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The influence of tinted lenses upon ocular accommodation

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Abstract

We determined the effect upon accommodative responses of tinted lenses prescribed for the relief of visual discomfort in a group of five long term lens wearers. Static and dynamic responses were measured under four viewing conditions (1) prescribed tinted lens (2) neutral density filter (3) tinted lens of complementary colour and (4) no absorptive lens. While similarity and normality of the mean stimulus–response functions between the four viewing conditions were evident, the low frequency component of the accommodation microfluctuations was significantly greater while viewing the target in the 'no lens' viewing condition. These increases in the low frequency components (LFC) of the accommodation may be a subtle indicator of visual stress in these patients. Colour specificity is not supported by this finding. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

It has been claimed that tinted lenses are beneficial in reducing perceptual distortions in patients with dyslexia and migraine (Wilkins et al., 1992a). Many of these patients complain of perceptual distortions and visual discomfort when viewing stressful visual stimuli such as text (Wilkins & Nimmo-Smith, 1987). These symptoms appear to be alleviated when text is illuminated by light with a specific colour different for each individual (Wilkins, Nimmo-Smith, & Jansons, 1992b).

The mechanism whereby tinted lenses alter the visual system in such a way as to alleviate perceptual distortions and visual discomfort is unclear. No studies have yet objectively defined and characterised visual function in these patients or identified which aspects, if any are being improved by the use of tinted lenses.

Although the physiological basis of the therapeutic effects of tinted lens therapy has not been elucidated, it has been speculated that the use of chromatic filters manipulate the response of the transient visual system (Stein & Walsh, 1997), or that the therapeutic colour may reduce excitation in areas of hyperexcitability in the visual cortex (Wilkins, 1995). The perceptual distortions/symptoms that these individuals describe are similar to the non-specific symptoms commonly associated with visual discomfort or uncorrected refractive error. Reported distortions of text include blurring, apparent motion/flickering, diplopia, shapes or colours on the page. Other commonly reported symptoms are glare from the page and headaches/sore eyes with sustained reading. Moreover, there is a similarity between these symptoms and those commonly associated with disorders of binocular vision (Scheiman et al., 1990) including accommodative anomalies (Scheiman et al.; Wilkins & Neary, 1991). Although these anomalies do not appear to be a sufficient explanation for the benefit from coloured filters (Evans, Busby, Jeanes, & Wilkins, 1995).

While evidence of anomalous accommodation is documented clinically in these patients (Evans et al., 1995; Evans et al., 1996) there are relatively few objective laboratory investigations which have studied the static and dynamic components of the accommodation response. A recent study by Ciuffreda, Scheiman, Ong, Rosenfield, and Solan (1997) examined the steady-state

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accommodation response in a group of Irlen (coloured) lens wearers. This study could demonstrate no significant difference between mean levels of accommodation with or without the use of coloured lenses, concluding that Irlen lenses do not improve accommodative accuracy at near.

The accommodation system is controlled through a negative feedback loop using retinal blur (Kotulak & Schor, 1986). The nominally steady-state accommodative response exhibits small temporal variations, which occur within an envelope of 0.5 D and with frequencies up to 3 Hz. There are two main frequency regions in these fluctuations, the low frequency components (LFC) (≤ 0.6 Hz) which are believed to be under neurological control (Winn & Gilmartin, 1992) and also demonstrate a coherence with respiration cycle (Collins, Davis, & Wood, 1995) and the high frequency component (HFC) (1.0 Hz $\leq \text{HFC} \leq 2.0$ Hz) which are correlated with the intraocular manifestation of arterial pulse (Winn, Pugh, Gilmartin, & Owens, 1990; Collins et al.). A functional role has been attributed to these microfluctuations, as they offer a means by which a directional cue can be derived from an even-error stimulus (Winn & Gilmartin). Rather than being a spurious characteristic of the accommodation response, microfluctuations could provide a mechanism for maintaining optimum mean response levels.

The accommodation system, therefore, can be a sensitive objective measure of the visual system's response to changes in target characteristics. In the following study we examined several components of the accommodative response and evaluated the effect of tinted lenses upon these responses.

2. Methods

2.1. Subjects

The visual stress subject group were referred from a local ophthalmology department and comprised four emmetropes and one corrected (Acuvue™ contact lens, Johnson and Johnson) hyperope (subject SM $+2.50$ DS) who had worn Precision Tints successfully for a minimum of 2 years (age range 22–30 years).

These subjects initially attended due to the signs and symptoms of visual stress/discomfort detailed above, which were not alleviated by conventional optometric and/or orthoptic treatment. Before the prescription of tinted lenses, patients reported a sustained subjective benefit (a reduction in symptoms of asthenopia and perceptual distortions) and an objective increase in reading speed (24–33%) through the use of colour. While there is evidence that reading speed improves with the use of a coloured overlay and is a useful prognostic indicator, this has yet to be validated in a double-blind placebo control trial for the use of tinted lenses.

