Visual improvement by selective filters in age-related macular degeneration involves effects other than light filtering

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Abstract

The use of wavelength-selective filters for patients with age-related macular degeneration (AMD) is common. An awareness of the expected effect of filters on central vision function, especially the magnitude of learning effects, is essential when deciding whether to prescribe. The aims of the present study were to examine the effect of selective and neutral-density filters on central visual function in patients with exudative AMD and to assess potential learning effects.

The study was a randomised cross-over study of the effect of selective and neutral-density filters on visual acuity (Early Treatment Diabetic Retinopathy Study [ETDRS] charts), contrast sensitivity (Pelli-Robson test), and colour vision (Hardy-Rand-Rittler test) in 31 patients with pseudophakia, aged 69 to 92 years, who had exudative AMD and central visual loss.

Selective filters significantly improved visual acuity (ETDRS), contrast sensitivity (Pelli-Robson), and red/green colour vision (Hardy-Rand-Rittler) in both eyes; however, they reduced blue/yellow colour vision. Neutral-density filters improved visual acuity for the better but not the worse eye and contrast sensitivity for the worse but not the better eye; they had no effect on colour vision. The improvement in contrast vision and red/green colour vision persisted immediately after the filters had been removed.

The study confirmed a positive effect of selective filters on visual acuity, contrast sensitivity, and red/green colour vision but a negative effect on blue/yellow colour vision, in patients with exudative AMD. The effect of neutral-density filters in these patients, however, was more ambiguous. There was evidence that the effect of the filters may have persisted immediately after their removal, suggesting the involvement of factors other than just the filtering of light.

Keywords: AMD, learning effect, selective filters, neutral-density filter

Introduction

Age-related macular degeneration (AMD) is the most frequent cause of irreversible visual impairment in developed countries (Wong et al., 2014). The disease has two vision-threatening manifestations: atrophic AMD with degenerative loss of retinal neurons and exudative AMD with ingrowth of choroidal neovascularisation that causes oedema and destruction of retinal tissue (Fleckenstein et al., 2024). The introduction of intravitreal anti-vascular endothelial growth factor (anti-VEGF) therapy has reduced the prevalence of, but not eliminated, visual loss secondary to exudative AMD (Bek & Bech, 2023; Bek & Klug, 2018; Ciulla et al., 2020). In some patients referral occurs too late, when visual acuity has fallen below the limit for treatment. In other patients, treatment delays but does not eliminate visual loss (Nguyen et al., 2019). These patients may benefit from optical aids that increase visual function by magnification (Matchinski et al., 2024). Some studies have shown improvement of visual function with selective filters that absorb short wavelengths (Abraham et al., 2023), but other studies have shown no such effect (Bailie et al., 2013).

The equivocal evidence for the use of selective filters may be due to differences in diagnostic criteria for AMD. In studies that showed improvement of visual function the effect could have been due either to the selective filtering properties or to a general reduction of light entering the eye, irrespective of wavelength; a comparison of these two filtering principles would require a cross-over study. The presence of cataract could overestimate the positive effect of filters in patients with AMD because the filters are likely to reduce glare from opacities in the crystalline lens (Zigman, 1990). Finally, improvement in contrast sensitivity after retesting has been reported (Higgins et al., 1988), suggesting that potential learning effects need to be addressed when investigating the effect of filters.

The purpose of the present study was to examine the effect of selective filters on central visual function in patients with reduced visual acuity secondary to exudative AMD. The study used a randomised cross-over design to assess the effect of selective filters and neutral-density filters in patients with bilateral pseudophakia. The examination was repeated after testing in order to evaluate potential learning effects.

Methods

Study design

Randomised cross-over study of the effect of selective and neutral-density filter spectacle lenses on visual acuity, contrast sensitivity, and colour vision in patients with exudative AMD and central visual loss. The study was approved by the Regional Ethics Committee in the Central Region of Denmark (Project No 1-10-72-1-20).

Participants

Between 1st October 2020, and 30th November 2022, all patients with bilateral pseudophakia at the Department of Ophthalmology, Aarhus University Hospital who had paused anti-VEGF treatment for exudative AMD for at least 3 months were asked to participate in the study if they met the following criteria:

1. Cataract surgery performed at least 3 months previously on both eyes.
2. Visual acuity equal to or worse than 0.3 logMAR (≤ 6/12) secondary to exudative AMD and that had not required treatment for at least 3 months in the worse eye.

