DIFFERENCES IN CHROMATIC SENSITIVITY ESTIMATED USING STATIC AND DYNAMIC COLOUR STIMULI

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The current study reports on a novel computerised colour vision test employing static and dynamic stimuli. The aim of the study was to assess if static and dynamic stimuli result in comparable chromatic discrimination thresholds when participant's age is taken into account. Participants (n = 20) were 21 to 77 years old, had normal colour vision and no history of any eye disease. They all participated in two sessions estimating chromatic sensitivity with static and dynamic stimuli, respectively, with six directions in colour space varying either along the red–green (RG) or yellow–blue (YB) directions. We found no significant differences in chromatic thresholds along a tritan axis obtained with static and dynamic stimuli. However, along protan and deitan axes, chromatic thresholds were lower if estimated using static stimuli than those estimated using the dynamic stimuli. As anticipated, chromatic sensitivity decreased with age and with greater chromatic sensitivity loss along the tritan confusion line. Research results suggest that differences between chromatic thresholds measured with static and dynamic stimuli become more apparent with increasing age of study participant.

Key words: *computerised colour vision test, static and dynamic stimuli, psyhophysics.*

INTRODUCTION

Approximately 8% Caucasian males and 0.5% females have some form of congenital colour vision deficiency; the condition is manifested as reduced ability to discriminate chromatic stimuli and, in some cases, achromatic stimuli from chromatic stimuli (Simunovic, 2010). To conduct a qualitative colour vision diagnosis for individuals in various age groups, it is necessary to evaluate appropriate performance of all age groups in colour vision tests. Setting average performance intervals for various age groups in each colour vision test, it is important to exclude observers with diverse conditions, such as diabetes (Muntoni *et al.*, 1982; Wong *et al.*, 2008), diabetic retinopathy (Barton, Fong, and Knatterud, 2004), glaucoma (for these patient's, colour perception inadequate for the age norm can frequently be observed) (Muntoni *et al.*, 1982; Barton, Fong, and Knatterud, 2004; Wong *et al.*, 2008), from further data processing. Previous research has shown that patients with type 2 diabetes demonstrate reduced colour discrimination for blue-yellow stimuli when tested with the Farnsworth-Munsell-100 hue test (FM-100), while the computerized Cambridge Colour Test (CCT) has demonstrated general chromatic sensitivity decrement in type 2 diabetes (Feitosa-Santana *et al.*, 2010).

Several studies have confirmed that chromatic sensitivity changes depend on age (Kinnear and Sahraie, 2002; Paramei and Oakley, 2014), and the highest chromatic sensitivity occurs at age 19–29 years (depending on the study). Typically colour sensitivity increases until 19–26 years of age and gradual impairment of chromatic sensitivity is observed after 26 years of age (Knoblauch *et al.*, 2001; Paramei and Oakley, 2014; Barbur and Rodriguez-Carmona, 2015). Differences in chromatic sensitivity might be attributed to lack of maturity of the visual system in children and adolescents, and chromatic discrimination depends on the test design and nonverbal IQ (Kinnear and Sahraie, 2002; Cranwell *et al.*, 2015).

As age increases, not only does the ability to discriminate colours in the blue-yellow axis decrease (which is explained by increased visible spectrum short wavelength absorption in the intraocular lens), but all visible spectrum transmission is reduced due to increase of intraocular lens thickness (Pokorny *et al.*, 1987; Weale, 1988). It is important to emphasise that commercially available computerised colour vision test stimuli have dissimilar characteristics. For example, the CCT is based on static pseudoisochromatic plate stimuli principles, while the Colour Assessment and Diagnosis (CAD) test (Rodriguez-Carmona *et al.*, 2005) is composed of dynamic stimuli moving across an achromatic background. When assessing changes in chromatic sensitivity due to aging, using different computerised stimuli, one cannot draw valid conclusions about the effect of stimulus

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temporal characteristics on chromatic sensitivity due to significant variations in stimulus design.

The aim of our study was to assess whether static and dynamic stimuli result in comparable chromatic discrimination thresholds when participant's age is taken into account. The option to include a dynamic component is foreseen without significantly changing overall test stimuli structure. Using our test stimuli, it is possible to directly evaluate the effect of the dynamic component on chromatic sensitivity.

MATERIALS AND METHODS

Participants. Twenty subjects with mean age 44 ± 4 years participated in the study, thirteen females and seven males. All participants had normal or corrected-to-normal visual acuity. Before computerised colour vision testing, colour vision of all participant was assessed with 4th edition Richmond HRR pseudoisochromatic test plates (2012) and in eleven cases with an Oculus HMC anomaloscope (type 47720). History of ophthalmic diseases was collected for all participants, with special emphasis on retinal pathologies, glaucoma, cataracts, general illness like diabetes and neurological diseases. None of the participants were excluded on the basis of systemic or ocular diseases. The study was conducted in accordance with the guidelines of the Commission of Ethics of University of Latvia.