A carefully age and sex matched control group were selected who had not worn tinted lenses, experienced visual stress or had any difficulties with near vision. This group comprised four visually normal emmetropes and one corrected (Acuvue™ contact lens, Johnson and Johnson) myope (-2.50 DS).

All subjects had normal binocular and colour vision and gave their full informed consent after the nature of the experiment had been explained.

2.2. Stimulus

The subjects were required to view monocularly a high contrast (90%) black Maltese cross target placed in a Badal stimulus system ($+5$ D). The target was mounted in a 35 mm slide and illuminated by a filament lamp with spectral power distribution similar to that of CIE Standard Illuminant A (Fig. 1). The base luminance of the target was 110 cd/m^2 using a digital spot photometer (Minolta Luminance Meter LS110).

2.3. Instrumentation

Accommodative responses were measured using a modified Canon Autoref R-1 infra-red optometer (Canon Europa, The Netherlands) which can be operated in its normal static shot mode or in continuous recording mode (Pugh & Winn, 1988, 1989). In normal operation, the optometer uses the principle of grating focus to drive a lens along a carriage until the output voltage is at a maximum and computes the time taken to reach this point. It has three sets of detectors in three different meridans and from these values it calculates a sphero-cylindrical value of the eyes' refractive power to ± 0.12 D. In a continuous recording mode the lens carriage is disabled and set manually to allow the voltage output from either one of the three detectors to be sampled continuously (Pugh & Winn).

The reliability and validity of the optometer has been evaluated previously (Matsummura et al., 1983; McBrien & Millodot, 1985) and has been found to be independent of apparent pupil sizes > 2.9 mm for static-shot recordings and > 3.8 mm for continuous recording (Winn, Pugh, Gilmartin, & Owens, 1989). The alignment system of the optometer provides a magnified image ($\times 8.2$) of the subjects' eye on an infra red video monitor allowing the apparent pupil size to be monitored during the experiment. Pupil diameter as measured on the video monitor was > 5 mm in the viewing eye at all times in every subject. The use of a dental bite and forehead restraint eliminates artefacts due to head movements. To minimise artefacts in the continuous accommodation signal due to eye movements fixation was monitored to ensure that it remained within $\pm 1°$.

The output from the Canon optometer was displayed on a digital storage oscilloscope (Gould 1604, Gould, UK) and transferred to an Hewlett Packard 286 computer via an IEEE-4888 interface for subsequent analysis using the Asystant software package (Keighly Instruments, UK, Fig. 1). This allowed the traces to be viewed in real time and ensured that data containing artefacts would be eliminated in subsequent analysis.

2.4. Procedure

On entering the laboratory subjects were fully aware of the position of the target and instrumentation, although all subjects were ignorant to the aim of the experiment. The subjects were first asked to sit in the dark for 5 min to allow the dissipation of any transient changes in the tonic position of accommodation due to previous near work (Krumholz, Fox, & Ciuffreda, 1986).

To determine whether the reported benefit of the tinted lens is attributable to a placebo effect or indeed whether the tint itself needs to be individually determined with any precision to be maximally beneficial, each subject was tested in each of the following four viewing conditions,

1. prescribed tinted lens;
2. tinted lens of a complementary colour with photopic transmission equal to that of the prescribed lens (the CIE 1976 hue angle (h_{uv}) differed by approximately 180° to that of the prescribed tinted lens with a similar CIE 1976 saturation (s_{uv}));
3. neutral density filter with photopic transmission equal to that of the prescribed lens;
4. no absorptive lens.

The order of the viewing condition was randomised across subjects. Table 1 shows the subject details including the chromaticity and photopic transmission of both the lens prescribed and complementary lens.

The static accommodative response was measured over a stimulus range of 0–4.5 in 0.5 D steps using the Canon in static-shot mode. A minimum of 15 spherocylindrical measures were taken at each stimulus level. The orders of viewing condition and stimulus presentations were randomised. These values were subsequently converted to mean spheres and a mean and S.D. calculated for each stimulus level.

Following the static measures of accommodation, ten continuous recordings of the accommodative response of 10 s duration were collected for each viewing condition at a sampling rate of 102.4 Hz. The target was placed at a stimulus vergence of 3 D.

A power spectrum analysis was then performed for each individual trace with a frequency resolution of 0.1 Hz. The individual power spectra from each recording condition were then averaged giving a final power spectrum with 10 d.f. It has been shown the probability density function of any one frequency bin (each of width 0.1 Hz) in a power spectrum obtained by a single Fourier transform is that of a χ^2 distribution of order 2. For such a distribution the S.D. is equal to the mean value. By averaging more power spectra the confidence in the distribution increases and the S.D. correspondingly decreases and becomes equal to $\sqrt{(2/2m)} \times$ mean value in each frequency bin (where m is the number of spectra). If the average value of multiple frequency bins is taken the confidence increases further and the S.D.