Exclusion criteria for the study were:

1. Optical Coherence Tomography scan showing intra- or subretinal fluid, or fundus photography showing subretinal haemorrhage indicative of active exudative AMD.
2. Subjective refraction differing from the habitually worn spectacle correction by more than 0.50 dioptres of hyperopia, myopia, or astigmatism or improvement in visual acuity of 2 or more Early Treatment Diabetic Retinopathy Study (ETDRS) letters (0.04 logMAR) with subjective refraction.
3. Presence of eye disease other than AMD.
4. Previous use of filter glasses.

In a pilot study of five patients with exudative AMD, which tested seven filters absorbing wavelengths below 400, 450, 500, 511, 527, 550, and 585 nm, respectively, the largest improvement in visual acuity was observed with the 511 nm filter (Multilens Optical Solutions, Gothenburg, Sweden), which was therefore selected for the present study. With this filter the minimum number of participants required to detect a change of 0.04 logMAR caused by a filter was calculated to be 24, assuming a standard deviation of 0.06 logMAR, a power of 90%, and a significance level of 5%. To compensate for possible dropout, 31 patients were recruited (25 female, 6 male), aged ($M \pm SD$, range) 83.5 ± 5.1, 69 to 92 years. Visual acuity in logMAR was ($M \pm SD$, range) 1.14 ± 0.57, 0.40 to 2.20 in the worse eye (6/83) and 0.53 ± 0.38, 0.19 to 1.98 in the better eye (6/22).

All procedures adhered to the Declaration of Helsinki (World Medical Association, 2025); participants gave both oral and written consent.

Examination programme

Participants were randomised into two groups. For Group 1 the examination consisted of the following programme, performed with the participants' habitual spectacle correction:

1. Monocular visual acuity in the eye with poorer visual acuity measured at 4 m distance using an ETDRS chart (19-inch flat panel with Occurity software, Acuity Pro, Elk City, Oklahoma, USA) with single line presentation. If visual acuity was worse than 0.1 logMAR (6/60) the test distance was reduced to 1 m and the angle of resolution required at 1 m was calculated and converted to logMAR values.
2. Monocular low spatial frequency contrast sensitivity for the eye with poorer visual acuity measured monocularly at 1 m using Pelli-Robson charts (Precision Vision, Woodstock, Illinois, USA). Uniform illumination of the chart was provided by a ceiling light. A lux meter was used to ensure illumination was approximately 85 cd/m^2. Each letter seen in addition to the first triplet was scored as 0.05 log additional contrast sensitivity.
3. Steps 1–2 were repeated on the better eye.
4. Colour vision was assessed binocularly at approximately 0.75 m using the Hardy-Rand-Rittler test, 4th edition (Bernell Corp, Indiana, USA).
5. Steps 1–4 were repeated with ML-511 selective filter spectacle lenses.
6. Steps 1–4 were repeated with neutral-density spectacles lenses that absorbed 50% of all visible wavelengths (Multilens Optical Solutions, Gothenburg, Sweden).
7. Steps 1–4 were repeated without filtering spectacle lenses (to test for learning effects).

To minimise memorisation, letters on the visual acuity charts were changed between presentations, the two different Pelli-Robson charts were alternated between presentations, and the 24 plates of the Hardy-Rand-Rittler test were shown with the booklet rotated 90 degrees counterclockwise for each repetition.

For Group 2 the examination consisted of the same programme but the order of assessment with filtering spectacles lenses (Steps 5 and 6) was reversed so that measurements were performed first with neutral-density filters and subsequently with selective filters.

Selection of filter to be tested at home

As a service, participants were given the opportunity to try either selective filter lenses or neutral-density filter lenses at home for 1 month to assess whether they would provide a meaningful improvement in visual function in their everyday life. Four participants opted out. The remaining 27 participants wore each filter type for 1 minute while focusing on objects at varying distances, in order to determine which filter provided the most comfortable vision. Of the 27 participants, 21 (77.8%) chose the ML-511 selective filter and 6 (22.8%) chose the neutral-density filter. The preference of filter was independent of visual acuity, contrast sensitivity, and colour vision ($p > 0.2$ for all comparisons). All 27 participants attended a follow-up consultation after (M, range) 41 days, 26 to 91 days, where they were asked if they still preferred to use the filter and whether their use was full-time or part-time.

