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The subtypes of visual hypersensitivity are transdiagnostic across neurodivergence, neurology and mental health☆

Alice Price *, Petroc Sumner, Georgina Powell

School of Psychology, Cardiff University, Cardiff, UK

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ABSTRACT

Many areas of neurodivergence are associated with heightened sensitivity, discomfort, and aversion to certain visual stimuli (e.g., bright lights, patterns, movement, flicker, complex scenes). This hypersensitivity also associates with mental health and some areas of neurology. However, it remains unclear whether this is a transdiagnostic phenomenon, implying a common underlying mechanism of shared vulnerability, or whether the forms of visual discomfort differ instructively across the wide range of associated conditions and areas of neurodivergence. We compared the four recently clarified subtypes of visual hypersensitivity (Brightness, Pattern, Strobing, Intense Visual Environments) self-reported by 2582 participants across 11 areas of neurodivergence, neurology, and mental health: Autism, ADHD, Dyslexia, Dyspraxia, Fibromyalgia, Migraine, PPPD, synaesthesia, Distress, Eating Pathology, and Fear (HiTOP System). Enhanced sensitivity in all four factors was reported for every area. Sensitivity to Intense Visual Environments was especially pronounced across Autism, ADHD, Dyslexia, and Dyspraxia, forming a shared pattern. The same pattern was shared with fibromyalgia and PPPD, and to some extent with Eating Pathology and Fear, while migraine and synaesthesia showed a different pattern. Regression analyses controlling for comorbidities showed significant unique prediction by 9 out of 11 neurodivergence/condition labels, the strongest predictors being autism, fibromyalgia, migraine, and PPPD. In conclusion, the four factors of visual hypersensitivity are all transdiagnostic, and the relative emphasis on each factor also forms transdiagnostic patterns that transcend traditional discipline boundaries. This implies there are common underlying vulnerabilities in the development of perceptual systems that can be associated with a wide range of other symptomologies.

1. Introduction

A feature of functional visual processing in many areas of neurodivergence is heightened sensitivity, discomfort, and aversion to certain visual stimuli, such as bright lights, patterns, flicker, movement or complex scenes. This sensitivity has been reported across autism (e.g., Parmar et al., 2021), attention deficit hyperactivity disorder (ADHD; Kamath et al., 2020), dyslexia (Singleton & Trotter, 2005), dyspraxia (Mayes, 2022), and synaesthesia (Ward et al., 2017).

Interestingly, this visual discomfort also associates with mental health diagnoses including disorders of anxiety (Digre & Brennan, 2012), depression (Qi et al., 2019), post-traumatic stress disorder (PTSD; Engel-Yeger et al., 2013), eating disorders (Kinnaird et al., 2020), obsessive compulsive disorder (OCD; Lewin et al., 2015), and areas of neurology including migraine (Marcus & Soso, 1989), epilepsy (Radhakrishnan et al., 2005), fibromyalgia (Ten Brink & Bultitude, 2022), traumatic brain injury (de Sain et al., 2023), persistent postural perceptual dizziness (PPPD; Powell et al., 2021), and Tourette's syndrome (Ludlow & Wilkins, 2016). In some diagnoses, such visual sensitivity appears at an early age and predicts later mental health outcomes (Lewin et al., 2015; Qi et al., 2019).

However, it remains unclear whether this is a truly transdiagnostic phenomenon, implying a widespread common underlying mechanism of shared vulnerability in brain development, or whether the forms of visual discomfort differ instructively across the wide range of neurodivergences and conditions in which it has been reported. Answering this question is central for advancing our understanding of the relationships between areas of neurodivergence, their shared and different vulnerabilities, and their associations with mental health challenges.

It is not yet established whether different types or subtypes of visual

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* Corresponding author.
E-mail addresses: PriceAJ6@cardiff.ac.uk (A. Price), SumnerP@cardiff.ac.uk (P. Sumner), PowellG7@cardiff.ac.uk (G. Powell).

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discomfort present across different conditions and neurodiversity dimensions, due to differences in focus and methodology in previous research (e.g., Parmar et al., 2021; Qi et al., 2019), as well as the wide range of potential triggers anecdotally reported. It is important to emphasise that hypersensitivity defined by visual discomfort is distinct from sensitivity in terms of detection or discrimination ability measured psychophysically. There appears to be no reliable correlation between the two (Schulz & Stevenson, 2021; Ward et al., 2017), but the implicit assumption has been made many times in the literature, confusing the field. For our purposes of examining the aversive perceptual experience, we must turn to self-report, rather than psychophysics.

Though several self-report measures of visual sensitivity exist, they often focus on specific aspects of the visual environment, omitting several triggers known to be problematic to those with high visual sensitivities (e.g., pattern sensitivity is absent from the AASP and GSQ; Brown & Dunn, 2002; Robertson & Simmons, 2013). In a related study where we investigated a comprehensive range of triggers drawn from qualitative reports, existing questionnaires and feedback through piloting, we consistently found four factors of self-reported visual hypersensitivity (discomfort), as well as a general factor (Price, Sumner, & Powell, 2025). The four factors are Brightness (e.g., sunlight, bright ceiling lights), Patterns (e.g., stripes), Strobing (e.g., temporal changes such as screen motion or flashing), and Intense Visual Environments (IVE; e.g., supermarkets, traffic, crowds). They can be measured and defined by the Cardiff Hypersensitivity Scale (CHYPS; Price, Sumner, & Powell, 2025). There is some reason to expect these factors may be differentially exacerbated in different areas of neurodivergence. For example, in dyslexia, discomfort to stripes has been emphasised due to the grating-like nature of text (Evans, Cook, Richards, & Drasdo, 1994; Nandakumar & Leat, 2008).

Further, a divergence between patterns of visual hypersensitivity might be predicted from the diverging approaches to current causal theories. One main theoretical approach concerns hyper-excitability of visual cortex, which may map onto the three factors of visual hypersensitivity describing basic features: Brightness, Strobing, and Pattern. A second major theoretical approach concerns networks of emotional and attentional regulation and information integration. This may map onto the fourth factor, describing situations that are intense overall, but not necessarily in one specific visual feature.

The first theoretical approach arose from vision-based and neurology-based literatures and has been used prominently for diagnoses such as dyslexia (Hancock et al., 2017; Nandakumar & Leat, 2008), epilepsy (Radhakrishnan et al., 2005), migraine (Wilkins et al., 2021), traumatic brain injury (TBI; Thielen et al., 2023), and PPPD (Powell et al., 2021), and has often focussed on visual features such as brightness (photophobia), flicker, motion, and stripes.

This body of work would appear to align with the three feature factors of visual hypersensitivity (Brightness, Strobing, and Pattern). These factors have tempting mapping to known properties of neuronal populations in visual cortex, as well as models of excitation and inhibition in local cortical circuitry (e.g., Orekhova et al., 2019; Radhakrishnan et al., 2005). For instance, many stimuli known to be problematic (e.g., patterns, flickering or bright lights) deviate from the statistical properties found in natural environments in terms of temporal frequency or spatial frequencies and orientations (Juricevic et al., 2010; Yoshimoto et al., 2017). These stimuli evoke large metabolic and electrophysiological responses in visual cortex (Huang et al., 2003; Orekhova et al., 2019), sometimes reported to be larger still in those susceptible to discomfort (e.g., individuals with migraine; Huang et al., 2003).