Materials. Each participant's chromatic sensitivity was assessed in two experimental sessions with dynamic and static stimuli. Chromatic stimuli were chosen to lie on confusion lines in CIE xyY colour space containing an achromatic point and corresponding confocal point (Birch, 1993). Measurements were made in 6 directions in colour space (from achromatic point along two directions of the protan, deutan, and tritan confusion lines). Chromatic stimuli were chosen for the closest possible match with theoretical confusion lines (see Equation 1 and Fig. 1). In Equation 1, s stands for point (xp, yp) distance to a confusion line, xp, yp – colour coordinates of the stimuli in CIE xyY colour space, k – confusion line slope, and b – confusion line intersection with Oy axis. For this study stimuli were chosen so that s ≤ 0.001 units in CIE xyY colour space.

$$s = \frac{|y_p - b - x_p k|}{\sqrt{k^2 + 1}}$$ Equation 1

Stimuli were presented on a Dell U2312 HM monitor calibrated with an Ocean Optics USB4000 spectrometer and Minolta CS-100A chroma meter. The test field was elliptically shaped with 9.1 × 8.9 degree of visual angle at 1 meter testing distance from the screen. The test field was composed of equilateral triangles alternately situated in 26 rows where each row was composed of up to 47 triangles. The chromatic stimulus was a hexagon and occupied a 2 degree of visual angle (Fig. 2). In the dynamic version, the chromatic stimuli travelled across the test field in one of four possible directions — up, down, right, or left. Demonstration of the dynamic stimuli occurred in 12 frames (frame re-
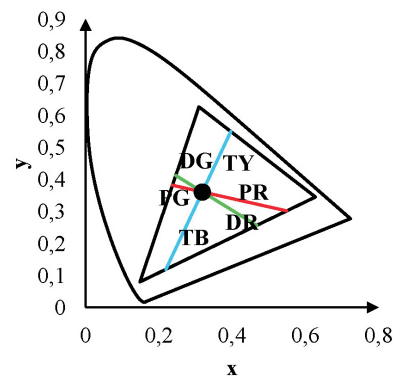

Fig. 1. CIExy diagram with colour direction codes along protan, deitan and tritan confusion lines, i.e. protan red (PR), protan green (PG), deitan green (DG), deitan red (DR), tritan blue (TB), tritan yellow (TY). Area limited by triangle represents the available monitor colour gamut. Monitor red (R) component colour coordinates (0.6305, 0.3329), green (0.3166, 0.6315) and blue (B) (0.1432, 0.0679). Monitor white point (black point in diagram) where chosen with coordinates (0.3188, 0.36). Confusion lines were selected to include corresponding confusion points protan (0.75, 0.25), deitan (1.4, -0.4), tritan (0, 0.17) and monitor white point.
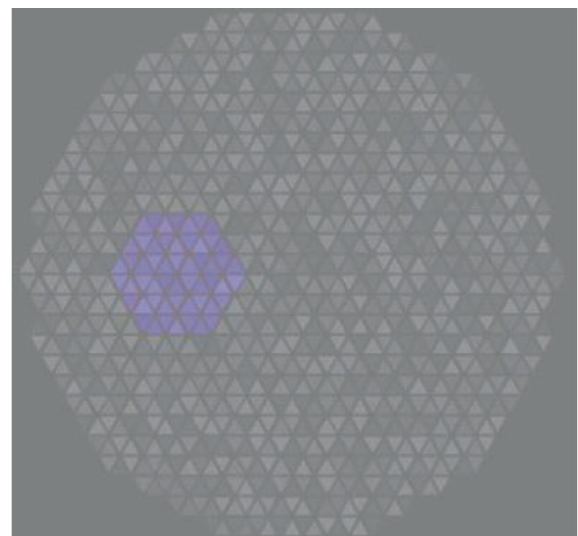

Fig. 2. Computerised test stimulus in the static version.

placement occurred each 100 ms). In the static version, the identical hexagon stimulus was presented in four possible locations in relation to test field centre: top, bottom, right, or left. For individuals aged up to 69 years, stimuli were presented for 1000 ms; for 70+ years old individuals, stimuli presentation duration was increased by 500 ms. Participants were requested to respond about the movement direction of the dynamic stimulus or location of the static stimulus by pressing a corresponding button within 3 seconds after stimulus disappearance.

For achromatic and chromatic triangle elements composing the test field and stimuli, we chose five luminance levels: 12, 14, 16, 18, and 20 cd/m^2. The number of elements was held equal at all times at a given moment on the screen with certain luminance values, also for most elements in each subsequent frame. Luminance values were replaced leaving stimulus chromaticity as the only characteristic enabling stimulus discrimination in the dynamic stimuli version.