Data analysis

The sum of scores for blue/yellow (Plates 5, 6, and 21 to 24) and for red/green (Plates 7 to 20) plates from the Hardy-Rand-Rittler test was calculated by assigning a score of 0, 0.5, or 1 to each plate for incorrect, partially correct, and correct responses, respectively (Huna-Baron et al., 2013). The red/green plates were also divided into plates with red objects and plates with green objects to allow for separate analysis of red and green objects.

Statistical analysis

The Shapiro-Wilks test and quantile–quantile plots were used to test for normal distribution of continuous variables (Mishra et al., 2019). For both visual acuity and contrast sensitivity, repeated measures analysis of variance (ANOVA) was used to compare results with and without filters; since all comparisons showed significant differences, post-test comparisons using paired t-tests were performed (Keselman et al., 2001). The Friedman test was used to analyse differences in colour vision with and without filters; since all comparisons showed significant differences, post-test comparisons using the Wilcoxon signed-rank test were performed.

Differences between participants who preferred no filter, neutral-density filters, or selective filters were examined with one-way ANOVA for visual acuity and contrast sensitivity and with the Kruskal-Walles test for colour vision (Mishra et al., 2019). All statistical analyses by were performed in STATA (version 19.0, StataCorp, Texas, USA).

Results

Visual acuity and contrast sensitivity

Figure 1 shows visual acuity and contrast sensitivity for the better and worse eye under the different experimental conditions. Variability between individual participants appeared to be greater for the worse than for the better eye, both with and without filters.

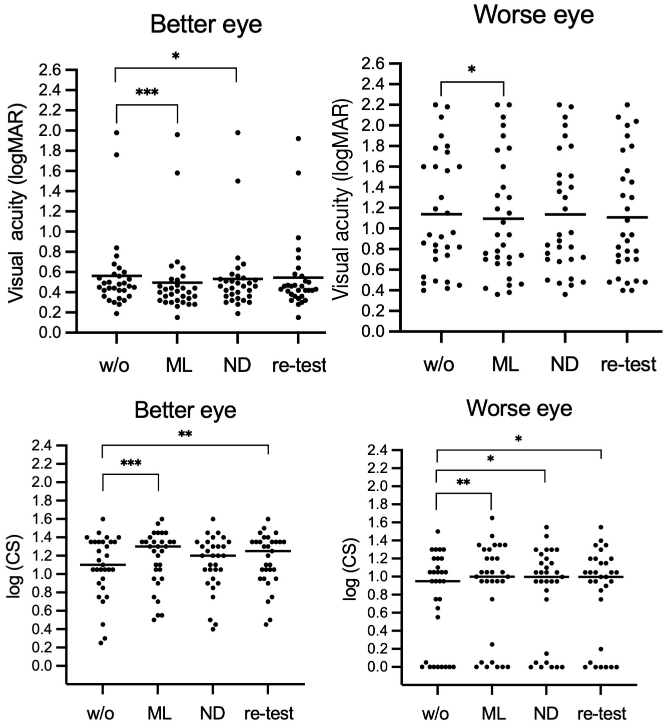

Figure 1: *Visual acuity (top, logMAR) and contrast sensitivity (bottom, log[CS]) at baseline without filter (w/o), with selective filter (ML), with neutral-density filter (ND), and re-tested without filters (re-test), for better eye (left) and worse eye (right). Horizontal black lines denote mean visual acuity and contrast sensitivity for each test condition. $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).*

The ML-511 selective filter significantly improved visual acuity in both the better and the worse eye (Table 1). The neutral-density filter significantly improved visual acuity in the better but not in the worse eye. There was no significant difference between visual acuity measured before testing with filters (“without filter” in Table 1) and after removing the filters and re-testing (“re-test without filters”) in either eye ($p \geq 0.39$ for all comparisons).

The ML-511 selective filter also significantly improved contrast sensitivity in both the better and the worse eye (Table 1). The neutral-density filter significantly improved contrast sensitivity in the worse but not in the better eye. After removing the filters and re-testing (“re-test without filters” in Table 1), contrast sensitivity was significantly better in both eyes than before testing with filters (“without filter”; $p \leq 0.04$ for all comparisons) and was not significantly different than during testing with filters ($p > 0.72$ for all comparisons).

Colour vision

The ML-511 selective filter significantly reduced binocular colour vision measured with the blue / yellow plates and significantly improved colour vision measured with the red / green plates ($p \leq 0.04$ for all comparisons), whereas the neutral-density filter had no significant effect on colour vision ($p \geq 0.08$ for all comparisons; Table 1). After removing the filters and re-testing (“re-test without filters” in Table 1) red / green colour vision was significantly better than before testing with filters (“without filter”; $p = 0.03$) and was not significantly different than during testing with filters ($p = 0.14$), whereas blue / yellow colour vision was not significantly different from before testing with filters ($p = 0.19$). The improvement in red / green colour vision with selective filters was solely due to more green objects being correctly identified.