Thus, a theoretical framework has developed in which the visual cortex is vulnerable to over-excite with stimuli that deviate from natural properties, and for some people this vulnerability is enhanced developmentally (for reasons unknown) or due to brain trauma (see Ward, 2019; Wilkins, 1995 for reviews). Relative vulnerability for different visual features might then change according to diagnoses; for example, light, flicker and motion are commonly researched in migraine and TBI (e.g., Diel et al., 2021), while for dyslexia, striped patterns have been emphasised (Evans, Cook, Richards, & Drasdo, 1994; Nandakumar & Leat, 2008), as mentioned above.

Other disciplines start from a very different theoretical perspective, emphasising influences on perceptual experience from outside the visual system itself. For example, research in PTSD and anxiety emphasises emotional regulation, arousal, defence mechanisms and hypervigilance (Fleming et al., 2024; Kimball, 2023) with some emphasis on overwhelm to cluttered and complex environments such as supermarkets (Parmar et al., 2021; Robertson & Simmons, 2018). This appears to map onto the fourth factor of visual hypersensitivity, Intense Visual Environments (IVE), which captures sensitivities triggered by these kinds of setting.

However, the picture is complicated by the fact that the IVE factor also appears to feature strongly in symptom descriptions in some neurological conditions such as PPPD (the condition has also been known as ‘supermarket syndrome’ due to supermarkets being a commonly reported triggering environment; Staab et al., 2017). This may imply little or no distinction between neurological conditions and mental health in terms of visual sensitivities. Indeed, it is well established that PPPD is commonly associated with anxiety (Popkirov, Staab, & Stone, 2018; Powell et al., 2020b; Staab, Rohe, Eggers, & Shepard, 2014).

We therefore set out to discover whether the four factors of visual hypersensitivity are transdiagnostic or differentially associated with certain conditions, areas of neurodivergence, or domains. One specific question we aimed to clarify is whether the ‘feature factors’ of Brightness, Pattern, and Strobing associate more strongly with some areas of neurodivergence (such as synaesthesia and dyslexia) and certain neurological conditions (migraine), while IVE associates more strongly with other areas of neurodivergence and mental health conditions. To anticipate, we find aspects of this prediction (for migraine and synaesthesia), but more generally we find that all four factors show enhancement in every area of neurodivergence and condition tested, with an extra enhancement of IVE being the most common pattern.

We also needed to grapple with the widespread presence of comorbidities and correlations between areas of neurodivergence and mental health conditions, which is expected (Kessler et al., 2005; Krueger & Eaton, 2015; Spinhoven et al., 2014; Swinbourne & Touyz, 2007; Smitherman et al., 2013; Carmichael et al., 2019; Price et al., 2021). There is no perfect way to do this, because we remain partially constrained by historic condition labels, while overlap is in the very nature of neurodiversity. For example, to regress out both anxiety and ADHD in analysing autism is arguably to lose the representation of key aspects of autism, given the common co-occurrence of these diagnoses (Hossain et al., 2020). Similarly, to regress out anxiety from PPPD is to lose a key aspect of the PPPD experience (e.g., Staab et al., 2014). The same conceptual dilemma applies across all the correlations between historic labels: does regression reveal or misrepresent? We return to this dilemma in Discussion. However, what a regression can do is represent what each specified label is uniquely contributing to the variance in reported hypersensitivities (in the current dataset, and relative to the other named categories included).

We therefore present the data both in raw form for each condition (z-scores against the general population), and after controlling for correlated labels (regression coefficients). The former provides a full picture of sensitivities present in people reporting that condition or area of neurodivergence, while the latter provides information on unique contributions of each named category to the reported sensitivities. Regression coefficients will also control for age, given its known relevance to both visual sensitivities (Evans & Stevenson, 2008; Ueno et al., 2019) and likelihood of self-identifying with some diagnoses (e.g., Simner, Ipser, Smees, & Alvarez, 2017; Ardeleanu et al., 2024).

To avoid creating too many regressors in the model, and to address very high correlations between some areas of mental health, we group relevant conditions according to the Hierarchical Taxonomy of

Psychopathology (HiTOP; Kotov et al., 2017). HiTOP is a hierarchically organized framework that conceptualizes psychopathology according to empirically derived spectra. Grouping our diagnoses in this way allowed us to reduce the collinearity in the regression model and additionally acknowledge the likely presence of dimensions which underlie these related diagnoses, despite not explicitly measuring them. This approach is only applied to mental health conditions.

2. Methods

2.1. Participants

The participant sample consisted of two cohorts:

2.1.1. Recruited via Prolific

The online research platform Prolific was used to recruit 797 participants, representative for UK age, sex and ethnicity as identified by the UK Office of National Statistics. Participants were compensated (£4.18) upon completion. In conducting online research, there is concern around ensuring participants are genuine, particularly when payment is involved (Pellicano et al., 2024). The Prolific server includes identity checks and has been found to have high data quality when compared to other online survey platforms (Douglas et al., 2023). However, we also removed participants ourselves who provided low-quality data; twenty-four participants were removed from analysis for responding incorrectly to simple checks of attention and/or comprehension. Ten participants were removed due to missing data. Open-text responses were also screened to ensure responses were not nonsensical in the context of the question. Of 765 remaining participants, 48.5 % identified as male, 50.3 % as female, and 1.2 % as another gender identity. Mean age was 45.8 (SD = 15.6), with a range of 18–88.

2.1.2. Recruited via HealthWise Wales (HWW)

Although the Prolific sample was representative for age, sex, and ethnicity, other biases will exist in any recruitment method; for example, a person who is willing and able to take hundreds of surveys per year (as is common on Prolific; Douglas et al., 2023) may be less likely to experience certain screen-based visual sensitivities (e.g., aversion to scrolling or to high- contrast text or pattern). Therefore, we also recruited by a second method (with different self-selection biases). We used a community health list in Wales (HWW), where participants are not compensated for their time (the advertised incentive is to improve health research in Wales), have an older demographic than Prolific users (e.g., Douglas et al., 2023; Hurt et al., 2019), and lower average digital literacy is required (the survey link is directly emailed). Volunteers in the community health list were emailed with an advert and link to participate in the survey; all materials were provided in English and in Welsh. The advert described the survey as investigating why some people experience visual sensitivities and others do not, and how this relates to other everyday experiences. The following text was included to emphasise the inclusivity of the study and help to limit self-selection biases: *"Everyone has a different sensory experience of the world, and therefore all HealthWise Wales participants over the age of 18 are welcome and encouraged to participate"*. We received 2500 responses. Exclusion criteria to maintain data quality were: completing less than half the survey (398), failing a comprehension check (67) or an attention check (101), incomplete responses for the visual sensitivity items (105) or implausible clinical diagnoses (12 participants reported 'yes' for every one of 20 listed conditions). The final sample for analysis consisted of 1817 participants. Mean age was 63 (SD = 13, range 18–97), 40 % identified as male, 59 % as female, and 0.6 % as another gender identity. Thirty individuals did not indicate their gender, and 62 participants did not provide their age.

