On interference between target and noise in visual stimuli

Bernt Christian Skottun

Ullevaalsalleen 4C

0852 Oslo

Norway

e-mail: berntchrskottun@gmail.com

Short title: Visual noise

ABSTRACT

Visual stimuli in which a target is presented on a background of noise have been used widely in vision research. Adding a background of noise tends to reduce performance. Such reductions have typically been attributed to factors in the visual system. The present analyses demonstrates how there may be interference between target and noise. This interference takes place in the stimuli rather than in the visual system. It takes place even if the stimuli are not being seen. The interference causes the amplitudes in the combined target and noise stimulus to be smaller than the amplitudes in the target plus the amplitudes in the noise when these are determined separately. Therefore, the full amplitudes of the target and those of the noise cannot all be contained in the amplitudes of the combined stimulus. As a consequence one cannot count on a target stimulus to have the same stimulus power when presented on a background of noise as when presented on a uniform background.

Key words: Fourier Transform; amplitude; phase; crowding; masking.

Many visual scientists have made use of visual stimuli to which noise has been added (e.g., Aihara et al., 2008; Attwell et al., 2021; Barthelme & Mamassian, 2009; Beattie et al., 2011; Barnhart & Goldinger, 2013; Chen et al., 2019; Coutanche & Thompson-Schill, 2015; Dakin et al., 2018; Dewhurst et al., 2018; Emadi & Esteki, 2013; Gold, 2015; Greve et al., 2017; Hall et al., 2014; Hall & McAnany, 2017; Jones et al., 2003; Kim & Alais, 2021; Kuniecki et al., 2017; Kruger et al., 1986; Legge et al., 1987; Lubner et al., 2020; Manahilov et al., 2003; Mareschal et al., 2010; Mihaylova et al., 2021; Milner & Michalski, 2003; Pardhan et al., 1996; Partosetal., 2016; Pelli et al., 2004, 2006, 2009; Rainer et al., 2004; Salmela & Laurinen, 2009). The general notion behind the use of such stimuli has been that they will tell us something about vision or the visual system.

Typically the adding of noise has a deleterious effect on the performance on the task in question (Attwell et al., 2021; Beattie et al., 2011; Dakin et al., 2018; Dewhurst et al., 2018; Emadi & Esteki, 2013; Hall et al., 2014; Kuboki et al., 2017; Mareschal et al., 2010; Milner & Michalski, 2003; Pelli et al., 2004). The effect of visual noise has commonly been attributed to factors in the visual system or has been discussed in relation to such factors (e.g., Asher et al., 2021; Attwell et al., 2021; Cropper et al., 2020; Dakin et al., 2018; Emadi & Esteki, 2013; Hall et al., 2014; Hall & McAnany, 2017; Jones et al., 2003; Kruger et al., 1986; Kuboki et al., 2017; Legge et al., 1987; Lubner et al., 2020; Pardhan et al., 1996; Quinlan & Allen, 2018; Rainer et al., 2004; Salmela & Laurinen, 2009; Stuke et al. 2021). However, it has become clear that in the case of stimuli containing several stimulus elements, such as, e.g., in the case of visual masking and visual crowding, there may be interference between the elements (Skottun, 2018a, b, c, d). Such interference which reduces the power of the stimuli (Skottun, 2018c) takes place in the stimuli. That is to say, it occurs whether or not the stimuli are seen or activate any visual system.

Interference can be most easily understood in regard to the amplitude spectra of stimuli. The Fourier Transform transforms a signal into a series of sine functions of various amplitudes and phases. Denoting the amplitude operator by $|\cdot|$ the amplitude of a sine function can be expressed as $|a e^{i\omega(x-\phi)}|$ where a is a scaling factor which determines the amplitude (without this factor the amplitude is 1.0), ω denotes the frequency, x gives position and ϕ denotes the phase. The value of $|a e^{i\omega(x-\phi)}|$ is equal to a irrespective of the values of ω , of x , and of ϕ . When adding the amplitudes of two sine functions we get $|a_1 e^{i\omega(x-\phi_1)}| + |a_2 e^{i\omega(x-\phi_2)}| = a_1 + a_2$. This applies to amplitudes which have been determined separately and then added. However, in experiments where two stimuli are presented together (such as, e.g., when noise has been added to a target) we need to determine the amplitude of the combined stimulus. For two sine functions presented together we then have

