Visual impairment on dentists related to occupational mercury exposure

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Available online 23 January 2005

Abstract

A detailed assessment of visual function was obtained in subjects with low-level occupational mercury exposure by measuring hue saturation thresholds and contrast sensitivity functions for luminance and chromatic modulation. General practice dentists (n = 15) were compared to age-matched healthy controls (n = 13). Color discrimination estimated by the area of Mac Adam ellipses was impaired, showing diffuse discrimination loss. There was also reduction of contrast sensitivity for luminance and chromatic (red-green and blue-yellow) modulation, in all tested spatial frequencies. Low concentrations of urinary mercury (1.97 ± 1.61 μg/g creatinine) were found in the dentists group. Color discrimination as well as contrast sensitivity function, assessed psychophysically, constitutes a sensitive indicator of subtle neurotoxic effect of elemental mercury exposure.

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Keywords: Color perception; Contrast sensitivity; Mercury; Dental amalgam; Dentists; Occupational exposure

1. Introduction

In recent years there has been great debate about the safety of dental amalgam; several authors share the opinion that the neuropsychological symptoms that characterize dental amalgam sickness are not evidence-based (Crossley et al., 2001; Langworth et al., 2002; Osborne and Albino, 1999; Spencer, 2000). Despite the fact that the question is far from being resolved, the dental office remains a potential mercury contamination source (Brune et al., 1980; Dun, 1988; Ngu et al., 1992; Pohl and Bergman, 1995; Ferracane et al., 1994; Glina et al., 1997; Stonehouse and Newman, 2001).

Dental amalgam is not a recent restorative material, it has been used since the beginning of the 19th century in France (Dodes, 2001) and today it is one of the most used restorative materials in Brazil. It is defined as an alloy that contains around 50% of elemental mercury, 35% silver, 12% tin and 3% copper (Giachetti, 1999).

Dentists have been reported to have higher levels of mercury than the general population (Urban et al., 1999; Echeverria et al., 1998; Cincinella et al., 1997; Steinberg et al., 1995). This is due to the manipulation of dental amalgam in several routine tasks: preparation, restoration, polishing, removal and discards of the dental amalgam residues and storage of mercury (Ely, 1997).

According to the World Health Organization, dentists are among the health professionals with higher occupational exposure to mercury vapor (World Health Organization, 1991). The International Union of Pure and Applied Chemistry (IUPAC, 1993) define micromercurialism as being “effects of exposure to mercury detected at the lowest exposure levels producing a measurable reaction”. This condition is an effect represented by an initial series of unspecific symptoms that become more severe as the time of exposure to low concentrations of mercury increases (Kostyniak, 1998; Fortes et al., 1999; Urban et al., 1999).

Besides being exposed to mercury, dentists also have a role in environmental contamination. Mercury and its compounds are naturally present in the environment as well as a
result of the contamination from human activities. Between 2.700 and 6.000 t of mercury are released yearly in the atmosphere mainly due to volcanic activity and natural emission of the oceans; around 2.000–3.000 t are due to human environmental contamination (World Health Organization, 1991) and 60–120 t originate from dental activities mainly due to the use of dental amalgam (Chin et al., 2000).

Occupational related impairment of visual functions gained attention in recent years. There is a report of visual field constriction related to mercury exposure (Clarkson, 1997). Color vision has been demonstrated as a sensitive indicator of subtle neurotoxic effects from exposure to solvents and heavy metals (Gobba, 2000; Ventura et al., 2004, 2005) and also in Brazilian gold miners, exposed to elemental mercury vapor, and riverside communities, due to methyl mercury in fish, in the Amazonian region (Damin, 2000; Silveira et al., 2003). Impairment of color discrimination and contrast sensitivity was shown in these studies.