In the combined sample of 2582, 43 % identified as male, 55.4 % as female, 0.8 % as another gender identity (1.2 % declined to provide information). Mean age was 58.1 (SD = 16.1), 2.4 % declined to provide age.

2.2. Measures and Procedure

Qualtrics survey was used to deliver all measures. Cardiff University's School of Psychology ethics committee provided ethical approval for all procedures.

2.2.1. Self-reported diagnoses

Alongside demographic information, participants were asked to indicate self-identification with, or diagnoses of, a range of clinical conditions and areas of neurodivergence. Space was also provided to indicate conditions not pre-specified.

2.2.2. Cardiff Hypersensitivity Scale – Visual (CHYPS-V)

The CHYPS-V is a 20-item questionnaire designed to measure four factors of subjective visual sensitivities: Brightness, Pattern, Strobing, and Intense Visual Environments (Price, Sumner, & Powell, 2025). Items ask about subjective sensitivities with a focus upon functional impact: e.g., *"I turn off or dim bright ceiling lights because they make my eyes or head feel uncomfortable"*. The measure shows good reliability (Cronbach's $\alpha = 0.94$; subscales $\alpha = 0.84$ (Pattern), 0.89 (Brightness), 0.88 (Strobing), 0.85 (IVE)), *Macdonald's* $\omega = 0.94$; subscales $\omega = 0.84$ (Brightness), 0.90 (Pattern), 0.88 (Strobing), 0.86 (IVE)). An initial comprehension question is included in the CHYPS-V, and participants were excluded from analysis if this was incorrectly answered twice.

2.3. Statistical analyses

CHYPS-V factors were assessed against participants' reported areas of neurodivergence or diagnoses. All analyses were completed using RStudio (R Core Team, 2022) and JASP (JASP Team, 2024). Due to high levels of comorbidity (see Supplementary Fig. S1 for associated phi coefficients), and to better align with dimensional models of psychopathology, some reported conditions were collapsed according to the HiTOP model (Kotov et al., 2017), using the subfactors of 'Internalizing'. Specifically, anorexia (n = 23), binge eating disorder (BED, n = 72), and bulimia (n = 19) were grouped into 'Eating Pathology'; OCD (n = 132), panic disorder (n = 100), agoraphobia (n = 1), and social anxiety (n = 270) were grouped under 'Fear'; depression (n = 526), GAD (n = 364), borderline personality disorder (n = 9), and PTSD (n = 177) were grouped under 'Distress'. We did not collapse any of the other reported areas of neurodivergence or conditions.

Analyses then focused only on areas of neurodivergence or diagnoses for which we had sufficient power (n > 23 based on power analysis for regression, stipulating $\alpha = 0.01$, power = 0.80, with a small effect size). This resulted in 11 groups: ADHD, autism, dyslexia, dyspraxia, Eating Pathology, Fear, Distress, fibromyalgia, migraine, PPPD, and synaesthesia. For clarity, comorbid diagnoses were not excluded, and thus participants can exist in multiple groups.

To investigate the patterns of visual sensitivities across these 11 groups, we calculated mean z-scores for each of the four CHYPS-V subscales, standardized against participants who reported no neurodivergence, condition, or clinical diagnoses (n = 1317).

In the second stage of analysis, we conducted four multiple regressions to assess the unique predictive ability of each group name upon each of the CHYPS-V subscales (forced entry method). Data met assumptions of normality (Kline, 2008) and homoscedascity (Osborne & Waters, 2003), and age was also included to control for its influence.

3. Results

Mean z-scores standardized against individuals reporting no clinical diagnoses are displayed in Fig. 1, where yellow represents the Brightness factor, pink represents Strobing, green represents Pattern and blue represents IVE. The main general result is that all four factors are

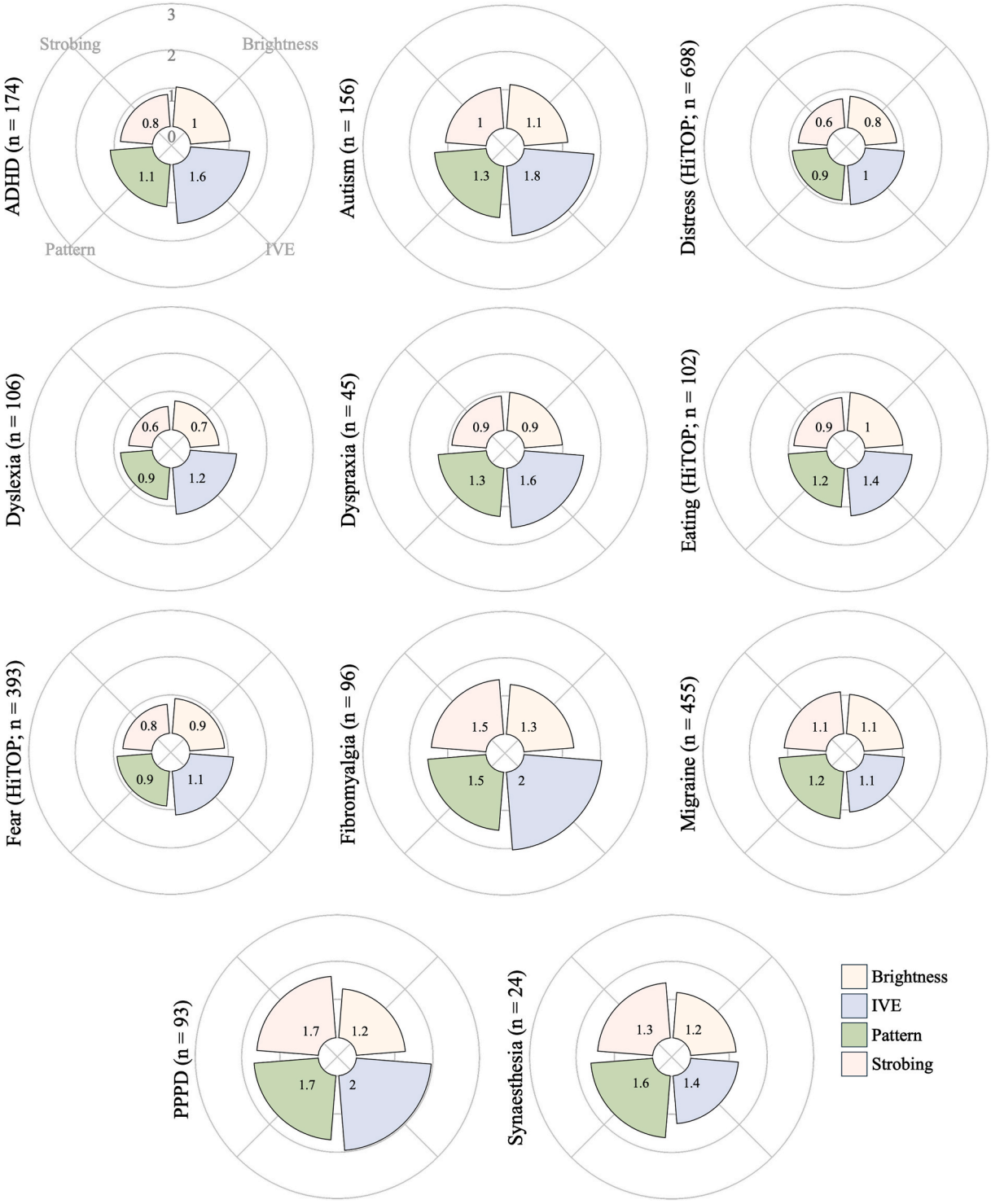

Fig. 1. For each self-reported area of neurodivergence or condition, z-scores for each factor of visual sensitivity are shown standardized against participants reporting no clinical diagnoses or neurodivergence (n = 1317), where a score of 0 would show comparable sensitivity to those reporting no diagnoses. Labels indicate raw z-scores for each CHYPS-V factor calculated against participants reporting no clinical diagnoses or neurodiversity (n = 1317). *Note. IVE = Intense Visual Environments, ADHD = attention deficit hyperactivity disorder, PPPD = persistent postural perceptual dizziness.*

enhanced, relative to the comparison participants, in every analysed area of neurodivergence, condition, or diagnosis.