Two psyhophysical methods (adaptive staircase and method of constant stimuli) were used to determine individual chromatic discrimination thresholds in six directions in colour space. The adaptive staircase procedure, 3 up 1 down modification (Levitt, 1971), was applied to measure approximate chromatic thresholds. In order to increase accuracy, the method of constant stimuli was applied. To determine the psychometric function, the probabilities of detecting chromatic stimuli of seven different saturation levels were ascertained. One of the chromatic stimuli saturation levels was chosen equivalent to the chromatic threshold value determined with the adaptive method and two stimuli saturation levels were chosen with detection probabilities 25% and 90%. The remaining four saturation levels were equally spaced between the saturation level, which according to the adaptive method results corresponded to the chromatic threshold and stimuli with saturations levels that corresponded to 25% and 90% detection probability (Fig. 3). Data were approximated using the Boltzmann sigmoidal model, where the threshold value was estimated at probability 62.5% of correct responses.

To assess measurement repeatability, we compared corresponding chromatic sensitivity thresholds obtained in two experimental sessions. In the case of static stimuli, there was no difference between data obtained in two sessions, with one exception in the TY direction, while in case of dynamic stimuli we did not observe any difference between test results in both sessions (Table 1).

All statistical analysis was carried out by different variants of t-tests. The paired t-test was used to assess differences in chromatic thresholds between experimental sessions and chromatic thresholds obtained with static and dynamic stimuli within both groups. To compare chromatic thresholds between both groups, the independent two sample t-test was used. Relationship between chromatic thresholds measured with static and dynamic stimuli were tested by linear regression coefficients. To confirm correlation between chromatic thresholds measured with static and dynamic stimuli, the t-test was used to determine linear regression slope confidence intervals. Effect of the dynamic component on chromatic thresholds was assessed by analysing linear regression slope and intercept with the t-test. In cases when the
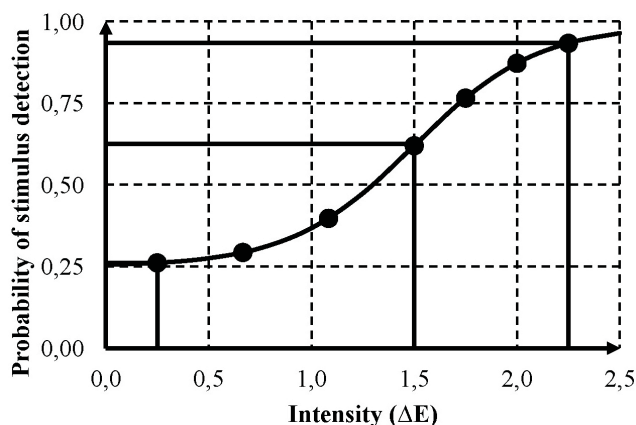
STATISTICAL ANALYSIS OF CHROMATIC THRESHOLD MEASUREMENT REPEATABILITY WITH STATIC AND DYNAMIC TEST STIMULI BETWEEN TWO SESSIONS*

Colour direction	Static stimuli	Dynamic stimuli
PG	$t = -1.18 > t_{0.05;19} = -2.09$	$t = 0.73 < t_{0.05;19} = -2.09$
PR	$t = -0.25 > t_{0.05;19} = -2.09$	$t = -1.25 > t_{0.05;19} = -2.09$
DG	$t = 0.82 < t_{0.05;19} = -2.09$	$t = 1.08 < t_{0.05;19} = -2.09$
DR	$t = 0.75 < t_{0.05;19} = -2.09$	$t = 0.98 < t_{0.05;19} = -2.09$
TY	$t = -2.48 < t_{0.05;19} = -2.09$	$t = -0.08 > t_{0.05;19} = -2.09$
TB	$t = -0.78 > t_{0.05;19} = -2.09$	$t = 0.13 < t_{0.05;19} = -2.09$

* Significant differences in chromatic thresholds were found only in tritan yellow direction with static stimuli.

linear regression slope did not significantly differ from unity and intercept from zero, it was assumed that there was a direct linear relationship between chromatic thresholds measured with static and dynamic stimuli. In cases when the linear regression slope was significantly less than unity and intercept greater than zero, a direct linear relationship was rejected.

RESULTS

Chromatic sensitivity changes before and after age 40. Participants in the study were divided into two groups depending on their age: participants under age of 40 years (n = 8, 26 ± 2 years) and participants older than 40 years (n = 12, 54 ± 3 years). There were no significant differences in chromatic sensitivity thresholds measured with static and dynamic stimuli among participants under age 40 years, except for deitan green direction in colour space, while significant differences were found in the elderly patient group in colour directions protan red, deitan green, tritan yellow and blue (Table 2).

