The Cortical Hyperexcitability Index (*CHi*): A New Measure for Quantifying Correlates of Visually Driven Cortical Hyperexcitability

Jason J. Braithwaite[1], Rachel Marchant[1], Chie Takahashi[1], Hayley Dewe[1],

Derrick G. Watson[2]

[1] Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham, Edgbaston, B15, 2TT

[2]Department of Psychology, University of Warwick, Coventry, CV4, 7AL

Corresponding author; Jason Braithwaite.
E-mail: j.j.braithwaite@bham.ac.uk

Acknowledgements

This project was funded by a Research grant from The Leverhulme Trust [RPG-2012-500] and a Bial grant bursary (#21/12) both awarded to the primary author (JJB). We gratefully acknowledge and sincerely thank the Trust and the Foundation for their generous support of our research.

Abstract

Introduction

Aberrations of visual experience, including visual hallucinations and visual distortions are known to be associated with increased cortical hyperexcitability. As a consequence, the presence, intensity and frequency of certain experiences may well be indicative of an underlying increase in cortical hyperexcitability.

Method

The current study presents a new proxy measure of cortical hyperexcitability, the Cortical Hyperexcitability Index (*CHi*). Two-hundred and fifty healthy participants completed the *CHi* with the results subjected to Exploratory Factor Analysis (EFA).

Results

The EFA revealed a 3-factor model as the most parsimonious solution. The 3 factors were defined as; (i) *heightened visual sensitivity and discomfort*; (ii) *negative aura-type visual aberrations*; and, (iii) *positive aura-type visual aberrations*. The identification of 3-factors suggests that multiple mechanisms underlie the notion of cortical hyperexcitability, providing researchers with new and greater precision in delineating these underlying features.

Conclusion

The factorial structure of the *CHi*, and the increased precision could aid the interpretation of findings from neuroscientific (i.e., brain-imaging / stimulation) examinations of cortical processes underlying aberrant perceptions across a host of clinical, neurological, and pathological conditions. As a consequence, the *CHi* is a useful and comprehensive proxy measure of cortical hyperexcitability with considerable scientific and clinical utility.

Keywords: Cortical hyperexcitability, Hallucinations, Visual stress, Aberrant experience, Consciousness.

Introduction

There is a well evidenced relationship between aberrant / increased neurophysiological activity and resultant anomalous experiences (Aleman & Larøi, 2008; Allen, Larøi, McGuire, & Aleman, 2008; Bien, Benninger, Urbach, Schramm, Kurthen, et al., 2000; Braun, Dumont, Duval, Hamel-Hébert, & Godbout, 2003; Manford & Andermann, 1998; Panayiotopoulos, 1999; 1994; Taylor, Scheffer, & Berkovic, 2003). Hyperexcitability in cortical neural circuits can lead to alterations in human consciousness, which can manifest itself in the form of mild alterations in the sensory quality of conscious experience, perceptual distortions, and both simple and / or complex sensory hallucinations (Allen et al., 2008; Bressloff, Cowan, Golubitsky, Thomas, & Weiner, 2001; 2002; Gloor, 1986; Siegel, 1977).

Anomalous experiences are associated with a variety of conditions, neurological disorders, and psychopathologies including; migraine with aura, occipital migraine, epilepsy, visual stress, Charles-Bonnet syndrome; schizophrenia, schizotypy, psychoses, depersonalization / derealization, dissociative disorders and anxiety disorders to name but a few (Allen et al., 2008; Bien et al., 2000; Braun et al., 2003; Feinberg & Keenan, 2005; ffytche & Howard, 1999; ffytch Howard, Brammer, & Williams, 1999; Manford & Andermann, 1998; Sierra, 2009). Without exception, these cases show that the presence of perceptual anomalies occur in concert with underlying aberrant neurophysiological activity.

In addition, not only can hallucinatory experiences be induced by electric and magnetic stimulation of the brain (Halgren, Walter, Cherlow, & Crandall, 1978; Penfield & Perot, 1963; Wassermann, 1998), but the success of inducing such experiences is significantly increased in those known to have pre-existing neural vulnerabilities - suggestive of a less inhibited, more excitable cortex (Aurora, Ahmed, Welch, Bhardwaj, & Ramadan, 1998; Aurora, Welch, & Al-Sayed, 2003; Young, Oshinsky, Shechter, Gebeline-Myers,

Bradley, et al., 2004). Collectively, the emerging picture is one in which the presence and increased frequency of anomalous experiences appear to reliably reflect increased degrees of underlying cortical hyperexcitability.

Although the relationship between anomalous experience and aberrant neural processing has been known for over 150 years, (e.g., de Boismont, 1853), there are few, if any, empirically established screening measures of cortical hyperexcitability underlying anomalous experiences *per se*. Furthermore, cortical hyperexcitability has often been cast as a relatively unitary phenomenon, which might not accurately quantify its structure.

Behaviourally speaking, one paradigm that has been used to quantify cortical hyperexcitability is the pattern-glare task in which viewing striped patterns (gratings) with a spatial frequency of approximately 3 cycles-per-degree of visual angle, can be highly irritable to observers, can induce increased visual stress (eye-strain / visual pain), and cause the perception of phantom visual distortions (Wilkins, 1995; Wilkins & Nimmo-smith, 1984; Evans & Drasdo, 1991; see Evans & Stevenson, 2008; for a review). The number of illusions reported correlates with the degree of visual irritability experienced, and are now known to reflect an underlying cortical hyperexcitability. Collectively, these symptoms have become known as 'pattern-glare' (Evans & Stevenson, 2008; Wilkins, 1995; Wilkins et al., 1984). According to the cortical hyperexcitability account of pattern-glare effects, medium-frequency gratings induce a spread of excitation, over-stimulating localised groups of visual neurons causing them to fire inappropriately. It is this aberrant neural activity which causes the perception of visual distortions. Therefore, susceptibility to such visual distortions should vary in sympathy with, and reflect, elevated degrees of latent cortical hyperexcitability.

Pattern-glare has been shown to be particularly prominent in those who experience migraine with aura (Friedman & De Ver Dye, 2009; Harle & Evans, 2004; Marcus & Soso,

1989), visual stress (Meares-Irlen syndrome: Evans, Busby, Jeanes, & Wilkins, 2002; Evans & Stevenson, 2008), photosensitive epilepsy and stroke (Beasley & Davies, 2012; Evans, 2005; Evans & Stevenson, 2008) and certain hallucinations in the non-clinical population (Braithwaite, Broglia, Bagshaw, & Wilkins, 2013a; Braithwaite, Broglia, Brincat, Stapley, Wilkins, et al., 2013b). It has also been implicated in cases of autism and anxiety / mood disorders and its severity can vary in sympathy with the presence of other co-morbid factors (see Ludlow, Wilkins, & Heaton, 2006; Nulty, Wilkins, & Williams, 1987; Wilkins, 1986). Computerised pattern-glare tasks have also recently revealed higher levels of cortical hyperexcitability in non-clinical hallucinators, (i.e., out-of-body experiences) thus extending the applicability of the concept to sub-clinical levels of aberrant perceptions (Braithwaite et al., 2013a; 2013b).

The argument that pattern-glare effects reflect centrally mediated cortical responses is evidenced by a number of findings. For example, (i) pattern-glare is magnified under binocular relative to monocular viewing conditions, suggestive of contributions coming from integrated cortical processes; (ii) findings from brain-imaging studies show significantly increased BOLD activation in visual association cortex but only for migraineurs with aura and only for the presentation of the irritable stimuli. In addition, the degree of visual distortion experienced by observers correlates with the level of neural activity in the visual association cortex; (iii) the time course of cortical responses is reduced for migraineurs (relative to controls) but only for the irritable medium-frequency stimuli - consistent with a more reactive and hyperexcitable visual cortex, and (iv) increased signs of pattern glare appear to be related to the presence of aura (hallucinations) rather than just the presence of migraine per-se (Huang et al., 2011; 2003; Datta et al., 2013; Welch et al., 2001; Wilkins et al., 2008; Wilkins et al., 1984). Collectively, these findings show that increases in the background excitability of the cortex can be associated with anomalous and aberrant

experiences in both neurological patient and non-patient (sub-clinical) groups. When sufficiently elevated, these background levels of excitability may make more transient (and possibly paroxysmal) neural activity more likely, resulting in temporary disorders of human consciousness.

