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Title:

Macular pigment spatial profiles in South Asian and White subjects

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Abstract (242 words)

Purpose: Variability in central macular pigment optical density (MPOD) has been reported amongst healthy individuals. These variations seem to be related to risk factors of age-related macular degeneration, such as female gender, smoking, and ethnicity. This study investigates the variations in MPOD spatial profiles amongst ethnicities.

Methods: Using heterochromatic flicker photometry (HFP), MPOD was measured at 7 retinal locations in 54 healthy young South Asian and 19 White subjects of similar age. Macular pigment spatial profiles were classified as either typical 'exponential', atypical 'ring-like' or atypical 'central dip'.

Results: Central MPOD was significantly greater in South Asian (0.56 ± 0.17) compared to White subjects (0.45 ± 0.18; $P = 0.015$). Integrated MPOD up to 1.8° i.e. MPODav(0-1.8) was also significantly increased in Asian (0.34 ± 0.09) versus White subjects (0.27 ± 0.10; $P = 0.003$). MPODav(0-1.8) was significantly increased in all subjects presenting a ring-like profile (0.35 ± 0.08) or central dip profile (0.39 ± 0.09), compared to typical exponential profiles (0.28 ± 0.09; $P < 0.0005$). We found a statistically significant association between ethnicity and spatial profile type ($P = 0.008$), whereby an exponential profile was present in 79% of White compared to 41% of the South Asian subjects.

Conclusion: Central MPOD, MPODav(0-1.8), and the prevalence of atypical spatial profiles were significantly increased in South Asian compared to White subjects. Atypical profiles resulted in increased integrated MPOD up to 1.8° and may therefore offer enhanced macular protection from harmful blue light.

Introduction

The spatial profile of macular pigment (MP) optical density has been shown to vary considerably amongst subjects. The optical density of MP, measured in log units, typically peaks centrally and declines sharply with eccentricity away from the foveola.[1-3] Central MP optical density (MPOD) has been reported to be lower with age,[4] smoking,[5] in the presence of inflammation promoting conditions (e.g. diabetes),[6] in females[7] and in the presence of light iris colour.[8, 9] Previous studies described MP spatial profiles with either a single peak decaying exponentially,[2, 10, 11] a central dip i.e. without a central peak,[10, 11] or exhibiting a secondary peak up to 2° eccentricity also referred to as a subpeak, shoulder, bi-modal or ring-like structure.[2, 10] Using psychophysical heterochromatic flicker photometry (HFP), Hammond *et al.* found that the MP distribution of 32 Caucasian subjects was best described by an exponential fit.[2] However, the authors also discovered that about 40% of subjects presented secondary subpeaks (defined as increments greater than 0.05 optical density units from the exponential fit) at 1° and 2°. More recent studies have shown similar bimodal MP spatial profiles in a significant proportion of subjects.[10, 12-15] The prevalence of a parafoveal ring was also shown in 20-50% of subjects when using objective autofluorescence imaging (AFI) techniques.[10, 15-17] Moreover, using AFI, the frequency of ring-like profiles was found to be significantly greater in females and in non-smokers,[15, 16] and in healthy subjects (43%) compared to patients with age-related maculopathy (23%).[15] Similar findings have also been demonstrated in ethnicities with a low prevalence of age-related macular degeneration (AMD), whereby 86% of African subjects presented with secondary peaks versus 68% non-Hispanic white subjects.[17] However, it was also suggested that the lack of a central peak could possibly have an adverse effect on the protective role of MP in AMD, as

the prevalence of a central dip has been found to increase with age and smoking in Caucasian subjects.[11]

