

Review Article

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Ocular Straylight Visual Cortical Processing and the Lived Experience of Visual Stress: Exploring a Potential Neuro-Optical Contribution

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ABSTRACT

Visual stress is characterised by visual discomfort and perceptual disturbance in response to particular visual stimuli and environments. Although its symptoms are increasingly recognised, the mechanisms underlying individual differences in susceptibility remain to yet be fully explored. Research has traditionally focused on the characteristics of visually stressful stimuli, including repetitive patterns and particular spatial frequencies, and on the possibility that these stimuli may trigger overstimulation of visual cortical processing. More recent research has broadened this perspective, identifying distinct dimensions of visual hypersensitivity that include brightness, repeating patterns, strobing and visually intense environments.

Ocular straylight represents a potentially relevant but perhaps less investigated aspect of this wider phenomenon. Straylight results from the scattering of light within the eye and produces a diffuse luminance over the retinal image, reducing contrast and contributing to disability glare. It is a well-established determinant of visual quality and can vary independently of visual acuity. However, the author has not been able to find existing research which has directly examined whether individual differences in ocular straylight are associated with visual stress or with the cortical responses associated with visual discomfort.

This narrative review considers the potential relationship between ocular straylight, visual cortical processing and the lived experience of visual stress. Existing evidence is examined across three related domains: the optical effects of intraocular light scatter, the neural mechanisms associated with visual discomfort and sensitivity to glare, and the phenomenology of visual stress and visual hypersensitivity. Although available evidence does not support the conclusion that straylight causes visual stress, it does, however, provide a plausible basis for investigating whether optical degradation of the retinal image may interact with individual differences in cortical processing to influence visual stress and the severity of the symptoms linked to this condition.

A neuro-optical model is proposed in which the experience of visual stress may arise from interactions between properties of the visual environment, optical characteristics of the eye and individual characteristics of visual cortical processing. This framework places the lived experience of visual stress at the centre of investigation while recognising that similar symptoms may arise through different combinations of optical and neurological factors. Future research should therefore examine ocular straylight alongside measures of visual hypersensitivity, the intensity of symptoms related to visual stress and cortical response rather than treating these phenomena as unconnected areas.

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Introduction

Visual stress is increasingly recognised as an important aspect of visual experience, particularly for people who report discomfort, perceptual disturbance or difficulty when reading and engaging with challenging environments such as brightly-lit areas, patterned wall and floor décor, and so on. The reported experiences are diverse. Individuals may describe text appearing to move, blur or distort, while others may report visual fatigue following sustained reading, as well as headaches; sensitivity to bright light, discomfort from repetitive patterns.

For those experiencing these symptoms, the consequences can extend well beyond the visual task itself. Reading may become draining, prolonged visual work may lead to fatigue and particular environments may be actively avoided. In educational and occupational settings, these experiences may affect learning progression, participation and performance. The subjective nature of such symptoms has historically presented a challenge to researchers and clinicians, particularly where conventional measures of visual acuity may not accurately capture the difficulties being described.

The scientific literature concerning visual stress has developed considerably over recent decades. Research by Wilkins and colleagues identified an association between visual stress and perceptual distortions induced by repetitive patterns, particularly patterns with spatial characteristics around 3 cycles per degree

[1]. Subsequent work has explored the relationship between visual discomfort, visual cortical activation and the statistical characteristics of visual stimuli [2-4]. More recently, research has sought to conceptualise visual hypersensitivity as a multidimensional phenomenon rather than a single response to a particular class of visual stimulus [5].

This developing literature raises an important question. If visual stress is influenced by the interaction between the characteristics of a visual stimulus and the way that stimulus is processed by the visual system, should greater attention also be given to the quality of the optical image that reaches the retina? One potentially relevant factor is ocular straylight. Straylight is produced by the scattering of light within the eye. It is an established component of the optical quality of vision and contributes to disability glare by producing a diffuse luminance over the retinal image and reducing contrast [6-8].

There is currently no evidence sufficient to establish straylight as a cause of visual stress. The proposition considered here is more cautious: could individual differences in the way straylight is processed contribute to the experience of visual stress in some people, either independently or through interaction with differences in visual cortical processing?

This question is particularly relevant when considered alongside the lived experience of people with visual stress. Brightness and glare are frequently reported as problematic visual conditions, yet the research literature on visual stress has historically placed greater emphasis on patterns and text than on optical factors affecting the retinal image.

The purpose of this review is therefore to bring these strands of research together and identify a research outline which could subsequently be tested to evaluate whether ocular straylight represents one component of the complex experience described as visual stress.

Visual Stress as a Lived Experience

A useful starting point for research into visual stress is the experience itself.