One commonly used questionnaire screening measure of the resultant visual distortions is the Meares-Irlen scale (Irlen, 1983; Hollis & Allen, 2006). Although the items on this measure have some intuitive appeal, they have never been investigated formally or established as a valid or reliable measure of visual stress or underlying cortical hyperexcitability. Furthermore, the simple yes / no response scale used might not be particularly sensitive to more subtle effects present in non-clinical populations. Another measure is the visual discomfort scale (VDS: Conlon, Lovegrove, Chekaluk, & Pattison, 1999). However, a close examination of some of the items on this scale reveals a poor question structure making them ambiguous and less tractable to the underlying neurocognition. For example, if a participant endorses VDS question 1 ("*Do your eyes ever feel watery, red, sore, strained, tired, dry, gritty, or do you rub them a lot, when viewing a striped pattern*?"), it is unclear which of the many differing options within the question is being confirmed. In addition, some studies examining the basis of cortical hyperexcitability via brain-imaging techniques have failed to find significant influence of the VDS when used as a covariate (whilst also observing significant effects with other behavioural measures: Datta, Aguirre, Hu, Detre, & Cucchiara, 2013). Findings also indicate that a number of items on the scale were poor measures of visual discomfort and might be indicative of difficulties other than visual discomfort *per se* (Conlon et al., 1999). Consequently, a number of items on the VDS might not index cortical hyperexcitability at all.

Other developments of questionnaire measures have focused more on the type of anomalous perceptions present rather than on the underlying driving factors (e.g., the Cardiff

Anomalous Perception Scale, CAPS: Bell, Halligan & Ellis, 2006 and the Cambridge Depersonalization Scale; Sierra & Berrios, 2000). The CAPS is a helpful development in that it seeks to measure anomalous perceptions across a range of senses, is not concerned with anomalous beliefs, and is somewhat liberated from a clinically oriented language and its underlying assumptions. The CDS recognised that experiences can independently vary in terms of both their frequency and duration in some conditions / disorders and that this was important to measure.

The present study aimed to provide a proxy screening measure of cortical hyperexcitability by exploring specific anomalous experiences that have been argued to reflect its presence. This was conducted with non-clinical participants, but included those predisposed to hallucinatory / anomalous experiences. There are a number of reasons for initially exploring this measure with those predisposed to sub-clinical levels of aberrant perceptions / hallucinations. First, previous findings have shown that elevated levels of cortical hyperexcitability can be present in some non-clinical hallucinating groups (Braithwaite et al., 2013a; 2013b; submitted). Therefore, the premise that such factors are present, in those groups, has been empirically established. Second, the presence of any co-morbid factors should be eliminated, or greatly reduced in such groups. Finally, there should be a reduced role of confounding prescription medications present which might impact on human experience and which is often unavoidable when examining neurological and clinical samples.

To our knowledge, this new measure, which we refer to as the Cortical Hyperexcitability Index (*CHi*), is the first to use an exploratory factor analysis (and parallel analysis) approach to produce a verified proxy measure of cortical hyperexcitability. The *CHi* also features a number of methodological improvements over previous measures. For example, the *CHi* uses fine-grained 7-point Likert response scales and has two scales per

question / item. One of these scales is for the frequency and one for the intensity of experiences. The MI and VDS use a unitary yes / no or 4-point response scales respectively. Studies have shown that the sensitivity of measures with less than a 5-point scale is questionable, with 7-point and 9-point scales being optimal (Finstad, 2010; Krosnick & Fabrigar, 1997). To summarise, despite decades of research on cortical hyperexcitability, there is currently no verified empirical proxy measure for its role in aberrant / anomalous experience. The present study sought to address this gap and produce a measure that will have considerable utility for the independent assessment of visually driven cortical hyperexcitability, both in its own right and as a covariate measure to complement additional neuroscientific protocols.

Method

Participants

Two hundred and fifty healthy participants (age range 18-54 years, M = 21.4) took part in return for research credits. Of these, 211 (84%) were female and 234 (93%) reported that they were right-handed). A pre-screening questionnaire, was used to identify certain conditions / disorders as exclusion criteria from the present study. The questions were presented on paper for a record of response and were also read out verbally by an experimenter to ensure participants understood what the questions were asking. The questions asked were as follows: (i) whether participants had been medically diagnosed with migraine (with and without aura), (ii) whether participants had been diagnosed with any of the epilepsies (i.e., temporal-lobe epilepsy, photosensitive epilepsy, etc), (iii) whether participants had ever suffered from any psychiatric or neurological conditions (and whether any medications were being taken for these conditions), and (iv) whether they had ever undergone any form of neurosurgery

(including eye-surgery). We also asked an open question as to whether there were any conditions / disorders they may want to inform us about that we had not specifically mentioned. A positive response to any of these questions was sufficient to qualify as exclusion criteria for this study. All participants were undergraduate or postgraduate students from the School of Psychology at the University of Birmingham, UK.

Questionnaire Measure: Constructing the *CHi*

To compile the *CHi*, an extensive literature on aura experiences was consulted and several existing measures were reviewed. The items chosen for the *CHi* measure represent a comprehensive selection of visual experiences including a minority used in some previous questionnaire measures (Bell Halligan & Ellis, 2006; Conlon et al., 1999; Hollis & Allen, 2006; Irlen, 1983; Sierra & Berrios, 2000), those experiences reported from more objective investigations (i.e., those complemented by psychophysical, brain-stimulation and brain-imaging studies on patient and control groups: Adjamian, Holliday, Barnes, Hillebrand, Hadjipapas et al., 2004; Brighina, Piazza, Daniele, & Fierro, 2002; Chronicle, Pearson, & Mulleners, 2006; Coutts, Cooper, Elwell, & Wilkins, 2012; Evans & Stevenson, 2008; Huang, Zong, Wilkins, Jenkins, Bozoki et al., 2003; 2011; Marcus & Soso, 1989; Palmer, Chronicle, Rolan, & Mulleners, 2000; Shepherd, Beaumont, & Hine, 2012; Wilkins et al., 1984; Wilkins, 1995), from experimental studies of hallucination proneness in non-clinical populations (Braithwaite et al., 2013a; 2013b; Braithwaite Hulleman, Samson, Boglia & Applery, 2011), and neurological / clinical reviews of aura and their underlying mechanisms (Allen et al., 2008; Bien et al., 2000; Bowyer, Aurora, Moran, Tepley, & Welch, 2001; Collerton, Perry, & McKeith, 2005; Elliot, Joyce & Shorvon, 2009a; 2009b; Hadjikhani, del Rio, Wu, Schwartz, Bakker et al., 2001; Lauritzen, 2001; 1994; Manford & Andermann,

1998; Panayiotopoulos, 1999; 1994; Pietrobon & Striessnig, 2003; Siegel, 1977; Silberstein, 2004). The items included in the *CHi* are summarised in Table 1. Some items were taken directly from existing measures, largely unaltered in expression (Q8, 9, 12, 22; The Cardiff Anomalous Perception Scale (CAPS; Bell et al., 2006); others were inspired by previous measures but with some adaptation from their original form (including the Meares-Irlen scale, Hollis & Allen, 2006; the Visual Discomfort Scale: Conlon et al., 1999; and the Cambridge Depersonalization Scale; Sierra & Berrios, 2000; Q5, 18, 20, 23). However, the majority of the items were newly created specifically for this measure, based on the literature outlined in the discussion above. As with the Cambridge Depersonalization Scale (Sierra & Berrios, 2000), the *CHi* utilized two response scales, one for the frequency of the experiences, and the other for the Intensity of experiences.

Table 1 here

Results

A value of one was subtracted from each Frequency and Intensity score which transformed the Likert scale responses from 1 - 7 to 0 - 6[1]. There was a significant correlation between the Frequency and Intensity scores, ($r(248) = .90$, $p<.001$) and both were summed to provide an overall indication of cortical hyperexcitability (with a range of 0 - 324) - which we refer to as a *'CHi'* score. The structure underlying the resultant *CHi* scores was then determined using Exploratory Factor Analysis (EFA).

[1] This was mainly to navigate around the counter-intuitive issue that someone who responded 'no' to every question, would still receive a score of 54, and that zeros may not be viewed as equivalent to integers above zero.

