Colored filters improve exclusion of perceptual noise in visually symptomatic dyslexics

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Dyslexic individuals have deficits in detecting visual stimuli embedded in high levels of perceptual noise. Here we show that visually symptomatic dyslexics, who otherwise had elevated contrast thresholds for discriminating symbols in visual noise, had thresholds similar to non-dyslexics when wearing colored filters. These findings provide evidence that colored filters, which minimize the visual distortions and discomfort of dyslexics when reading, improve dyslexics' noise exclusion to normal levels.

Developmental dyslexia is manifested as a difficulty with reading given normal individual intelligence that cannot be explained by other factors such as sensory acuity, learning opportunities or brain injuries[1]. Recently, an influential theory [2-4] proposed that the reading difficulties of dyslexics may reflect deficits in extracting important sensory information from irrelevant distractors. Dyslexic children need higher contrast levels than normal readers for detecting patterns [3] or motion coherence[4] in the presence of visual noise, but not in the absence of noise. Converging evidence shows that children with language learning disabilities[5] and dyslexia[6] also have substantial deficits in speech perception and detection of tonal targets only under conditions with auditory noise.

Dyslexic readers frequently experience perceptual distortions of shape, color, motion and asthenopia (sore, tired eyes, headaches and photophobia) which impair their reading abilities[7]. The symptoms of visual stress[7] (also known Meares-Irlen syndrome[8]) have not been clearly defined in the literature, but some subjects report a sustained reduction of the discomfort and perceptual distortions and show improvement of reading speed when using precision tinted lenses.

We hypothesized that if a noise-exclusion deficit is an underlying characteristic of dyslexia, colored filters may have an effect on the visual performance of visually symptomatic dyslexics in the presence of noise, but not in the absence of noise. We measured contrast thresholds for discriminating letter-like symbols in the presence and absence of luminance noise using a two-interval forced choice procedure (Fig. 1 and Supplementary Methods). Dyslexic and non-dyslexic individuals were tested without filters, with colored filters and neutral density filters whose transmittances matched those of the colored filters.

Figure 1 about here

Dyslexics with visual stress syndrome (n=10) had reported visual distortions, headaches and discomfort which were reduced by colored filters selected by means of the Intuitive Colorimeter[9] (Supplementary Methods). They had shown an improvement in reading speed of more than 5% when using their precision tinted filters[10] and had been wearing their colored filters for a minimum of 4 months. The non-dyslexics (n=10) had no visual abnormality and did not receive any benefit from the use of colored filters.

The presence of noise elevated significantly (ANOVA, main effect of noise, $F(1,18)=670$, $P<0.001$, Supplementary Methods) the contrast thresholds (Fig. 2). Tukey *post hoc* comparisons showed that when the stimuli were presented on a uniform background (Fig. 2a), there were no significant differences between the thresholds of different subject groups. When the stimuli were embedded in noise (Fig. 2b), dyslexics had significantly ($P<0.005$) higher contrast thresholds (8.0%) than non-dyslexics (5.3%). With colored filters, however, the differences between the dyslexics' and non-dyslexics' thresholds were not significant. The use of neutral density filters also resulted in significantly ($P<0.05$) higher contrast thresholds of dyslexics (8.2%) as compared to non-dyslexics (5.8%). Intriguingly, colored filters reduced significantly the dyslexics' contrast thresholds (5.1%) as compared with those without filters (8.0%, P=0.001) or with neutral density filters (8.2%, P<0.001). The thresholds of non-dyslexics without filters, with colored and with neutral density filters were not significantly different.

Figure 2 about here

This study showed that visually symptomatic dyslexics had noise-exclusion deficits when discriminating symbols without filters and with neutral density filters but not with colored filters. The ability to exclude noise (distractors) depends on the tuning characteristics of the perceptual templates[11]. At the neuronal level, the tuning characteristics of visual neurons are modulated by cortical suppression, for example GABA mediated suppression[12]. Therefore, the non-optimal visual processing in dyslexics might be due to reduced cortical suppression[4]. This impairment of cortical suppressive mechanisms might result in hyperexcitability which has been regarded as a possible neural mechanism underlying the perception of visual distortions in individuals with visual stress syndrome[13].