Several studies have investigated ethnic differences in central MPOD.[14, 17-21] White subjects presented significantly lower mean central MPOD compared to South Asian,[18] African,[17, 19] and non-White subjects including Asian, Black and Hispanic ethnicities.[14] However, the central MPOD of White subjects did not differ greatly compared to Chinese subjects.[21] Additionally, in a study where darker iris colour was linked to increased average MPOD over the central 1° area, the results implied that central MPOD was not related to ethnicity. However, possible differences in MP density due to race were minimized as only a small percentage of non-Caucasian (Asian and African-American) subjects were included.[9] Published data on MPOD variations between South Asian (from India, Pakistan, and Bangladesh) and White subjects is limited.[2, 9, 14, 18] Using the HFP technique, Howells *et al.* reported a significantly increased mean central MPOD in South Asian (0.43 ± 0.14 log units) versus White subjects (0.33 ± 0.13 log units; $P < 0.0005$), with increased MPOD in the Asian males compared to Asian females ($P < 0.01$).[18] This was not true for the White subjects: while the males presented with lower central MPOD, this was not statistically significant ($P = 0.39$). Less is known about the ethnic differences in the distribution of MP away from the fovea. A study by Hammond *et al*. found that MPOD distribution was not related to ethnicity.[2, 9] Nolan *et al.* also reported no association between the prevalence of a ring-like profile and ethnicity.[14] However, both studies included limited numbers of non-White subjects (including South Asian) in comparison to the White group. To our knowledge, this is the first comparison study to investigate the prevalence of MP spatial profiles amongst South Asian and White subjects.

Methods

Macular pigment measurements

MPOD was assessed using a visual display unit based Macular Assessment Profile (MAP) test.[22] The MAP test uses heterochromatic flicker photometry (HFP) to measure MPOD at the centre of the fovea (0°) and at 6 other retinal locations (at 0.8°, 1.8°, 2.8°, 3.8°, 6.8°, 7.8° eccentricity from the fovea). Like other tests employing HFP techniques, the MAP test is based on the spectrally selective properties of MP. Two beams of light are produced optically by the phosphors of the MAP test display unit. The test beam is composed of short wavelength (SW) blue light, peaking at ~450nm which is maximally absorbed in the central retina by MP. The reference beam is of a longer wavelength (LW) light that is not absorbed by the MP.[23] A 'notch' filter is used in front of the test eye to increase the separation between the test and the reference beam. When the luminance of these wavelengths is not equal, a counter phased sinusoidal pattern is produced and the stimulus appears to flicker.[1, 24] A larger difference in luminance yields a stronger sensation of flicker.

The centre stimulus is a disc of 0.36° diameter. The peripheral stimuli are sectors of an annulus which are presented concentric to the fovea. Both the angular subtense and the width of the peripheral stimuli increase with eccentricity [22] to ensure greater flicker sensitivity in the peripheral retina. Although the test supports any selected meridian, all the measurements reported in this study were performed with the stimulus centred along the horizontal meridian. In addition, a static mirror symmetric stimulus was presented at the corresponding location in the visual field to minimize the subject's tendency to saccade to the flickering peripheral target.

During the MAP test, the luminance of the test beam is altered until the perception of flicker is cancelled or minimized. In order to ascertain the range of luminance for which the perception of flicker is absent, the MAP test calculates a low and a high threshold using a double reversal technique. The average of the low and high values is computed to give the luminance of the test beam required to cancel the reference beam (the flicker null point). The test is repeated in a random order eight times (four high and four low thresholds) at each eccentricity and the average is calculated to give the mean luminance of the SW test beam required to achieve the flicker null point. MPOD is calculated by comparing the mean luminance adjustment of this SW light in the central retina to a reference point in the peripheral retina using the equation:

$$MPOD = \log_{10}(L_i/L_o)$$

where L*i* is the mean luminance of the SW test beam at location *i* and L*o* is the average of the test beam luminance of the 6.8° and 7.8° peripheral locations (where MP levels are thought to be negligible[10]).

Study protocol

The study took place at the Division of Optometry and Visual Science at City University London. Study data was collected from 54 Asian and 19 White participants between May 2008 and November 2010. The average age of the Asian participants was not statistically different from the average age of the White participants (P = 0.068). Ethnicity was self-reported as White or South Asian (born in India, Pakistan, or Bangladesh, or born in UK from Indian, Pakistani, or Bangladeshi