The mean *CHi* score for the overall sample was 52.2 (median = 45) with a standard deviation of 36.9 (range = 0 - 189). To examine the normality of the distribution of *CHi* scores, a Shapiro-Wilks test was carried out which revealed a non-normal distribution, W=.914 (df 250), $p<.001$. This is to be expected to some degree with a measure tapping into a wide range of experiences possibly reflecting diverse underlying factors which may not co-occur. However, the main purpose of this test was to guide the type of factor analysis conducted on the data. Additional descriptive statistics are shown in Tables 2 and 3

Tables 2 & 3 here

Exploratory Factor Analysis (EFA)

As the *CHi* is a new measure with no verified empirical precedent, its factorial structure was examined via an Exploratory Factor Analysis (EFA). The method of extraction chosen was Principal Axis Factoring (PAF), which is regarded as a truer measure for factor analysis than principal components analysis, and is more suitable when assumptions of normality have not been met (Beavers, Lounsbury, Richards, Huck, Skolits, et al., 2013; Conway & Huffcutt, 2003; Fabrigar, Wegener, MacCallum, & Strahan, 1999; Costello & Osbourne, 2005).

The Kaiser-Meyer-Oklin (KMO) measure of sampling adequacy (.88), exceeded the minimum recommended value of .60 (Kaiser, 1974; Tabachnick & Fidell, 2001), supporting a high factorability for the sample. Bartlett's Test of Sphericity was also significant (χ^2 = 2820

(df =351), p<.001), justifying the use of EFA for these data. Extracted communalities for each original item were, on the whole, respectable ($\overline{X}$ = 0.40; see Table 4). In line with recent recommendations concerning psychological investigations, and theoretical reasons for assuming that the separate factors may be related, some correlation between the concepts in the model was assumed *a-priori*. Accordingly, the EFA used an oblique (correlated) Promax rotation with a Kappa of 4. (Fabrigar et al., 1999). An examination of the original Scree Plot implied a 3-factor model, which explained a cumulative total of 45.8% of the variance (initial values) and 39.4% after extraction.

To further confirm that the appropriate number of factors were extracted, a more objective parallel analysis (PA) was also conducted (Courtney, 2013; Garrido, Abad, & Ponsoda, 2013; Hayton, Allen, & Scarpello, 2004; Henson & Roberts, 2006; Fabrigar et al., 1999; Turner, 1998). It has been repeatedly argued that PA is the most accurate method of factor extraction (Hayton et al., 2004; Henson & Roberts, 2006; Matsunaga, 2010; Velicer, Eaton, & Fava, 2000; Williams, Brown, & Onsman, 2010). Parallel analysis consists of using Monte-Carlo simulations to generate simulated random eigenvalues. The actual eigenvalues are then compared with the simulated random ones. The underlying assumption of PA is that the important components from the original data set should have larger eigenvalues than those from randomly generated data sets with the same numbers of variables and sample size. Therefore, the estimated number of factors corresponds to the number of real eigenvalues that exceed the simulated eigenvalues.

The parallel analysis was conducted using the fa.parallel command (with the factoring method set to pa) from the psych package (Revelle, 2014) running under the R statistical package (version 3.0.0, R Core Team, 2013)[2]. The PA analysis suggested the presence of 6

[2] To fully explore the structure of the model we ran both a factor analysis (FA) and a principal components analysis (PCA) for the parallel analysis. For transparency, both outcomes are reported in the Scree plot (Figure 1). Note, the PCA always converged on a 3-factor solution.

factors and 3 components. However, as illustrated in the PA Scree Plot (Figure 1), the first three data points deviate the most from the series, and the reduction in eigenvalues was extremely minimal after the first 3-factors. In addition, when an initial 6-factor model was explored, the last three factors had only one or two items loading onto them, making them highly unstable. It has been argued that factors with fewer than 3 items loading onto them are weak, unstable and unreliable, and are unlikely to reflect sound factors and thus, should be removed from the model (Beavers et al., 2013; Costello & Osbourne, 2005). As a consequence, such loadings were rejected from the final model.

Figure 1 here

Taken together, and in line with guidelines for EFA interpretation, we consider that the data are most compatible with a three factor solution (see Crawford, Green, Levy, Lo, Scott et al., 2010; for discussion of conducting PA using PCA or FA to determine the number of factors). Accordingly, the final factor analysis was carried out based on a 3-factor solution.

The Promax rotation converged within 6 iterations. All loadings < .40 were suppressed - which led to only 3 items not loading reliably onto any factor (Question 19: *Have you ever noticed the presence of perceptual distortions in your vision as a result of lack of sleep*?; Question 17, *Have you ever been aware of a 'flicker' on your computer screen*? Question 13, *Have you ever seen an apparition / ghost*?). There were no cross-loadings when applying these criteria. No factor had loadings of fewer than 3 items (even with a cut off of

.50 all factors had no fewer than 3 loadings). The present data compare favourably with such observations and suggest a solid and stable factor structure.

Most of the items that significantly loaded onto Factor 1 reflected signs of *"heightened visual sensitivity and discomfort"*, with individuals reporting elevated discomfort / irritation / visual pain from being exposed to certain properties of the environment. Factor 2 contained items mainly representing the presence of *"negative aura-type visual aberrations"*. These items appeared similar to those typically associated with diminished vision, (i.e., scotoma, partial loss of vision, loss of peripheral vision (fading), tunnel vision, fortification hallucinations, and distortions like macropsia, micropsia, teleopsia). Factor 3 contained items mainly relating to *"positive aura-type visual aberrations"* such as phosphenes and low-level elementary hallucinations and distortions (flashing lights, flashing colours, shapes, shadows, visual distortions)[3]. The factorial structure is shown in Table 4, and correlations between the factors in Table 5.

Table 4 here

All correlations between the factors exceeded 0.32, indicating 10% or more overlap in variance among the separate factors which is sufficient to justify an oblique rotation and supports our *a-priori* assumptions (partially overlapping but not identical sources of variance: Tabachnick & Fiddell, 2007).

---

[3] The term 'aberrations' is preferred for both these factors, as opposed to visual hallucinations, to acknowledge the co-presence of visual distortions on both factors which are not technically hallucinations.

Table 5 here

Reliability was high with Cronbach's alpha values for the whole measure being, 0.91, and for the individual factors of *Heightened visual sensitivity and discomfort* 0.89; *Negative aura-type visual aberrations,* 0.78; and *Positive aura-type hallucinations,* 0.77.

On the whole the appropriateness and parsimony of the resultant three-factor model is collectively supported by: (i) the presence of high loadings on each factor, (ii) a clear and well defined simple structure (no complex loadings at 0.40), (iii) evidence from both independent Scree Plot and parallel analysis procedures, (iv) all factors having at least 4 loadings (i.e., stable factors), and (v) theoretically intuitive descriptors for the factors. Descriptive statistics (good communalities, high KMO values, Bartlett's test), and clear factor structure suggest that the sample size was sufficient and appropriate for EFA.

General Discussion

The present study sought to construct an indirect proxy measure of cortical hyperexcitability. This was done by exploring experiences known to reflect underlying hyperexcitability across a variety of conditions and disorders. The exploratory factor analysis revealed that such experiences likely reflect several underlying dimensions - thus fractionating the somewhat unitary notion of cortical hyperexcitability. The inter-correlated nature of the factorial model suggests that the dimensions, although distinct, do reflect some interdependence in the response.

The factorial structure of the *CHi*

The EFA revealed a factor structure underlying experiential phenomena commonly thought to reflect different aspects of cortical hyperexcitability. The largest extracted factor contained 13 items and was termed the *"heightened visual sensitivity and discomfort"* factor. Items on this component ranged from those identifying the sources of irritation in the environment to the experiential phenomena they induce in individuals.

The second *"negative aura-type visual aberrations"* factor contained 6 items . This factor reflected experiences primarily associated with diminished vision or negative aura, as well as distortions like macropsia, micropsia metamorphopsia, and teleopsia. These items have also been shown to be associated with cortical spreading depression models of neural dysfunction (Hadjikhan, et al., 2001; Lashley, 1941; Lauritzen, 1994, 2001; Leao, 1944; Pietrobon & Striessnig, 2003) and thus show some prima-facia similarity to migraine aura-type experiences. Indeed, Question 26 relates to elementary fortification hallucinations which are a predominant, almost diagnostic, feature of migraine aura.