The second general result is that there are only three main patterns of enhancement: IVE dominant, approximately isometric (all factors enhanced similarly) or Pattern dominant (and degrees in between). Therefore, it is not the case that many different patterns of visual sensitivity exist across these varied conditions or neurodivergences. For example, no group showed most enhancement in Brightness (even though brightness is the most common type of visual sensitivity question in the range of questionnaires in the literature). Notably, ADHD, autism, dyslexia and dyspraxia share a similar pattern where IVE is the most enhanced. This is also the case for fibromyalgia and PPPD, while Fear and Eating Pathology are more isometric but maintain a slight IVE bias. Distress and migraine appear more isometric still, while synaesthesia

shows the most enhancement in pattern sensitivity (arguably migraine is also Pattern-biased). Note that none of migraine, synaesthesia, Eating Pathology, Distress, or Fear showed a difference larger than 0.5 across factors.

Fig. 2 shows that even after grouping into HiTOP areas, there remained some substantial correlations (or co-occurrence) between several of the groups for neurodivergence and mental health (see Supplementary Fig. S1 for correlations before grouping). Table 1 therefore displays regression coefficients (unstandardized) representing the predictive value of each of the 11 group names for each factor of visual hypersensitivity, controlling for correlations with the others. Fig. 3 provides these coefficients graphically, to provide comparison against Fig 1. Each regression model was significant overall, as expected, showing significant variance in each visual sensitivity factor was accounted for by the self-reported conditions and areas of neurodivergence: Brightness, $F(12, 2506) = 37$, $R^2 = 0.15$, $p < 0.001$; Pattern, $F(12, 2506) = 44$, $R^2 = 0.17$, $p < 0.001$; Strobing, $F(12, 2506) = 39$, $R^2 = 0.16$, $p < 0.001$; IVE: $F(12,2506) = 50$, $R^2 = 0.19$, $p < 0.001$.

The main finding from the regression analyses is that most group labels still contribute to enhanced scores in visual sensitivity, in at least one factor. In other words, there are few groups where the enhanced sensitivity reported by participants was entirely accounted for by the participants also reporting other conditions/neurodivergences, and these tended to be for groups with lower N.

Specifically, we found significant increases in all four CHYPS-V factors for autism, fibromyalgia, migraine, PPPD and Distress. Additional significant increases in IVE were associated with ADHD, Dyslexia and Fear, with the latter also showing significant increase in Brightness. Synaesthesia was instead associated with increased Strobing and Pattern

Table 1
Unstandardized coefficients (with standard error) for the four multiple regressions used to assess the unique predictive ability of each diagnosis label upon each of the CHYPS-V subscales (forced entry method; significance at $p < 0.05$ is indicted by *). *Note. IVE = Intense Visual Environments, ADHD = attention deficit hyperactivity disorder, PPPD = persistent postural perceptual dizziness.*

	Brightness	Pattern	Strobing	IVE
ADHD	0.53 [.30]	0.37 [.24]	0.49 [.30]	0.65* [.18]
Autism	1.17* [.31]	1.21* [.25]	1.28* [.31]	1.36* [.19]
Distress	0.78* [.18]	0.76* [.15]	0.92* [.18]	0.44* [.11]
Dyslexia	0.36 [.35]	0.22 [.29]	0.09 [.35]	0.55* [.21]
Dyspraxia	0.10 [.54]	0.46 [.44]	0.15 [.54]	0.48 [.33]
Eating Pathology	0.69 [.36]	0.43 [.30]	0.62 [.37]	0.39 [.22]
Fear	0.66* [.22]	0.25 [.18]	0.34 [.22]	0.36* [.13]
Fibromyalgia	1.64* [.37]	1.44* [.30]	1.94* [.37]	1.70* [.22]
Migraine	2.13* [.18]	1.94* [.15]	2.32* [.18]	0.92* [.11]
PPPD	2.12* [.38]	2.35* [.31]	2.91* [.38]	1.78* [.23]
Synaesthesia	0.92 [.73]	1.42* [.59]	1.90* [.73]	0.11 [.44]
Age	−0.02* [.005]	−0.01* [.004]	0.02* [.005]	−0.01* [.003]