Statistical analysis showed that chromatic thresholds obtained with static stimuli differed between age groups for deitan and tritan confusion lines, and chromatic thresholds

COMPARISONS BETWEEN CHROMATIC THRESHOLDS OBTAINED WITH DYNAMIC AND STATIC COMPUTERISED STIMULI*

Colour direction	Age (())	Age (40)
PG	$t = 0.69 < t_{0.05;8} = 2.36$	$t = -1.50 > t_{0.05;11} = -2.20$
PR	$t = -2.35 > t_{0.05;8} = -2.36$	$t = -1.59 > t_{0.05;11} = -2.20$
DG	$t = -3.10 < t_{0.05;8} = -3.10$	$t = -4.05 < t_{0.05;11} = -2.20$
DR	$t = -1.79 > t_{0.05;8} = -2.36$	$t = -3.51 < t_{0.05;11} = -2.20$
TY	$t = -0.11 > t_{0.05;8} = -2.36$	$t = -3.01 < t_{0.05;11} = -2.20$
TB	$t = -2.09 > t_{0.05;8} = -2.36$	$t = -2.69 < t_{0.05;11} = -2.20$

* Chromatic thresholds in the younger group differed only in the deitan green colour direction whereas in the elderly group chromatic thresholds differed in all colour directions except deitan red and protan green.

Fig. 3. Theoretical psychometric function.

COMPARISON BETWEEN YOUNGER AND ELDERLY PARTICI-
PANT GROUP THRESHOLDS OBTAINED WITH STATIC AND DY-
NAMIC TEST STIMULI*

Colour direction	Static stimuli	Dynamic stimuli
PG	$t = 3.34 > t_{0.05;18} = 2.10$	$t = 3.22 > t_{0.05;18} = 2.1$
PR	$t = 4.05 > t_{0.05;18} = 2.10$	$t = 3.34 > t_{0.05;17} = 2.1$
DG	$t = 1.22 < t_{0.05;17} = 2.11$	$t = 2.88 > t_{0.05;17} = 2.11$
DR	$t = 1.10 < t_{0.05;16} = 2.12$	$t = 2.81 > t_{0.05;16} = 2.12$
TY	$t = 3.22 > t_{0.05;12} = 2.18$	$t = 3.58 > t_{0.05;12} = 2.18$
TB	$t = 2.31 > t_{0.05;12} = 2.18$	$t = 2.56 > t_{0.05;12} = 2.18$

* Statistical analysis showed significant differences in chromatic thresholds
between both age groups in deutan and tritan colour directions with static
stimuli, and in all studied colour directions with dynamic test stimuli.

obtained with dynamic stimuli differed between age groups
for all researched confusion lines (Table 3).

When chromatic thresholds of both age groups were com-
pared, reduction in chromatic sensitivity was found with
both test stimuli. However, differences in chromatic thresh-
olds between both age groups were more prominent with
dynamic test stimuli. In the elderly participant group, static
and dynamic stimuli resulted in significant differences in
chromatic sensitivity, which was not the case for the youn-
ger group. It seems that differences between chromatic
thresholds obtained with static and dynamic stimuli become
more prominent with increasing age, which suggests that
mechanisms responsible for detection of static and dynamic
stimuli degrade with different rate.