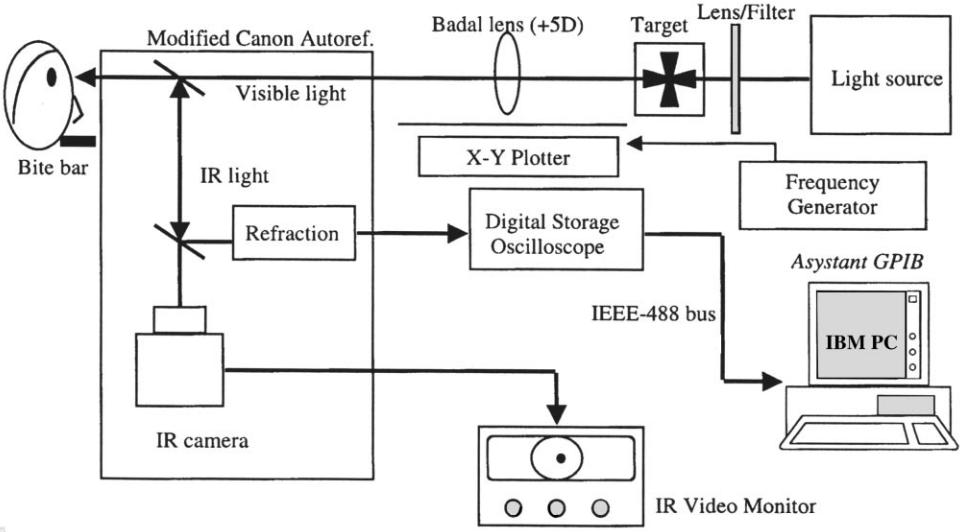

Fig. 1. Schematic diagram of the experimental apparatus. The Badal system was illuminated by a diffuse light source. Both static and continuous accommodation recordings were taken using a modified Canon Autoref R-1 infrared optometer the output of which was fed into a digital oscilloscope. The oscilloscope was controlled by the computer and continuous recordings were stored in the computer for subsequent analysis. The infra red video monitor alignment system of the optometer allows a real magnified image of the eye to be viewed at all times during the experiment to ensure that pupil size remains greater than the minimum required for continuous recording.

Table 1
The colour appearance, the chromaticity coordinates and transmission of each prescribed lens (and complementary lens in *italics*) under CIE Standard Illuminant A

Subject	Colour appearance of lens	Colour coordinates of lens		Transmission of lens (%)
		u'	v'	
CW	Turquoise	0.146	0.492	24.6
	Rose	*0.289*	*0.488*	*23.7*
CM	Rose	0.422	0.531	16.7[a]
	Turquoise	*0.099*	*0.437*	*7.6*
IM	Green	0.085	0.525	5.9
	Rose	*0.374*	*0.468*	*5.6*
KC	Green	0.090	0.508	5.9
	Rose/purple	*0.356*	*0.480*	*5.9*
SM	Turquoise	0.107	0.477	11.7
	Rose	*0.337*	*0.489*	*11.3*

[a] The transmission of this lens was further reduced to match that of the complementary lens using neutral density filters.

then becomes $\sqrt{(2/2mn)}$ × mean value of all frequency bins averaged (n is the number of frequency bins averaged, Pugh, Eadie, Winn, & Heron, 1987).

Finally, the effects of variations in target vergence on the dynamic accommodation response were examined. The target was moved in a stepwise fashion about an intermediate position (3 D). The Badal stimulus optometer allowed stimulus vergence to be modulated without changing stimulus size, position or luminance. Stimuli were presented in 1 D vergence steps over a range of 2.5–3.5 and 2 D vergence steps over a range of 2–4 D in the four viewing conditions described above. For each vergence level six steps were recorded for both far- to near- and near- to far. Reaction and response times were calculated from the step data.

Individual subject data were collected over several experimental sessions to allow stimulus presentation/viewing to be randomised and to avoid fatigue.

3. Results

3.1. Static accommodation responses

The group mean accommodative stimulus/response curves for the visual stress subjects in each of the four viewing conditions are presented in Fig. 2.

Similarity and normality of responses between the four viewing conditions is evident. A two factor analysis of variance (ANOVA) revealed no significant effect of viewing condition ($P = 0.85$), a significant effect of accommodative stimulus ($P = 0.001$) and no significant interaction ($P = 0.99$). Leads and lags are approximately 0.5 D a value typical of this type of response, with an expected increase in lag for the highest vergence.

ANOVA also revealed no significant effect of viewing condition ($P = 0.98$) in the control group, the dashed line in Fig. 2, therefore, illustrates the mean accommodative stimulus/response curve for all four viewing conditions in this subject group.