$|a_1 e^{i\omega(x-\phi_1)} + a_2 e^{i\omega(x-\phi_2)}| < a_1 + a_2$ when $\phi_1 \neq \phi_2$ [FOOTNOTE 1]. In other words, the amplitude of the sum is smaller than the sum of amplitudes when the phases differ [FOOTNOTE 2]. As a consequence, two stimuli which differ in phase spectra cannot both have their full amplitudes contained in the amplitudes of the combined stimulus (Skottun, 2018a, b, c, d; 2020). In the case of visual stimuli which involve the combining of two or more stimulus elements (such as, e.g., in visual masking, Skottun, 2018b, d, and in visual crowding, Skottun, 2020) the different elements practically always differ in their phase spectra. It seems reasonable to think that this is also the case for a target and noise. It is the aim of the present report to explore the issue of interference between a target stimulus and visual noise. [FOOTNOTE 3]

METHODS

Quantitative analyses were carried out using *GNU Octave*.

RESULTS

The stimulus was modeled roughly after the one shown in Fig. 2 of Hall & McAnany (2017). It is depicted in Fig. 1 and consisted of a field of noise (Fig. 1A) upon which was added a target stimulus consisting of a white "H" (Fig. 1B) resulting in a stimulus consisting of a white "H" on a background of noise (Fig. 1C). The whole image had the dimensions of 256 x 256 image elements. The noise (Fig. 1A) was made up of 32 x 32 squares, each having the dimensions of 8 x 8 image elements. The luminance of each square was determined by a random number between 0.0 and 1.0. In the target stimulus (Fig. 1B) the white "H" had a value of 1.0 and the background was set to 0.0.

If we denote the Fourier spectra of the target stimulus (Fig. 1B) and that of the noise (Fig. 1A) by T and N , respectively, we can define the *relative amplitude sum* as $\sum |T + N| / (\sum |T| + \sum |N|)$ (Skottun, 2018 a, b, c). The *relative amplitude sum* gives the sum of amplitudes in the combined stimulus relative to the sum of amplitudes in the target plus the sum of amplitudes in the noise. A *relative amplitude sum* of 1.0 indicates full linear summation and no interference. The amount by which the *relative amplitude sum* falls below 1.0 is a measure of interference. (Note that the *relative amplitude sum* can never be above 1.0.) For the stimuli in Fig. 1 the *relative amplitude sum* was 0.83 meaning there was a 17 % reduction in stimulus amplitudes due to interference between the target stimulus (Fig. 1B) and the background noise (Fig. 1A) when the two stimuli were combined (as shown in Fig. 1C).

Fig. 1

Fig. 1. The random noise stimulus (Panel A) on top of which were placed a white "H" (Panel B) giving, when the two are added together, a target stimulus on a background of visual noise (Panel C). The white "H" (in Panel B) has a value of 1.0 on a background of 0.0. The noise background (Panel A) consisted of 32 x 32 squares each subtending 8 x 8 pixels. The luminance value of each square was set to a random value between 0.0 and 1.0.

This entails that the full amplitudes of both the target and the noise cannot be contained in the combined stimulus (i.e., in Fig. 1C). Based on this result we are not in a position to determine if the reduction is in the target, in the noise, or in both. What is clear, however, is that one cannot count on a target stimulus to have the same stimulus power when presented on top of noise as when presented alone. The reduction in stimulus power, it should be emphasized, takes place in the stimuli and is a consequence inherent in the adding of signals. It takes place whether or not the stimuli are seen.

In Fig. 2A is shown the effect of "noise contrast" on the *relative amplitude sum*. The "noise contrast" refers to the scaling of the noise. The noise was generated by random numbers in the range of 0.0 to 1.0. These values were then multiplied by a constant to alter the "noise contrast". "Noise contrast" refers to the value of this constant. For instance, a noise contrast on 0.2 means that the random numbers were all multiplied with this value. The horizontal dashed line indicates a *relative amplitude sum* of 1.0 which entails that the $\sum |T + N| = \sum |T| + \sum |N|$ and, consequently, that there is no interference. Values below 1.0, on the other hand, means that $\sum |T + N| < \sum |T| + \sum |N|$ and that there is interference between the target and the noise. The amount by which the *relative amplitude sum* falls below 1.0 is a measure of interference.