Table 1: *Visual acuity, contrast sensitivity, and Hardy-Rand-Rittler (HRR) colour vision before, during and after the use of neutral-density filters and ML-511 selective filters. Significant changes are marked in bold.*

	Without filter	Selective filter	Neutral-density filter	Re-test without filters
Visual acuity (logMAR)				
Better eye				
M (*SD*)	0.56 (0.38)	**0.50 (0.37)**	**0.53 (0.35)**	0.54 (0.36)
Change from baseline (*SD*)		0.07 (0.06)	0.03 (0.07)	0.2 (0.08)
p		< 0.001	0.03	0.24
Worse eye				
M (*SD*)	1.14 (0.57)	**1.09 (0.57)**	1.14 (0.57)	1.11 (0.57)
Change from baseline (*SD*)		0.05 (0.15)	0.00 (0.13)	0.03 (0.11)
p		0.04	0.47	0.07
Contrast sensitivity (log Contrast sensitivity value)				
Better eye				
M (*SD*)	1.08 (0.34)	**1.17 (0.30)**	1.12 (0.30)	**1.16 (0.29)**
Change from baseline (*SD*)		0.09 (0.11)	0.04 (0.13)	0.07 (0.13)
p		< 0.001	0.12	0.004
Worse eye				
M (*SD*)	0.75 (0.52)	**0.86 (0.53)**	**0.83 (0.51)**	**0.83 (0.51)**
Change from baseline (*SD*)		0.11 (0.23)	0.09 (0.21)	0.08 (0.20)
p		0.009	0.03	0.04
HRR – colour vision (additive score)				
Red/green plates				
M (*IQR*)	8.0 (6.0;10.0)	**8.5 (7.0; 11.0)**	8.5 (7.0;11.0)	**9.0 (7.0; 10.5)**
Change from baseline (*IQR*)		0.5 (0.0; 1.5)	0.0 (-0.5; 1.0)	0.0 (0.0; 1.5)
p		0.01	0.16	0.04
Blue/yellow plates				
M (*IQR*)	3.5 (2.5; 4.5)	**3.0 (1.5; 4)**	3.0 (2.0; 4.0)	4.0 (2.0; 4.5)
Change from baseline (*IQR*)		-0.5 (-1.5; 0.0)	0.0 (-1.0; 0.5)	0.5 (0.0; 1.5)
p		0.03	0.17	0.40

Discussion

The present study is, to the authors’ knowledge, the first to use a randomised cross-over design to study the effect of wavelength-selective and neutral-density filters on visual acuity, contrast sensitivity, and colour vision in patients with exudative AMD, with a consideration of potential learning effects.

The observed improvement of visual acuity induced by selective filters confirmed results from previous studies in patients with AMD (Zigman, 1990). Although the observed improvement was small, it could be beneficial for patients with reduced visual acuity. This is supported by a previous study that found improvement in reading ability, visual information processing, and visual motor skills following low-vision rehabilitation of patients with macular diseases (Stelmack et al., 2017).

The observed improvement in red/green colour vision is discrepant from examinations of colour vision where different wavelengths were not separated (Bailie et al., 2013; Wolffsohn et al., 2002), implying that effects other than red/green colour vision could have been involved in the response in these studies. Furthermore, in the present study red/green colour vision only improved in plates with green objects, which may have appeared darker and more visible through selective filters against the grey background due to increased absorption of light reflected from green objects compared with the background. However, the improvement in red/green colour vision may also have a retinal origin because it has been shown that decreased excitation of the cone blocked by the filter is accompanied by increased excitation of the other two types of cones (Coia et al., 2024).

