

Assessing spatial perception in aging using an adapted Landolt-C technique

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This study investigated luminance and texture-defined spatial information processing in normal aging using an adapted Landolt-C technique. Sensitivity to C-target stimuli (optotypes) was measured for four age groups: 18–34, 35–49, 50–64, and 65+ years. Participants indicated optotype gap-opening orientations (up, down, left, or right) at different levels of luminance or texture contrast. Although sensitivity did not differ across age group for the luminance-defined optotypes, sensitivity for texture-defined optotypes for the 65+ years age group was significantly decreased relative to that of the youngest group (18–34 years). Results suggest that age-related changes in visual function can be dissociated at different levels of processing, and may be better defined using stimuli that necessarily depend on higher levels of neural functioning

Introduction

Many human visual abilities decrease with nonpathological aging, reflected by decreased sensitivity to a variety of visually presented items and stimuli [1,2]. Clinically, such abilities are most often defined by performance on various types of acuity and contrast sensitivity charts that (i) present letters or visual stimuli of varying sizes displayed at maximum luminance contrast (Snellen and Landolt-C acuity charts) or (ii) measure an observer's ability to detect same-sized items at variable luminance contrast (Pelli–Robson and Vistech Contrast Sensitivity Charts [3,4]). This type of assessment targets the integrity of ocular and/or low-level neural mechanisms that process spatial information through linear or standard processing mediated by spatial frequency channels selectively sensitive to a range of luminance-defined or first-order information [5,6].

It is generally well accepted that the integrity of both optical and neural circuits involved in visual functioning are progressively compromised with age [1,2,7,8]. Evidence suggests that age-related declines in visual information processing cannot be solely accounted for changes in the optical characteristics of the eye [1,9]. We, therefore, suggest that to dissociate the relative optical and neural contributions of age-related visual functioning, it is necessary to assess sensitivity to stimuli that access and isolate different levels of visual analysis.

One way in which this can be accomplished is by measuring sensitivity in both luminance and texture-defined static targets. Unlike the former, texture-defined (or second order) information is defined by variations in

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stimulus attributes other than luminance, such as texture or disparity [10,11]. The perception of texture-defined information is of theoretical interest in that standard, linear mechanisms operating within the primary visual cortex are in effect 'blind' to this class of information; additional nonlinear neural processing is required before it can be extracted by standard mechanisms [12].

This study assessed the different levels of processing during nonpathological aging by measuring the ability of participants to indicate the gap-opening orientation of Landolt-C optotypes defined by either luminance (first order) or texture contrast (second order). As optical changes affect the processing of luminance-defined and texture-defined optotypes equally, it can be argued that a selective decrease in the texture-defined condition would be the result of age-related changes specific to high level neural processing occurring beyond the primary visual cortex.

Methods

Participants

All participants were recruited through the Clinique Universitaire de la Vision of the Université de Montréal. A total of 40 participants with normal or corrected-to-normal vision were placed into four age groups ($n = 10$ for all groups): 18–34 years (mean: 25.51 ± 3.44 years), 35–49 years (mean: 39.86 ± 3.93 years), 50–64 years (mean: 55.16 ± 4.43 years), and 65+ years (mean: 70.25 ± 1.7 years). A trained optometrist performed complete ocular health examinations on all participants above the age of 50 years to ensure that no ocular pathologies, especially cataracts, were present at the time

of testing. All participants had completed their secondary education, were in good overall health, highly autonomous, and frequented our laboratory independently on a regular basis. None of the participants reported any neurological impairment or cognitive difficulty at the time of this study. Each testing session lasted for approximately 45 min. The study was explained to each participant before commencement, and all participants gave their written consent. Ethics approval was granted from the Universite de Montreal ethics committee.

Stimuli

Stimulus generation, presentation and data collection were controlled by an IBM compatible computer with a 10-bit Matrox Parhelia 512 graphic card using a custom C++ graphics program. Stimuli were presented on an 18-inch Viewsonic E90FB 0.25 CRT monitor (1280 × 1024 pixels), refreshed at a rate of 75 Hz. The luminance of the monitor was γ -corrected to minimize the nonlinearities in the display by using a color look-up table using a Minolta Chromameter (Konica Minolta Sensing Inc., Ramsey, New Jersey, USA); γ correction was re-assessed at regular intervals during testing. The mean luminance of the display was then set to 26.0 cd/m² ($u' = 0.1942$, $v' = 0.4370$ in Commission Internationale de l'Eclairage $u' v'$ color space) where L_{\min} and L_{\max} were 0.10 and 52.60 cd/m², respectively.