As can be seen from Fig. 2A, there is a rapid drop in the *relative amplitude sum* with increasing noise contrast at the lowest levels followed by a very gradual increase. For all noise contrasts other than 0 there is clear evidence of interference. The rapid drop at low noise contrasts entails that a small amount of noise can cause pronounced interference.

In Fig. 2B is shown the effect of "target contrast" upon the *relative amplitude sum*. The "target contrast" refers to the scaling of the intensity of the target stimulus. The target stimulus (Fig. 1B) was generated as a white "H" with a value of 1.0 on a black background having a value of 0.0. The "target contrast" refers to the scaling of the intensity of the white "H". As can be seen in Fig. 2B, relative to noise contrast as shown in Fig. 2A there is a more gradual decrease in the *relative amplitude sum* with increasing target contrast. Also, there is no "upturn" of the curve at the highest "target contrasts".

Fig. 2 (A) The *relative amplitude sum* as function of "noise contrast". (B) The *relative amplitude sum* as function of "target contrast". The amount of interference is indicated by the magnitude by which the values fall below 1.0 which is indicated with horizontal dashed lines. In Panel A the target contrast was 1.0 and in Panel B the noise contrast was 1.0.

In fig. 3 is shown a contour plot of the *relative amplitude sum* as function of noise contrast and target contrast. Darker areas indicate lower *relative amplitude sums*. The horizontal and vertical dashed lines indicate the location for the plots in Fig. 2A and Fig. 2B, respectively. The stimuli shown in Fig. 1 correspond to the intersection of these lines. The positive diagonal in Fig. 3 (the diagonal along which noise

contrast and target contrast are both increasing) represents the case where the noise contrast is equal to the target contrast. The *relative amplitude sum* values along this line are all 0.83. The lowest value observed

Fig. 3. Contour plot of *relative amplitude sum* as a function of noise contrast and target contrast. Darker areas indicate lower values. The profiles shown in Fig. 2A and Fig. 2B are indicated by horizontal and vertical dashed lines, respectively. Please be aware there is little stimulation in the lower left. In fact, at the lower left corner both stimuli are zero.

Fig. 4

Fig. 4.”Hybrid” stimuli in which the target (the white ”H”) and the background noise have the same phase spectrum. In Panel A is shown the case where the image has the amplitudes of the noise (i.e., of Fig. 1A) and the phases of the target (i.e., of Fig. 1B). In Panel B is shown the case where the target stimulus (i.e., of Fig. 1B) has been added to the image in Panel A. Thus, in this case both target and noise have the phase spectrum of the target.

was 0.79 corresponding to a reduction in *relative amplitude sum* of 21 %. This is found for a noise contrast of 0.3 and a target contrast of 0.8.

Interference occurs when two stimuli with different phase spectra are combined. Consequently, when

the two stimuli have identical phase spectra there will be no interference (and the *relative amplitude sum* will be 1.0). It is clearly possible to create pairs of stimuli in which the two stimuli have the same phase spectra. Based on the two stimuli in Fig. 1A and Fig. 1B there are two obvious ways of doing so (and there is an infinity of other possibilities). The first is to take the amplitudes of the noise (i.e., of Fig 1A) and combine them with the phases of the target (i.e., with the phases of Fig. 1B). If we denote the amplitude spectrum of the noise by $|N|$ and the phase spectrum of the target by Φ_T we can create a Fourier spectrum as $|N| \exp(i \Phi_T)$ which has the amplitudes of the noise and the phases of the target. From this hybrid Fourier spectrum a hybrid stimulus can be generated by inverse Fourier Transform. The resulting stimulus is shown in Fig. 4A. In Fig. 4B is shown this stimulus after the original target stimulus (as shown in Fig. 1B) has been added to it.

