruited from the general population. They had no neuropsychiatric disorders according to the Structured Clinical Interview for the DSM (American Psychiatric Association, 2013).

All of the heavy smokers met the criteria for tobacco use disorder according to the DSM-5, currently smoked > 20 cigarettes/day, and had a score > 7 on the Fagerström Test for Nicotine Dependence (FTND) (Heatherton et al., 1991). Smokers were allowed to smoke until the beginning of the experiment (similar to our previous studies) and were free from cognitive disorders (as observed in Fernandes et al., 2018c). All of the heavy smokers had no comorbidities such as attention disorder, and did not use nicotine patches during the last years. HCs met the criteria for never-smokers (currently smoked < 15 cigarettes per lifetime) (Pomerleau et al., 2004). The time since the last cigarette was assessed by self-report to equate withdrawal across smokers. In addition, the participants with tobacco use disorders reported no withdrawal or attempt to stop smoking.

To assess subjective craving for a cigarette, the smokers provided self-reports and completed psychometric measures, such as the Program to Aid Smokers (PAS) comfort scale (Issa, 2012) and the brief version of the Questionnaire of Smoking Urges (QSU-B) (Cox et al., 2001). The dataset of contrast sensitivity measurements and Cambridge Colour Test are available on request.

2.3. Stimuli and apparatus

The stimuli were presented on a 19-inch LG CRT monitor with 1024 × 786 resolution and a refresh rate of 100 Hz. Stimuli were generated using a VSG 2/5 video card (Cambridge Research Systems, Rochester, UK), which was run on a Precision T3500 computer with a W3530 graphics card. The average luminance was 50 cd/m². All of the procedures were performed in a room at 26°C ± 1 °C, with the walls covered in gray to better control luminance during the experiments. Measurements were performed with binocular vision at a distance of 150 cm from the computer monitor. Monitor luminance and chromatic calibrations were performed using a ColCAL MKII photometer (Cambridge Research Systems, Rochester, UK). The contrast sensitivity measurements were taken using Metropsis software (Cambridge Research Systems, Rochester, UK). The Metropsis vision-testing suite provides precise, repeatable, psychophysical threshold measurements for general research applications.

2.3.1. Contrast sensitivity function

The stimuli were linear, vertically oriented sine-wave gratings with spatial frequencies of 0.2, 0.6, 1.0, 3.1, 6.1, 8.8, 13.2 and 16.0 cpd. The gratings were equiluminant of 5 degrees of visual angle and were presented on the monitor at 2.5° from the central fixation cross (for stimulus details, see Fernandes et al., 2018a; Fernandes et al., 2017b) Measurements were performed with binocular vision at a distance of 150 cm from the computer monitor.

2.3.2. Cambridge Colour Test (CCT)

The CCT stimulus is a pattern of small circles randomly varying in diameter with no spatial structure (variation of 5.7° arcmin of external diameter and 2.8° arcmin of internal diameter) and in luminance (from 8 to 18 cd/m²) (Paramei and Oakley, 2014). The CCT does not require multiple applications, or that valuable time be spent in a preliminary determination of luminance sensitivity for each participant. CCT tasks are cognitively simple and are readily grasped by subjects. There are two subtests in CCT, the Trivector and the Ellipse. The Trivector, a short (3–5 min) test, estimates sensitivity to short, medium, and long wavelengths through the protan, deutan, and tritan confusion lines, respectively (Mollon and Regan, 2000; Regan et al., 1994). The pairs of staircase related to the three confusion lines are run simultaneously in an interleaved and random way (for details see Paramei and Oakley, 2014, p. A377). The Ellipse test maps three MacAdam Ellipses in different regions of the CIE u'v' chromaticity diagram along a tritan line. The three confusion axes converge at a co-punctal point (0.14744, 0.4184). The following u'v' coordinates (CIE 1976) were used: protan (0.6579, 0.5013), deutan (−1.2174, 0.7826), and tritan (0.2573, 0.0000); for further details, see Mollon and Regan (2000). The area of the ellipses represents color discrimination in the u'v' units. That is, the smaller the ellipse, the better the discrimination ability. We used each ellipse's area to quantify possible losses in color discrimination. The Landolt-like "C" had an opening at 1.25° of visual angle, minimum luminance of 8 cd/m², maximum luminance of 18 cd/m², 6 s response time for each trial.