How could colored filters modify the noise-exclusion mechanisms of dyslexics? The selection of colored filters by means of the Intuitive Colorimeter is based on adjustments of saturation and hue of light illuminating a page of text until visual distortions and discomfort are minimized[9]. The reduction of visual distortions and discomfort might be based on "emotional attention"[14] driven by color. Specific colors can elicit specific emotional responses in humans which may have impact on mood and performance. Warm colors (red, yellow) have been associated with excitement and stimulation and they improve performance in tasks involving short-term memory and problem solving[15]. Cool colors (blue and green) have been related to comfort, security and calm. It should be noted that some dyslexics reported that the colors selected by the Intuitive Colorimeter were similar to the colors of their home environment. Anecdotally, facial tension is seen to reduce in subjects when their preferred color is in use, along with subjective reports of increased relaxation.

We speculate that the observed effects of colored filters on noise exclusion might reflect some improvement of suppressive cortical mechanisms of dyslexics due to top-down influences of "emotional attention". Whatever the mechanisms underlying the effects of colored filters are, such filters may improve the ability of dyslexics with visual stress syndrome to extract important sensory information from irrelevant distractors.

References:

1. Critchley, M. *The dyslexic child.* (London: Heinemann Medical 1970).
2. Sperling, A.J., Lu, Z.L. & Manis, F.R. *Ann. Dysl.* **54**, 281-303 (2004).
3. Sperling, A.J., Lu, Z.L., Manis, F.R. & Seidenberg, M.S. *Nat. Neurosci.* **8**, 862-863 (2005).
4. Sperling, A.J. Lu, Z.L., Manis, F.R. & Seidenberg, M.S. *Psychol. Sci.* **17**, 1047-1053 (2006).
5. Ziegler, J.C., Pech-Georgel, C., George, F., Alario, F.-X. & Lorenzi, C. *PNAS*, **102**, 14110-13115 (2005).
6. Chait, M., Eden, G., Poeppel, D., Simon, J.Z., Hill, D.F. & Flowers, D.L. *Brain Lang*. **102**, 80-90 (2007).
7. Wilkins, A, *Visual Stress*. (Oxfords Psychology Series. Oxford Science Publications 1995).
8. Irlen, H. *Reading by the Colors.* (New York: Avery Publishing Group Inc. 1991).
9. Wilkins, A.J., Nimmo-Smith, M.I. & Jansons, *J. Ophth. Physiol*. *Opt*. **12**, 381-385 (1992).
10. Wilkins, A.J. Ophthal. *Physiol. Opt.* **22**, 448-454 (2002).
11. Lu, Z.L. & Dosher, B.A. *Vision Res.*, **38**, 1183-1198 (1998).
12. Tsumoto, T., Ecksrt, W. & Creutzfeldt, *O. Exp Brain Res*. **34**, 351-363 (1979).
13. Wilkins, A.J., Huang, J. & Cao, Y. *J Res. Read.* **27**, 152-162 (2004).
14. Vuilleumier, P. *Trends Cogn. Sci.* **9**, 585-594 (2005).
15. Knez, I. *J Environ. Psych.* **21**, 201-208 (2001).

Figure Captions

Figure 1. High contrast examples of symbol strings embedded in luminance noise. In each trial, subjects were presented with two intervals each of which contained a three-symbol string built up by a random selection of symbols resembling “u” and “n”. The middle symbols in the first and second intervals were different; the flanking symbols in each interval were randomly selected. Subjects judged whether the middle symbol “u” was presented in the first or second interval. Contrast thresholds were measured by a staircase method in the absence and presence of 2D dynamic Gaussian noise whose spectral density was 1.4 μsdeg^2 (Supplementary Methods).

Figure 2. Contrast thresholds of non-dyslexics (empty markers) and dyslexics (filled markers) for discriminating symbols in the absence (a) and presence (b) of luminance noise without filters (NoFs), with colored filters (ColFs) and neutral density filters (NDFs). Error bars show 95% confidence intervals.