People reporting visual stress do not generally describe their difficulties when they attempt to engage with visual information. These descriptions may include visual distortions, movement or instability of text, difficulty maintaining visual attention, discomfort, eyestrain, headaches, light sensitivity and fatigue. Such symptoms can vary considerably between individuals and may also vary according to context. This heterogeneity is increasingly reflected in the research literature. Reviewing the Pattern Glare Test, described visual perceptual distortions associated with particular striped patterns and noted increased susceptibility among people with migraine and those reporting visual stress [9]. More recent research has questioned whether pattern-related sensitivity should be regarded as synonymous with visual hypersensitivity more broadly.

Examined a large qualitative dataset and identified four distinct but related dimensions of visual hypersensitivity: brightness, repeating patterns, strobing and visually intense environments [5]. Their findings are particularly relevant to the present discussion because they suggest that sensitivity to brightness patterns may represent related but distinguishable aspects of visual experience. When considering straylight, this distinction becomes meaningful. In fact, if all visual stress occurred as a response to repetitive patterns,

there would be relatively little reason to investigate optical light scatter. If, however, visual hypersensitivity also encompasses sensitivity brightness and glare sensitivity, then ocular factors related to light processing should be evaluated in more detail.

Ocular Straylight and the Quality of the Retinal Image

As the optical system of the eye does not transmit light perfectly, when light passes through the cornea, lens and other ocular structures, light is scattered and is known as ocular straylight. In optical terms, straylight represents the large-angle, low-intensity component of the eye's point-spread function, distinct from the central component associated more closely with optical deviations and image sharpness [8].

The distinction is important because straylight is not simply another form of blurred vision. Instead, scattered light can spread across the retina and create what is commonly described as a veiling luminance, an occurrence which reduces the effective contrast of the retinal image and can obscure visual information, particularly in the presence of a bright source elsewhere in the visual field [7]. The relationship between straylight and visual acuity is also important. Straylight and visual acuity represent different aspects of visual quality and can vary relatively independently [11, 12]. Consequently, a person may have relatively good conventional visual acuity while experiencing challenges associated with glare. This is an interesting connection which could be relevant to visual stress because normal visual acuity does not necessarily imply normal visual comfort.

Straylight Glare and the Experience of Brightness

The term "glare" encompasses more than one phenomenon: While disability glare refers primarily to the deterioration of visual performance caused by scattered light, discomfort glare, on the other hand, refers to the subjective experience of discomfort, annoyance, strain or pain associated with bright light or luminance differences. The distinction is important because the two phenomena are not necessarily explained by the same mechanism.

Straylight provides a well-established optical explanation for disability glare. It does not, however, fully explain why one person may find a light source extremely uncomfortable while another person exposed to the same light may not.

Research into discomfort glare suggests that neural processing may contribute to this individual variability. Used fMRI to compare people with high and low sensitivity to discomfort glare [13]. Participants who were more sensitive to glare showed increased activity in specific bilateral cortical regions, including the cuneus, lingual gyri and superior parietal lobules. Importantly, this difference was observed across several levels of glare, including levels that did not necessarily produce subjective discomfort. The authors proposed that individual differences in visual neuronal excitability might contribute to sensitivity to discomfort glare. This finding is particularly relevant to the question posed here, as it suggests that the subjective experience of light cannot necessarily be understood simply by measuring the amount of light entering the eye. The optical properties of the eye, in fact, may influence the visual signal, but the response to that signal is also influenced by the nervous system.

Visual Cortical Processing and Visual Stress

A substantial body of research has considered the role of the visual cortex in visual stress.

Wilkins' visual stress theory proposed that particular visual patterns

can produce excessive or inefficient cortical responses, resulting in perceptual distortions and discomfort [2]. This work developed from observations that certain repetitive patterns, particularly those around 3 cycles per degree, produce substantially greater perceptual disturbance in susceptible individuals than patterns with other spatial characteristics.

The Pattern Glare Test has subsequently been used to investigate this phenomenon. According to research, people who are susceptible to pattern glare report greater numbers of perceptual distortions when viewing particular striped patterns [9].

Furthermore, neuroimaging research provides additional support for the involvement of the visual cortex. Found that visually stressful striped patterns altered functional connectivity within the visual system, including connectivity involving the visual cortex [4]. The changes persisted beyond the period of stimulation, although the significance of this finding for everyday visual stress remains to be established.

Subsequently developed a mechanistic model linking visual discomfort to the way the visual cortex processes images whose spatial characteristics differ from those commonly found in natural scenes [15]. Their modelling work suggested that uncomfortable stimuli produce greater overall activation, less sparse neural responses and a less balanced distribution of activity across spatial orientations. The authors proposed that individual differences in the balance between excitation and inhibition could contribute to susceptibility to visual discomfort.