**Differences between static and dynamic stimuli chro-
matic thresholds.** In computerised colour vision testing,
two quite distinctive and different colour vision tests are
used — CAD and CCT. The key differences between both
test stimuli designs are presence of dynamic noise and chro-
matic stimuli motion. To compare whenever chromatic
thresholds depend on stimuli design, a novel computerised
colour vision test design was introduced. Linear regression
functions describing the relationship between dynamic and
static thresholds were calculated to test for differences in
thresholds obtained with the test stimuli. Linear regression
functions showed moderate to high correlation between
chromatic thresholds obtained with static and dynamic test
stimuli (Fig. 4). Regression functions for protan and deitan
deviated from a direct linear relationship; chromatic thresh-
olds obtained with dynamic stimuli were higher than chro-
matic thresholds obtained with static stimuli (Table 4). The
regression function for tritan blue colour direction indicated
a direct linear relationship between chromatic thresholds
obtained with the computerised stimuli. Tritan yellow re-
gression function slightly differ from a direct linear rela-
tionship, i.e. the regression model slope was significantly
higher than unity, which implied that chromatic thresholds
measured with static stimuli are lower than chromatic
thresholds measured with dynamic stimuli. The results
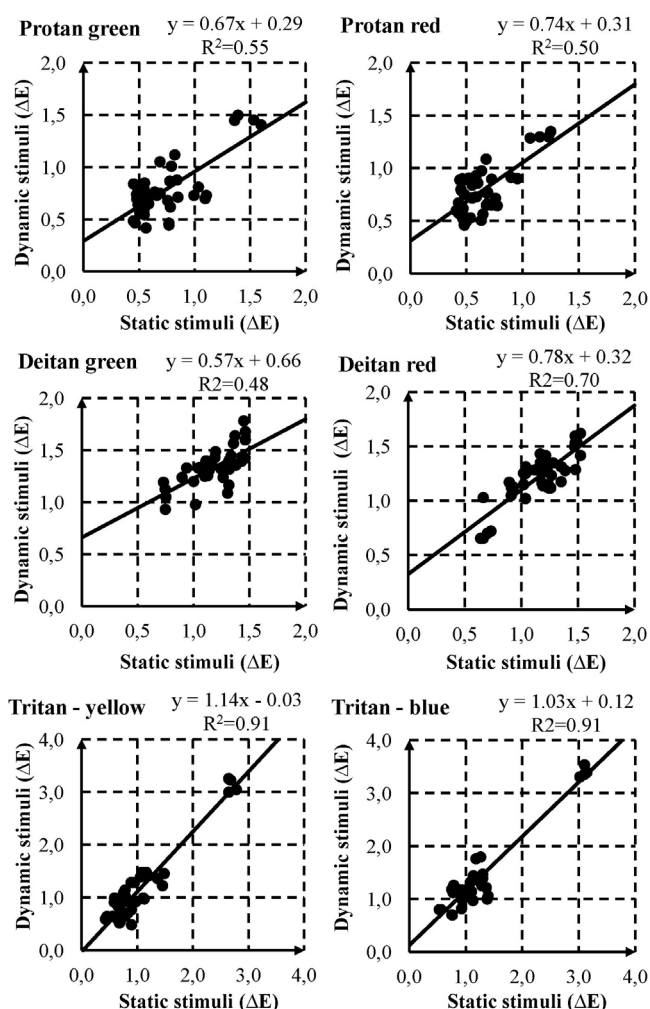showed that the dynamic component had a measurable in-

Fig. 4. Regression analyses chromatic discrimination thresholds obtained
with dynamic and static stimuli.

fluence on colour perception mechanisms responsible for
stimulus perception along protan and deitan confusion lines,
whereas effect of the dynamic component on tritan stimuli
perception was significantly less.

Deviation in a direct linear relationship between chromatic
thresholds for protan and deitan measured with static and
dynamic stimuli cannot be explained by performance differ-
ences between both age groups, since linear regression
functions for tritan colour directions did not deviate from a
direct linear relationship. It can be speculated that the YB
mechanism is less susceptible to test stimuli dynamic prop-
erties than RG mechanisms, as tritan stimuli were chosen
along a confusion line with slope 67.54 degrees, which cor-
responds to the YB mechanism and yields zero L and M
cone contrast.

**Anomaloscope and computerized colour test result com-
parison.** Colour vision was evaluated for eleven of twenty
participants with anomaloscope and computerised colour vi-
sion tests. Significant correlations were not found between
the anomaloscope matching range and chromatic thresholds
obtained with the computerised colour vision test, confirm-
ing the poor correlations obtained in previous studies

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STATISTICAL ANALYSIS OF LINEAR REGRESSION MODEL CO-
EFFICIENTS

Colour direction	Variables	Coefficient	SE	95% CI	p
PG	slope	0.74	0.01	0.50 to 0.98	< 0.05
	intercept	0.31	0.08	0.15 to 0.48	< 0.05
PR	slope	0.67	0.10	0.47 to 0.86	< 0.05
	intercept	0.29	0.08	0.13 to 0.45	< 0.05
DG	slope	0.78	0.08	0.61 to 0.94	< 0.05
	intercept	0.32	0.10	0.13 to 0.52	< 0.05
DR	slope	0.57	0.10	0.37 to 0.76	< 0.05
	intercept	0.66	0.12	0.43 to 0.90	< 0.05
TY	slope	1.14	0.06	1.02 to 1.26	< 0.05
	intercept	-0.03	0.07	–0.18 to 0.12	ns
TB	slope	1.01	0.08	0.84 to 1.19	< 0.05
	intercept	0.14	0.11	–0.09 to 0.37	ns

Linear regression models describe relationship between chromatic thresh-
old values obtained with static and dynamic test stimuli. Linear regression
models for protan and deitan colour directions deviate from a direct linear
relationship which implies that chromatic thresholds measured with dy-
namic stimuli are higher than chromatic thresholds measured with static
stimuli. The regression model for the tritan blue colour direction confirms
direct linear relationship, confirmed by slope equal to unity and intercept
zero. The regression model obtained for the tritan yellow colour direction
slightly differed from a linear regression model implying that chromatic
thresholds measured with static stimuli are higher than when measured
with dynamic stimuli. ns – not statistically significant.