2.4. Procedure

Prior to starting the tests, detailed task instructions were provided to the participants. Accuracy was emphasized over speed. A practice session was conducted to familiarize participants with the procedure and avoid misunderstanding. Metropsis software incorporates a check of the validity of the data by using catch trials to detect random responding. The procedures were performed in two stages. In the first stage, the participants were referred to our laboratory where we conducted the CSF measurements. In a second meeting, the participants performed the color vision measurements. Each stage lasted from 10 min to 40 min, depending on to the participant. Additionally, to avoid fatigue, the participants were encouraged to take breaks at their discretion every time they completed a reversal for any spatial frequency or for any color mesaurement.

2.4.1. Contrast sensitivity function

The participants were instructed to maintain fixation on a small black fixation cross in the center of the display monitor. A two-alternative forced-choice (2-AFC) method was used. The participants' task was to identify, using a remote controlled response box, whether the grating was presented on either the left or right side of the computer screen (Fig. 1). The Metropsis programs use a psychometric function that estimates thresholds without interference from participant's guessing or learning effects. The order of the spatial frequencies that were tested was randomized within a session. The session ended after 12 contrast reversals occurred. Higher contrast sensitivity values indicate that the participant has a higher sensitivity. The participants were encouraged to take breaks at their discretion to avoid fatigue. Procedural details are extensively described elsewhere (Costa et al., 2012; Fernandes et al., 2018a; Fernandes et al., 2018b; Zachi et al., 2017).

2.4.2. Cambridge Colour Test

A practice session to familiarize participants with the procedure and to avoid misunderstanding was performed. Accuracy over speed was emphasized in the instruction. Tests began only after the individual understood that he or she should respond based on the location of the

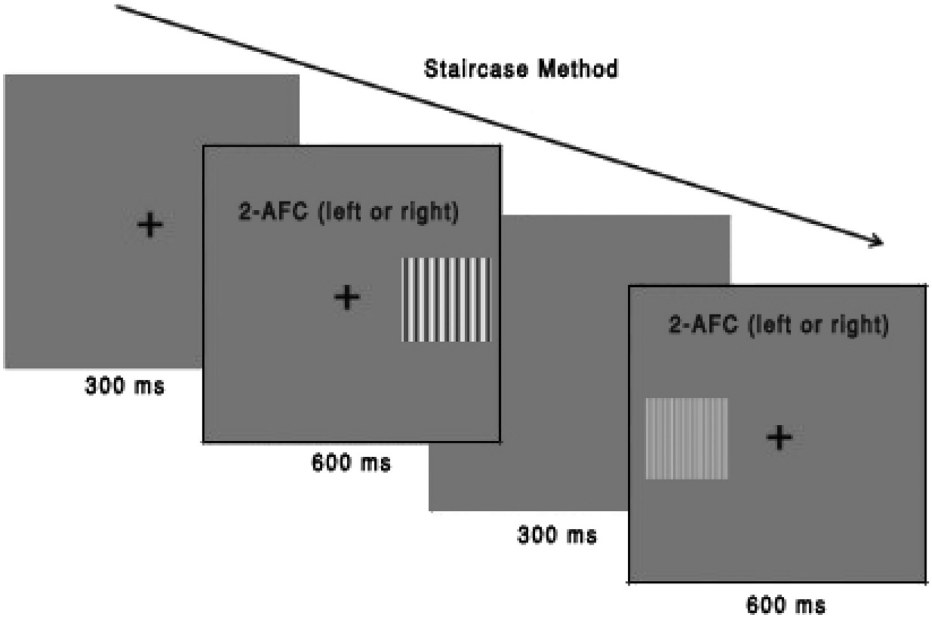

Fig. 1. Contrast sensitivity function task. The task was to identify, using a remote control response box, whether the gratings was presented either on the left or right side of the computer screen. Each stimulus had an exposure time of 600 ms, the participant then pressed the button, and the next trial started after 300 ms. The Metropsis algorithm randomizes spatial frequencies (low, medium and high) and contrast values.