This factor also contained an item on out-of-body experiences (OBEs), a high-level complex hallucination thought to reflect a breakdown in multisensory integration (Braithwaite et al., 2011). While this may at first appear at odds with the other items on this factor, it should be noted that OBEs have indeed been documented as being part of migraine aura experiences (Comfort, 1982; Lippman, 1953; Podoll & Robinson, 1999; Siegel, 1977) and it is not uncommon for migraine aura to consist of higher-level (polysensory) hallucinations (Petrusic, Zidverc-Trajkovic, Podgorac, & Sternic, 2013). Therefore, its presence on a factor that appears to represent migraine-like aura experiences is not unprecedented.

The third *"positive aura-type visual aberrations"* factor consisted of 5 items , associated with phosphenes, low-level elementary hallucinations and distortions. Although thematically distinct from the 2nd factor, these items are also implicated in conditions and

disorders with well-known underlying anomalies in neurophysiological activity (e.g., ocular and temporal-lobe epilepsy, migraine with aura: Allen, et al., 2008; Bien et al., 2000; Braun et al., 2003; Manford & Andermann, 1998; Siegel, 1977). Only three items out of 27 items (11%) failed to load onto any factor (Q19, Q13, Q17), and thus, based on the EFA, should be discarded from future research using this measure.

What do the different factors represent?

The factor structure suggests that the three emerging factors, though correlated to some degree, reflect differing constructs. The *"heightened visual sensitivity and discomfort"* factor contained no items pertaining to actual aura or hallucinations (of a simple or complex nature). Without exception, the items making up this factor pertained only to distortions in existing perceptions, to physical somatic experiences (discomfort, pain, irritation), and known potent sources associated with visual discomfort (Wilkins et al., 1984; Wilkins, 1986, 1995).

Factors two and three appear distinct in that they revolve around elementary hallucinatory experiences (with some additional visual distortions also noted). Simple elementary and complex hallucinatory experiences are associated with a range of conditions and disorders - which are, almost without exception, associated with cortically mediated aberrant neurophysiological activity (Aleman & Vercammen, 2012; Allen et al., 2008; Bien et al., 2000; Braun et al., 2003; Elliot et al., 2009a; 2009b; Manford & Andermann, 1998; Panayiotopoulos, 1994; 1999). Depending on the balance between the level of excitation / suppression, the proliferation through the brain of aberrant levels of activity, and the brain regions involved in conscious experience, then the resultant experiences reported will vary from visual illusions and distortions to simple or complex visual hallucination.

The thematic difference between the factors of *"negative aura-type visual aberrations"* and *"positive aura-type visual aberrations"* is particularly noteworthy. Taylor

et al., (2003) noted two distinct categories for hallucinatory aura. These were: (i) *negative manifestations* - instances when aspects of conscious vision were degraded, diminished or removed from visual experience (which included scotoma, partially diminished vision, and hemianopia, - but would also apply to tunnel vision, ictal blindness, and a fading out of peripheral vision), and (ii) *positive manifestations* - instances when elementary hallucinatory phenomena are actually added to visual experience and superimposed onto the perception of the external visual world (including phosphenes, geometric patterns, and flashes of light and colour; see also Bolay, Reuter, Dunn, Huang, Boas et al., 2002; Elliot et al., 2009a; 2009b; Panayiotopoulos, 1999). What is striking is that this conceptual distinction appears to map reasonably faithfully onto the second and third factors identified for the *CHi* respectively - even with non-clinical samples.

In addition, the conceptual distinction between these factors also dovetails neatly onto recent models of cortical spreading depression (CSD) linked to migraine aura. CSD refers to a wave of suppressed neural activity which propagates slowly across the visual cortex and beyond. Preceding the wave of cortical silence is a wave of depolarization, which causes neurons to become initially over-excited before then becoming severely suppressed (Larrosa, Pastor, Lopez-Aguado, & Herreras, 2006; Lauritzen, 1994). It is well known that the presence and propagation of CSD is primarily linked to the phenomenological contents of conscious experience in migraine aura (Bowyer et al., 2001; Eikermann-Haerter & Ayata, 2010; Hadjikhani, et al., 2001; Lashley, 1941; Lauritzen, 2001; 1994; Leao, 1944; Pietrobon & Striessnig, 2003).

Although migraine auras have many different features, many are thought to originate from Brodmann area 17 (the primary visual cortex) - a region with the highest neuronal density and lowest density of astrocytes (thus an area with low inhibitory control: Largo, Ibarz, & Herreras, 1997; Lauritzen, Dreier, Fabricus, Hartings, Graf, et al., 2011). In

addition, magnetoencephalography (MEG) has shown that visually evoked CSD-like activations could be artificially induced in patients, but only in migraine-with-aura patients (those that already displayed signs of cortical hyperexcitability via the presence of aura experiences: Welch, Bowyer, Aurora, Moran, & Tepley, 2001). These studies suggest that aberrant CSD processes not only reflect the presence of a hyperexcitable cortex, but are also directly involved in the production of elementary hallucinations and aberrant perceptions connected to the pathophysiology of the aura itself.

Bringing these themes together, the implication from CSD models is that the initial wave of depolarization could be responsible for the more positive aspects of such aberrant perceptions. In contrast, the actual wave of suppression which follows may underlie the loss of perceptual aspects of consciousness (Elliot et al., 2009a; 2009b; Hadjikhani, et al., 2001; Pietrobon & Striessnig, 2003; Silberstein, 2004; Taylor et al., 2003; see Figure 2).

If the not unreasonable assumption is made that attenuated degrees of transient cortical hyperexcitability may be present in non-clinical / neurological groups, then one possibility is that the experiences represented by the *"positive aura-type visual aberrations"* factor might be associated with initial states of depolarization (excitation) within neural systems located in primary and association visual cortex. Conversely, the *"negative aura-type visual aberrations"* factor may reflect states of relative neural suppression in these and related areas. It is therefore noteworthy that there was some correlation between the factor model (as both types of experiences can co-occur within the same patients), while also loading significantly onto different factors, possibly reflecting diverse (excitatory / suppressive) neural processes.

Figure 2 here

The utility of the *CHi*

Aberrations of human consciousness, visual hallucinations and visual distortions are defining features of a range of conditions, neurological disorders, and psychopathologies. A truism for these and other contexts is that the resultant anomalous sensory experiences reported are typically associated with aberrant neurophysiological activity.

The factor structure of the *CHi* is important and revealing in several ways. The *CHi* has revealed, for the first time, that the experience of different types of anomalous experience cluster onto separable factors. That is to say, certain experiences display a 'proximal' relationship to other experiences, while also displaying a 'distal' relationship to yet other experiences. The implication is that these factors may reflect contributions from differing underlying processes propagating through an inter-connected and interdependent neural architecture. Hence, one might expect some patient groups to produce higher *CHi* scores than control groups. However, in the case of the *CHi*, the increased precision means that the researcher can speculate as to how the endorsement of the different *CHi* factors might vary within individuals and across patient groups which would be informative for scientific theory.

The factor structure makes a great deal of intuitive sense, and is supported by the broader literature on pattern-induced visual irritability and cortical hyperexcitability (Marcus & Soso, 1989; Wilkins, 1986; 1995; Wilkins et al., 1984). Put simply, environments that contain irritable stimuli (light / patterns) will impact more on observers with a hyperexcitable cortex, which might in turn be associated with elevated degrees of visual pain, more visual

distortions, and, in more extreme cases, trigger specific hallucinations or dissociative episodes due to the co-presence of specific neural vulnerabilities.

The *CHi* has been developed to provide an assessment of experiences reflecting signs of cortical hyperexcitability, and it may well enjoy broad utility with relevance to abnormal psychology, neuroscience, neuropsychiatry and the clinical sciences. Unlike previous untested and informal measures, the *CHi* has been explored and verified by EFA procedures. As the *CHi* is directly concerned with aberrant visual experience, it provides a new comprehensive measure of visual anomalies specifically, thus addressing an explanatory gap in research on the quantification of factors implicated in anomalous visual experience.