(Barbur *et al*., 2008). Linear regression functions between
chromatic thresholds measured with computerised stimuli
and the anomaloscope matching range indicated that slope
did not significantly differ from 0, thereby confirming lack
of correlation between anomaloscope matching range and
chromatic thresholds measured along protan and deitan con-
fusion lines (Table 5).

DISCUSSION

In colour vision experiments, patients with normal colour
vision are often perceived as a homogeneous group. How-
ever, there is abundant evidence that individuals with nor-
mal colour vision have considerable variability in estimated
scores (Baraas, 2008; Rodriguez-Carmona *et al*., 2008). It is
well known that women with trichromatic colour vision
may have more than two spectrally different photopigments
in the middle and long ranges of the visible light spectrum
(Jordan and Mollon, 1993; Sun and Shevell, 2008). It is also
known that there are at least two L and M photopigment
versions among men and women (Neitz and Jacobs, 1990;
Neitz *et al*., 1993). Photopigments have not only different
absorption spectra but also optical density (Elsner *et al*.,
1993; Renner *et al*., 2004) and relative quantities of L and
M pigments in the retina, which may affect colour percep-
tion (Miyahara *et al*., 1996; Bieber *et al*., 1998; Kremers *et
al*., 2000). Colour vision test results might be affected by
the above mentioned factors, and also by preretinal absorp-
tion properties, particularly by intraocular lens absorption.

CORRELATION ANALYSIS BETWEEN CHROMATIC THRESH-
OLDS MEASURED WITH COMPUTERISED TEST STIMULI AND
THE ANOMALSCOPE MATCHING RANGE*

Colour direction	Static stimuli	Dynamic stimuli
PZ	$t = 0.37 < t_{0.05;10} = 2.26$	$t = 0.93 < t_{0.05;10} = 2.26$
PR	$t = 0.59 < t_{0.05;10} = 2.26$	$t = 1.15 < t_{0.05;10} = 2.26$
DG	$t = 0.01 < t_{0.05;10} = 2.26$	$t = 0.06 < t_{0.05;10} = 2.26$
DR	$t = 0.53 < t_{0.05;10} = 2.26$	$t = 0.25 < t_{0.05;10} = 2.26$

* Correlation analysis suggests that there is no correlation between
anomaloscope matching rage and chromatic thresholds measured with
computerised test stimuli.

To successfully evaluate chromatic sensitivity changes with
age or during illness, which may affect colour vision, it is
necessary to use a reliable method with high measurement
repeatability. In order to use our computerised colour test as
a diagnostic method, it is necessary to carry out additional
experiments with a larger participant group in various age
intervals (with and without colour vision deficiency), as
well as with persons who have systemic or ocular diseases
that affect colour vision.

In spite of the shortcomings, we were able to demonstrate
decrease in chromatic sensitivity with age along protan,
deitan and tritan confusion lines and differences between
hromatic thresholds measured with static and dynamic
stimuli. No significant differences were found in the youn-
ger participant group in chromatic thresholds obtained with
static and dynamic stimuli in most colour directions, which
was in agreement with other studies (Barbur, 2004). Differ-
ences in chromatic sensitivity thresholds measured with
static test stimuli were observed between the age groups in
four of six colour directions. This was expected, as chro-
matic sensitivity has been shown to decrease with age
(Paramei, 2012; Paramei and Oakley, 2014). Similarly, for
dynamic stimuli, the elderly participant group showed
higher chromatic thresholds for the studied colour direc-
tions, as found in other studies (Barbur and Rodriguez-
Carmona, 2015). However, in the elderly participant group,
chromatic thresholds obtained with static and dynamic stim-
uli significantly differed for all studied colour directions;
chromatic thresholds measured with dynamic test stimuli
were significantly higher. The above indicates that the esti-
mated chromatic sensitivity decline differs depending on
whether chromatic thresholds are measured with dynamic or
static stimuli. The results suggest that motion perception
mechanisms responsible for coloured stimuli movement
perception decreases faster than sensitivity of mechanisms
necessary for static coloured stimuli perception. It has been
suggested that chromatic thresholds obtained with dynamic
stimuli may be higher than chromatic thresholds measured
with static stimuli due to additional noise in nervous path-
ways introduced by a flickering background (Regan *et al*.,
1994).