In Fig. 5 is shown the converse relationship where the amplitudes of the target (i.e., of Fig. 1B) have been combined with the phases of the noise (i.e., of Fig. 1A). The resulting hybrid stimulus is shown in Fig. 5A. In Fig. 5B the noise stimulus (i.e., Fig. 1A) has been added to it. (Note that we cannot add the original target to it since the two stimuli would then not have the same phase spectra.)

Neither of these stimuli appear particularly interesting from the point of view of visual science. In the stimuli in Fig. 4 an outline of target stimulus is clearly visible in the "noise" (i.e., in Fig. 4A). In the stimuli in Fig. 5, in which both stimuli have the phases of the noise (i.e., of Fig. 1A) there are no clearly defined shapes. These observations, however, should not be taken to mean that interesting stimuli in which target and background have the same phase spectra cannot be created.

DISCUSSION

Based on the present stimuli the present analyses have shown that the sum of the amplitudes of the target and the noise together is smaller than the sum of the amplitudes in the target plus the sum of the amplitudes in the noise. The reductions, which reflect interference, may amount to about 20 % for some amounts of noise and target contrast (Fig. 2 and Fig. 3). This means that the full amplitudes of the target and those of the noise cannot both be contained in the amplitudes of the combined stimulus. If the reduction is in the target, or in the noise, or in both cannot be determined. What is certain, however, is that one cannot count on a target stimulus to have the same stimulus power when presented together with noise as when presented alone. Thus, if one were to carry out an experiment in which one determined performance with a target stimulus presented on a uniform background and then carried out the same experiment with

the target presented on a background of noise one may not assume that the target is the same stimulus in the two cases. Clearly, even if its shape and appearance remains the same the target stimulus cannot be said to be the same stimulus if its stimulus power (i.e., the sum of its amplitudes) is reduced. Thus, one must not confuse the stimulus with its appearance.

Fig. 5

Fig. 5. Same as in Fig. 3 but here Panel A shows the stimulus in which the amplitudes are those of the target (i.e. of Fig. 1B) and the phases are those of the noise (i.e. of Fig. 1A). In Panel B the noise (i.e. of Fig. 1A) has been added to the image in Panel A. In this case both stimuli have the phases of the noise.

As a consequence, were one to find reduced responses to a target stimulus on a noise background as compared to when it is presented on a uniform background one would not be in a position to attribute the reduction to factors in the visual system (that is, unless one has controlled for interference in the stimuli). In this regard the adding of noise is similar to what has been found for visual crowding and masking in which the adding of masking or flanking stimuli reduces the stimulus power of a target stimulus (Skottun, 2018b, d; 2020). This emphasises the need to take interference into account whenever one is interpreting the effects of adding stimulus elements. Again, interference takes place *in the stimuli* and does not depend on the stimuli being seen.

Also noteworthy is the finding, as can be seen from Fig. 2A and Fig. 3, that only a relatively small amount of noise (i.e., a small amount of noise contrast) can give a pronounced reduction in *relative amplitude sum*. It should also be emphasised that the present results are obtained with particular stimuli. One can therefore not extrapolate from the present results to noise stimuli in general. Rather, what is needed in other cases is for assessment to be carried out with the particular stimuli in question.

Some investigators have presented the target stimulus and the noise after one another in time or have alternated them in time (Liberman et al., 2014; Mattson et al., 1994; Mitra et al., 2014; Quinlan & Allen, 2018). In this connection it should be pointed out that interference may also occur across time. What is required is that the stimuli fall within the temporal window within which stimulation is integrated (Skottun, 2018d). In the case of temporal stimuli there may be interference both across time and space. To assess interference in such cases a 3-dimensional Fourier Transform may be required (Skottun, 2018d).

The present analyses have estimated interference by summing amplitudes over the whole spectrum. This entails that there may be larger amounts of interference for individual components in the spectrum. Also, for some components the interference may be less. However, for no component can $|T_{\omega_x, \omega_y} + N_{\omega_x, \omega_y}|$ be larger than $|T_{\omega_x, \omega_y}| + |N_{\omega_x, \omega_y}|$ where T_{ω_x, ω_y} and N_{ω_x, ω_y} denote individual components in the 2-D Fourier spectra.