Both visual acuity and red/green colour vision involve the foveal area. Observations in patients with central retinal disease may, therefore, potentially be caused by a shift in fixation to the extrafoveal retina, which contains a higher proportion of short wavelength sensitive cones than the foveal area (Curcio et al., 1991). The resulting blur from chromatic aberration may consequently be counteracted by the exclusion of short wavelengths (Diaz-Gonzalez et al., 2015). This interpretation is supported by studies showing a lack of effect of selective filters on visual acuity in people with normal vision (Eperjesi & Agelis, 2011), but a beneficial effect of these filters with increasing progression of AMD and its accompanying increase in eccentric fixation (Caballe-Fontanet et al., 2020). However, with fixation shifted to extrafoveal areas, selective filters will reduce illumination and thereby increase vulnerability to loss of short wavelength sensitive cones (Neelam et al., 2009; Vemala et al., 2017). This may explain the observed worsening of blue/yellow colour vision with selective filters in the present study and other studies (Kiser et al., 2008; Wolffsohn et al., 2002). Improvement in contrast sensitivity induced by selective filters has previously been observed at both normal (Frennesson & Nilsson, 1993; Langagergaard et al., 2003) and low illumination (Abraham et al., 2023). Therefore, the effect may be due to an improvement in visual acuity rather than in contrast. It is important, therefore, that studies are conducted with a separation of the effects of selective filters on resolution and contrast. In the present study it was notable that among the participants who decided after the initial examination to try using filter lenses at home, most chose the selective filter. This is in accordance with findings that these filters may improve the quality of life related to vision (Caballe-Fontanet et al., 2020). This may be due to the positive effect of the filters on visual acuity, contrast sensitivity, and red/green colour vision, which may improve the distinguishment of facial features and isolation of objects from the background and may lead to improved vision during changes in illumination (Wolffsohn et al., 2002). It is also likely that the participants in the current study wore the selective filters for a sufficiently long time to initiate recalibration of colour perception towards a natural viewing condition (Shimakura & Sakata, 2022). However, the effect may nevertheless be at the expense of the facility to perform eye-hand tasks with objects in blue colour (Kiser et al., 2008).

The observed improvement of visual acuity induced by neutral-density filtering in the better eye may also be due to reduction in short wavelengths, which provides a positive effect that is larger than the negative effect of a reduction in the total light entering the eye. This balance would be expected to be more negative in patients with low visual acuity and reduced light sensitivity, which may explain the lack of positive effect of the neutral-density filter in the worse eye. Neutral-density filters have not been shown to improve visual acuity in patients with AMD, but in previous studies the filter was used as a control rather than an intervention (Bailie et al., 2013; Wolffsohn et al., 2002). The lack of effect of the neutral-density filters on colour vision in the present study indicates that the trichromatic input had been maintained and that the size and contrast in the symbols of the test were above the stimulus threshold for both the better and the worse eye. However, it is notable that one study participant preferred the neutral-density filter for full-time wear at the follow up examination, which might argue for a role of this filter type in specific patients. These findings underline the need for further studies to investigate the mechanism of action and effects of neutral-density filters in patients with AMD, and in particular to study whether there is a threshold below which filtering is beneficial for visual acuity and colour vision.

The normalisation of visual acuity and blue/yellow colour vision after testing with filters indicates that the observed visual effects had been caused by the filters. However, the persistence of improved contrast sensitivity and red/green colour vision immediately after the filters had been removed is suggestive of a learning effect. Such learning effects have received little attention in the scientific literature (Lamoureux et al., 2007) but are important to consider in the interpretation of results from psychophysical tests (Wu et al., 2020). However, persistent improvement following the use of selective filters may also be due to increased excitation of middle and long wavelength sensitive cones (Coia et al., 2024). Regardless of the underlying mechanism, the present study's findings underline that improvements in visual performance with filters and other low vision optical aids should be interpreted with caution and that re-examination without optical aids following testing is necessary in order to evaluate the true effects of the aids on vision. Although it is likely that learning effects are transient, the duration of the effects should be investigated in more detail.

In conclusion, this study confirmed a positive effect of selective filters on visual acuity, contrast sensitivity, and red/green colour vision but a negative effect on blue/yellow colour vision, in patients with exudative AMD. The effect of neutral-density filters was more ambiguous. A further understanding of the effects of selective filters and identification of thresholds for positive effects of these aids would require studies of patients with a wider span of visual acuities and eccentric fixation than was the case in the present study. The observation that the effect of using filters can persist after testing suggests the involvement of factors other than just the filtering of light. The existence and duration of such learning effects should be considered when interpreting the effects of visual aids in patients with AMD and other retinal diseases.

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Bruk av bølgelengdeselektive filtre ved aldersrelatert makuladegenerasjon gir synsforbedringer som innebærer mekanismer utover ren lysfiltrering

Sammendrag

Bruken av bølgelengdeselektive filtre hos pasienter med aldersrelatert makuladegenerasjon (AMD) er utbredt. Kunnskap om forventet effekt av slike filtre på makulær synsfunksjon, særlig omfanget av læringseffekter, er avgjørende ved vurdering av forskrivning. Hensikten med denne studien var å undersøke effekten av selektive og nøytralgrå filtre på makulær synsfunksjon hos pasienter med våt AMD, samt å vurdere mulige læringseffekter.