To explore differences in dynamic properties along protan, deitan, and tritan confusion lines, we compared dynamic and static chromatic thresholds. Our results suggest that the stimulus dynamic component does not have a significant effect on chromatic thresholds when measured along tritan colour directions. Linear regression functions were derived to describe relationships between chromatic thresholds measured with static and dynamic stimuli for several colour directions. The linear regression coefficients for protan and deitan suggested lack of a direct linear relationship, as linear regression slopes were significantly less than unity and intercepts significantly differed from zero. The obtained results might be explained by increased chromatic thresholds among elderly participants, i.e. elderly participants show significant differences between static and dynamic test results. However, in tritan colour directions, the linear regression intercepts did not significantly differ from zero and the slopes were equal or larger than unity. This contradicted the expected results, but might be explained by reduced dynamic properties of the blue-yellow mechanism compared to the red-green colour opponent mechanism (Gegenfurtner and Hawken, 1995). However, to raise general conclusions on the effect of the dynamic component on the blue-yellow colour mechanism, it is necessary to determine if the described effect occurs different dynamic stimulus settings.

The results of our study suggest that chromatic thresholds along tritan confusion lines are less affected by the dynamic component than chromatic thresholds obtained along protan and deitan confusion lines. This was unexpected, as mechanisms responsible for tritan stimuli perception are considered inferior to mechanisms for protan and deutan stimuli perception. The estimated chromatic thresholds within and between both age groups suggest that the decrease in chromatic sensitivity due to aging is more prominent when chromatic sensitivity is assessed with dynamic stimuli. However, additional studies with more participants and stimuli settings are needed to confirm the obtained results.

REFERENCES

Baraas, R. C. (2008). Poorer color discrimination by females when tested with pseudoisochromatic plates containing vanishing designs on neutral backgrounds. *Vis. Neurosci.*, **25** (3), 501–505.

Barbur, J. L. (2004). 'Double-blindsight' revealed through the processing of color and luminance contrast defined motion signals. *Progr. Brain Res.*, **144**, 243–259.

Barbur, J. L., Rodriguez-Carmona, M. (2015). Color vision changes in normal aging. In: Elliott, A. J. Fairchild, M. D., Franklin, A. (eds.). *Handbook of Color Psychology*. Cambridge University Press, UK, pp. 180–196.

Barbur, J. L., Rodriguez-Carmona, M., Harlow, J. A., Mancuso, K., Neitz, J., Neitz, M. (2008). A study of unusual Rayleigh matches in deutan deficiency. *Vis. Neurosci.*, **25** (3), 507–516.

Barton, F. B., Fong, D. S., Knatterud, G. L. (2004). Classification of Farnsworth-Munsell 100-hue test results in the early treatment diabetic retinopathy study. *Amer. J. Ophthalmol.*, **138** (1), 119–124.

Bieber, M. L., Kraft, J. M., Werner, J. S. (1998). Effects of known variations in photopigments on L/M cone ratios estimated from luminous efficiency functions. *Vis. Res.*, **38** (13), 1961–1966.

Birch, J. (1993). *Diagnosis of Defective Color Vision*. Oxford University Press, New York. 187 pp. (at p. 37).

Cranwell, M. B, Pearce, B., Loveridge, C., Hurlbert, A. C. (2015). Performance on the Farnsworth-Munsell 100-Hue Test is significantly related to nonverbal IQ. *Investig. Ophthalmol. Vis. Sci.*, **56** (5), 3171–3178.

Elsner, A. E., Burns, S. A., Webb, R. H. (1993). Mapping cone photopigment optical density. *J. Opt. Soc. Amer. A*, **10** (1), 52–58.

Feitosa-Santana, C., Paramei, G. V., Nishi, M., Gualtieri, M., Costa, M. F., Ventura, D. F. (2010). Color vision impairment in type 2 diabetes assessed by the D-15d test and the Cambridge Colour Test. *Opthalm. Physiol. Opt.*, **30** (5), 717–723.

Gegenfurtner, K. R., Hawken, M. J. (1995). Temporal and chromatic properties of motion mechanisms. *Vis. Res.*, **35** (11), 1547–1563.

Jordan, G., Mollon, J. D. (1993). A study of women heterozygous for colour deficiencies. *Vis. Res.*, **33** (11), 1495–1508.

Kinnear, P. R., Sahraie, A. (2002). New Farnsworth-Munsell 100 hue test norms of normal observers for each year of age 5–22 and for age decades 30–70. *Brit. J. Ophthalmol.*, **86** (12), 1408–1411.

Knoblauch, K., Vital-Durand, F., Barbur, J. L. (2001). Variation of chromatic sensitivity across the life span. *Vis. Res.*, **41** (1), 23–36.

Kremers, J., Scholl, H. P. N., Knau, H., Berendschot, T. T. J. M., Usui, T., Sharpe, L. T. (2000). L/M cone ratios in human trichromats assessed by psychophysics, electroretinography, and retinal densitometry. *J. Opt. Soc. Amer. A*, **17** (3), 517–526.

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *J. Acoust. Soc. Amer.*, **49** (2), 467–477.

Miyahara, E., Pokorny, J., Smith, V. C., Baron, R., Baron, E. (1996). Color vision in two observers with highly biased LWS/MWS cone ratios. *Vis. Res.*, **38** (4), 601–612.