More recently, reviewed evidence supporting a neurological basis for visual stress and argued that perceptual distortions and discomfort associated with reading may arise from excitability within the visual cortex [16]. Taken together, these findings provide a credible basis for considering visual stress as involving central visual processing rather than being attributable exclusively to ocular or mechanical factors.

The Emerging Concept of Visual Hypersensitivity

The recent literature has also begun to move beyond the idea that visual discomfort is one homogeneous phenomenon. The Cardiff Hypersensitivity Scale developed by Price, Sumner and identified four factors: brightness, repeating patterns, strobing and visually intense environments [5]. The research was based on large datasets, including a qualitative dataset of 765 participants and multiple subsequent cohorts.

The significance of this study is important as not only does it provide empirical support for the lived experience that different visual conditions can provoke different forms of discomfort, but it also creates a conceptual framework in which optical factors such as straylight might be investigated without assuming that they explain all forms of visual stress.

In particular, it should be considered whether straylight might be more relevant to the brightness and glare dimensions of visual hypersensitivity than to susceptibility to repetitive patterns. This possibility has not yet been adequately tested, according to this literature review undertaken as part of this article.

A Potential Neuro-Optical Interaction

The central proposition of this review is therefore optical and cortical factors may interact to either cause or affect the severity of visual stress and their relationship may be evaluated on three

levels as follows:

- **The visual Environment:** Environmental stimuli, such as artificial lighting, glare, patterns, may trigger the symptoms associated with visual stress.
- **The Eye:** The optics of the eye transforms the visual stimuli, which can be impacted by intraocular straylight introducing additional luminance to the retinal image and reducing effective contrast.
- **The Brain:** The altered retinal signal is subsequently processed by the visual system. As visual information is processed differently in each individual, it could be suggested that some people may show stronger or less efficient cortical responses to particular stimuli.

The subjective experience may therefore arise from the interaction: Visual Stimulus × Ocular Optics × Cortical Processing × Individual Susceptibility

This framework should be further evaluated for consistency with the heterogeneous nature of visual stress.

Relationship Between Straylight and Visual Stress: Plausible but Unproven

There are several reasons why the hypothesis merits investigation. Firstly, according to existing research, straylight is known to alter the retinal image and its relationship with disability glare and visual quality is reported in academic literature [17,18].

Additionally, visual discomfort is known to involve more than the physical intensity of light. Individuals differ in their subjective response to glare and these differences have been associated with differences in visual cortical activity and visual stress research provides evidence that susceptibility to particular visual stimuli is associated with differences in cortical processing [4,13,15]. Finally, recent research suggests that brightness sensitivity represents a distinct dimension of visual hypersensitivity rather than merely another manifestation of pattern sensitivity [5]. These observations provide a logical basis for investigating whether optical light scatter might contribute to individual differences in visual discomfort. However it is important to note that these studies do not demonstrate a causal pathway from straylight to visual stress, as the direct evidence is missing, thus demonstrating a possible research gap which may offer an interesting exploration opportunity.

The 2026 Perspective: Visual Discomfort as a Cerebral Phenomenon

A particularly important recent contribution is the 2026 review by A Cerebral Basis for Visual Discomfort and Visual Stress [19]. The authors propose that visual discomfort may arise when certain characteristics of visual stimuli are processed inefficiently by the visual system, resulting in increased neural and metabolic demands. They explicitly distinguish visual discomfort from the more severe experiences described as visual stress while placing both within a broader framework of cerebral visual processing.

Importantly for the present argument, their discussion of glare acknowledges that disability glare is associated with intraocular light scatter, while discomfort glare involves a subjective response that may involve the visual cortex. They identify the relationship between these phenomena as an unresolved research question, which provides a particularly useful conceptual context for investigating straylight. Rather than positioning optical scatter

and cortical processing as competing explanations, it may be more productive to regard them as different stages of visual processing. The potential significance of this for people with visual stress will require to be assessed in greater details.

If some people with visual stress have an optical component to their symptoms, this could help explain why changes to the visual environment sometimes make such a substantial difference to their experience. For example, if an individual reports that reading becomes significantly more difficult in bright or reflective environments, there may be several possible explanations, such as:

- The problem might relate primarily to the characteristics of the text.
- It might relate to cortical sensitivity to repetitive spatial patterns.
- It might involve sensitivity to brightness.
- It might involve ocular optics.
- It might reflect an interaction between several of these factors.

Based on the research reviewed in this article, clinical and research approaches do not appear to allow these possibilities to be separated. This is particularly significant because visual stress is often discussed in terms of the stimulus rather than the complete visual system through which that stimulus is experienced. A suggested more comprehensive approach should consider the stimulus, the eye, the brain and the individual's reported experience.