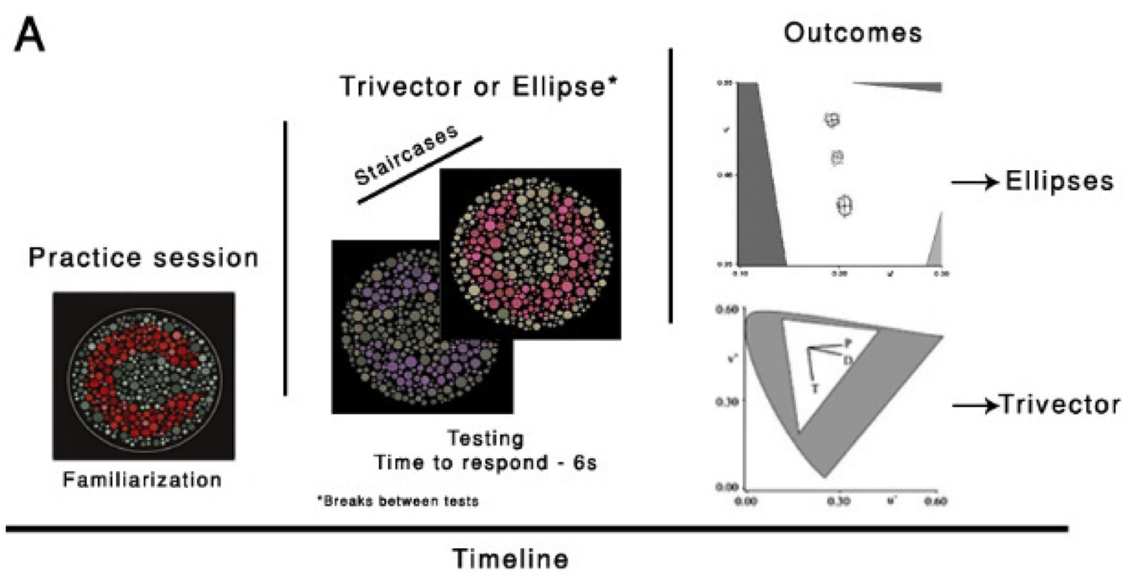

Fig. 2. Cambridge Colour Test. The subjects' task was to identify, using a remote control response box, whether the stimuli was presented with its gaps randomized in one of four positions (left, right, up, or bottom). A practice session was performed for the individuals grasp the test. Then, the participant was tested at Trivector or Ellipse subtests (A). The stimulus, embedded in the luminance noise background, is a pattern of small circles randomly varying in diameter and in luminance.

opening of the Landolt 'C' stimulus. There were no catch trials since all of the participants were able to understand to procedure. Observers were dark adapted and tested binocularly; they were positioned at 3 m from the monitor. The CCT uses a staircase psychophysical to measure the thresholds. Two interleaved staircases were run in random order. Each of them began with a target of high saturation; the chromaticity of the target was then varied to reduce the contrast with the background (Paramei and Oakley, 2014). The distance between target and background decreased along a line connecting the two, every time the subject made a correct response, and increased when the response was incorrect (1 up/1 down staircase rule with a step size of 20% of the average chromaticity). Periodically, a control target at maximum saturation was presented. After 12 staircase reversals, thresholds along each vector were computed (Trivector test), and also used to construct an Ellipse using the method of minimum squares (Ellipse test). A four-alternative forced-choice (4-AFC) method was used, and the subjects' task was to identify, using a remote control response box, whether the target was presented with its gaps randomized in one of four positions (left, right, up, or bottom) (Fig. 2). The participants were also instructed to indicate if they could not identify the stimulus gap (Regan et al., 1994). The missed answers were computed to the staircase procedure. Each session of the CCT lasted from five to 45 min. The participants were encouraged to take breaks between each block of measurements to avoid fatigue. The dependent variables for CCT are protan, deutan and tritan color confusion lines (Trivector test), and length of major axis (u'v' units), axis ratio, and angle of the major axis (Ellipse). Eccentricity and Ellipse area were calculated using the variables provided by the CCT.

2.5. Statistical analysis

The distributions for each group were compared using the Shapiro-

Wilk *W* and Kolmogorov-Smirnov tests. Outliers were verified using Cook's distance and leverage values and then transformed using the Fractional Rank method (applying inverse cumulative distribution functions; Beasley et al., 2009). A general linear model and linear mixed-model were used to analyze the data. The assumption of variance homogeneity / sphericity was not violated. Therefore, parametric statistical tests were used to analyze the data. For the CSF, each spatial frequency was considered individually as a dependent variable. However, to avoid the inflation of type 1 errors, values of $p < .006$ (*p*-value / number of comparisons) were considered statistically significant. For categorical variables, the chi-squared test was used. For the Trivector test, the dependent variables are the protan, deutan and tritan measurements. For the Ellipse test, the dependent variables are length of the major axis, major-to-minor axis ratio, and angle of the major axis. Ellipse area was calculated using the formula [Area = π × angle × axis ratio × length of the major axis]. For a better fitting of ellipses' area, we performed 2000 bootstrapping resamples. Effect sizes > 0.80 were considered large.