Limitations & further research

Although the *CHi* is based on established research from the cognitive neurosciences, questionnaire measures are indeed indirect proxy instruments for the factors they seek to quantify. Therefore, one argument might be that as no direct measures of cortical activity were taken during this study, the extent to which cortical processes are being quantified can be questioned. However, there is broad evidence supporting our general supposition that the *CHi*, though indirect, is a useful proxy measure of anomalies in centrally mediated processing.

First, many of the items making up the *CHi* are associated with increased levels of cortical activation as evidenced by studies utilising more direct measures of cortical hyperexcitability (i.e., brain-imaging: Adjamian et al., 2004; Chouinard, Zhou, Hrybouski, Kim, & Cummine, 2012; Coutts et al., 2012; Datta et al., 2013; Huang et al., 2011; 2003; Welch et al., 2001). Importantly, these aberrant increases in neural responses are seen only

for patient groups that report aura / hallucinations (i.e., migraine with aura) and not similar groups who experience just migraine. Many of the aura components reported by these patients are represented in the *CHi*. Therefore the premise that these specific aura are an indicative concomitant of aberrant neurophysiological activity is empirically established.

Second, the clearly distinct factor structure is also consistent with current theories of pattern-induced irritability - that certain visual anomalies reflect aberrant neurophysiological activity in primary and association visual cortex (Wilkins et al., 1984; Wilkins, 1986). Further research involving more objective methods including: (i) magnetic and electrical brain stimulation (trans-cranial magnetic stimulation: TMS: trans-cranial direct-current stimulation, tDCS), (ii) brain-imaging, and (iii) exploring how the CHi and its factors map onto different psychiatric, neurological, and clinical disorders, are now justified, and provide welcome future avenues for research. A clear prediction is that the different factors of the *CHi* may act as informative covariates in a broader assessment of underlying cortical processes mediating anomalous experiences across a range of conditions and disorders. Therefore, we suggest that future studies exploring the veracity of the *CHi*, across a range of patient groups, and utilising a variety of neuroscientific techniques would help to further establish the assumptions of this measure.

Conclusion

The present study has established a new proxy measure for cortical hyperexcitability - the *CHi*. The factor structure dovetails neatly with previous research on the nature of aberrant visual experience reported by individuals with cortical hyperexcitability. It also meshes well with wider neurophysiological studies postulating both increases and decreases in levels of cortical activity (i.e., studies of cortical spreading depression) underlying different aspects of aberrant perception. The existence of the 3-factor model suggests that multiple mechanisms may underlie the notion of cortical hyperexcitability, providing researchers with new and

greater precision in delineating these underlying features. A multi-factor model also questions unitary notions of cortical hyperexcitability or studies which merely take an overall index from an untested pool of items as an indicator of cortical hyperexcitability. In addition, the different factors of the *CHi* have considerable potential to be explored, either collectively or individually as covariates coupled to more direct methods of neuroscientific investigation. Such an approach would aid the interpretation of findings from brain-stimulation and brain-imaging examinations of cortical processes underlying aberrant perceptions across a legion of clinical, neurological, and pathological conditions. As a consequence, the *CHi* is a useful and comprehensive proxy measure of cortical hyperexcitability with considerable scientific and clinical utility.

References

Adjamian, P., Holliday, I., Barnes, G., Hillebrand, A., Hadjipapas, A., & Singh, K. (2004). Induced visual illusions and gamma oscillations in human primary visual cortex. *European Journal of Neuroscience, 20*(2), 587-592. doi:10.1111/j.1460-9568.2004.03495.x

Aleman, A., & Vercammen, A. (2012). Functional neuroimaging of hallucinations. In D. Blom & I. E. C. Sommer (eds), *Hallucinations; Research and Practice* (pp267-281). New York, NY: Springer.

Aleman, A., & Laroi, F. (2008). *Hallucinations: The science of idiosyncratic perception*. Washington, DC, USA: American Psychological Association.

Allen, P., Larøi, F., McGuire, P., & Aleman, A. (2008). The hallucination brain: A review of structural and functional neuroimaging studies of hallucinations. *Neuroscience and Biobehavioural Reviews, 32*, 175-191. doi:10.1016/j.neubiorev.2007.07.012

Aurora, S. K, Ahmad, B. K, Welch, K. M. A, Bhardwaj, P, & Ramadan, N. M. (1998). Transcranial magnetic stimulation confirms hyperexcitability of occipital cortex in migraine. Neurology, *50*: 1111-1114.

Aurora, S., Welch, K., & Al-Sayed, F. (2003). The threshold for phosphenes is lower in migraine. *Cephalalgia,* 23(4): 258-263.

Beasley, I., & Davies, L. (2012). Susceptibility to pattern glare following stroke. *Journal of Neurology, 259*(9), 1832-1839.

Beavers, A. S., Lounsbury, J. W., Richards, J. K., Huck, S. W., Skolits, G. J. & Esquivel, S. L. (2013). Practical considerations for using exploratory factor analysis in educational research. *Practical Assessment, Research & Evaluation, 18*(6), 1-13.

Bell, V., Halligan, P., & Ellis, H. (2006). The Cardiff Anomalous Perceptions Scale: A new

validated measure of anomalous perceptual experience. *Schizophrenia Bulletin, 32*(2), 366-377.

Bien, C. G., Benninger, F. O., Urbach, H., Schramm, J., Kurthen, M., & Elger, C. E. (2000). Localizing value of epileptic visual auras. *Brain : A Journal of Neurology, 123(Pt 2)*, 244–53.

Blackwell, C. (2008). *Migraine III Extra Details.* [online] Available at: <http://www.blackwelleyesight.com/migraine-extra-details/>

Bolay, H., Reuter, U., Dunn, A. K., Huang, Z., Boas, D., & Moskowitz, M. (2002). Intrinsic brain activity triggers trigeminal meningeal afferents in a migraine model. *Nature Medicine*, *8*(2), 136–42. doi:10.1038/nm0202-136

Bowyer, S. M., Aurora, S. K., Moran, J. E., Tepley, N., & Welch, K. M. A. (2001). Magnetoencephalographic Fields from Patients with Spontaneous and Induced Migraine Aura. *Annals of Neurology*, *50*(5), 582–587. doi:10.1002/ana.1235

Braithwaite, J. J., Broglia, E., Bagshaw, A. P., & Wilkins, A. J. (2013a). Evidence for elevated cortical hyperexcitability and its association with out-of-body experiences in the non-clinical population: New findings from a pattern-glare task. *Cortex, 49,* 793-805.

Braithwaite, J. J., Broglia, E., Brincat, O., Stapley, L., Wilkins, A. J., & Takahashi, C. (2013b). Signs of increased cortical hyperexcitability selectively associated with spontaneous anomalous bodily experiences in a non-clinical population. *Cognitive Neuropsychiatry, 18*, 549-573.

Braithwaite, J., Hulleman, J., Samson, D., Broglia, E., & Apperly, I. (2011). Cognitive correlates of the spontaneous out-of-body experience in the psychologically normal

population: Evidence for a role of temporal-lobe disturbance, body-distortion processing, and impairments in own body transformations. *Cortex, 47,* 839-853.

Braun, C. M. J., Dumont, M., Duval, J., Hamel-Hébert, I., & Godbout, L. (2003). Brain modules of hallucination: an analysis of multiple patients with brain lesions. *Journal of Psychiatry & Neuroscience : JPN*, *28*(6), 432–49.

Bressloff, P., Cowan, J. D., Golubitsky, M., Thomas, P. J., & Wiener, M. C. (2002). What geometric visual hallucinations tell us about the visual cortex. *Neural Computation, 14*, 473-491.

Brighina, F., Piazza, A., Daniele, O., & Fierro, B. (2002). Modulation of visual cortical excitability in migraine with aura: effects of 1 Hz repetitive transcranial magnetic stimulation. *Experimental Brain Research, 145*(2), 177–81. doi:10.1007/s00221-002-1096-7

Chouinard, B., Zhou, C., Hrybouski, S., Kim, E., & Cummine, J. (2012). A functional neuroimaging case study of Meares-Irlen Syndrome/Visual Stress (MISViS). *Brain Topography, 25*(3), 293-307. doi:10.1007/s10548-011-0212-z

Chronicle E. P., Pearson A. J., & Mulleners, W. M. (2006). Objective assessment of cortical excitability in migraine with and without aura. *Cephalalgia, 26*, 801-808. doi:10.1111/j.1468-2982.2006.01144.x

Collerton, D., Perry, E., & McKeith, I. (2005). Why people see things that are not there: a novel Perception and Attention Deficit model for recurrent complex visual hallucinations. *The Behavioral and Brain Sciences, 28*(6), 737–57. doi:10.1017/S0140525X05000130

Comfort, A. (1982). Out-of-body experiences and migraine. *American Journal of Psychiatry, 139*, 1379–1380.