What is presented here is not an "alternative account" to explanations in terms of factors in the visual system. Rather, it is an attempt to understand visual stimuli. It is first when one understands the stimuli that one finds oneself in a position to evaluate the potential role of the visual system. In other words, in order to understand the responses to visual stimuli one must first understand the stimuli.

FOOTNOTES

1. $|a_1 e^{i\omega(x-\phi_1)}| + |a_2 e^{i\omega(x-\phi_2)}|$ on the one hand and $a_1 e^{i\omega(x-\phi_1)} + a_2 e^{i\omega(x-\phi_2)}$ on the other are more different than may appear. $|a_1 e^{i\omega(x-\phi_1)}| + |a_2 e^{i\omega(x-\phi_2)}|$ is the addition of two real numbers (i.e., $|a_1 e^{i\omega(x-\phi_1)}|, |a_2 e^{i\omega(x-\phi_2)}| \in \mathbb{R}$) whereas $a_1 e^{i\omega(x-\phi_1)} + a_2 e^{i\omega(x-\phi_2)}$ is the addition of two vectors in the complex plane. (The "complex plane" is a plane with one imaginary axis, where $i = \sqrt{-1}$ is the unit, and one real axis, where $1 \in \mathbb{R}$ is the unit.) The length of the sum of two vectors is smaller than the length of the one plus the length of the other when their directions differ. (This is known as the "triangle inequality".) Since the directions reflect the phases and the length of the vectors give the amplitudes we have that the amplitude of the sum is smaller than the sum of the amplitudes when the phases differ (see Fig. 1 of Skottun, 2018c; Fig. 3 of Skottun, 2018d; Fig. 1 of Skottun, 2018e).

2. The transform of a signal into its Fourier spectrum is one-to-one and linear. The transform of a signal into its amplitude spectrum is (generally) neither. It is therefore important to not confuse the Fourier spectrum and the amplitude spectrum.

3. It may seem counterintuitive that the power of a target stimulus may be reduced by adding something to it, e.g., by adding a background, a masking stimulus, or a flanking stimulus. That is, it may seem puzzling that it is reduced, not by subtracting from it, but by adding to it. If this seems puzzling one should consider the case of adding a pedestal to the background of a target. This will reduce the stimulus power of the target if we take the Weber-fraction to be a measure of stimulus power.

REFERENCES

- Aihara, T., Kitajo, K., Nozaki, D., & Yamamoto, Y. (2008) Internal noise determines external stochastic resonance in visual perception. *Vision Research*, 48, 1569-1573.
- Asher, J.M., O'Hare, L., & Hibbard, P.B. (2021) No evidence of reduced contrast sensitivity in migraine-with-aura for large, narrowband, centrally presented noise-masked stimuli. *Vision (Basel)*, 5(2):32. doi:10.3390/vision5020032
- Attwell, J.R., Ioannou, C.C., Reid, C.R., & Herbert-Read, J.E. (2021) Fish avoid visually noisy environments where prey targeting is reduced. *The American Naturalist*, 198, 421-432.
- Barnhart, A.S., & Goldinger, S.D. (2013) Rotation reveals the importance of configural cues in handwritten word perception. *Psychonomic Bulletin and Review*, 20, 1319-1326.
- Barthelme, S., & Mamassian, P. (2009) Evaluation of objective uncertainty in the visual system. *PLoS Computational Biology*, 5(9): e1000504. doi:10.1371/journal.pcbi.1000504