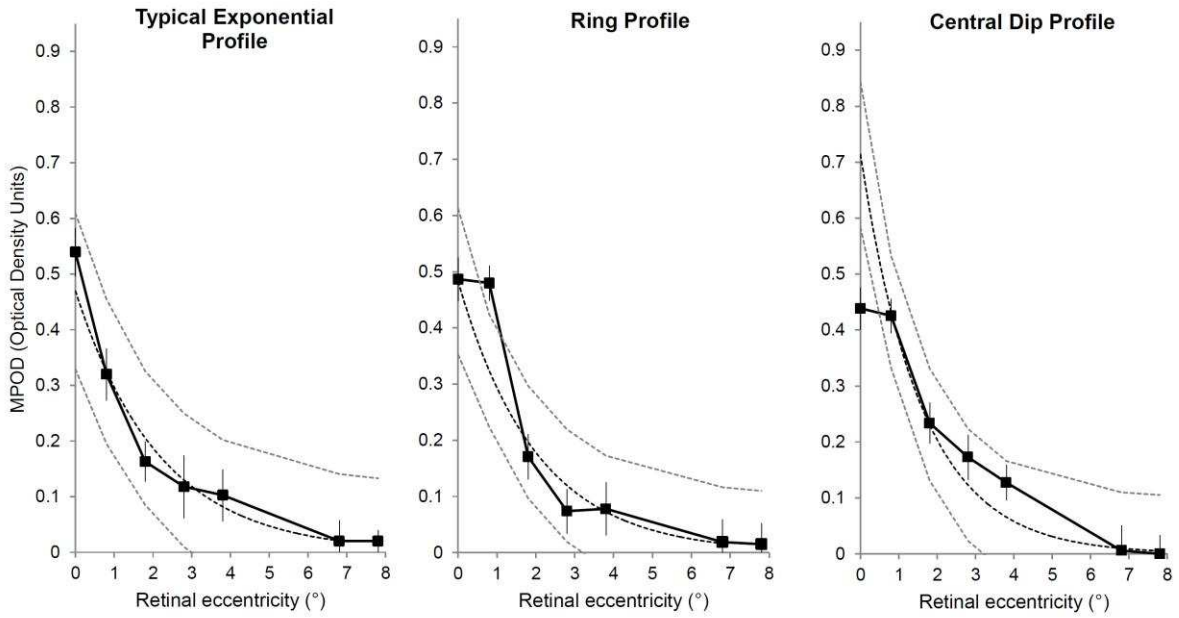
parents; hereafter referred to as Asian). All participants had LogMAR visual acuity greater than 0.3 log units in the eye being tested. Exclusion criteria were: ocular pathology including inflammation, AMD or cataract, (self-reported) pregnancy, current use of carotenoid supplementation and/or medication that may affect retinal function. Participants completed a lifestyle and health questionnaire, providing information about general and ocular health, use of medication, nutritional supplementation, and smoking history. Prior to using the MAP test, each participant was given a practice run of the 0°, 1.8° and 2.8° spatial locations. This provided a uniform introduction to the test and ensured complete dark adaptation.

Classification of MP spatial profiles

For each study participant, an exponential curve was fitted to the average absolute MPOD measurements at all retinal locations. The MP spatial profile presentation of each study participant was classified into typical exponential or atypical (non-exponential). The coefficient of repeatability (CoR), i.e. the average within-subject standard deviation (SD), was calculated from the eight repeated MPOD measurements at each eccentricity for both ethnicities. The exponential profile was classified by MPOD at 0°, 0.8° and 1.8° being within one CoR of the value predicted by the exponential curve. All others were assumed atypical. We sub-classified our atypical group into ring-like and central dip profiles. Using the method described by Hammond *et al.*,[2] a positive deviation greater than the MAP test CoR from the exponential curve at 0.8° and/or 1.8° was classified as a ring-like profile. A negative deviation from the exponential profile greater than the MAP test CoR from the exponential curve at 0° was considered to be a central dip profile (Figure 1).[10]

Figure 1. Macular pigment optical density as a function of eccentricity for three participants: examples of exponential, ring and central dip profiles.

All three graphs include the mean absolute MPOD values ± SD of 8 measurements at each eccentricity. The black dotted line represents the exponential curve fitting to the mean absolute MPOD values. The grey dashed lines represent the MAP test measurement error according to the subject's ethnicity at each eccentricity from the exponential curve. Note the MPOD at 0.8° in the ring-like profile presents more than one coefficient of repeatability (CoR) above the expected exponential curve at 0.8°. The MPOD at 0° in the central dip profile shows more than one CoR below exponential curve.