We performed a detailed psychophysical assessment of visual functions in dentists exposed to mercury vapor using a recently developed test that measures Mac Adam ellipses (Mollon and Reffin, 2000; Ventura et al., 2003), in addition to the traditional Lanthony desaturated D15d, the Cambridge color test (CCT), offering the advantage of quantification of impairment in terms of area in the CIE chromaticity diagram. Since this diagram is a representation of color space, the results convey direct information about a perceptual loss. We also measured luminance contrast and chromatic contrast sensitivity functions, which according to Grandjean et al. (2001) constitute a sensitive indicator of visual function impairment induced by the neurotoxic effect of mercury.

2. Materials and methods

2.1. Subjects

General practice dentists (n = 15), six males and nine females, ranging from 30 to 45 years of age (39.86 ± 2.17) years, were submitted to the test. Controls (n = 13), six males and seven females, ranging from 27 to 43 years of age (36.6 ± 2.33 years) were submitted to the same procedures for comparison. Exclusion criteria: 20/25 Snellen best-corrected visual acuity or better and absence of known ophthalmological pathologies. Fundus and anterior segment examination was performed for each subject; non-occupational mercury exposure (fish consumption and number of dental amalgams in the subject’s mouth) was recorded for all subjects. Exclusion criteria: use of alcohol, smoking or consumption of any other drug. A detailed anamnesis and the working routine for the dentists’ group (e.g. number of dental amalgams placed/removed, weekly workload, etc.) were recorded. The tests were then performed after all subjects had received proper information and signed their informed consent. The procedures followed the tenets of the Declaration of Helsinki and were approved by an ethics committee at the Institute of Psychology of the University of São Paulo, where this work was carried out.

2.2. Tests

Elementary mercury (Hg) concentrations in the urine from both groups were analyzed by cold vapor atomic absorption spectrophotometry and expressed in µg/g creatinine. All visual tests were done monocularly, in the dominant eye, after a 20-min adaptation period in the dark. Color vision was assessed with the following tests:

- Lanthony desaturated test (Laneau).
- Cambridge color test v 2.0 (Cambridge Research Systems Ltd.) using a Sony Trinitron 21 in (GPD-520) monitor driven by a Cambridge research VSG 2/5 graphics board with a refresh rate of 160 Hz non-interlaced and an 800 × 600 resolution.

The stimulus was a Landolt C target in a background of luminance and spatial noise (Mollon and Reffin, 2000; Regan et al., 1994; Ventura et al., 2003). The subject’s task was to indicate the position of the Landolt C opening, in a four option alternate forced choice paradigm (4AFC), by pressing the corresponding button in a response box. All stimuli had an average luminance ranging from 4 to 18 cd/m² with a visual angle of 1°. The determination of five Mac Adam ellipses with eight vectors was obtained through a double staircase psychophysical procedure and their center coordinates were: Field 1: 0.197, 0.469; Field 2: 0.193, 0.509; Field 3: 0.204, 0.416; Field 4: 0.158, 0.473 and Field 5: 0.242, 0.4634. These coordinates correspond to the two sets of the Ellipses tests of the CCT (for details see Mollon and Reffin, 2000), with three ellipses each, sharing the center ellipse (Field 1). The chromaticities lie along two orthogonal confusion lines. Fields 2, 1 and 3 lie along a tritan confusion line or S-cone isolating line, and Fields 4, 1 and 5 lie along a proton-dentan confusion line or L-M isolating line. The results were expressed in a’u’v’ coordinates in 1976 CIE color space and then fitted with an ellipse contour (Ventura et al., 2003).

Contrast sensitivity functions were also measured psychophysically with the software PSYCHO for Windows v 2.36 (Cambridge Research) using a Sony Trinitron 19 in (GPD-420) monitor driven by a Cambridge Research VSG 2/4 graphics board with a refresh rate of 100 Hz non-interlaced and an 800 × 600 resolution with the following tests:

- Luminance contrast.
- Red-green chromatic contrast.
- Blue-yellow chromatic contrast.