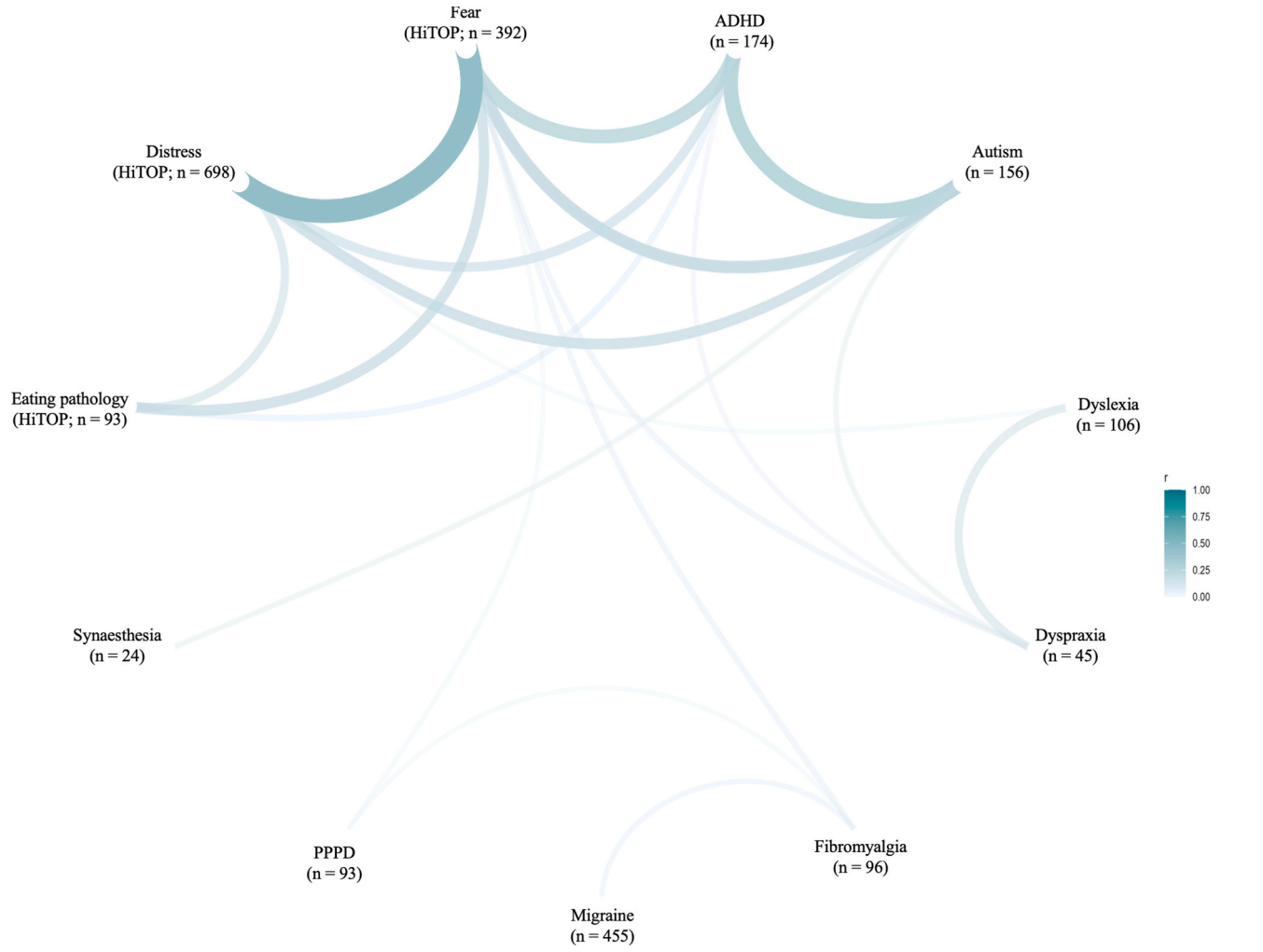

Fig. 2. Patterns of comorbidity across self-reported diagnoses following use of HiTOP model to collapse mental health diagnoses. Lines represent associated strength of phi coefficients. *Note. ADHD = attention deficit hyperactivity disorder, PPPD = persistent postural perceptual dizziness, HiTOP = Hierarchical Taxonomy of Psychopathology.*

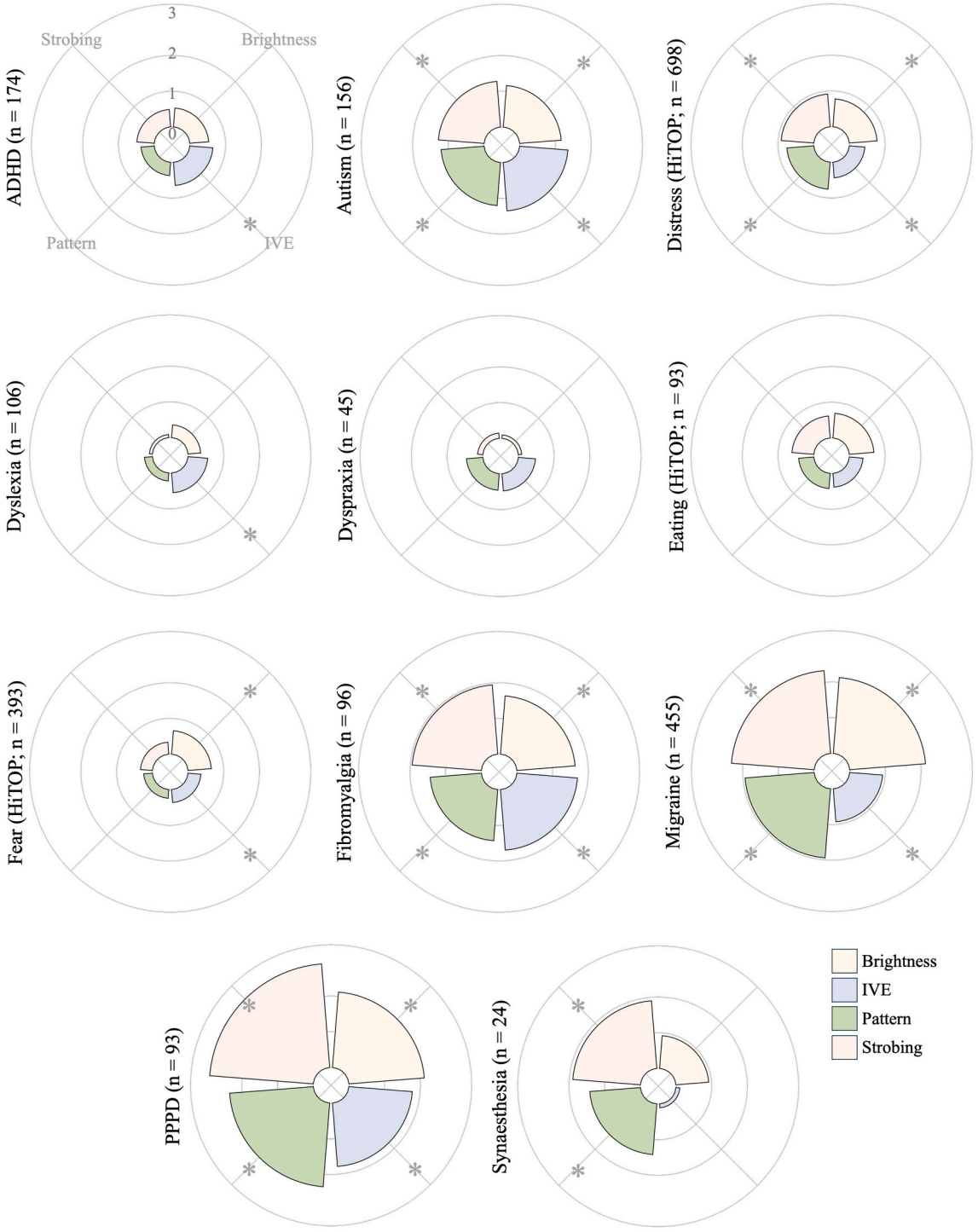

Fig. 3. For each self-reported area of neurodivergence or condition unstandardized regression coefficients are shown, taken from linear regression analyses for each factor of visual sensitivity showing the unique predictive ability of each diagnosis/neurodiversgence label (significance at $p < 0.05$ is indicted by *). *Note. IVE = Intense Visual Environments, ADHD = attention deficit hyperactivity disorder, PPPD = persistent postural perceptual dizziness.*

scores. Age showed small significant negative associations with Brightness, Pattern and IVE, and significant positive association with Strobing (see Table 1 for all regression coefficients).

It is clear that the regression coefficients are much stronger for some areas/conditions, which tend to be those with lowest correlations with other areas/conditions with which to share the variance: PPPD, fibromyalgia, migraine, synaesthesia (see Fig. 2). A notable exception is autism, which retains strong regression coefficients despite high correlation with ADHD, Distress, and Fear. Rather, it seems that for these latter three, a marked degree of the enhancement in visual sensitivity seen in Fig. 1 has been accounted for by autism (and each other) in the regression model. Dyslexia and dyspraxia were correlated and appear to have accounted for some of each other's enhancements. They also had correlations with Fear and Distress and suffered from lower N than these large groups in the model (where the N between two groups is very different, the comorbidity can be very asymmetrical, so a large degree of variance in the smaller group can potentially be accounted for even when the overall correlation between the groups is not high). The

relative emphasis on IVE is reduced for many charts, presumably due to its widespread shared variance across correlated conditions. Strobing showed the strongest regression coefficients for PPPD, migraine, fibromyalgia and synaesthesia, which had not been anticipated.