- Beattie, R.L., Lu, Z.L., & Manis, F.R. (2011) Dyslexic adults can learn from repeated stimulus presentation but have difficulties in excluding external noise. *PLoS One*. 6(11):e27893. doi: 10.1371/journal.pone.0027893
- Chen, J., Kaur, J., Abbas, H., Wu, M., Luo, W., Osman, S., & Niemeier, M. (2019) Evidence for a common mechanism of spatial attention and visual awareness: Towards construct validity of pseudoneglect. *PLoS One*. 14(3):e0212998. doi: 10.1371/journal.pone.0212998
- Coutanche, M.N., & Thompson-Schill, S.L. (2015) Creating concepts from converging features in human cortex. *Cerebral Cortex*. 25, 2584-2593.
- Cropper, S.J., McCauley, A., Gwinn, O.S., Bartlett, M., & Nicholls, M.E.R. (2020) Flowers in the attic: Lateralization of the detection of meaning in visual noise. *Journal of Vision*, 20(10):11. doi: 10.1167/jov.20.10.11
- Dakin, C.J., Peters, A., Giunti, P., & Day, B.L. (2018) Cerebellar degeneration increases visual influence on dynamic estimates of verticality. *Current Biology*, 28, 3589-3598.
- Dewhurst, R., Foulsham, T., Jarodzka, H., Johansson, R., Holmqvist, K., & Nystrom, M. (2018) How task demands influence scanpath similarity in a sequential number-search task. *Vision Research*, 149, 9-23.
- Emadi, N., & Esteky, H. (2013) Neural representation of ambiguous visual objects in the inferior temporal cortex. *PLoS One*. 8(10):e76856. doi: 10.1371/journal.pone.0076856
- Gold, J.M. (2014) Information processing correlates of a size-contrast illusion. *Frontiers in Psychology*, 19;5:142. doi: 10.3389/fpsyg.2014.00142
- Greve, A., Cooper, E., Kaula, A., Anderson, M.C., & Henson, R. (2017) Does prediction error drive one-shot declarative learning? *Journal of Memory and Language*, 94, 149-165.
- Hall, C.M. & McAnany, J.J. (2017) Luminance noise as a novel approach for measuring contrast sensitivity within the magnocellular and parvocellular pathways. *Journal of Vision*, 17(8):5, 110. doi: 10.1167/17.8.5
- Hall, C., Wang, S., Bhagat, R., & McAnany, J.J. (2014) Effect of luminance noise on the object frequencies mediating letter identification. *Frontiers in Psychology*, 5:663. doi: 10.3389/fpsyg.2014.00663
- Hansen, B.C., & Hess, R.F. (2006) Discrimination of amplitude spectrum slope in the fovea and parafovea and the local amplitude distributions of natural scene imagery. *Journal of Vision*, 6, 696711.
- Jones, D.G., Anderson, N.D., & Murphy, K.M. (2003) Orientation discrimination in visual noise using global and local stimuli. *Vision Research*, 43, 1223-1233.
- Kim, S., & Alais, D. (2021) Individual differences in serial dependence manifest when sensory uncertainty is high. *Vision Research*, 188, 274-282.
- Kruger, K., Heitlander-Fansa, H., Dinse, H., & Berlucchi, G. (1986) Detection performance of normal cats and those lacking areas 17 and 18: a behavioral approach to analyse pattern recognition deficits. *Experimental Brain Research*, 63, 233-247.
- Kuboki, R., Sugase-Miyamoto, Y., Matsumoto, N., Richmond, B.J., & Shidara, M. (2017) Information accumulation over time in monkey inferior temporal cortex neurons explains pattern recognition reaction time under visual noise. *Frontiers in Integrative Neuroscience*. 10:43. doi: 10.3389/fnint.2016.00043
- Kuniecki, M., Wooszyn, K., Domagalik, A., & Pilarczyk, J. (2017) Effects of scene properties and emotional valence on brain activations: A fixation-related fMRI study. *Frontiers in Human Neuroscience*, 11:429. doi: 10.3389/fnhum.2017.00429
- Legge, G.E., Kersten, D., & Burgess, A.E. (1987) Contrast discrimination in noise. *Journal of the Optical Society of America A*. 4, 391-404.
- Liberman, A., Fischer, J., & Whitney, D. (2014) Serial dependence in the perception of faces. *Current*

Biology, 24, 2569-2574.

Luber, B., Jangraw, D.C., Appelbaum, G., Harrison, A., Hilbig, S., Beynel, L., Jones, T., Sajda, P., & Lisanby, S.H. (2020) Using transcranial magnetic stimulation to test a network model of perceptual decision making in the human brain. *Frontiers in Human Neuroscience*, 14:4. doi: 10.3389/fnhum.2020.00004

Manahilov, V., Calvert, J., & Simpson, W.A. (2003) Temporal properties of the visual responses to luminance and contrast modulated noise. *Vision Research*, 43, 1855-1867.