3. Results

3.1. Sample characteristics

Characteristics of the participants are summarized in Table 1. The groups did not differ with regard to age, level of education, or the ratio of males to females (all *p*-values > .05). There were no statistically significant differences between PAS scores and QSU-B scores before vs. after the experiment in the tobacco addiction group. There were no differences in visual acuity between the groups. Also, no correlations were found between visual outcomes and biosociodemographic variables (all *p*-values > .05)

3.2. Contrast sensitivity function

The results of the psychophysical measurements for linear contrast sensitivity are shown in Fig. 3. There were effects of spatial frequency ($F_{7,924} = 1982.84$, $p < .001$, $f^2 = 0.972$), group ($F_{1,132} = 246.71$, $p < .001$, $f^2 = 0.751$) and a significant frequency × group interaction ($F_{7,924} = 96.84$, $p < .001$, $f^2 = 0.523$). The *post hoc* indicated an overall reduction of contrast sensitivity in the tobacco addiction group compared with healthy controls for all spatial frequencies ($p < .001$).

Table 1
Sample characteristics of healthy controls and heavy smokers ($N = 134$).

Variable	Healthy controls ($n = 71$)	Heavy smokers ($n = 63$)	*P*
Gender			
Male	45	42	.697[a]
Female	26	21	.755[a]
Age			
Age, years (*SD*)	33.5 (5.4)	34.7 (4.8)	.180[b]
Level of education, years (*SD*)	12.9 (2.6)	12.1 (2.9)	.051[b]
Cigarette use			
Age at first use	–	16 (2.3)	–
Years of use	–	19.0 (5.1)	–
FTND score	–	7 (0.7)	–
PAS comfort scale			
Before experiment	–	16.15 (0.8)	–
After experiment	–	17.19 (0.49)	–
QSU-B			
Before experiment	–	22.0 (1.3)	–
After experiment	–	23.74 (1.5)	–
Hamilton rating scale for depression	2.09 (0.9)	2.21 (1.7)	.620[b]

*Statistically significant difference.
[a] $\chi 2$ test.
[b] Student's *t*-test.

To investigate the existence of a tendency (e.g., whether biosociodemographic played a role in those results), additional multivariate analysis of variance revealed no statistically significant interaction between age and level of education on the dependent variables ($F_{8,123} = 0.967$, $p = .465$, Wilks' Λ = 0.941).

3.3. Cambridge Colour Test – Trivector test

The results of the Trivector test are shown in Fig. 4. There were significant differences in discrimination thresholds along the Protan ($t_{132} = 7.01$, $p < .001$, Hedges' $g = 1.21$ [0.84–1.58]), Deutan ($t_{132} = 14.60$, $p < .001$, Hedges' $g = 2.52$ [2.07–2.98]), and Tritan ($t_{132} = 21.37$, $p < .001$, Hedges' $g = 3.70$ [3.14–4.25]) axes.

3.4. Cambridge Colour Test – Ellipse test

3.4.1. Length of the major axis (10^{-5} u'v' units)

The results of the ellipse's length measurements are presented in Fig. 5. There were significant differences in discrimination thresholds along the Ellipse 1 ($t_{132} = 5.20$, $p < .001$, Hedges' $g = 0.90$ [0.54–1.25]), Ellipse 2 ($t_{132} = 13.07$, $p < .001$, Hedges' $g = 2.26$ [1.83–2.70]), and Ellipse 3 ($t_{132} = 7.42$, $p < .001$, Hedges' $g = 1.28$ [0.92–1.65]).

3.4.2. Major-to-minor axis ratio

There were significant differences in discrimination thresholds along the Ellipse 1 ($t_{132} = 15.28$, $p < .001$, Hedges' $g = 2.65$ [2.18–3.11]), Ellipse 2 ($t_{132} = 34.03$, $p < .001$, Hedges' $g = 2.26$ [1.83–2.70]), and Ellipse 3 ($t_{132} = 22.88$, $p < .001$, Hedges' $g = 4.89$ [5.10–6.67]).

3.4.3. Angle of the major axis

There were no differences along the Ellipse 1 ($t_{132} = 0.980$, $p < .001$), and Ellipse 2 ($t_{132} = 34.03$, $p < .001$). Statistically significant differences were found in discrimination thresholds along the Ellipse 3 ($t_{132} = 6.13$, $p < .001$, Hedges' $g = 1.07$ [0.70–1.42]).

3.4.4. Area of the ellipses

The results of the ellipse's areas measurements are presented in Fig. 6. There were significant differences in discrimination thresholds along the Ellipse 1 ($t_{132} = 8.19$, $p < .001$, Hedges' $g = 1.40$ [1.02–1.78]), Ellipse 2 ($t_{132} = 11.49$, $p < .001$, Hedges' $g = 1.99$ [1.57–2.40]), and Ellipse 3 ($t_{132} = 24.03$, $p < .001$, Hedges' $g = 4.16$ [3.55–4.76]).