4. Discussion

The overarching finding of this work was that all four factors of visual hypersensitivity were enhanced across the traditional discipline boundaries of developmental neurodiversity, mental health, and neurology. Moreover, the relative emphasis on each factor was broadly similar across many areas of neurodivergence or clinical conditions. Sensitivity to Intense Visual Environments was especially pronounced for autism, ADHD, dyslexia, and dyspraxia, forming an apparently common shared pattern. The same pattern was interestingly shared with fibromyalgia and PPPD. A similar, but more isometric, pattern was also present for Fear, Distress, and Eating Pathology. Only migraine and synaesthesia showed a qualitatively different pattern, with pattern sensitivity as the quantitatively most enhanced factor rather than IVE.

Regression analyses controlling for co-occurrence of other conditions or areas of neurodivergence showed the unique contributions to the variance for each condition/neurodivergence name; the highest coefficients being associated with autism, fibromyalgia, migraine, and PPPD, which are reassuringly the conditions in the literature most strongly associated with visual hypersensitivities as a core experience or symptom conditions (e.g., Dorris et al., 2022; Friedman & De Ver Dye, 2009; Marcus & Soso, 1989; Parmar et al., 2021; Schulz & Stevenson, 2021; Ten Brink & Bultitude, 2022; Wilkins et al., 2021).

We now discuss the implications of this transdiagnostic finding, before more detailed discussion of the patterns for area of neurodivergence and other conditions, as well as the limitations of the regression analysis and other limitations of the work.

4.1. Two theories for aversive visual hypersensitivity?

One of the questions we set out to address was whether the two types of theory for aversive visual sensitivity would map onto two distinct patterns for the four factors. The first type of theory is hyper-excitability of visual cortex (Huang et al., 2003; O'Hare, 2017; Orekhova et al., 2019; Ward, 2019; Wilkins, 1995), which could predict enhanced aversive sensitivity to specific visual features processed in visual cortex – striped patterns, strobing and motion, or brightness. The second class of theory emphasises networks that extend beyond visual cortex: attention, emotion, the integration of top-down and bottom up or cross-modal information (e.g., Kimball, 2023; Ward, 2019; Zald, 2003). Such theories have been associated with experiences of overload in complex multisensory environments (e.g., Homberg et al., 2016), rather than aversion to specific types of visual feature. Thus, they would be expected to predict the strongest enhancement for the IVE factor (although the prediction must be nuanced because IVE, such as supermarkets, would also strongly activate early visual cortex).

In comparing the raw ratings to people reporting no condition or neurodivergence (Fig. 1), we did not find such a clear distinction. Rather, we found broad similarity across conditions and neurodivergences, regardless of the theories in each field. Moreover, the differences of degree that did exist were often not in the expected direction for the above theories: for example, IVE was not especially prominent in the Distress group where it would have been especially predicted (as the group contains generalised anxiety and PTSD). This transdiagnostic pattern may be taken to imply a common underlying vulnerability to aversive visual experience across a wide range of otherwise diverse symptomologies. Such a common underpinning may include elements of both types of theory: sensory cortex excitability and wider network differences.

However, migraine and synaesthesia show intriguing patterns that bucked the main trend. Sensitivity to each factor was similar in the z scores, with the Pattern factor numerically the most enhanced in both cases. In the regression, sensitivity to IVE was mostly or completely accounted for by other regressors (even though correlations with other conditions were not markedly high, Fig. 2). Coefficients for the Pattern and Strobing factors remained strong (and Brightness for migraine). These are the types of sensitivity associated most clearly with theories of excitation/inhibition balance in visual cortex, and deviation of stimuli from natural scene statistics.

Our data also allow no clear differentiation between conditions or areas where visual sensitivity has previously been regarded a cause of other symptoms (e.g., in autism; Feldman et al., 2024) and those where it has been regarded as a consequence (e.g., of emotional or physical trauma; de Sain et al., 2023; Fleming et al., 2024). A full understanding of how visual sensitivity might act as a risk factor in some cases, or a be a consequent vulnerability in others, will require much deeper investigation.

4.2. Visual sensitivity pattern in neurodivergence

There was a consistent pattern of higher IVE sensitivities across autism, ADHD, dyslexia, and dyspraxia. This is consistent with the autism literature where sensory overload is a common finding (Howe & Stagg, 2016; MacLennan, O'Brien, & Tavassoli, 2022; MacLennan et al., 2022; Parmar et al., 2021). There are a number of possible explanations for the specific relevance of this factor, associated as it is with multiple sources of visual input (crowds, supermarkets, clutter). For example, there is evidence to suggest reduced adaptation to numerate incoming stimuli in children with autism (Turi et al., 2015).

In the regression analysis autism showed strong coefficients for all visual sensitivity factors, but for ADHD, much of the variance was accounted for by comorbidity. ADHD and autism were strongly correlated in the data, and both were correlated with Fear and Distress (Fig. 2). Only IVE remained significant for ADHD. However, it is worth using the example of ADHD to emphasise the limitations of a regression analysis that attempts to control for comorbidity when comorbidity is an inherent feature of neurodivergence. As many as 70 % of adults with ADHD have a co-occurring diagnosis or area of neurodivergence (Piñeiro-Dieguez et al., 2016; Sobanski et al., 2007). The diagnosis of ADHD itself thus exists in the context of significant overlap with other concepts and symptoms, and controlling for the ones that happen to have a separate diagnosis name may change the conceptual nature of ADHD, removing something fundamental about how it generally presents. Thus, the regression should not be taken to represent ADHD better than the z-scores. It is the z-scores that represent the experiences of people with ADHD, while the regression does not represent any person's actual experience, but rather represents what the category name 'ADHD' uniquely contributes to the variance beyond the other category names included the same analysis (see Limitations section for further discussion).

It is notable that dyslexia showed a similar pattern to ADHD, with IVE emphasised in the z-scores, and being the only factor surviving regression. This occurred despite much lower correlation with autism in the data (Fig. 2). These results may appear to stand in contrast to existing work emphasising pattern and flicker in dyslexia. For example, discomfort triggered by flickering stimuli and repeating patterns is increased in children with dyslexia. However, much of this work on dyslexia (Kriss & Evans, 2005; Singleton & Henderson, 2007; Singleton & Trotter, 2005) has understandably focussed on reading speed or distortions during reading. Neither rule out strong sensitivity to IVE. Moreover, the Pattern factor of visual sensitivity is distinct from reading problems; items relating to reading consistently failed to load with this factor (Price, 2023; Price, Sumner, & Powell, 2025). Convergently, Saksida et al. (2016) report children with dyslexia show similar levels of visual sensitivity to striped patterns (measured by the Pattern Glare test; Evans & Stevenson, 2008; Wilkins, 1995) as other children, suggesting that distortions whilst reading are likely dissociable from aversive visual

sensitivities. It should be noted that all our dyslexic participants were all able to engage with an online questionnaire, and therefore we do not know what the pattern of results might have been for any not able to do so.