Average blue light transmittance (Tav) and average MPOD (MPODav)

At each eccentricity measured by the MAP test, the transmittance (T_i) is a measure of the SW blue light-filtering capacity of the MP at location *i* and is given by:

$$T_i = 10^{-MPOD_i}$$

The value of T_i was plotted against retinal eccentricity, and the trapezium rule was used to calculate the area under the curve (Tav), representing the integrated transmittance of the MP between eccentricities. Tav between 0° and 1.8° corresponding to a 3.6° diameter circular aperture was calculated using the formula:

$$T_{av(0\text{-}1.8)} = \frac{0.5(T_0 + T_{0.8})(\pi 0.8^2 - 0) + 0.5(T_{0.8} + T_{1.8})(\pi 1.8^2 - \pi 0.8^2)}{\pi 1.8^2}$$

where $T_0 = 10^{-MPOD}$ at 0°, $T_{0.8} = 10^{-MPOD}$ at 0.8°, and $T_{1.8} = 10^{-MPOD}$ at 1.8°. The value of Tav(0-1.8) was used to calculate an average integrated MPOD between 0° and 1.8°:

$$MPOD_{av(0\text{-}1.8)} = -\log_{10} T_{av(0\text{-}1.8)}$$

Ethical approval and consent

Ethical approval was obtained from the Optometry Research & Ethics Committee and written informed consent was obtained from all subjects, conforming to the tenets of the Declaration of Helsinki.

Statistical analysis

All statistical analyses were performed using SPSS version 19.0 for Windows (SPSS Inc., Chicago, USA). Values in the text and tables are presented as the mean ± standard deviation (SD). Kolmogorov-Smirnov tests revealed no significant deviation from a normal distribution for MPOD at different spatial locations. Independent student t tests and one-way between-groups analysis of variance (ANOVA) analyzed the differences between the ethnic groups, gender, and smoking status. The Pearson Chi squared test and Mann-Whitney U test were used to assess any difference between categories and groups that showed an abnormal distribution. ANOVA was used to investigate any differences between the three different distribution profiles of MP. Statistical significance was accepted at the 95% confidence level ($P < 0.05$). Power statistics revealed that a sample size of 38, 19 subjects per group, was needed to detect a standardized difference of 0.91, using 80% power at 5% significance level.[25] This calculation was based on an estimated significant mean difference in MPOD of 0.1 with group SDs of 0.11 (based on the average MAP test coefficient of repeatability; *unpublished data 2010*).

Results

Demographics between the ethnic groups, and mean MPOD measured at each eccentricity are summarized in Table 1. There was a significant difference between the two ethnic groups: the Asian group included fewer current smokers compared to the White group (P = 0.039). Age was not significantly correlated with central MPOD or any of the other spatial locations (r = -0.110; P = 0.35). Mean MPOD for individual eccentricities up to 2° showed a significant difference between the groups (Table 1). MPODav(0-1.8) (corresponding to integrated MPOD over the central 3.6° area) was significantly increased in Asian versus White subjects (t(71) = 3.07; P = 0.003). The significant difference in MPODav up to 1.8° between ethnicities was maintained with smoking as a covariant (F(1,70) = 7.43; P = 0.008).

Table 1. Demographics and MPOD results for all subjects and separate ethnic backgrounds. Independent t tests and chi-square tests were conducted to determine statistically significant differences in MP measurements between Asian and White participants. * Indicates statistical significance at the 0.05 level.

	All	**Asian**	**White**	***p-value***
Number	73	54	19	
Age (years)				
Mean ± SD		20.9 ± 3.2	22.4 ± 2.8	0.068
Range		18-34	16-28	
Gender				
Male	24 (33%)	14 (26%)	10 (53%)	0.065
Female	49 (67%)	40 (74%)	9 (47%)	
Current smoker?				
Yes	8 (12%)	3 (6%)	5 (26%)	0.039*
No	65 (88%)	51 (94%)	14 (74%)	
	Mean ± SD MPOD (log units)			
MPOD 0°	0.53 ± 0.18	0.56 ± 0.17	0.45 ± 0.18	0.015*
MPOD 0.8°	0.44 ± 0.14	0.46 ± 0.13	0.37 ± 0.14	0.010*
MPOD 1.8°	0.19 ± 0.08	0.20 ± 0.09	0.14 ± 0.07	0.007*
MPODav(0-1.8)	0.32 ± 0.10	0.34 ± 0.09	0.27 ± 0.10	0.003*

Gender

When the group was considered as a whole (n=73), females had higher central MPOD values (0.55 ± 0.19) compared to males (0.50 ± 0.16); however this difference was not statistically significant ($t(71) = 1.25$; $P = 0.22$). A one-way between-groups analysis was conducted to explore the impact of gender on MPODav(0-1.8) between the ethnicities. MPODav(0-1.8) did not show a statistically significant difference between Asian males, Asian females, White males, and White females ($F(3,69) = 2.25$; $P = 0.06$).