4. Discussion

To investigate the association between tobacco addiction and visual impairment, and to clarify the results of previous studies, we aimed to replicate and evaluate disturbances of the visual system by measuring the CSF and color discrimination ability. Based on previous findings, we hypothesized that smokers would exhibit lower contrast sensitivity and lower color discrimination compared with healthy controls. These results suggested that tobacco addiction may affect form perception and color vision, and/or that tobacco compounds may play a fundamental role on these losses. Of note, our results suggest an overall impairment for all spatial frequencies, as well for short, medium and high wavelengths, replicating previous findings from Fernandes et al., 2017a, Fernandes et al., 2018a, 2018d) and Kunchulia et al. (2014).

Our results do support the assumption of overall impairments, considering the existence of nAChRs in the primary visual cortex and visual pathways (Levin, 2001). Being a basic reflection of input to V1, reflecting optics and receptive field structure (Wilson and Humanski, 1993), the contrast sensitivity function (CSF) provides the threshold between the visible and invisible (Pelli and Bex, 2013). A higher CSF curve is associated with better visual discrimination. Here

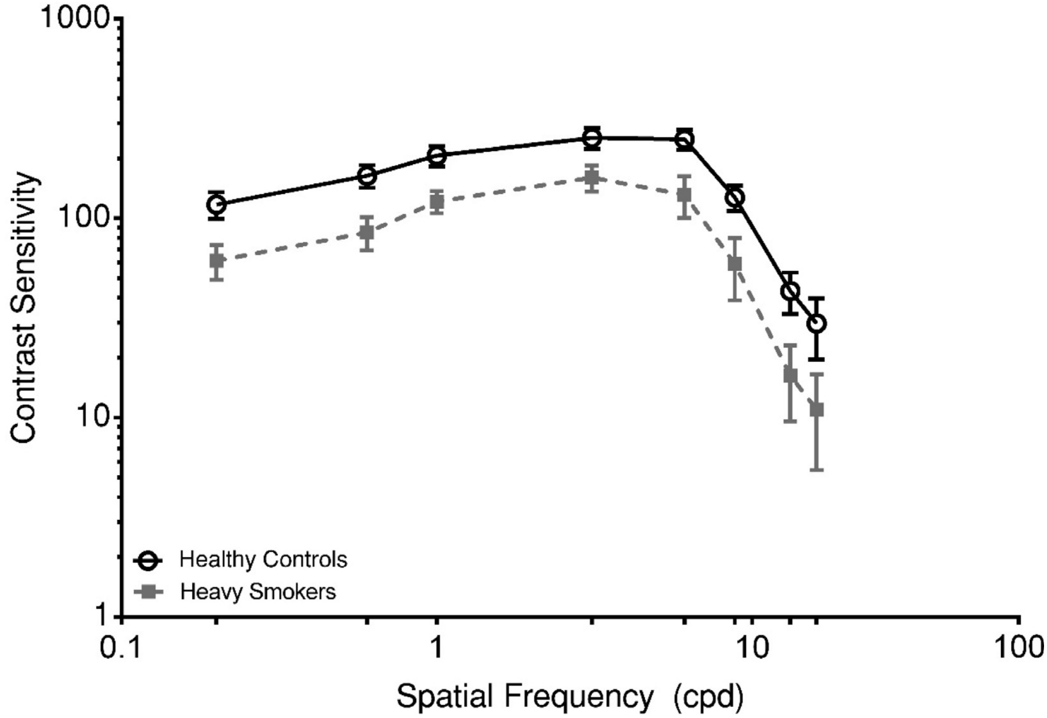

Fig. 3. Contrast sensitivity curves as a function of spatial frequency (cpd) in healthy controls and heavy smokers. Each data point represents the mean sensitivity (reciprocal of contrast threshold), and error bars represent the standard deviation (*SD*) of mean sensitivity based on 2000 bootstrapping resamples.