The stimuli used were horizontal sinusoidal gratings with an average luminance of 10 cd/m², i.e. 34.4 cd/m², measured by Optical OP200-E photometer (Cambridge Research) and a visual angle of 4°. To determine the contrast sensitivity...
function, we used method of adjustments (MOA). With this psychophysical method, the subject's task was to adjust the contrast to its minimum perceived level in steps of 1%, through a response box; the procedure was randomized in spatial frequency, was repeated three times, averaged, and two reversions were used each time. Luminance and chromatic (blue-yellow and red-green) contrast sensitivity functions were measured. Before the tests, an equiluminance adjustment for the red-green and blue-yellow pairs was obtained at all tested frequencies, using heterochromatic flicker photometry at 20 Hz. The stimuli $u'v'$ coordinates were: D6500: 0.198, 0.468; red: 0.258, 0.454; green: 0.133, 0.469; blue: 0.210, 0.397 and yellow: 0.188, 0.551. The contrast sensitivity measurements were performed in 10 subjects of the dentists' group as well as in the control group. Both groups had no previous training in this test and they also received the same instructions.

2.3. Statistical analysis

Two-sided t-tests were applied for the confounding factors (fish consumption and number of dental amalgams in the subject's mouth). Non-parametric Mann–Whitney Sum of Ranks test was used to analyze the data obtained in urinary mercury and in the visual tests. The statistical significance level used was $P < 0.05$. A linear regression analysis was used to address the associations between urinary mercury and the visual functions.

3. Results

3.1. Hg urine analysis

Urinary Hg concentrations in both groups, dentists and controls, are shown in Table 1. Urinary mercury found in the dentists group ($1.97 \pm 1.61 \mu g/g$ creatinine) was significantly higher than controls ($0.75 \pm 0.40 \mu g/g$ creatinine) ($P=0.0215$). No correlation with workload, exposure period or work routine (e.g. number of dental amalgams placed/removed, weekly workload, etc.) was found.

3.1.1. Non-occupational sources of mercury exposure

Two sources of non-occupational mercury exposure were recorded, number of personal dental amalgams and fish consumption (portions per week). The values obtained were 3.62 $\pm$ 2.89 and 0.54 $\pm$ 0.68, respectively for the dentists, and 2.81 $\pm$ 2.24 and 0.88 $\pm$ 0.96, respectively for the control group. There was no statistical difference between the two groups.

3.2. Lanthony desaturated test

There was no statistical difference between the mean error score of the dentists group ($125.95 \pm 13.97$) and that of the control group ($125.07 \pm 5.69$) in the Lanthony desaturated test. Bowman's Color Confusion Index (Bowman, 1982) values were: 1.07 $\pm$ 0.11 and 1.07 $\pm$ 0.04 for dentists and controls, respectively.

3.3. Cambridge color vision test

Statistical analysis (Mann–Whitney Sum of Ranks) showed that the areas of the Mac Adam ellipses obtained for dentists were significantly larger than those of controls for Field 2 ($P=0.004$), Field 3 ($P=0.007$), Field 4 ($P=0.008$) and Field 5 ($P=0.008$), but not for Field 1 ($P=0.051$) (Fig. 1). The average Mac Adam ellipses obtained in both groups were plotted in CIE $u'v'$ chromaticity coordinates (Figs. 2 and 3). The color vision loss observed was of a diffuse nature without any trend towards the protan, deutan or tritan axes.

The relevant parameters for the classification of the color discrimination are: the area of the ellipses, that indicates the amount of the loss; the axis ratio, classifying the loss in diffuse or specific and the angle of the major axis of the ellipse indicating one of the three kinds of deficiency (tritan, protan and deutan). The ellipses of control subjects (Fig. 2) are small compared to those obtained in the dentists' group (Fig. 3). The ellipse areas of the control subjects are within the normative values obtained for younger subjects (age range from 18 to 30 years old) from our laboratory (Ventura et al., 2003) for Fields 1 and 2 but are larger for Field 3. This is to be expected due to the age difference between normative and control groups.