Smoking status

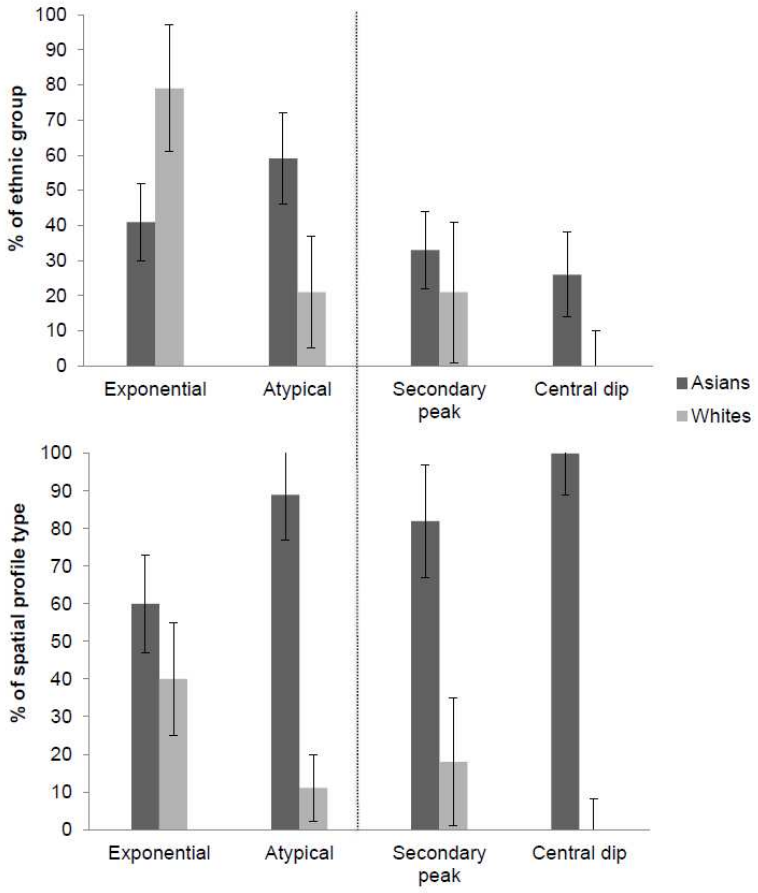
Among all participants, central MPOD was increased in non-smokers (0.54 ± 0.18) when compared to current smokers (0.47 ± 0.17); however, this difference was not statistically significant ($t(71) = 1.01$; $P = 0.32$). Additionally, a one-way between-groups analysis did not show a significant difference in MPODav(0-1.8) between smoking and non-smoking Asian and White subjects ($F(3,69) = 2.69$; $P = 0.053$).

Spatial profiles

When the group was considered as a whole, a typical exponential profile was seen in half of the group (n=37), while 36 participants showed a non-exponential (i.e. atypical) profile. A Pearson Chi-square test using the appropriate continuity correction indicated a statistically significant association between ethnicity and spatial profile type (χ^2 (1, n=73) = 6.75, $P = 0.009$, Cramer's V = 0.335). The results show that within ethnicities, 79% of White subjects presented an exponential profile in comparison to 41% of the Asian subjects (Figure 2). Ninety-eight percent of

participants showing an atypical profile were of Asian phenotype. We also observed an interesting relationship between the ethnicities and the three spatial profiles of MP as described in the Methods. When the group was considered as a whole, an exponential profile occurred in half the group, a ring in 30% of the group and the central dip profile was present in 19% of the subjects. Furthermore, 82% of subjects showing a ring and 100% of subjects showing a central dip profile were of Asian descend (Figure 2). Pearson Chi-square test indicated a statistically significant association between ethnicity and spatial profile type (χ^2 (2, n=73) = 9.68, P = 0.008, Cramer's V = 0.364).