3.2. Continuous accommodation responses

The root mean square (r.m.s.) value is commonly used to describe complex waveforms and is equivalent to the S.D. of the waveform. This value is unaffected by any sudden change in amplitude and gives a measure of the variability of the static accommodative response (Pugh et al., 1987). The mean r.m.s value was calculated for each subject at the four viewing conditions (Fig. 3).

ANOVA revealed a significant difference in the r.m.s. values between subject groups (visual stress v.s.' control, $P = 0.0001$), while further analyses revealed a significant effect of viewing condition in the visual stress subject group only ($P = 0.03$) with no significant effect of viewing condition demonstrable in the control subject group ($P = 0.3$).

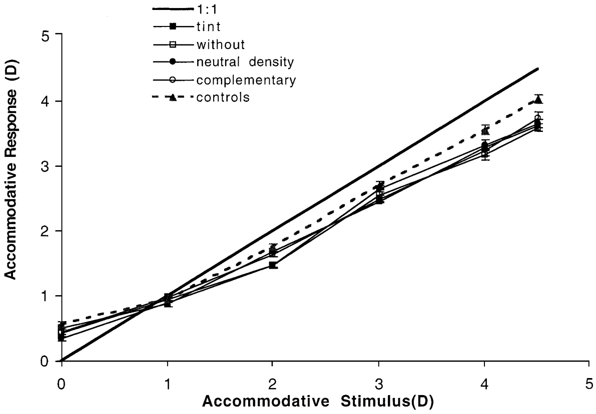

Fig. 2. Mean ± 1 S.E.M. accommodative stimulus response curve, for each of the four viewing conditions in the visual stress subject group. The solid line is 1:1. The dashed line (...............) represents the mean response in the control subject group.

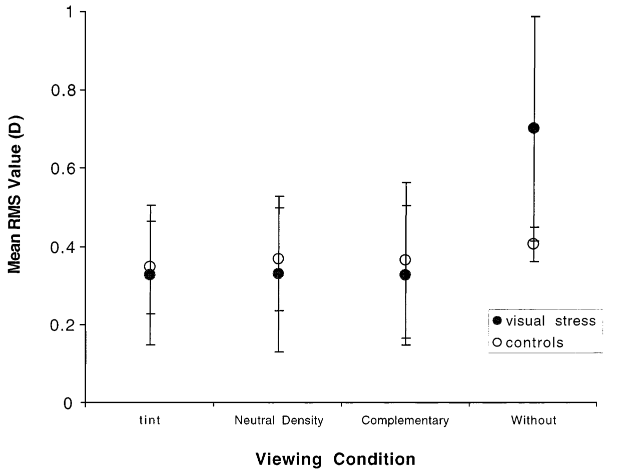

Fig. 3. Mean r.m.s. ± 1 S.D. for each of the four viewing conditions in both the visual stress (●) and control (○) subject group.

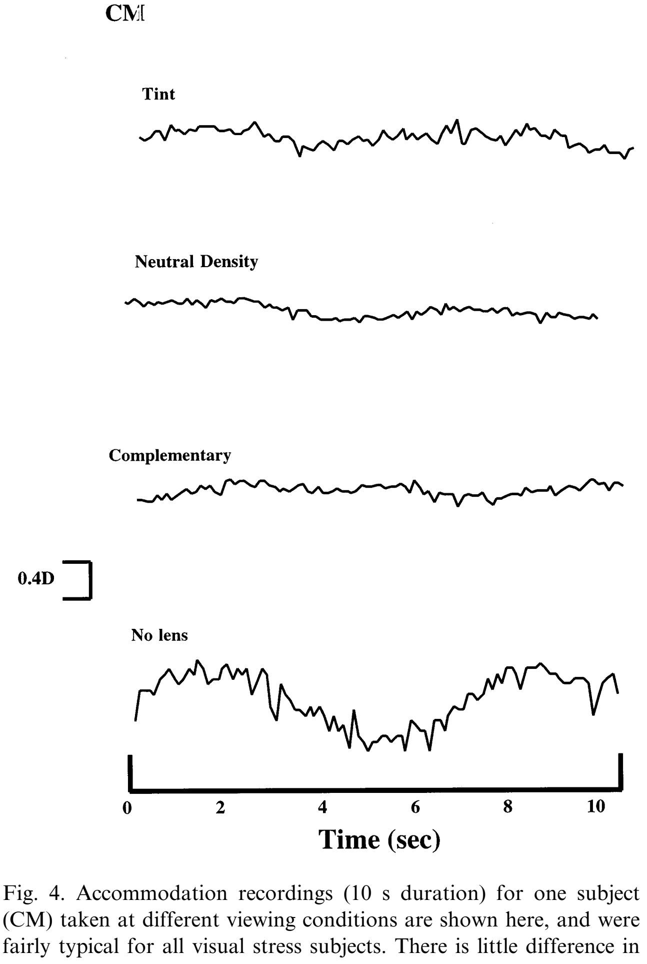

Fig. 4. Accommodation recordings (10 s duration) for one subject (CM) taken at different viewing conditions are shown here, and were fairly typical for all visual stress subjects. There is little difference in the continuous accommodative response with either a tinted lens, neutral density filter or complementary lens. In the viewing condition with 'no lens' the presence of larger amplitude low frequency components can be identified.