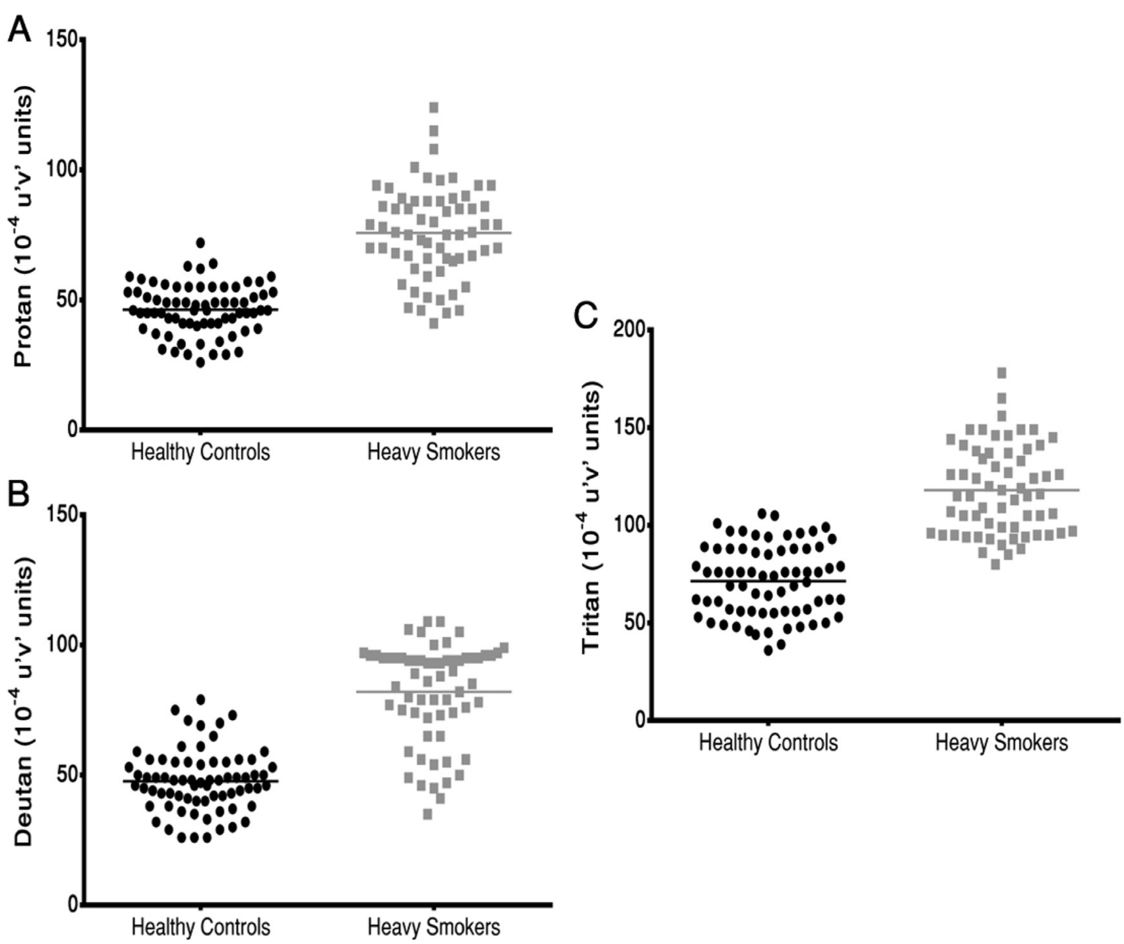

Fig. 4. Scattergram of color vision data by Trivector for the Protan (A), Deutan (B) and Tritan (C) color confusion axes in healthy controls and heavy smokers. Data were presented in 10^{-4} u'v' units of the CIE 1976.