Muntoni, S., Serra, A., Mascia, C., Songini, M. (1982). Dyschromatopsia in diabetes mellitus and its relation to metabolic control. *Diabetes Care*, **5** (4), 375–378.

Neitz, J., Jacobs, G. H. (1990). Polymorphism in normal human color vision and its mechanism. *Vis. Res.*, **30** (4), 621–636.

Neitz, J., Neitz, M., Jacobs, G. H. (1993). More than three different cone pigments among people with normal color vision. *Vis. Res.*, **33** (1), 117–122.

Paramei, G. V. (2012). Color discrimination across four life decades assessed by the Cambridge Colour Test. *Opt. Soc. Amer.*, **29** (2), A290–A297.

Paramei, G. V., Oakley, B. (2014). Variation of color discrimination across the life span. *J. Opt. Soc. Amer. A*, **31** (4), A375–A384.

Pokorny, J., Smith, V. C., Lutze, M. (1987). Aging of the human lens. *Appl. Opt.*, **26** (8), 1437–1440.

Regan, B. C., Reffin, J. P., Mollon, J. D. (1994). Luminance noise and the rapid determination of discrimination ellipses in colour deficiency. *Vis. Res.*, **34** (10), 1279–1299.

Renner, A. B., Knau, H., Neitz, M., Neitz, J., Werner, J. S. (2004). Photopigment optical density of the human foveola and a paradoxical senescent increase outside the fovea. *Vis. Neurosci.*, **21** (6), 827–834.

Rodriguez-Carmona, M, Sharpe, L. T., Harlow, J. A., Barbur, J. L. (2008). Sex-related differences in chromatic sensitivity. *Vis. Neurosci.*, **25** (3), 433–440.

Rodriguez-Carmona, M. L., Harlow, A. J., Walker, G., Barbur, J. L. (2005). The variability of normal trichromatic vision and the establishment of the "normal" range. In: *Proceedings of 10th Congress of the International Colour Association, 8–13 May 2005, Granada*, pp. 979–982.

Simunovic, M. P. (2010). Colour vision deficiency. *Eye*, **24** (5), 747–755.

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Sun, Y., Shevell, S. K. (2008). Rayleigh matches in carriers of inherited color vision defects: The contribution from the third L/M photopigment. *Vis. Neurosci.*, **25** (3), 455–462.

Weale, R. A. (1988). Age and the transmittance of the human crystalline lens. *J. Physiol.*, **395** (1), 577–587.

Wong, R., Khan, J., Adewoyin, T., Sivaprasad, S., Arden, G. B., Chong, V. (2008). The ChromaTest, a digital color contrast sensitivity analyzer, for diabetic maculopathy: A pilot study. *BioMed Central*, **8** (5), 1–6.

HROMATISKĀS JUTĪBAS ATŠĶIRĪBAS, KAS NOSKAIDROTAS AR STATISKIEM UN DINAMISKIEM KRĀSU STIMULIEM

Pētījuma ietvaros izveidots datorizēts testa stimuls, kas ietver gan statisku, gan dinamisku testa stimula režīmu. Mērījumi veikti ar mērķi noskaidrot, vai hromatiskās jutības sliekšņu vērtības, kas novērtētas ar statisku un dinamisku testa stimulu, ir būtiski atšķirīgas. Pētījumā piedalījās 20 dalībnieki vecumā no 21 līdz 77 gadiem. Nevienam no pētījuma dalībniekiem iepriekš nav konstatēti krāsu redzes deficīti vai acu saslimšanas, kas var ietekmēt hromatisko jutību. Visi pētījuma dalībnieki piedalījās divās mērījumu sesijās, kur katrā no tām hromatiskā jutība tika izvērtēta ar statiskiem un dinamiskiem stimuliem sešos virzienos krāsu telpā, kas atbilst sarkani–zaļajiem (RG) un dzelteni–zilajiem (YB) krāsu virzieniem. Tritanopijas krāsu virzienos būtiskas hromatiskās jutības atšķirības ar statiskiem un dinamiskiem stimuliem netika konstatētas, savukārt ievērojamas atšķirības tika apstiprinātas protanopijas un deiteranopijas krāsu virzienos ar statiskiem un dinamiskiem stimuliem, proti, zemākas hromatisko sliekšņu vērtības tika konstatētas ar statiskiem testa stimuliem. Tika apstiprināta hromatiskās jutības samazināšanās, pieaugot vecumam, un straujāka hromatiskās jutības samazināšanās tritanopijai atbilstošos krāsu virzienos. Balstoties uz pētījuma rezultātiem, tiek ierosināts, ka atšķirības starp statisku un dinamisku krāsu redzes testu rezultātiem kļūst ievērojamākas, pieaugot pacientu vecumam.