Conlon, E., Lovegrove, W., Chekaluk, E., & Pattison, P. (1999). Measuring visual discomfort. *Visual Cognition, 6*(6), 637-663.

Conway, J. M., & Huffcutt, A. I. (2003). A review and evaluation of exploratory factor analysis practices in organizational research. *Organizational Research Methods, 6*(2), 147-168. doi: 10.1177/1094428103251541.

Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Practical Assessment Research & Evaluation, 10*(7), 1-9.

Courtney, M. G. R. (2013). Determining the number of factors to retain in EFA: Using the SPSS R-Menu v2.0 to make more judicious estimations. *Practical Assessment, Research & Evaluation, 18*(8), 1–14.

Coutts, L., Cooper, C., Elwell, C., & Wilkins, A. (2012). Time course of the haemodynamic response to visual stimulation in migraine, measured using near-infrared spectroscopy. *Cephalalgia, 2*, 621-629. doi:10.1177/0333102412444474

Crawford, A.V., Green, S. B., Levy, R., Lo, W., Scott, L., Svetina, D. S., & Thompson, M. S. (2010). Evaluation of parallel analysis methods for determining the number of factors. *Educational and Psychological Measurement, 70*(6), 885-901. doi: 10.1177/0013164410379332.

Datta, R., Aguirre, G., Hu, S., Detre, J., & Cucchiara, B. (2013). Interictal cortical hyperresponsiveness in migraine is directly related to the presence of aura. *Cephalalgia, 33*(6), 365-374.

de Boismont, A. J. F. B. (1853). *Hallucinations. The rational history of apparitions, visions, dreams, ecstasy, magnetism, and somnambulism*. Philidelphia, USA: Lindsay and Blakiston.

Eikermann-Haerter, K., & Ayata, C. (2010). Cortical spreading depression and migraine. *Current Neurology and Neuroscience Reports*, *10*(3), 167–73. doi:10.1007/s11910-010-0099-1

Elliott, B., Joyce, E., & Shorvon, S. (2009a). Delusions, illusions and hallucinations in epilepsy: 1. Elementary phenomena. *Epilepsy Research, 85*, 162-171.

Elliott, B., Joyce, E., & Shorvon, S. (2009b). Delusions, illusions and hallucinations in epilepsy: 2. Complex phenomena and psychosis. *Epilepsy Research, 85,* 172-186.

Evans, B. (2005). The need for optometric investigation in susptected Meares-Irlen syndrome or visual stress. *Opthalmic and Physiological Optics, 25,* 363-370.

Evans, B., & Stevenson, S. (2008). The pattern glare test: A review and determination of normative values. *Ophthalmic and Physiological Optics, 28*(4), 295-309.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 4*(3), 272-299.

Feinberg, T., & Keenan, J. (2005). *The lost self: Pathologies of the brain and identity*. New York: Oxford University Press.

Finstad, K. (2010). Response interpolation and scale sensitivity: Evidence against 5-point scales. *Journal of Usability Studies, 5,* 104-110.

Friedman, D., & De Ver Dye, T. (2009). Migraine and the environment. *Headache, 49,* 941-952.

ffytche, D. H., & Howard, R. J. (1999). The perceptual consequences of visual loss: 'positive' pathologies of vision. *Brain, 122,* 1247-1260.

ffytche, D. H., Howard, R. J., Brammer, A., D.P., W., & Williams, S. (1998). The anatomy of conscious vision: an fMRI study of visual hallucination. *Nature Neuroscience, 1*(8), 738-742.

Garrido, L. E., Abad, F. J., & Ponsoda, V. (2013). A new look at Horn's parallel analysis with ordinal variables. *Psychological Methods, 18*(4), 454-474. doi:10.1037/a0030005.

Gloor, P. (1986). Consciousness as a neurological concept in epileptology: A critical review. *Epilepsia, 27,* S14-S26.

Hadjikhani, N., del Rio, M., Wu, O., Schwartz, D., Bakker, D., Fischl, B., … Moskowitz, M. (2001). Mechanisms of migraine aura revealed by functional MRI in human visual cortex. *PNAS, 98*(8), 4687-4692.

Halgren, E., Walter, R. D., Cherlow, D. G., & Crandall, P. H. (1978). Mental phenomena evoked by the electrical stimulation of the human hippocampal formation and amygdala. *Brain, 101,* 83-117.

Hayton, J. C., Allen, D. G. & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis. *Organizational Research Methods, 7*(2), 191-205. doi: 10.1177/1094428104263675.

Henson, R. K., & Roberts, J. K. (2006). Use of exploratory factor analysis in published research. *Educational and Psychological Measurement, 66*(3), 393-416. doi: 10.1177/0013164405282485.

Hollis, J., & Allen, P. (2006). Screening for Meares-Irlen sensitivity in adults: Can assessment methods predict changes in reading speed? *Opthalmic and Physiological Optics, 26*, 566-571. doi:10.1111/j.1475-1313.2006.00401.x

Huang, J., Cooper, T., Satana, B., Kaufman, D., & Cao, Y. (2003). Visual distortion provoked by a stimulus in migraine associated with hyperneuronal activity. *Headache, 43*(6), 664-671.

Huang, J., Zong, X., Wilkins, A., Jenkins, B., Bozoki, A., & Cao, Y. (2011). fMRI evidence that precision ophthalmic tints reduce cortical hyperactivation in migraine. *Cephalalgia, 31*, 925-936. doi:10.1177/0333102411409076

Irlen, H. (1983). *Successful treatment of learning difficulties*. The Annual Convention of the American Psychological Association, Anaheim, USA.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31-36.

Krosnick, J. A., & Fabrigar, L. R. (1997). Designing rating scales for effective measurement in surveys. In: L. Lyberg, B. Biemer, M. Collins, et al. (eds). *Survey Measurement and Process Quality* (pp141-164). New York, NY: John Wiley & Sons, Inc.

Largo, C., Ibarz, J., & Herreras, O. (1997). Effects of the gliotoxin fluorocitrate on spreading depression and glial membrane potential in rat brain in situ. *Journal of Neurophysiology, 78*, 295–307.

Larrosa, B., Pastor, J., López-Aguado, L., & Herreras, O. (2006). A role for glutamate and glia in the fast network oscillations preceding spreading depression. *Neuroscience, 141*(2), 1057–68. doi:10.1016/j.neuroscience.2006.04.005

Lashley K. (1941). Patterns of cerebral integration indicated by the scotomas of migraine. *Archives of Neurology and Psychiatry, 46*, 333-339.

Lauritzen, M. (1994). Pathophysiology of the migraine aura. The spreading depression theory. *Brain : A Journal of Neurology, 117 (Pt 1)*, 199–210.

Lauritzen, M. (2001). Cortical spreading depression in migraine. *Cephalalgia : An International Journal of Headache, 21*(7), 757–60.

Lauritzen, M., Dreier, J., Fabricius, M., Hartings, J., Graf, R., & Strong, A. (2011). Clinical

relevance of cortical spreading depression in neurological disorders: Migraine, malignant stroke, subarachnoid and intracranial hemorrhage, and traumatic brain injury. *Journal of Cerebral Blood Flow & Metabolism, 31*, 17-35.

Leao, A. (1944). Pial circulation and spreading depression of activity in the cerebral cortex. *Journal of Neurophysiology, 7,* 359–390.

Lippman, C.W. (1953). Hallucination of physical duality in migraine. *Journal of Nervous and Mental Disease, 117*, 345-350.

Ludlow, A., Wilkins, A., & Heaton, P. (2006). The effect of coloured overlays on reading ability in children with autism. *Journal of Autism and Developmental Disorders, 36,* 507-516.

Manford, M., & Andermann, F. (1998). Complex visual hallucinations. Clinical and neurobiological insights. *Brain : A Journal of Neurology, 121 (Pt 1),* 1819–40.