![Fig. 1. Mac Adam ellipse areas for Fields 1–5 for dentists and controls (mean and S.E.). (*) Indicates statistically significant differences ($P < 0.05$) between the groups.](image-url)
In the dentists’ group, the approximately circular shape of the ellipses characterizes the loss in this group as diffuse.

3.4. Contrast sensitivity function tests

Luminance contrast sensitivity as well as chromatic contrast (red-green and blue-yellow) was significantly lower in dentists compared to controls at all spatial frequencies ($P < 0.001$), showing a uniform reduction of the contrast sensitivity functions (Figs. 4-6).

Linear regression analysis did not reveal associations between urinary mercury and the visual functions, probably because of the narrow range of values in urinary mercury levels and small sample size.
4. Discussion

The present study showed a significant effect of elemental mercury exposure on color discrimination, as determined by the area of Mac Adam ellipses using the Cambridge color test, which evaluates hue and saturation simultaneously. However, there were no significant differences in constant saturation test such as Lambeth desaturated hue test. The CCT appears to be more sensitive than the arrangement tests in a subclinical color vision impairment condition such as that of the dentists studied here.

Contrast sensitivity functions were also significantly affected in the group of dentists compared to the age-matched control group. They were uniformly reduced at all spatial frequencies examined for both luminance and chromatic (red-green and blue-yellow) contrasts. An analogous result was obtained in Amazonian gold miners and in Brazilian workers from fluorescent lamp factories intoxicated with mercury vapor and evaluated with the same color vision and contrast sensitivity procedures (Damin, 2000; Silveira et al., 2003; Ventura et al., 2004, 2005).

The visual impairment found in the dentist sample supports the findings of early signs of mercury neurotoxicity at very low levels (Echeverria et al., 1998). No dose effect could be demonstrated in the present study, probably due to the small sample of dentists analyzed and narrow range of values in urinary mercury levels.

Non-occupational sources of mercury exposure, such as fish consumption and number of dental amalgams in the subject’s mouth, do not seem to be associated with the visual impairment found in the dentists sample. It is known that different aspects of the luminance contrast sensitivity function reflect the participation of the magnocellular and parvocellular retino-geniculo-strate systems (Merigan, 1991). The magnocellular system is involved in the processing of low spatial frequencies, while the high spatial frequencies are preferentially processed by parvocellular system. The fact that these separate processing pathways are not affected differentially in mercury contamination may be interpreted as meaning one of two possibilities: either that the damage occurs before their differentiation, i.e., at the level of the outer retina, or that the entire visual system is affected in a diffuse way. This second possibility is perhaps closer to what must be the cause for the impairment since many other neural functions are also affected in mercury contaminated patients with high levels of contamination (Damin, 2000; Silveira et al., 2003).

The losses that were detected in visual functions are relevant not only by themselves but also as an indication that subclinical impairment in other functions may also be found if tested with sensitive methods. They lead to a recommendation for monitoring of the dentist’s work situation, for a reduction of the use of Hg and adoption of safety protection measures and for the regular monitoring of dentists’ visual functions in order to evaluate the presence of very low-level mercury exposure. Cautionary measures may lead to the disappearance of losses as found by Cavalleri and Gobba (1998) in the case of workers after a period away from the source of contamination.

Acknowledgements

To Prof John M. Souza and Henrique Della Rosa (University of São Paulo) and Dr. José Luiz F. Vieira (Núcleo de Medicina Tropical, Universidade Federal do Pará) for their collaboration in several aspects of this article. This research was supported by grants from FAPESP (Projeto Temático), FINEP #66.95.0407.00, CNPq #523303/95-5, USF-PROESP and Capes/PROCAD #001901-1 to D.F.V. L.C.L.S. and D.F.V are CNPq research fellows. L.H.M.C.P has a doctoral CNPq fellowship.

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