For both the luminance and texture-defined conditions, a square display area subtending 8.6° served as a surround and was centered on the screen (Fig. 1). The surround was filled with a noise pattern consisting of dots (1 pixel × 1 pixel, measuring approximately 2 arc min) with their individual luminance randomly assigned a luminance value between 0.10 and 52.60 cd/m². The average luminance ($L_{\text{surround}} = 26.0$ cd/m²) and contrast (C_{surround} set at 50% – or 0.5 – its maximal value) of the

noise in the surround was kept constant for all conditions. Luminance and texture-defined Landolt-C stimuli were presented within this surround area. These optotypes had an outside and inside diameter of 5.0 and 3.0°, respectively.

For the luminance-defined condition, the form of optotype was defined by the difference in average luminance between the noise defining the optotype's form and that of its surrounding background. For the texture-defined condition, the contrast of the noise defining the form of optotype was varied, resulting in a form defined by the difference in contrast of the noise defining its form and that of its background. The average luminance of the form and its background were equal.

Thresholds (performance) in the luminance-defined condition were defined as the minimal luminance difference between the background and the optotype needed to identify the orientation of the gap-opening at threshold, measured by a Weber contrast

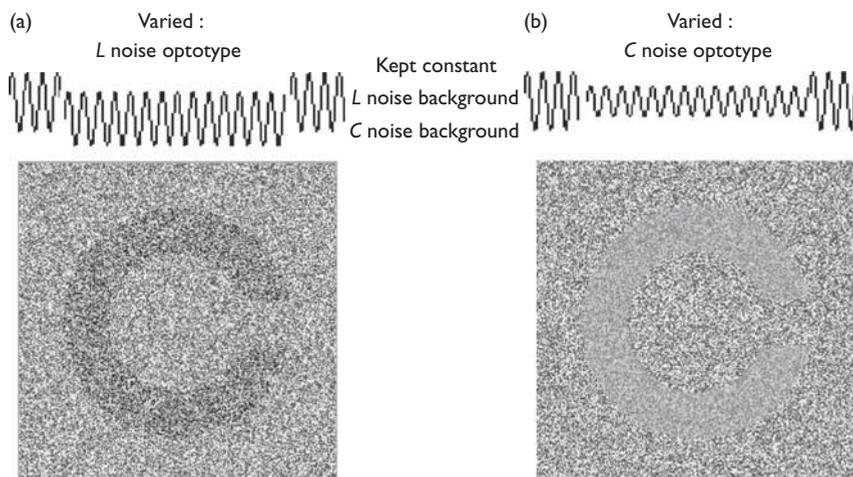
$$C = (L_{\text{background}} - L_{\text{optotype}}) / (L_{\text{background}}),$$

where L_{optotype} and $L_{\text{background}}$ are the average luminance of optotype and background noise, respectively. For the texture-defined condition, thresholds were defined as the minimal difference between the noise contrast of the background and the optotype needed to identify the orientation of the gap-opening at threshold, measured by a Weber contrast