Marcus, D. A., & Soso, M. J. (1989). Migraine and stripe-induced visual discomfort. *Archives of Neurology, 46,* 1129-1132.

Matsunaga, M. (2010). How to factor-analyze your data right: Do's, Don'ts, and How-To's. *International Journal of Psychological Research, 13*(1), 97-110.

Nulty, D., Wilkins, A., & Williams, J. (1987). Mood, pattern sensitivity and headache: A longitudinal study. *Psychological Medicine, 17,* 705-713.

Palmer, J., Chronicle, E., Rolan, P., & Mulleners, W. (2000). Cortical hyperexcitability is cortical under-inhibition: Evidence from a novel functional test of migraine patients. *Cephalalgia, 20*(6), 525-532.

Panayiotopoulos, C. P. (1994). Elementary visual hallucinations in migraine and epilepsy. *Journal of Neurology, Neurosurgery, and Psychiatry*, *57*(11), 1371–4.

Panayiotopoulos, C. P. (1999). Elementary visual hallucinations, blindness, and headache in idiopathic occipital epilepsy: differentiation from migraine. *Journal of Neurology, Neurosurgery, and Psychiatry*, *66*(4), 536–40.

Penfield, W., & Perot, P. (1963). The brain's record of auditory and visual experience. *Brain*, *86*, 595-596.

Petrusic, I., Zidverc-Trajkovic, J., Podgorac, A., & Sternic, N. (2013). Underestimated phenomena: higher cortical dysfunctions during migraine aura. *Cephalalgia*, *33*(10), 861–7. doi:10.1177/0333102413476373.

Pietrobon, D., & Striessnig, J. (2003). Neurobiology of migraine. *Nature Reviews Neuroscience*, *4*(5), 386–398. doi:10.1038/nrn1102

Podoll, K., & Robinson, D. (1999). Out-of-body experiences and related phenomena in migraine art. *Cephalalgia*, *6*(19), 886–896.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Revelle, W. (2014). psych: Procedures for Personality and Psychological Research. R package version 1.4.2.

Shepherd, A. J., Beaumont, H. M., & Hine, T. J. (2012). Motion processing deficits in migraine are related to contrast sensitivity. *Cephalalgia*, *32*(7), 554–70. doi:10.1177/0333102412445222.

Siegel, R. K. (1977). Hallucinations. *Scientific American*, *237*, 132–140.

Sierra, M. (2009). *Depersonalization: A new look at a neglected syndrome*. Cambridge, UK: Cambridge University Press.

Sierra, M., & Berrios, G. E. (2000). The Cambridge Depersonalisation Scale: A new instrument for the measurement of depersonalisation. *Psychiatry Research, 93*(2), 153–164. doi:10.1016/S0165-1781(00)00100-1

Silberstein, S. D. (2004). Migraine pathophysiology and its clinical implications. *Cephalalgia, 24 Suppl 2*, 2–7. doi:10.1111/j.1468-2982.2004.00892.x

Tabachnick, B. & Fidell, L. (2001). *Using multivariate statistics*. Needham Heights: Allyn & Bacon.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston, MA: Allyn & Bacon.

Taylor, I., Scheffer, I. E., & Berkovic, S. F. (2003). Occipital epilepsies: identification of specific and newly recognized syndromes. *Brain, 126*(4), 753–769. doi:10.1093/brain/awg080

Turner, N. E. (1998). The effect of common variance and structure pattern on random data eigenvalues: Implications for the accuracy of parallel analysis. *Educational and Psychological Measurement, 58*(4), 541-568. doi: 10.1177/0013164498058004001.

Velicer, W. F., Eaton, C. A., & Fava, J. L. (2000). Construct explication through factor or component analysis: A review and evaluation of alternative procedures for determining the number of factors or components. In R. D. Goffin & E. Helmes (eds.), *Problems and solutions in human assessment: Honoring Douglas N. Jackson at seventy.* Norwell, MA: Kluwer Academic.

Wassermann, E. M. (1998). Risk and safety of repetitive transcranial magnetic stimulation: Report and suggested guidelines from the International Workshop on the Safety of

Repetitive Transcranial Magnetic Stimulation, June 5–7, 1996. *Electroencephalography and Clinical Neurophysiology, 108,* 1-16.

Welch., K.M.A., Bowyer, S,M., Aurora, S.K., Moran, J.E., Tepley, N (2001). Visual stress-induced migraine aura compared to spontaneous aura studies by magnetoencephalography. Journal of Headache Pain, *2*, 131-136.

Wilkins, A. (1986). What is visual stress? *Trends in Neurosciences, 9*, 343-346.

Wilkins, A. (1995). Visual stress. New York, NY: Oxford University Press.

Wilkins, A.J., Binnie, C.D., & Darby, C. (1980). Visually induced seizures. Progress in Neurobiology, *15*, 85-117.

Wilkins, A., Nimmo-Smith, M., Tait, A., McManuc, C., Della Sala, S., Tilley, A., … Scott, S. (1984). A neurological basis for visual discomfort. *Brain, 107*(4), 989-1017.

Williams, B., Brown, T., & Onsman, A. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine, 8*(3), 1-13.

Young, W., Oshinsky, M., Shechter, A., Gebeline-Myers, C., Bradley, K., & Wassermann, E. (2004). Consecutive transcranial magnetic stimulation: Phosphene thresholds in migraneurs and controls. *Headache, 44,* 131-135.

Table 1. Table showing abbreviated *CHi* questions and sources.

Question	Source
1) Vision more sensitive to external sensory information?	New
2) Overwhelmed by visual information?	New
3) Visual perception seems heightened or enhanced?	New
4) Irritation from indoor lights?	New
5) Everyday objects look different?	Adapted from CAPS/ CDS
6) Ever experienced phosphenes?	New
7) Find certain environments irritating?	New
8) Ever see shapes, lights, or colours?	CAPS item
9) Find the appearance of things or people changes?	CAPS item
10) Seen shadows or movement in peripheral vision?	New
11) Felt dizzy / nauseous due to strong light or patterns?	New
12) Lights or colours seem brighter or more intense?	CAPS item
13) Seen an apparition / ghost?	New
14) Experienced visual discomfort from objects and patterns?	New
15) Had a headache / migraine induced by visual information?	New
16) Experienced visual distortions?	New
17) Seen a 'flicker' on your computer?	New
18) Working on computer for long periods irritates eyes?	Adapted from MI
19) Noticed perceptual distortions in vision?	New
20) Fluorescent lights irritate your eyes?	Adapted from MI & VDS
21) Had an out-of-body experience?	New
22) Sensed the presence of another being?	CAPS item
23) Headlights from oncoming traffic irritate eyes?	Adapted from MI
24) Experienced visual discomfort from reading?	New
25) Experienced a narrowing of your visual field?	New
26) Experienced flashes of moving patterns?	New
27) Experienced loss of visual information?	New

Table 2. Descriptive statistics for overall *CHi* scores (CI = confidence interval).

	Mean	**95% CI (Lower bound)**	**95% CI (Upper bound)**	**Skewness**	**Kurtosis**
CHi	52.2	47.59	56.81	1.19	1.61

Table 3. Percentiles for *CHi* scores.