Figure 2. The frequency of spatial profile types. The upper graph shows typical exponential versus atypical MP spatial profiles as a percentage of each ethnic group. The lower graph shows the prevalence of ethnicity within each of the spatial profile groups. On the right side, the prevalence of individual atypical profiles (ring and central dip) is shown for both ethnic groups. Error bars represent the 95% confidence interval for proportions.



We explored the relationship between spatial profile type and MPOD at individual spatial locations up to 2° and MPODav(0-1.8) (Table 2). MPODav(0-1.8) was significantly increased in participants that showed an atypical when compared to an exponential spatial profile ($t(71) = -4.56$; $P < 0.0005$). This was also true for MPOD at 0.8° and MPOD at 1.8°, but not for central MPOD ($t(67) = -1.35$; $P = 0.19$). When the same analysis was conducted for each ethnicity, identical statistically significant results were found for the Asian subjects but not for the White subjects. ANOVA showed statistically significant differences for all MPOD values (Table 2) when all three spatial profiles (exponential, ring, and central dip) were considered, with the exception of central MPOD ($P = 0.43$). Post-hoc analysis using the Tukey HSD test indicated that the mean MPODav(0-1.8) for the exponential profile group (0.28 ± 0.09) was significantly decreased compared to the MP ring group (0.35 ± 0.08) and the central dip group (0.39 ± 0.09), but not between the two atypical profile groups. This was also true for MPOD at 0.8°. Interestingly, mean MPOD at 1.8° for the exponential group (0.16 ± 0.06) was not significantly different from the ring group (0.19 ± 0.08), but they were both significantly decreased from the subjects in the central dip group (0.27 ± 0.10; $P < 0.0005$).

306 **Table 2. Summary of MPOD values per spatial profile type for all participants.** *
307 Indicates statistical significance at the 0.05 level; † Statistically significantly different
308 from ring-like profile; ‡ Statistically significantly different from central dip profile.

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	Typical exponential N=37	**Atypical N=36**		***P* value**
	Mean ± SD MPOD (log units)			
MPOD 0°	0.51 ± 0.20	0.56 ± 0.15		0.19
MPOD 0.8°	0.36 ± 0.13	0.52 ± 0.11		< 0.0005*
MPOD 1.8°	0.16 ± 0.06	0.22 ± 0.09		0.003*
MPODav(0-1.8)	0.28 ± 0.09	0.37 ± 0.08		< 0.0005*
	Typical exponential N=37	**MP ring N=22**	**Central dip N=14**	
	Mean ± SD MPOD (log units)			
MPOD 0°	0.51 ± 0.20	0.57 ± 0.16	0.55 ± 0.14	0.43
MPOD 0.8°	0.36 ± 0.13 †,‡	0.52 ± 0.11	0.51 ± 0.11	< 0.0005*
MPOD 1.8°	0.16 ± 0.06 ‡	0.19 ± 0.08 ‡	0.27 ± 0.10	< 0.0005*
MPODav(0-1.8)	0.28 ± 0.09 †,‡	0.35 ± 0.08	0.39 ± 0.09	< 0.0005*

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311

Discussion

Consistent with previous studies,[18, 26] we found increased central MPOD in Asian (0.56 ± 0.17) versus White subjects (0.45 ± 0.18; t(71) = 2.50; *P* = 0.015). This is in agreement with the work of Howells *et al.* where an average of 0.43 ± 0.14 in 117 Asian and 0.33 ± 0.13 in 52 White subjects was reported.[18] Overall, their slightly lower average MPOD values compared to the present study are possibly due to the different HFP instruments used. However, the difference in central MPOD values between the ethnicities is similar between the studies. In contrast, Raman *et al.* reported a mean central MPOD (at 0.25° retinal eccentricity) of 0.63 ± 0.16 in 60 Asian subjects aged 20-29 years old, and 0.72 ± 0.22 in 60 Asian subjects age 30-39 years old.[26] These values are higher when compared to our results, which again may be due to the different HFP instruments. Furthermore, the Asian subjects were of South Indian origin living in India (Mumbai); however, similar to Howell's study,[19] the Asian subjects included in our study were of Indian, Pakistani, and Bangladeshi descent, the majority born and living in the UK (78%; 42 out of 54 Asian subjects). The country of origin and residence may be significant because of differences in diet. The traditional south Asian diet typically consisting of a diet rich in carotenoids may be altered after migration, particularly in the young or second generation Asians [27]; this may contribute to the lower MPOD levels found in our group.