Fig. 3 clearly shows the increase in the r.m.s. value when the visual stress subject group viewed the target in the no lens condition.

Accommodation recordings (10 s duration) for subject CM taken at different viewing conditions are shown here in Fig. 4, and were fairly typical for all visual stress subjects. There is very little difference in the continuous accommodation response with either a tinted lens, neutral density filter or complementary lens. For the viewing condition with no lens the presence of larger amplitude low frequency components can be identified.

3.3. Power spectrum analysis

As the changes in the form of the microfluctuations showed the same pattern for all subjects in the control group an average was taken of all power spectra for each viewing condition giving an overall power spectrum with 50 d.f. (the number of degrees of freedom is calculated as described in the Section 2, and for further explanation see Pugh et al., 1987). Fig. 5 shows the mean power spectrum analysis in the control subject group for the four different viewing conditions.

However, power spectrum analysis in the visual stress subject group revealed individual changes in the two dominant frequency components of the microfluctuations with changing viewing condition (Fig. 6). For the no lens condition increases in the power of the LFC from 0 to 0.6 Hz can be seen quite clearly whereas there appears little variation in either the power or the peak position of the HFC as the viewing condition changes.

The changes which occur in the two dominant components of the microfluctuations can be seen more clearly in Fig. 7 which shows the mean power in the LFC and HFC calculated for both subject groups. ANOVA showed a significant difference in the LFC ($P = 0.01$) and no significant difference ($P = 0.5$) in the HFC in the visual stress subject group in the four

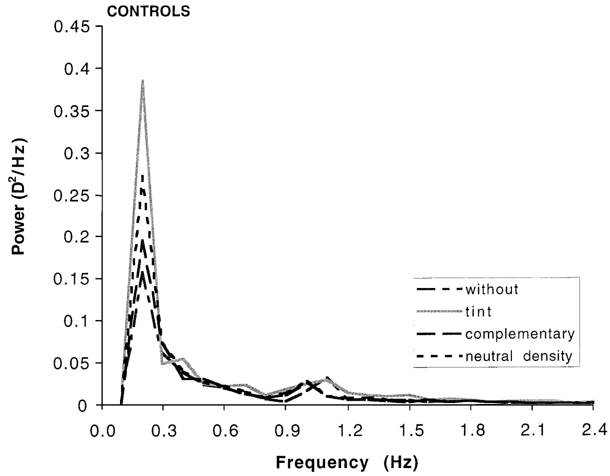

Fig. 5. Mean power spectra for the different viewing conditions in the control subject group.