Dyspraxia showed the same pattern as other neurodivergences discussed above in the z-scores, and in the regression no coefficient reached significance; the variance was therefore mainly accounted for by comorbidity (the main correlation was with dyslexia). Dyspraxia also had relatively low N and asymmetrical comorbidity with Fear, ADHD, and autism (proportionally more people with dyspraxia reported autism, for example, than the proportion with autism that reported dyspraxia). Adults with developmental co-ordination disorder, of which dyspraxia is considered a subtype, have previously been found to score significantly higher in the visual hypersensitivity subscale of the GSQ (Mayes, 2022), in analyses where participants with co-occurring neurological or neurodevelopmental diagnoses were removed. Differences in methodology may influence these divergent findings; for instance, differences in diagnostic approach (confirmed diagnoses of DCD used by Mayes, 2022) versus self-reported dyspraxia, or in exclusion criteria (only co-occurring neurodevelopmental diagnoses were excluded by Mayes, whereas a range of conditions and neurodivergence were statistically controlled for here). It is possible that visual sensitivities are mainly explained by comorbid diagnoses in dyspraxia, as reported here, but further work is needed.

Fibromyalgia and PPPD are both neurological conditions that have been associated with, or considered under the umbrella of, functional neurological disorder (FND; Steinruecke et al., 2024; Teodoro et al., 2018; Trinidade et al., 2023). It is striking then how similar their results are to those of autism. Fibromyalgia has been associated with autism, as has FND generally (Cole et al., 2023) but PPPD has not, as far as we are aware. Both show correlation with anxiety symptoms, and it is often assumed that anxiety arises secondarily as a consequence of these debilitating disorders (e.g., Staab et al., 2017). Both have also been associated with migraine (Staab et al., 2017; Sarna et al., 2021; Vij et al., 2015), and some similarity between the results for PPPD and migraine can be observed here (they have the two highest coefficients for the Strobing factor).

Aside from the association with FND, PPPD has historically been considered a vestibular disorder, with visual sensitivities to motion and complex environments arising secondarily from maladaptive responses to vestibular insult (Staab et al., 2017). We have previously hypothesised that instead, PPPD arises due to an interaction of vestibular challenges with a pre-existing vulnerability to sensory hypersensitivities (Powell et al., 2020b, 2021; Powell, Derry-Sumner, Rajenderkumar, Rushton, & Sumner, 2020a). The strong enhancement of all visual factors in our data, not just those relevant for balance (motion and complex environments), would seem consistent with this hypothesis. We have previously shown raised visual sensitivities in PPPD to images with high spatial frequencies (Powell et al., 2021); this is the first study to confirm raised sensitivities for brightness even when controlling for relevant comorbid diagnoses such as migraine and anxiety.

4.3. Alternative visual sensitivity patterns

Although IVE was dominant for most areas of neurodivergence and clinical conditions, another pattern was evident in some. Synaesthesia is also considered a neurodivergence and is correlated with autism (both in literature and here; Ward et al., 2017), but the data showed a distinct pattern, more similar to that in migraine. These were the only two plots in Fig. 1 where IVE was not the most enhanced factor. Moreover, in the regression, IVE was mostly or entirely accounted for by comorbidities (note, though, the low N in our data for synaesthesia). As discussed above, this left Pattern, Strobing, and to some extent, Brightness, as the factors most strongly associated with synaesthesia and migraine. We are tempted to interpret this pattern as indicating strong visual cortex involvement. For example, discomfort in response to flickering light (conceptually covered by the CHYPS-V Strobing factor) correlates with evoked responses in early visual cortex (Gentile & Aguirre, 2020). While cortical hyperexcitability has been hypothesised to underlie both conditions/experiences, synaesthesia does not appear to show a straightforward correlation with migraine (Jonas & Hibbard, 2015). Therefore, more research is needed on this intriguing aspect of our results.

The HiTOP category of Distress groups together generalised anxiety (GAD), depression, and PTSD, all of which featured strongly and were strongly correlated in our dataset (see supplementary Fig. S1; it also includes borderline personality disorder and dysthymia, for which we had much lower numbers of reports). Both anxiety and PTSD have an extensive literature showing association with sensory sensitivity and experiences of overload (e.g. Engel-Yeger et al., 2013; Engel-Yeger & Dunn, 2011; Fleming et al., 2024; Homberg et al., 2016; Isaacs et al., 2020; Kimball, 2023; Lewin et al., 2015), but less specifically with certain features. From this literature, then, our prediction would have been for IVE dominance in the results for Distress. But interestingly, IVE was relatively less pronounced than in most other results, and after regression it was the three other factors for which Distress had the strongest predictive value.

This result, then, acts as a double dissociation with dyslexia, where the prediction was for association with visual features, and instead IVE came to the fore. Taken together, we clearly cannot simplistically map the more 'visual' conditions (e.g., dyslexia) onto the three feature factors, and mental health conditions onto IVE.

This result also demonstrates that anxiety is not the common factor explaining sensitivity in other conditions, even though many clinical diagnoses investigated here are known to associate with increased symptoms of anxiety (e.g., autism, Zaboski & Storch, 2018; ADHD, Schatz & Rostain, 2006; fibromyalgia, Alok et al., 2011; migraine, Lantéri-Minet et al., 2005; PPPD, Powell et al., 2020b). One aspect of previous literature consistent with a more isometric enhancement of factors in Distress is the association between migraine and depression, which are thought to share dysfunction in the serotonin system (Zhang et al., 2019), although they are only correlated weakly in our data.

The HiTOP category of Fear includes social phobia, panic disorder, and OCD (which feature strongly in our data, see supplementary Fig. S1), as well as other phobias such as agoraphobia and specific phobia (for which we had fewer reports). The category is highly correlated with Distress in our data, due to the high correlations of social phobia and panic disorder with GAD and depression. For similar reasons, we would have made the same prediction for emphasis on IVE: for example, individuals with panic disorder show increased sensitivity to complex stimuli like supermarkets and crowds (Asmundson, Larsen, & Stein, 1998). This was apparent in the z-scores, but less so in the regression where Brightness came to the fore. Although previous work has defined a relationship between flickering or patterned stimuli and conditions such as agoraphobia (Hazell & Wilkins, 1990), we do not have an explanation for the specific relevance of Brightness.

Eating Pathology showed a similar transdiagnostic pattern to Fear and several other conditions and areas of neurodivergence in the z-scores, but none of the coefficients was significant in the regression (it has lower N than Distress and Fear). The category groups together bulimia nervosa, anorexia and BED, which were actually not highly correlated in the raw data, consistent with previous reports (e.g., Eddy et al., 2008). However, this category is thought to represent underlying eating related pathologies associated with the HiTOP model.

Previous research has found cross modal sensory sensitivities to be present in individuals with anorexia and bulimia (Bell et al., 2017; Merwin et al., 2013; Zucker et al., 2013). The sensory differences of adults with BED have not previously been investigated. These analyses suggest that visual sensitivities are not uniquely increased when controlling for co-occurring conditions. This is particularly noteworthy given recent investigation which finds that increased autistic traits may be important to the experience of sensory sensitivities in anorexia (Kinnaird et al., 2020). It is possible that sensory differences might

manifest in other sensory modalities however, or, as recent hypotheses suggest, hypo-sensitivities may be present (Nimbley, Golds, Sharpe, Gillespie-Smith, & Duffy, 2022). As the CHYPS-V does not assess cross-modal or hypo-sensitivities, this is something we hope to investigate in the future.