	Percentiles						
	5	**10**	**25**	**50**	**75**	**90**	**95**
CHi **Weighted average**	7.00	11.10	23.75	45.00	73.00	99.70	131.15

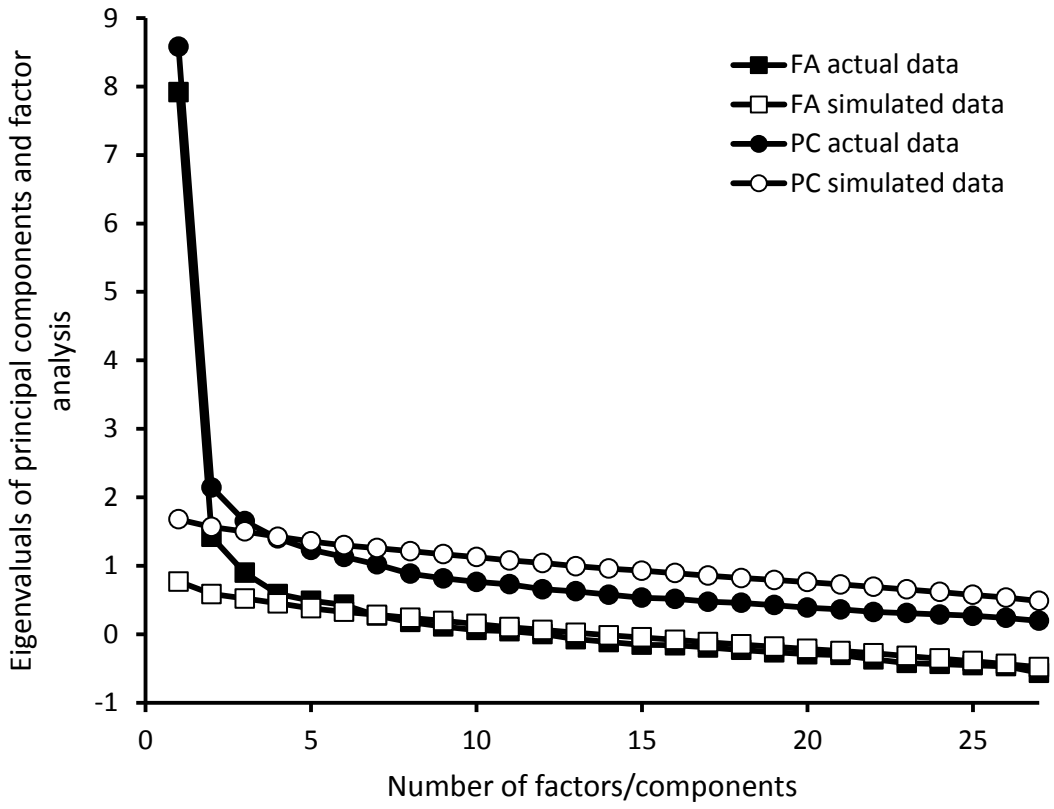

Figure 1. Factor Analysis (FA) and Principle Component (PC) parallel analysis Scree Plot. The eigenvalues for the actual data, simulated data and re-sampled data are shown and suggest that a three-factor solution is the most appropriate.

Table 4. The factorial structure of the *CHi*.	Factor			Communalities	
	1	2	3	Initial	Extraction
20) Working / reading under fluorescent lights irritate / bother your eyes?	0.794			0.514	0.480
4) Indoor lights ever seemed so bright that they have irritated and bothered your eyes?	0.729			0.563	0.532
11) Felt dizzy / nauseous due to strong light levels or the presence of certain visual patterns?	0.723			0.437	0.407
18) Working on a computer for long periods ever irritate / bother your eyes?	0.691			0.490	0.503
24) Experience visual discomfort / irritation from reading certain letter fonts / styles?	0.633			0.408	0.320
1) Vision more sensitive to external sensory information (e.g., light / patterns) than is usually the case?	0.609			0.573	0.476
3) Visual perception seems heightened or enhanced?	0.572			0.534	0.372
7) Certain environments to be visually uncomfortable / irritative?	0.558			0.508	0.480
15) Had a headache / migraine that you felt was induced by visual information in your immediate surroundings?	0.558			0.379	0.300
14) Experience visual pain / discomfort from looking at certain objects and patterns?	0.551			0.391	0.286
12) Days when lights or colours seem brighter or more intense than usual?	0.525			0.569	0.469
2) Feel overwhelmed by visual information?	0.500			0.433	0.328
23) Headlights from oncoming traffic / cars irritate or bother your eyes?	0.461			0.386	0.304
27) Localised / partial alterations in field of vision, resulting in a diminished, distorted, or transient loss of visual information?		0.824		0.595	0.606
26) Sudden and unexpected flashes of moving patterns (e.g., stripes / zigzags) imposed on the visual world?		0.776		0.577	0.548
5) Everyday objects ever looked different to you than their typical appearance (e.g., larger / smaller)?		0.632		0.577	0.473
9) Appearance of things or people seems to change in a puzzling way, (e.g. distorted shapes or sizes or colours)?		0.567		0.508	0.401
21) An out-of-body experience, convinced you experienced the world from a vantage point outside of your physical body?		0.413		0.368	0.153
25) Experienced a sudden and unexpected narrowing of your visual field (greying out of peripheral vision / tunnel vision)?		0.410		0.343	0.235
10) Been distracted by shadows or movement in your peripheral vision, when nothing was there?			0.775	0.497	0.557
8) See shapes, lights, or colours even though there is nothing really there?			0.606	0.484	0.425
22) Sense the presence of another being, despite being unable to see any evidence?			0.553	0.395	0.258
6) Experienced the phenomena of phosphenes (transient flashes / sparkles of light) for no apparent reason?			0.499	0.458	0.385
16) Experienced visual distortions (e.g., shimmer, flicker, bending lines, shadows) when you have been tired or fatigued?			0.432	0.602	0.546

Table 5. Correlations between extracted factors (factor correlation matrix).

Factor	Heightened sensitivity	Neg visual aberrations	Pos visual aberrations
Heightened sensitivity	-	.56	.58
Neg visual aberrations	.56	-	.53
Pos visual aberrations	.58	.53	-

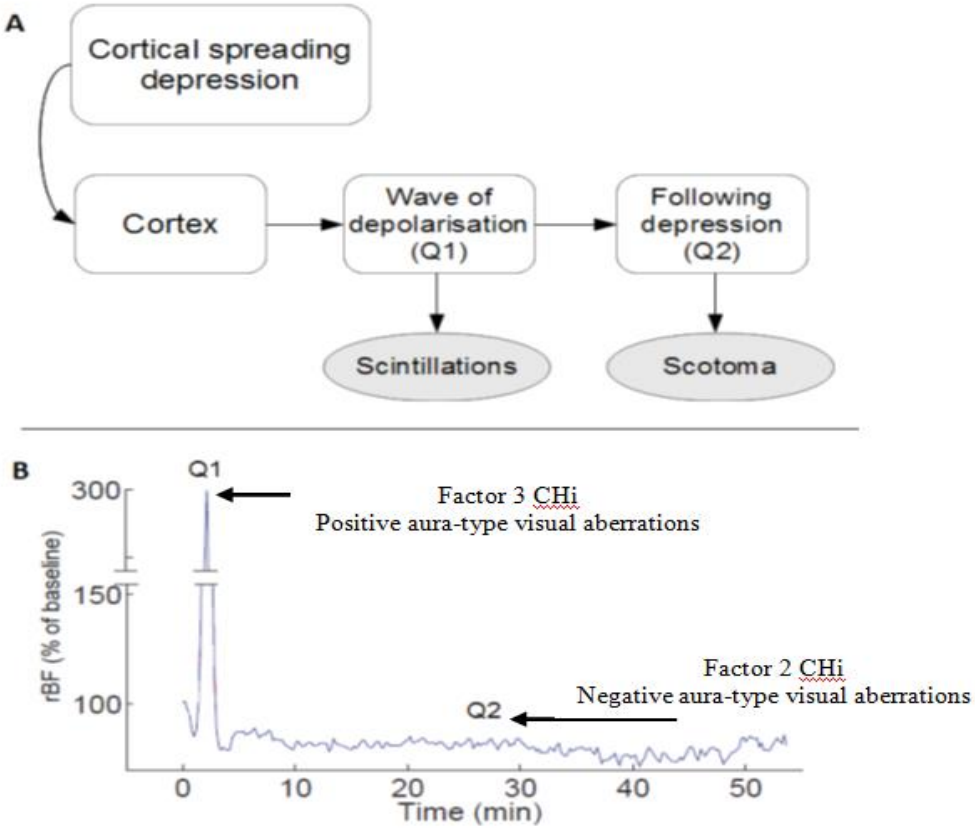

Figure 2. A Diagram of CSD within the cortex (adapted from Blackwell, 2008 and Bolay et al., 2002). Top panel (A) illustrates the sequence of events involved in CSD, with hallucinations shown in grey (Q1 = scintillations / sparkles or flashes of light and Q2 = scotoma / isolated areas of diminished vision). Bottom panel (B) shows a time course of the change in relative blood flow within the cerebral cortex, illustrating the blood-flow elevations typical of CSD, hyper-activity (Q1) followed by depression (Q2): Bolay et al., 2002). The prolonged decrease at period Q2 is likely due to suppressed neuronal activity.