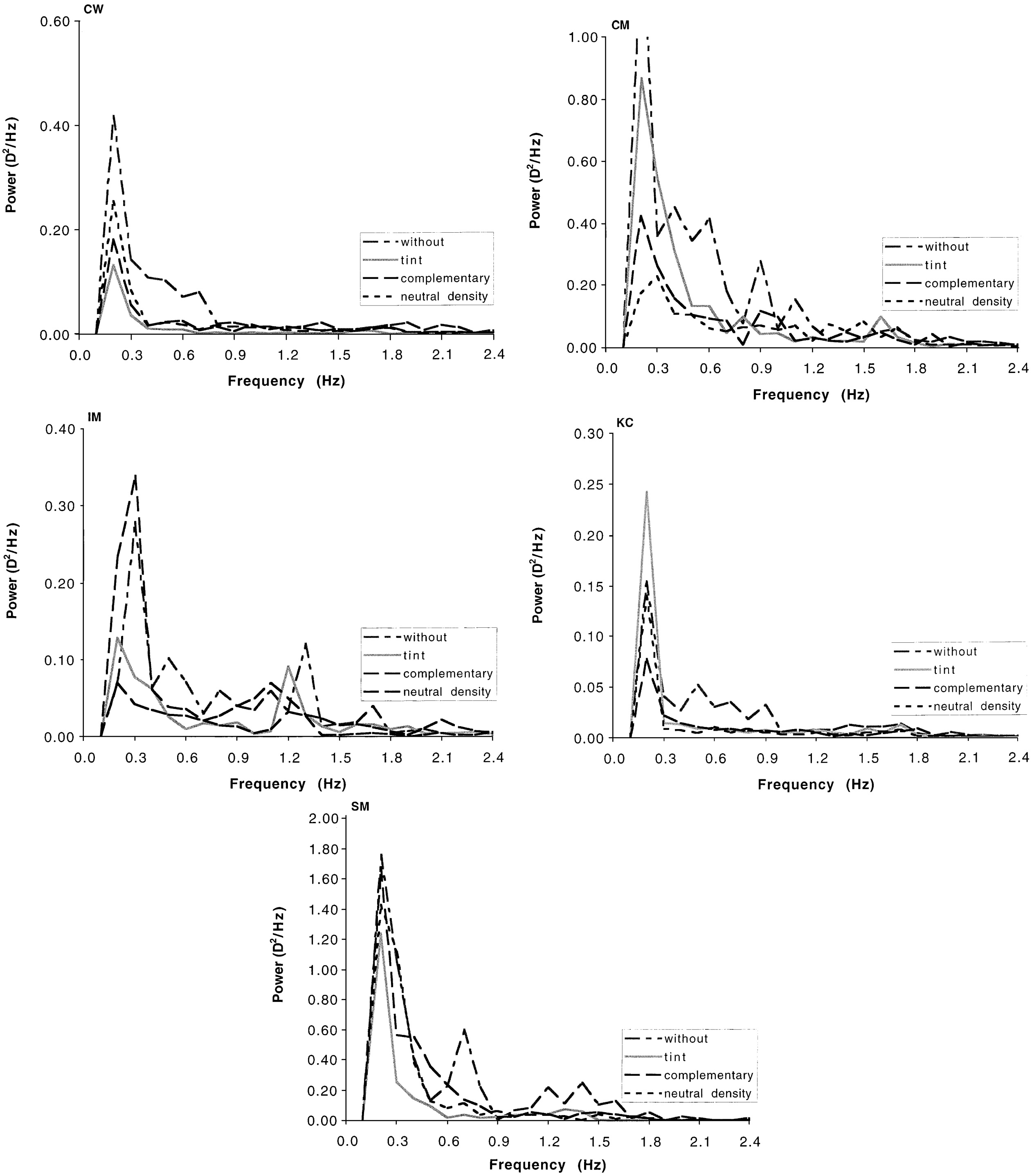

Fig. 6. Cumulative power spectra for the different viewing conditions in individual visual stress subjects. Each plot represents the average of ten power spectra for each viewing condition. Increases in the low frequency component can be clearly identified in the 'no lens' condition (- .-.-.-. .) while the high frequency component is seen to be relatively constant for the remaining viewing conditions.

different viewing conditions. No significant difference was demonstrable in either the LFC ($P = 0.8$) or HFC ($P = 0.9$) for the normal subject group.

Variations in pupil diameter between the different viewing conditions, were no greater than 1–1.5 mm in the viewing eye at all times in every subject.

3.4. Dynamic accommodation responses

Typical accommodative traces are shown in Fig. 8 and are consistent with previous reports on accommodative dynamics (O'Neil & Stark, 1968; Tucker & Charman, 1979).

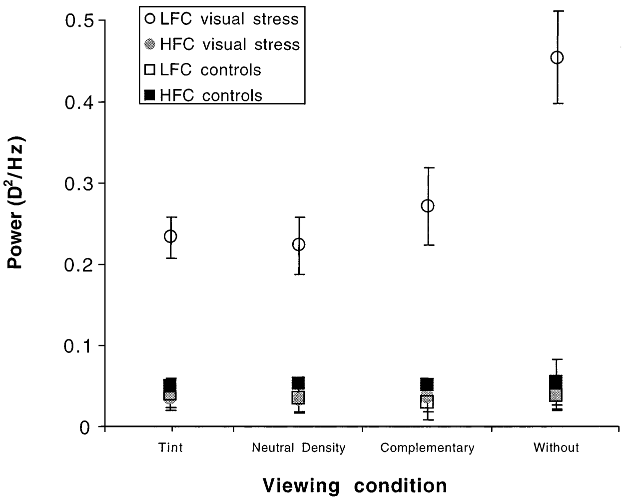

Fig. 7. Mean power in the low frequency (open symbols) and high frequency components (filled symbols) as a function of viewing condition for both subject groups. Each point represents the mean of ten power spectra and is calculated for the LFC by the three frequency bins encompassed by the range 0.3–0.6 Hz and the HFC by the area under the power spectrum in the three frequency bins centred round this peak frequency bin. Error bars represent ± 1 S.D.