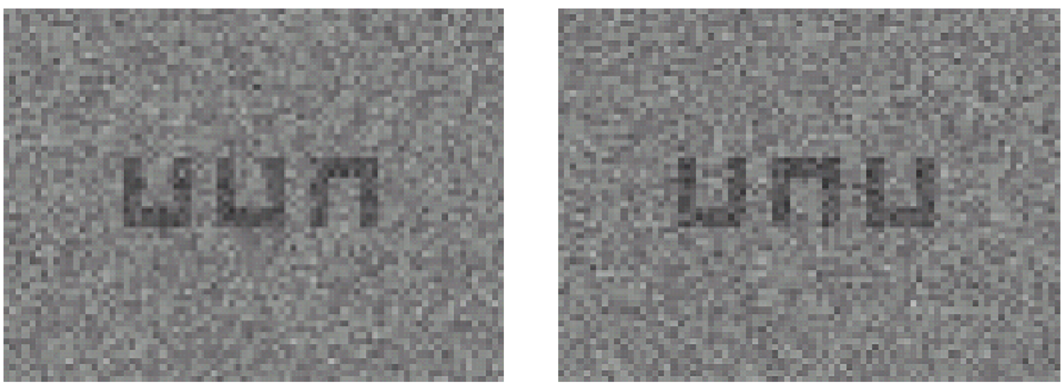
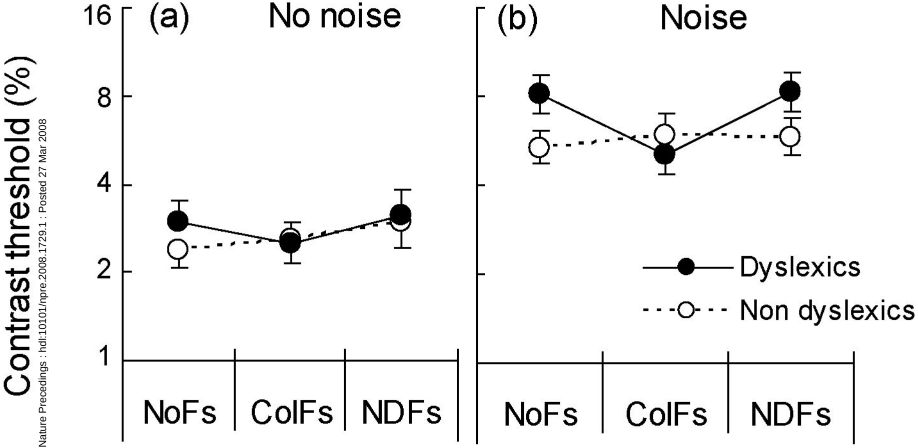


Figure 1



Contrast threshold (%)
16
8
4
2
1
(a)
No noise
NoFs
ColFs
NDFs
(b)
Noise
NoFs
ColFs
NDFs
Dyslexics
Non dyslexics

Figure 2

Supplementary Table 1. Reading and cognitive scores (means and s.d.).

	Non dyslexic (n=10)	Dyslexic (n=10)	*P*
Age (years)	24(4)	20(7)	n.s.
Rate of reading without filters (words per minute)	112(26)	66(13)	<0.01
Rate of reading with colored filters (words per minute)	106(23)	84(16)	<0.01
Sight Word Reading*	116(14)	85(24)	<0.01
Phonemic decoding*	113(13)	79(19)	<0.01
Non verbal IQ**	114(12)	110(18)	n.s.
Verbal IQ**	115(13)	111(19)	n.s.

* TOWRE Test; **Kaufman Brief Intelligence Test;

n.s. = non significant.

Supplementary Table 2. Chromaticity and transmission co-ordinates for the colored filters used by the dyslexic and non-dyslexic subjects. Mean transmittance for the dyslexic subjects is 39.8%.

Subject	*x* chromaticity	*y* chromaticity	Luminous Transmittance %
1	0.204	0.298	23
2	0.275	0.345	39
3	0.194	0.373	14
4	0.269	0.320	48
5	0.371	0.258	32
6	0.335	0.408	57
7	0.324	0.330	41
8	0.298	0.315	59
9	0.204	0.254	27
10	0.279	0.298	58
Non-dyslexics	0.275	0.345	40

Supplementary Figure 1. Example of the words used and crowded nature of the rate of reading test.

come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
is you dog for not cat my look come and up to play see the