$$C = (L_{\text{background}} - L_{\text{optotype}}) / (L_{\text{background}}),$$

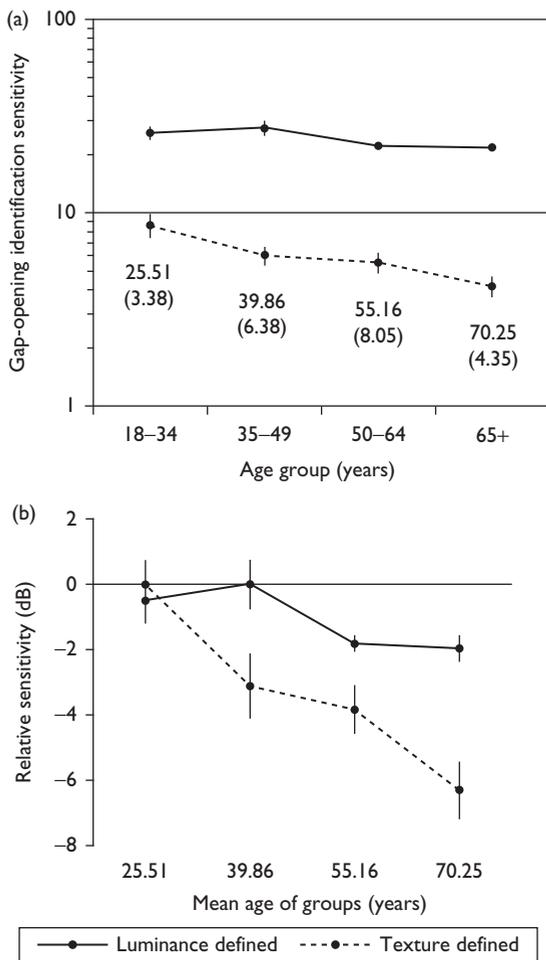
where L_{optotype} and $L_{\text{background}}$ are the average luminance of optotype and background noise, respectively. Seven levels of contrast and texture contrast were used for each gap-opening orientation for both luminance and texture-defined conditions.

Fig. 1



Schematic representation of the C-optotype stimuli defined by luminance (a) and texture contrast (b) that were used in this study.

Fig. 2



(a) Gap-opening orientation identification sensitivity for luminance (solid line) and texture-defined (dotted line) conditions as a function of age group. The vertical error bars represent the standard error of the mean sensitivity and the horizontal error bars (gray) represent ± 1 standard deviation of the age group means. (b) The relative sensitivity (dB) as a function of the mean age of groups assessed for luminance (solid line) and texture-defined (dotted line) optotypes.

Procedure

Testing was conducted individually in a dimly lit laboratory room where they viewed the display binocularly from a distance of 54 cm for all conditions. After completing one practice block, each participant completed two testing blocks: one consisting of luminance-defined optotypes and the other texture-defined optotypes. The gap orientations were presented in either of the orientations (up, down, left, or right). Stimuli were presented 10 times at each gap orientation for each level of modulation, resulting in a total of 280 trials in each condition (four orientations \times seven levels of modulation \times 10 repetitions). Each trial consisted of a 2 s stimulus presentation after which the participants were asked to verbally indicate the orientation of the gap opening. An experimenter, who was present during testing, then

recorded the participant's response by pressing either of the four response arrow keys (up, down, left, or right). Weibull [13] functions were fitted to the responses for each condition (luminance and texture) to compute gap orientation identification threshold at a 62.5% correct level of performance.

Results

Gap-opening orientation identification thresholds for luminance and texture-defined stimuli were expressed in terms of sensitivity for each condition (1/luminance- or texture-defined Weber contrasts). Figure 2a shows the mean gap-opening orientation identification sensitivity for luminance and texture-defined stimuli as a function of mean age of each group assessed. Each bar represents the mean threshold for 10 participants; standard error bars are shown. As the mean differences between luminance and texture-defined conditions are not informative owing to the different attributes defining each condition, gap-opening orientation identification sensitivity for the different age groups were analyzed separately for each condition using separate single-factor between-subject analyses of variance.

Although sensitivity decreased with age for the luminance-defined condition, analysis revealed that the effect of age group on gap-opening orientation sensitivity failed to reach significance [$F(3,36) = 2.7011$, $P = 0.0600$]. However, a significant age group effect was found for the texture-defined condition [$F(3,36) = 5.3853$, $P = 0.0036$]. Pairwise comparisons, with a Bonferroni corrected α level of 0.00833, revealed that compared with the mean of the 18–35-year-old age group, gap-opening orientation sensitivity was significantly decreased for the 65+ -year-old age group ($P = 0.0004$), but not for the 35–50 ($P = 0.0280$) nor the 50–65-year-old ($P = 0.0100$) age groups.