Studien var en randomisert cross-over-studie av effekten av selektive og nøytralgrå filtre på synsskarphet (Early Treatment Diabetic Retinopathy Study [ETDRS]-tavler), kontrastsensitivitet (Pelli-Robson-test) og fargesyn (Hardy-Rand-Rittler-test) hos 31 pasienter med pseudofaki, i alderen 69 til 92 år, som hadde våt AMD og makulært synstap.

Selektive filtre ga en signifikant forbedring av synsskarphet (ETDRS), kontrastsensitivitet (Pelli-Robson) og rødt/grønt-fargesyn (Hardy-Rand-Rittler) i begge øyne, men reduserte blått/gult-fargesyn. Nøytralgrå filtre forbedret synsskarphet for det beste, men ikke for det dårligste øyet, og kontrastsensitivitet for det dårligste, men ikke for det beste øyet; de hadde ingen effekt på fargesyn. Forbedringen i kontrastsyn og rødt/grønt-fargesyn vedvarte umiddelbart etter at filtrene var fjernet.

Studien bekreftet en positiv effekt av selektive filtre på synsskarphet, kontrastsensitivitet og rødt/grønt-fargesyn, men en negativ effekt på blått/gult-fargesyn hos pasienter med våt AMD. Effekten av nøytralgrå filtre hos disse pasientene var imidlertid mer tvetydig. Det forelå indikasjoner på at effekten av filtrene kunne vedvare umiddelbart etter at de var fjernet, noe som antyder at andre faktorer enn ren lysfiltrering kan være involvert.

Nøkkelord: AMD, læringseffekt, bølgelengdeselektive filtre, nøytralgrå filter

Il miglioramento visivo mediante filtri selettivi nella degenerazione maculare legata all'età coinvolge effetti diversi dal semplice filtraggio della luce

Riassunto

L'uso di filtri selettivi per lunghezza d'onda nei pazienti con degenerazione maculare legata all'età (AMD) è comune. La consapevolezza dell'effetto atteso dei filtri sulla funzione visiva centrale, in particolare dell'entità sugli effetti di apprendimento, è essenziale nel decidere se prescriverli. Gli obiettivi del presente studio erano esaminare l'effetto dei filtri selettivi e dei filtri a densità neutra sulla funzione visiva centrale in pazienti con AMD essudativa e valutare i potenziali effetti di apprendimento.

Lo studio è stato un trial randomizzato con disegno cross-over sull'effetto dei filtri selettivi e dei filtri a densità neutra sull'acuità visiva (tabelle Early Treatment Diabetic Retinopathy Study [ETDRS]), sulla sensibilità al contrasto (test di Pelli-Robson) e sulla visione dei colori (test Hardy-Rand-Rittler) in 31 pazienti pseudofachici, di età compresa tra 69 e 92 anni, affetti da AMD essudativa con perdita della visione centrale.

I filtri selettivi hanno migliorato in modo significativo l'acuità visiva (ETDRS), la sensibilità al contrasto (Pelli-Robson) e la visione dei colori rosso/verde (Hardy-Rand-Rittler) in entrambi gli occhi; tuttavia, hanno ridotto la visione dei colori blu/giallo. I filtri a densità neutra hanno migliorato l'acuità visiva nell'occhio migliore ma non in quello peggiore e la sensibilità al contrasto nell'occhio peggiore ma non in quello migliore; non hanno avuto effetti sulla visione dei colori. Il miglioramento della sensibilità al contrasto e della visione rosso/verde è persistito immediatamente dopo la rimozione dei filtri.

Lo studio ha confermato un effetto positivo dei filtri selettivi su acuità visiva, sensibilità al contrasto e visione rosso/verde, ma un effetto negativo sulla visione blu/giallo nei pazienti con AMD essudativa. L'effetto dei filtri a densità neutra in questi pazienti, tuttavia, è risultato più ambiguo. È emersa evidenza che l'effetto dei filtri possa persistere immediatamente dopo la loro rimozione, suggerendo il coinvolgimento di fattori diversi dal semplice filtraggio della luce.

Parole chiave: AMD, effetto di apprendimento, filtri selettivi, filtri a densità neutra