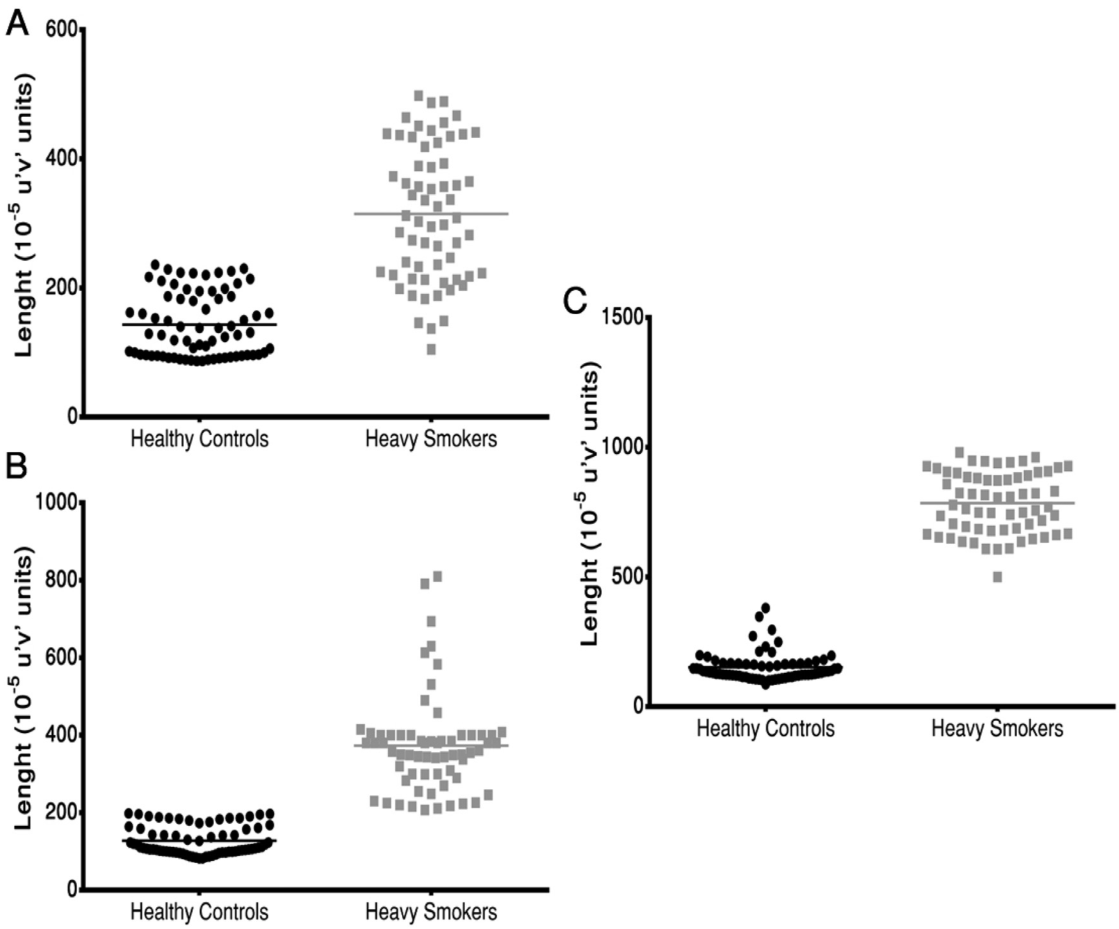

Fig. 5. Scattergram of lengths of the major axes data by Ellipse for the Ellipse 1 (A), Ellipse 2 (B) and Ellipse 3 (C) in healthy controls and heavy smokers. Data were presented in 10^{-5} u'v' units of the CIE 1976.

we observed lower contrast sensitivity in smoker's at all spatial frequencies (Fig. 3). However, these results do not support the notion of channel selectivity deficits, contrary to long standing proposals (Herzog and Brand, 2015; Klistorner et al., 1997; Silva et al., 2005). With regard to color discrimination, the existence of an overall impairment in short, medium and long wavelengths was observed (Fig. 4, Fig. 5, and Fig. 6). Again, we observed significant changes in the red-green and blue-yellow color vision systems, suggesting that self-administered consumption of substances containing neurotoxic chemicals may be responsible for an overall color vision loss, without differential levels of dyschromatopsia across color axes (Paramei, 2012). For a broad discussion about mechanisms involved in smoker's visual impairments, see Fernandes et al., 2017a; Fernandes et al., 2018c). Important issues were whether smoking story, cognitive functioning or comorbidities would play a role in visual impairments. However, we had a continuous evaluation of the smoking history and did not observe subjects that used nicotine patch, successfully quit smoking or even had comorbidities. In view of this, we do believe that the chronic smoking (in the form of tobacco addiction) had a major role in those findings.

Also, we also cannot reduce the decrease in visual discrimination to simply the photorefraction factor (e.g., smokers were allowed to smoke until the beginning of the experiment). Previous studies (Fernandes