To compare the relative rate with which sensitivity changed as a function of age group for each condition, sensitivity measures were normalized by expressing them in terms of relative sensitivity (dB). By measuring relative sensitivity, the relative rate of performance increase with age was compared across luminance and texture-defined conditions independent of the absolute differences in sensitivity between the conditions. To do so, the sensitivity of each individual was calculated relative to the mean sensitivity of the best group for each condition (luminance or texture), using the following equation:

$$\text{dB} = 20 \times \log_{10} (S_i / S_{\max}),$$

where S_i refers to the sensitivity of each individual and S_{\max} refers to the mean sensitivity of the best age group. A relative sensitivity approaching 0 dB represents sensitivity comparable with the best age group for each optotype condition. A mixed-factorial ANOVA revealed an effect of age [$F(3,36) = 8.179$, $P = 0.0003$] and

condition [$F(1,36) = 24.709$, $P = 0.0001$]. As depicted in Fig. 2b, a significant relative sensitivity \times age. Group interaction effect [$F(3,36) = 3.029$, $P = 0.0418$] suggests that sensitivity to texture and luminance-defined information differs as a function of age.

Discussion

The present study assessed visual sensitivity to luminance and texture-defined static information as a function of age using an adapted Landolt-C technique to evaluate the additive effect of neural processing on nonpathological age-related visual functioning: a factor not usually associated with standard acuity measures. Results indicate that compared with young adults (18–35 years), sensitivity to luminance-defined static information slightly declined across the age groups assessed (from 18–35 to 65+ years), whereas sensitivity to texture-defined information decreased significantly. This result agrees with the earlier data suggesting that behaviorally, a decreased efficiency in complex information processing (i.e. motion) during the normal aging process is only evidenced after a certain age (70 years) [14]. This dissociation supports the notion that there may be a decreased efficiency in neurally based visual functioning during the normal aging process that is not typically revealed by conventional visual acuity assessments. Our results are in agreement with those of a study using a Landolt-C task where the target stimuli were defined from their background by motion contrast alone [15]. With stimuli similar to the texture-defined optotypes used in this study (i.e. defined by cues other than luminance), it was found that dynamic visual acuity initially decreased with age at 40 years, and more steeply at approximately 55 years, particularly for lower motion contrast conditions. In another study, Andersen and Ni [16] showed that older participants (mean age approximately 75 years) were less able to recover two-dimensional shape from kinetic occlusion, interpreted as the result of less efficient spatial (but not temporal) integration capabilities with age. From these studies, it is clear that the ability to resolve optotypes requiring neural analysis beyond standard (or linear) processing, defined by either static (texture-defined form) or dynamic (motion-defined form) second-order attributes, declines at approximately at the age of 50 years.

The resolution of the texture-defined stimuli used in this study necessitated additional nonlinear processing (squaring or rectification) and the involvement of extrastriate visual processing (i.e. area V2/V3) [17–19]. It is therefore argued that the dissociation between relatively intact (luminance defined) and reduced (texture defined) sensitivity to the optotypes as a function of normal aging is contingent on the amount of neural processing involved in the optotype resolution. At a physiological level, it is likely that diffuse neural loss or functional alteration occurring during nonpathological

aging affects high-level visual analysis to a greater extent than low-level information processing [2]. Emerging physiological evidence from animal studies supports this proposition by showing that relative to low-level, striate-mediated mechanisms [20,21], aging preferentially affects the response properties of high-level neural mechanisms operating within extrastriate areas (i.e. V2, MT). Different types of neural changes associated with decreased sensitivity to orientation and motion direction of neurons in primate V1 or V2 neurons have been proposed, resulting in decreased response selectivity, increased spontaneous response to visually presented stimuli and decreased signal-to-noise ratio [22–24]. Such findings suggest the implication of altered cortico–cortico inhibitory connectivity as a plausible origin of decreased low-level perceptual functioning during nonpathological aging: a working hypothesis used to explain atypical age-related performance for both dynamic and spatial information processing [16,25].

Conclusion

Our results show that the adapted Landolt-C paradigm is a behavioral technique sensitive enough to measure age-related differences in visual processing. Specifically, participants aged 65 years and above were selectively less sensitive to C-optotypes defined by texture: a type of visual attribute necessitating additional, extrastriate processing to be resolved. These results are consistent with the suggestion that diffuse neuronal loss or functional neural alteration occurring during normal aging would affect the processing of high-level visual information to a greater extent than that of low-level visual information [2].

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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