5. Limitations

The tension between unmasking vs misrepresentation in regression had already been noted.

Comorbidity between symptoms in different traditionally-named areas of neurodivergence or clinical conditions is part of the intrinsic nature of neurodiversity and mental health presentations. This has both theoretical and practical consequences when attempting to 'control' for comorbidity in regression analyses. Theoretically, rather than revealing the nature of a hypothetical pure condition, one may be removing variance associated with key aspects of people's experience, and hence misrepresenting rather than revealing the nature of a condition.

The practical consideration is that, without a full dimensional symptom workup for each person, we could only use regressors where history has provided us with a name for a condition or neurodivergence, and this has been influenced by discipline boundaries. The influence of regressors with high cross-correlation may be somewhat unpredictable and unstable across different cohorts, especially when numbers are not large or are very different between groups (such as for Distress and dyspraxia, here, for example).

There are also advantages and limitations of our materials; of CHYPS-V as a questionnaire compared to other questionnaires. The advantage is that CHYPS-V is based on replicated factor analysis in large cohorts (Price, Sumner, & Powell, 2025), and was designed cover the full range of aversive visual sensitivity triggers beyond measures which focus on light or pattern specifically (e.g., Conlon et al., 1999; Cortez et al., 2019). It does not, however, measure hypersensitivities in other senses, or hyposensitivities. It also attempts to help people calibrate their answers by using functional questions (about avoiding certain stimuli, for example, rather than disliking them). However, such a strategy inevitably collapses across the concepts of behavioural avoidance and sensory experience, which may be a useful distinction, especially in children (Tavassoli, Hoekstra, & Baron-Cohen, 2014; Tavassoli et al., 2019). In adults, the subscales of sensory avoidance and sensory sensitivity in the AASP questionnaire are generally highly correlated (e.g., Price et al., 2021). CHYPS-V uses questions based on previous literature and on extensive qualitative reports by people experiencing hypersensitivity. For each subfactor, five questions were selected that loaded well on both the general factor and one subfactor, behaved consistently across cohorts, and referred to everyday situations most people would recognise and encounter. There are drawbacks to this data-driven approach. For example, the question *"I turn off or dim bright ceiling lights because they make my eyes or head feel uncomfortable*", dimming presents a potential difficulty because it can introduce flicker, even if imperceptible. However, we included dimming in the question due to the qualitative reports of this behaviour and our aim to provide relevant functional questions. Note that if the issue of flicker was a major confound for this question, it would have disrupted its loading on the Brightness factor and thus not have met our threshold for selection.

Lastly, there are limitations for any chosen cohort. Any recruitment technique contains biases. We combined two types of recruitment technique to attempt to ameliorate any specific biases associated with each technique. However, a general bias for digital literacy and willingness to read online questionnaires will apply, potentially ruling out people with high visual aversion to screens or reading. We also relied on self-identification for areas of neurodivergence and clinical conditions. The limitation is that we cannot confirm such reports. The advantages are that it allows for a large cohort and is inclusive for those that have not accessed formal healthcare. The survey was available worldwide for the Prolific cohort; health services are diverse, and some diagnoses can be difficult and time consuming to obtain (Hezel, Rose, & Simpson, 2022; Remschmidt & Belfer, 2005). The approach is consistent with recent inclusivity moves towards self-identification with clinical conditions or neurodivergence in research (Angulo-Jiménez & DeThorne, 2019; Hswen, Gopaluni, Brownstein, & Hawkins, 2019; Pavelko & Myrick, 2015; Ardeleanu et al., 2024). With the advent of dimensional models of psychopathology (Watson et al., 2022), it is possible that even if a given participant would not meet the DSM (American Psychiatric Association, 2013) defined diagnostic criteria, their self-identification may reflect experience of subclinical symptoms that are relevant to experiences of sensory sensitivity. However, given that it is also possible participants may be misdiagnosed or misinformed in this sample, results should only be interpreted in the context of self-report.

A further consequence of our recruitment was highly uneven group sizes across the areas of neurodivergence and conditions. These differences broadly reflect prevalence in the population, but they add difficulties for statistical comparison. For example, we did not use cluster analysis here because such analyses would be dominated by the larger groups and not reveal if there were distinct patterns in groups with smaller N amongst the data. There are also a number of diagnoses and areas of neurodivergence that could be theoretically relevant to sensory sensitivities but could not be investigated here due to lack of numbers. For instance, schizophrenia, bipolar disorder, substance-related disorders, and borderline personality disorder have all been associated with increased subjective sensitivities (van den Boogert et al., 2022). Similarly, epilepsy shows clear associations with visual sensitivities (e.g., Harding & Harding, 1999; Wilkins et al., 1979) and has important associations with possible mechanisms for visual sensitivity (e.g., investigated in pattern sensitivity; Hermes et al., 2017). This work could not investigate these groups.

5.1. Two recommendations for future research

The fact that brightness sensitivity was never the most enhanced factor could help distinguish the kind of cortical sensitivities investigated here from photophobia with causes in the retina or early visual pathways (Burstein, Noseda, & Fulton, 2019). Practically, the dominance of IVE in our data suggests that experiences in IVE (cluttered spaces, supermarkets, high visual motion environments), rather than questions about aversion to brightness, might be particularly useful in distinguishing visual sensitivity experienced by individuals with neurodivergence, mental health conditions or neurological conditions from those without.

Further, the transdiagnostic nature of visual sensitivity shown here supports recent proposals for a sensory domain to be incorporated into the dimensional Research Domain Criteria (RDoC) initiative, a multidimensional framework to understand psychopathology and guide associated research. Specifically, Harrison et al. (2019) argue that given the relevance of sensory processing (which includes sensory sensitivity, but additionally perceptual signalling or interoception) to a range of diagnoses, a sensory domain would be important for progressing understanding of mental health using this framework. This initial suggestion focused on autism, anxiety, depression, and OCD, which we would broaden to include neurodivergence in general, as well as relevant neurology. Similarly, recent study also finds empirical support for a novel 'Altered Sensation' subfactor (to include sensory sensitivities) in the HiTOP model (Forbes et al., 2024), which straddles traditional diagnoses, and which the current work would support. Cluster or network-based approaches may be particularly useful in future transdiagnostic work, to understand how patterns of sensitivity may present differently across sensory modalities and across individuals.

6. Conclusion

While there are four factors of visual hypersensitivity, they are all transdiagnostic, and the relative emphasis on each factor also forms

transdiagnostic patterns that transcend traditional discipline boundaries. We conclude there are common underlying vulnerabilities in the development of perceptual systems shared across areas of neurodivergence and with several psychiatric and neurological conditions.

Author Contributions.

Alice Price: Conceptualization, methodology, formal analysis, investigation, writing – original draft, reviewing and editing, visualization. **Petroc Sumner**: Conceptualization, methodology, writing – reviewing and editing, supervision. **Georgie Powell:** Conceptualization, methodology, writing – reviewing and editing, supervision.

CRediT authorship contribution statement

Alice Price: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Petroc Sumner:** Writing – review & editing, Supervision, Methodology. **Georgina Powell:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.visres.2025.108640.

Data availability

Data will be made available on request.

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