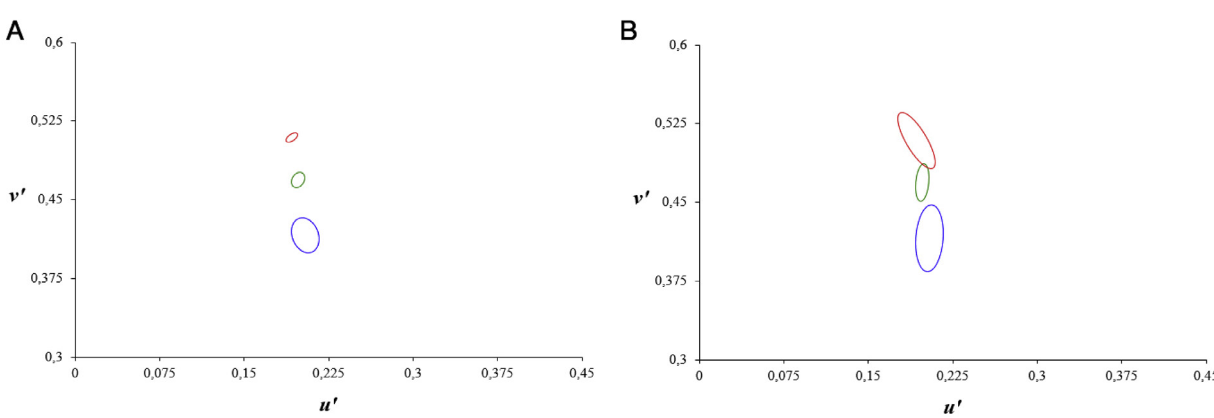

Fig. 6. Area of Ellipse 1 (green), Ellipse 2 (red) and Ellipse 3 (blue) for the healthy controls (A), and heavy smokers (B). The data are plotted on the CIE 1976 chromaticity diagram. Data estimated and replicated by 2000 bootstrapping resamplings.

et al., 2017a; Fernandes et al., 2018c; Kunchulia et al., 2014) allowed groups of smokers to smoke before and after the experiment and had similar results as the control group. Here we employed the same conditions and found different results as the control group. Despite the previous limitations, this study pointed that the addiction may play a fundamental role on visual processing, and these finds were marked when the sample size was increased. Some proposals pointed that long-term smoking may be related to age-related macular degeneration, lens yellowing, and inflammatory pathways. We are not denying the existence of these intervenient factors on visual losses; nevertheless, the absence of abnormalities in OCT can provide some insights about these losses (e.g., they may be cortical or subcortical, and not on the retinal-only level) (Silverstein et al., 2017). Even replicated in a large sample, we cannot offer a physiological explanation for the present results, but we can speculate that tobacco compounds may act as chemical modulators of addiction and visual sensitivity through dopamine γ-aminobutyric acid, and glutamate neurotransmission deficits (Fernandes et al., 2017a; Melis et al., 2009; Shiraishi-Yokoyama et al., 2006; Ward et al., 1997). Further studies should investigate this issue in a randomized study with smokers, non-smokers and using nicotine gum.

Our results suggested impairment at all spatial frequencies; however these impairments are more pronounced at low and medium spatial frequencies (Fig. 3, see effect sizes), and this can corroborate our chromatic results. Although we used photopic condition and stationary stimuli (e.g., we are unable to investigate magnocellular pathway), both combined results points to further investigation on these pathways separately. Our conclusion is that one needs to be careful when comparing studies when comparing visual pathways to the tested paradigms.

Finally, the participants were carefully selected for this study, building a homogenous sample. Our previous findings (Fernandes et al., 2017c; Fernandes et al., 2018c) showed the absence of cognitive impairments as well as the absence of level of education and age (with the same age of this study) on visual processing in heavy smoking. Also, the tasks employed here are extensively reported elsewhere and the results pointed out to absence of learning effects; then, cognition could not play a fundamental role on the perception sphere. This also needs to be better addressed in a randomized clinical trial, but our results points to a direction for this.

Although our results can be only attributable to the tobacco addiction per se, it is possible that another variable, one associated with a predisposition to smoking, could be driving the results. It is important to mention that reduction on blood flow in the retina, oxidative stress, and even nutrient absorption needs to be investigated in further studies. As stated, we did not observe impairments in visual acuity and OCT, but this should be better investigated. Future studies that examine the extent to which smoking vs. characteristics of people who smoke are related to visual processing differences are needed. In addition, the issue of visual processing and smoking needs to be investigated with a wider range of behavioral, electrophysiological, and imaging techniques, to more fully establish the effects of smoking on visual function, and these effects over time.

The use of the CSF and CCT as potential noninvasive methods of visual processing assessment may have direct application in clinical setting. Both of the two paradigms may allow the early detection of visual deficits, and detecting such changes early may be beneficial for the studied or treated population. The use of these tests can have direct implications for basic and clinical research. In conclusion, the present findings indicate that heavy long-term smokers (i.e. tobacco addiction users) have lower contrast sensitivity and poorer color discrimination abilities than their non-smoking peers. These data have implications for extending our understanding of the detrimental effects of smoking, suggesting that the visual system can be affected. In addition, this data suggest that research into visual processing impairments (e.g., reduced contrast sensitivity or color discrimination) in clinical populations, such as schizophrenia, that are associated with both increased smoking (Dickerson et al., 2013; Fernandes et al., 2018b; Fernandes et al., 2018d) and impaired visual processing (Silverstein, 2016) needs to control for smoking rate or to independently examine smokers vs. non-smokers with the disorder in question.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2018.11.024.

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