Implications

Reading provides an especially relevant context for investigating this interaction, as text has complex spatial characteristics. Rows of words create repeated horizontal structures, while the letters themselves contain repeated vertical and horizontal components. Research has demonstrated that text and repetitive patterns can produce perceptual distortions and discomfort in susceptible individuals [2]. At the same time, reading usually occurs within an environment rather than in isolation, and this means that the reader may be exposed to artificial lighting, glare, screen luminance, high contrast, patterns and more, resulting in prolonged visual stimulation.

The experience of reading may therefore reflect an interaction between the characteristics of the text and the conditions under which it is viewed. This provides an important reason to investigate optical factors such as straylight alongside established measures of visual stress, as it may also help explain why an individual can report substantial challenges in one reading environment but considerably less difficulty in another. Educational implications also merit particular attention, given that visual stress may interfere with core learning activities, particularly reading and screen-based tasks.

Where visual discomfort is persistent, the consequences may extend beyond the immediate symptom. Individuals may reduce reading time, avoid particular tasks, experience fatigue or develop strategies to minimise exposure to visually demanding material. This is further validated by recent literature which recognises that visual discomfort can affect cognitive performance and participation and that environmental modifications may have a role in reducing unnecessary visual stress [18]. This supports an important shift in perspective: rather than solely focussing on whether an individual experiences a particular visual condition, it would be interesting to also explore the way in which the visual environment characteristics impact the person's visual system.

If optical factors contribute to individual differences in visual discomfort, environmental accessibility may need to consider not only colour, contrast, pattern and lighting design, but also the interaction between those environmental characteristics and the optical properties of the individual eye.

Limitations and Alternative Explanations

It is important to note that there are several limitations which need to be taken into account.

Firstly, as part of this research, it was not possible to find any direct evidence demonstrating that people with visual stress have elevated ocular straylight. Furthermore, straylight increases with age and is influenced by ocular factors including the crystalline lens and corneal conditions [11,17]. Age and ocular health would therefore need to be carefully controlled in any study. A conceptual distinction between disability glare and discomfort glare should be highlighted. A person may experience substantial discomfort without measurable impairment of visual performance, while another may experience significant disability glare without reporting equivalent discomfort.

Similarly, increased cortical activity should not automatically be interpreted as pathological "hyperexcitability". Neuroimaging measures such as BOLD signal provide indirect measures of neural activity, and their interpretation requires caution.

Finally, visual stress itself appears to be a heterogeneous and incompletely defined construct. A 2025 study developing the Ulster Visual Stress Questionnaire noted the absence of universally accepted diagnostic criteria and identified several symptom dimensions potentially associated with different underlying mechanisms. These limitations reinforce the need for a multidimensional research approach.

Conclusion

Based on the literature research undertaken as part of this article, which may not be exhaustive, it can be concluded that the experience of visual stress cannot be reduced to a single symptom or to a single mechanism. Research has established that certain visual stimuli can provoke perceptual distortions and discomfort, that susceptibility varies substantially between individuals and that visual cortical processing is likely to play an important role. More recent work suggests that visual hypersensitivity encompasses several dimensions, including sensitivity to brightness, repetitive patterns, strobing and visually intense environments.

Ocular straylight represents a separate but potentially relevant aspect of this picture.

Straylight is a well-established optical phenomenon. By scattering light within the eye, it can reduce retinal image contrast and contribute to disability glare. Its effects are sufficiently distinct from visual acuity that conventional measures of visual acuity cannot be assumed to capture its impact on visual experience. The unresolved question is whether this optical alteration of the visual signal has any meaningful connection with visual stress.

The existing evidence provides a plausible basis for investigation. Research into discomfort glare demonstrates that people who are more sensitive to glare can show stronger responses in visual cortical regions. Research into visual stress similarly identifies differences in cortical processing associated with visually stressful stimuli. The recent literature increasingly views visual discomfort as an interaction between properties of the visual stimulus and

individual characteristics of visual processing, thus suggesting that straylight could potentially form part of that interaction. Based on the literature reviewed as part of this article, it can be concluded that ocular straylight should be considered a potentially relevant optical factor within a broader neuro-optical model of visual discomfort and visual stress.

Future research combining measures of ocular straylight, visual hypersensitivity, visual-stress symptoms and cortical response could determine whether optical scatter contributes to visual stress, whether it is relevant only to particular subgroups or whether the relationship is not relevant or important. Investigating the question would contribute to a more complete understanding of visual stress by bringing together four elements that have too often been considered separately the visual environment, the eye, the brain and the lived experience.

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