The integrated transmittance of the MP between eccentricities was used to calculate the average MPOD up to 1.8°. Similar to central MPOD, mean MPODav(0-1.8) was significantly increased in Asian (0.34 ± 0.09) compared to White subjects (0.27 ± 0.10; t(71) = 3.07; *P* = 0.003). Lower central MPOD has been associated with factors that may increase the risk of AMD, such as female gender [4, 7, 20, 21, 28, 29] and smoking.[5, 28] The relationship between spatial profiles and ethnicities including

337 covariates such as gender and smoking status were difficult to establish in the
338 present study due to the small sample size of each subgroup. Nonetheless, we did
339 not find a gender association with MPOD, with central MPOD values of 0.55 ± 0.19
340 for the females compared to 0.50 ± 0.16 for the males (P = 0.22).

341 When the groups were analysed by ethnicity, a similar trend was found for
342 both Asian and White participants. Previous studies of Asian subjects with a similar
343 age range to our study have reported that males have higher mean MPOD than
344 females.[18, 26] One study found this to be statistically significant.[18] The difference
345 between MPODav(0-1.8) in non-smokers (0.33 ± 0.09) compared to smokers (0.27 ±
346 0.11) did not reach statistical significance (P = 0.15). We note that the lack of a
347 difference may be due to the small sample of smoking subjects (8 out of 73 subjects)
348 and the short smoking history.

349 Our data suggests that atypical profiles (i.e. ring and central dip) occur more
350 frequently in Asian compared to White subjects (P = 0.009). The average integrated
351 MPOD up to 1.8° was significantly increased in Asian subjects presenting with
352 atypical (0.38 ± 0.08) versus exponential profiles (0.29 ± 0.10; t(52) = -3.86; P <
353 0.0005). In White subjects, this finding was not significant (0.30 ± 0.07 and 0.26 ±
354 0.10 respectively; t(17) = -0.85; P = 0.41). Therefore, it seems that an atypical spatial
355 profile is a representative characteristic of the Asian group, and indeed may be
356 considered ‘’typical’’ in this ethnic group. Since there was no significant difference
357 between central MPOD in Asian (t(35) = -0.71; P = 0.48) or in White subjects
358 presenting with an atypical profile compared to an exponential profile (t(17) = 0.26; P
359 = 0.80), our results suggest that, compared to an individual MPOD measurement at
360 a single retinal spatial location or an average of MPOD measurements at several
361 retinal spatial locations, MPODav(0-1.8) provides a better representation of the

amount of MP present. Although some of the subjects show a sizable decrease in MPOD at the fovea, many others do not. In spite of large variability in MPOD caused by averaging MPOD over the area of the stimulus and the variability in fixation accuracy during the HFP test, the results using a small central target (i.e. 0.36° diameter) suggest that a ring-like profile is possible. However, the main conclusion of the study based on the measured differences in short wavelength transmittance over the centre 3.6° has become more significant by analyzing the results in terms of area weighted central transmittance.

This is the first comparative study to investigate MP spatial profiles in Asian and White subjects. Several studies have reported on the different spatial distributions of MP; however there is little consensus on the definition of an atypical profile. Additionally, there are various methodologies used to measure MP density and results are consequently not always interchangeable. The spatial profile of MP is normally described as following an exponential decline, although 20-50% of the population in studies where MP is measured by HFP and objective imaging techniques have shown a deviation from the exponential curve at 0° or at a location away from the central fovea.[10, 15, 16] The lack of spatial resolution in the measurement of central MPOD can be largely attributed to the size of the central target, as well as the subject's ability to maintain steady fixation. In comparison to other HFP techniques, the MAP test aims to minimize this effect by employing a very small central (0.36°) and static peripheral stimuli. A non-exponential spatial profile was found in 21% (4 out of 19) White subjects and 59% (32 out of 54) Asian subjects. Atypical profiles have been previously defined as those not exhibiting a typical exponential profile but showing either a annulus of higher MP or ring, where the central peak is surrounded by a ring of increased density,[15] or a central dip (i.e.