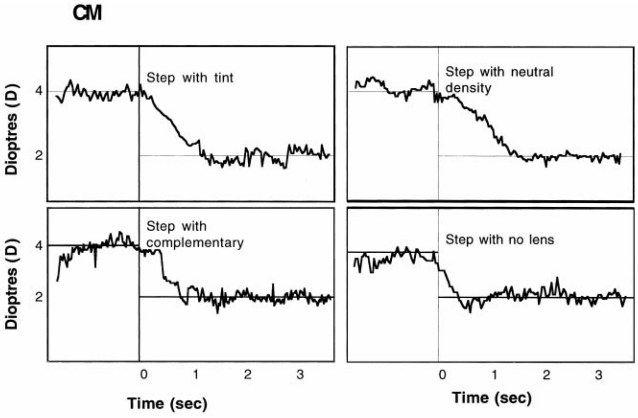

Fig. 8. An example of typical accommodation traces for subject CM in the four viewing conditions, for near-to-far (4–2 D) target modulation. Zero time indicates the introduction of a step change in stimulus vergence.

Table 2
Mean reaction times (seconds ± S.D.) for each of the four viewing conditions in the visual stress subject group

Step modulation (D)	Tinted	Complementary	Neutral density	No lens
3.5–2.5	0.42 ± 0.11	0.42 ± 0.19	0.38 ± 0.18	0.47 ± 0.14
2.5–3.5	0.32 ± 0.16	0.40 ± 0.14	0.34 ± 0.12	0.47 ± 0.12
4–2	0.41 ± 0.16	0.41 ± 0.12	0.39 ± 0.11	0.43 ± 0.14
2–4	0.33 ± 0.18	0.39 ± 0.18	0.38 ± 0.15	0.37 ± 0.12

Table 3
Mean response times (seconds ± S.D.) for each of the four viewing conditions in the visual stress subject group

Step modulation (D)	Tinted	Complementary	Neutral density	No lens
3.5–2.5	0.83 ± 0.12	0.83 ± 0.12	0.86 ± 0.11	0.86 ± 0.11
2.5–3.5	0.80 ± 0.11	0.75 ± 0.12	0.86 ± 0.20	0.81 ± 0.13
4–2	0.89 ± 0.12	0.83 ± 0.13	0.84 ± 0.10	0.81 ± 0.09
2–4	0.85 ± 0.10	0.82 ± 0.11	0.83 ± 0.15	0.80 ± 0.11

3.5. Reaction time

The mean and S.D. of the reaction times for each of the four viewing conditions with different target vergence modulations are shown in Table 2. ANOVA revealed no significant effect of either viewing condition ($P = 0.1$) direction of stimulus ($P = 0.6$) or accommodative stimulus magnitude ($P = 0.7$).

3.6. Response time

The mean response times for each viewing condition and the two step directions are shown in Table 3. ANOVA revealed no significant interaction between either viewing condition ($P = 0.2$) direction of response ($P = 0.5$) or accommodation stimulus ($P = 0.6$).

Reaction and response times in all four viewing conditions are consistent with previous reports of accommodation dynamics. The reaction time was approximately 0.81 ms independent of step size, and produced a completed accommodative response in about 1 s.

4. Discussion

Examination of the steady-state accommodation stimulus–response curve revealed that individuals prescribed tinted lenses can produce accurate steady-state accommodation responses, confirming both previous clinical (Evans et al., 1995, 1996) and experimental observations (Ciuffreda et al., 1997). Although binocular and accommodative anomalies are often associated with the use of tinted lenses it would appear that these ocular motor anomalies are most likely a correlate of dysfunction rather, than the underlying physiological basis.

The increase in the magnitude of the microfluctuations in the 'no lens' condition can be attributed to changes in the power of the LFC (Fig. 7). It is evident that while there is no systematic change in the HFC as a function of viewing condition, the changes in the LFC parallel to those identified in the r.m.s. values showing an increased response variability in the 'no lens' condition. Therefore, although a steady-state level can be reached, it is subject to increased variation in the 'no lens' condition. This unstable response could indicate a failure of the blur feedback mechanism or simply a stress response. Response times, however remain unchanged by viewing condition (Tables 2 and 3) largely dismissing too high a gain in either the neural components of the feedback loop, or the motor output. Nevertheless, these results would appear consistent with the reported reduction in reading speed and the unpleasant somatic and perceptual side-effects these patients experience during a sustained reading task, although it would also be prudent to note that this experiment deals with non-textual conditions.

Accommodative microfluctuations are sensitive to changes in stimulus conditions and environment, with an increase in oscillations reported for both reduced target contrast (Ward, 1987), reduced illumination to levels below photopic and an increased depth of focus (Campbell & Robson, 1958; Gray, Winn, & Gilmartin, 1993a,b). These studies cannot explain the findings of the present study, with a *reduced* LFC and response variability in all three 'lens' conditions where illumination is reduced. It is also unlikely that the specific increase in LFC in the 'no lens' condition, is due solely to changes in respiration although some element of the low frequencies is respiration (Collins et al., 1995). Recently, significant changes in the amplitude and phase of visually evoked potentials (VEP) have also been reported in tinted lens wearers (Riddell, Wilkins, Zemori, Gordon, & Hainline, 1998), this may be explained by the variations in accommodation we have noted in this study. Changes in VEP's may reflect perceptual change.