MPOD at 0.25° not visually exceeding MPOD at 0.5°,[13] or MPOD at 0.25° not exceeding MPOD at 0.5° by more than 0.04 optical density units [30]). The presence of a MP ring has been found significantly increased in ethnicities with low AMD prevalence,[17] suggesting it may enhance the MP's protective role. Wolf-Schnurrbusch *et al.* showed significantly increased frequency of a parafoveal ring ($P < 0.0001$) and central MPOD ($P < 0.0001$) in African subjects, when compared to non-Hispanic white subjects.[17] In contrast, since increased prevalence of a central dip was found to be associated with increased age and smoking, it was proposed that a central dip decreased the protective role of MP.[11]

Interestingly, when we considered the atypical spatial profiles in all participants, we found that MPOD values at 0.8° and 1.8° and MPODav(0-1.8) were increased in the profiles showing a ring or central dip, compared to the exponential profile. Table 2 shows that this was statistically significant, with the exception of central MPOD. There was no difference in central MPOD between the exponential, ring and surprisingly, the central dip profile groups. Unexpectedly, the mean MPOD at 1.8° for the group presenting a ring was not significantly different from the exponential group, but was significantly lower than for the central dip group ($P < 0.0005$). These results show that the central dip profile has more MPOD at or close to the location where the MP ring profile shows its additional peak. It seems that a central dip has not 'lost' its peak, but possibly broadened its lateral distribution. We therefore propose that the presence of a central dip profile may actually offer increased integrated MPOD up to 1.8° and therefore increased macular protection from harmful blue light. Moreover, our data suggests that there may be a disparity in the occurrence of MP spatial profiles amongst ethnicities. Not only were atypical spatial profiles more frequently present in Asian subjects ($P = 0.008$), but also the

central dip was entirely absent in White subjects. This implies that there may be need for sub-classification of MP spatial profiles other than typical (i.e. exponential) versus atypical, as previously suggested by Berendschot and van Norren.[10] Additionally, we propose using exponential versus non-exponential profile types, since atypical profiles for some ethnicities may represent typical characteristics for that group.

Considering previous reports of dietary differences between ethnicities,[31, 32] our data supports the hypothesis that the central dip could be the result of a high conversion of lutein to meso-zeaxanthin [33, 34] resulting in an increased MPOD at the 0.8° and 1.8° locations. Additionally, there is supporting evidence that lutein and zeaxanthin supplementation increases MPOD in the human foveal and parafoveal areas.[35-37] The distribution of zeaxanthin (centrally) and lutein (more peripherally) within the macula may suggests that an exponential or atypical ring profile represent a relative enrichment of zeaxanthin, while an atypical central dip profile represents a relative enrichment of lutein. However, Zeimer *et al.* suggested that lutein and zeaxanthin supplementation in AMD and control subjects might amplify, not create, atypical MP spatial profiles.[38] A limitation of our study was that we did not measure lutein and zeaxanthin dietary intake. Neither could we relate these differences in spatial profiles to the iris colour, or family history of AMD, since we did not collect this data. While not controlled for in our study, iris colour and dietary intake of carotenoids may be the largest source of variation between our two groups. Nonetheless, our results have shown an uneven distribution of MP spatial profile types between White and Asian subjects, which confirms the need for wider scale studies including other ethnic phenotypes, iris colour, and dietary intake of carotenoids.

Conclusions

This is the first study to investigate the prevalence of different MP spatial distributions for Asian and White subjects. Our results show that central MPOD was significantly increased in our 54 Asian subjects, compared to 19 White subjects of similar age. We classified spatial distributions of macular pigment into typical exponential and atypical (non-exponential) profiles. Atypical profiles were significantly more prevalent in Asian compared to White subjects. Additionally, we noted that ring and central dip spatial profiles varied between the ethnicities, whereby the prevalence of central dip was significantly increased in Asian group. Additionally, integrated MPOD up to 1.8° was significantly increased in a central dip compared to an exponential profile. This suggests that, similar to a MP ring, a central dip represents enhanced retinal protection from harmful blue light.

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