Significant increases in the LFC of the accommodation microfluctuations while viewing the target in the 'no lens' viewing condition provide an objective indicator of visual change and may in these patients be a subtle indicator of visual stress. If the accommodative microfluctuations are indeed a result of central neurological control (Winn & Gilmartin, 1992; Collins et al., 1995) differences in the response characteristics may be expected, due to the abnormal sensory information reaching the accommodative controller in these patients. Previous studies (Westheimer, 1957; Gray et al., 1993b) have shown an increase in LFC with a reduction in luminance but only for luminances < 0.1 cd/m^2 (Gray et al.), although in this study the difference in the LFC appears to be produced by an attenuation of the luminance of the target, this luminance is still within the photopic range. The difference in accommodative response, therefore, appears attributable not to the colour specificity of the lens, but to the difference in luminance between the no lens condition and the remaining conditions. Colour specificity is not supported by this finding.

The types of perceptual distortions reported by the subjects in this study and associated with visual discomfort are similar to those illusions that have been shown to be caused by levels of blur comparable to that found in the 'no lens' condition. Fixation of certain high contrast patterns have long been known to produce intriguing visual illusions (Mackay, 1957a,b, 1958; Campbell & Robson, 1958), although these illusions have been extensively studied over the years there appears little consensus as to their origin. Induction of illusory features occurs in most individuals although significant differences in susceptibility severity are found between observers. It has been postulated that small eye movements and ocular aberrations are responsible for some of the illusions of motion (Mon-Williams & Wann, 1996), illusory effects have also been attributed to accommodative microfluctuations (Campbell & Robson; Gregory, 1993). Other illusions especially those of shape (rhomboid lattice) have no simple explanation in terms of peripheral factors. It has been proposed that cortical mechanisms (Mackay; Georgeson, 1976, 1980; Zeki, Watson, & Frackowiak, 1993) are involved although this has been recently refuted as the primary origin (Mon-Williams & Wann). Illusions of colour are often integrated with those of shape in a unitary percept and considerations of parsimony would suggest that illusions other than those of shape, for example motion also have cortical mechanisms.

Although previous proposals do not provide satisfactory explanations for these illusory phenomena, it could be hypothesised that in individuals who benefit from the use of tinted lenses, the perceptual distortions or if you prefer 'illusions' they experience may be attributed in part to the increased magnitude of the accommodative microfluctuations. Although, the LFC is often ascribed a neurological function, there is no evidence that it reflects more than a 'hunting' mechanism oscillating between the retinal (as opposed to the perceptual) thresholds of blur detection (Mon-Williams & Wann, 1996). Relevant to this present discussion, increased levels of defocus are well documented with the phenomenon of spurious resolution (Walsh & Charman, 1989; Smith, 1992). If these individuals are experiencing an unstable steady-state response it is conceivable that their illusions are based on the spurious resolution and contrast reversal of the image (Smith, 1992). Indeed seminal work on accommodation (Charman & Tucker, 1977; Walsh & Charman) has long attributed anomalous results to this phenomenon. Also an accommodation system that is constantly fluctuating, beyond the depth of focus would bring about a constant lateral motion of the retinal image (Mon-Williams & Wann), this confounded by the competing effects of small eye movements would strongly predispose to the dynamic shimmer reported by the visual stress subjects in this study.

In summary, the results of this study demonstrate the following;

- individuals using tinted lenses and reporting visual stress when the lenses are not worn can produce accurate steady-state and step accommodation responses;
- during attempted sustained focusing with no filter, the accommodation response demonstrates a large degree of instability, with a significant increase in the size of the accommodation microfluctuations;
- the increases in the magnitude of the fluctuations are mediated by significant increases in the LFC of the microfluctuations waveform. No systematic change in the HFC of the accommodation microfluctuations was observed as a function of viewing condition;
- these significant increases in the LFC of the accommodation microfluctuations while viewing the target in the 'no lens' viewing condition may be a subtle indicator of visual stress;
- the greater stability of sustained accommodation responses found with tinted lenses appears independent of the colour specificity of the lens, and may be related to the reduction in luminance.

The neural substrate of the increased fluctuations in accommodation cannot be determined from the results of this study, it may be postulated that either;

- a primary, sensory neural change in visual cortex, could precipitate changes in accommodation characteristics due to abnormal sensory visual information. Perceptual distortions could lead to a reduced quality of signal for the sustained accommodation response leading to an increase in magnitude of the fluctuations;
- however, it is possible that increased fluctuations leading to suprathreshold variations in retinal image blur may cause some of the perceptual distortions reported.

We believe that some combination of the above is likely although an improvement in our understanding of the neurophysiology of the mechanisms involved, will be required to identify precisely the disruptive effects of these increased fluctuations and/or perceptual illusions and the level at which they occur which in turn.

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