Mareschal, I., Morgan, M.J., & Solomon, J.A. (2010) Cortical distance determines whether flankers cause crowding or the tilt illusion. *Journal of Vision*, 10(8):13, 1-14. doi: 10.1167/10.8.13

Mattson, A.J., Levin, H.S., & Breitmeyer, B.G. (1994) Visual information processing after severe closed head injury: effects of forward and backward masking. *Journal of Neurology, Neurosurgery and Psychiatry*, 57, 818-824.

Milner, R., & Michalski, A. (2003) Cortical responsiveness is reduced during P300 potential. Does the level of initial activity affect this inhibition? *Acta Neurobiologi Experimentalis (Warsaw)*, 63, 351-360.

Mihaylova, M.S., Bocheva, N.B., Totev, T.T., & Staykova, S.N. (2021) Visual noise effect on contour integration and gaze allocation in autism spectrum disorder. *Frontiers in Neuroscience*, 15:623663. doi: 10.3389/fnins.2021.623663

Mitra, S., Nizamie, S.H., Goyal, N., & Tikka, S.K. (2014) Mu-wave activity in schizophrenia: Evidence of a dysfunctional mirror neuron system from an Indian study. *Indian Journal of Psychological Medicine*, 36, 276-281.

Pardhan, S., Gilchrist, J., Elliott, D.B., & Beh, G.K. (1996) A comparison of sampling efficiency and internal noise level in young and old subjects. *Vision Research*, 36, 1641-1648.

Partos, T.R., Cropper, S.J., & Rawlings, D. (2016) You don't see what I see: Individual differences in the perception of meaning from visual stimuli. *PLoS One*. 11(3):e0150615. doi: 10.1371/journal.pone.0150615

Pelli, D.G., Burns, C.W., Farell, B., & Moore-Page, D.C. (2006) Feature detection and letter identification. *Vision Research*, 46, 4646-4674.

Pelli, D.G., Levi, D.M., & Chung, S.T. (2004) Using visual noise to characterize amblyopic letter identification. *Journal of Vision*, 4(10):904-920. doi: 10.1167/4.10.6

Pelli, D.G., Majaj, N.J., Raizman, N., Christian, C.J., Kim, E., & Palomares, M.C. (2009) Grouping in object recognition: The role of a Gestalt law in letter identification. *Cognitive Neuropsychology*, 26, 36-49.

Quinlan, P.T., & Allen, K. (2018) The nature of shape constancy mechanisms as revealed by shape priming. *Journal of Vision*, 18(6):14, 1-17. doi: 10.1167/18.6.14.

Rainer, G., Lee, H., & Logothetis, N.K. (2004) The effect of learning on the function of monkey extrastriate visual cortex. *PLoS Biology*, 2(2):e44. doi: 10.1371/journal.pbio.0020044

Salmela, V.R., & Laurinen, P.I. (2009) Low-level features determine brightness in Whites and Benarys illusions. *Vision Research*, 49, 682-690.

Skottun, B.C. (2018a) A few remarks on spatial interference in visual stimuli. *Behavior Research Methods*, 50, 1716-1722.

Skottun, B.C. (2018b) Interference in lateral masking stimuli—The effects of relative phase, position, orientation, and spatial frequency. *Behavioural Brain Research*. 349, 137-144.

Skottun, B.C. (2018c) A few remarks on stimulus power and interference in visual stimuli. *PsyArXiv*, doi: 10.31234/OSF.IO/3NT84

Skottun, B.C. (2018d) Interference and visual masking. PsyArXiv. doi: 10.31234/OSF.IO/H8WCR

Skottun, B.C. (2018e) Interference in visual search stimuli. PsyArXiv. doi: 10.31234/OSF.IO/6DZUC

Skottun, B.C. (2020) Interference in visual crowding stimuli with small separations between target and flanking stimuli. PsyArXiv, doi: 10.31234/osf.io/ah6w7

Stuke, H., Kress, E., Weinhhammer, V.A., Sterzer, P., & Schmack, K. (2021) Overly strong priors for socially meaningful visual signals are linked to psychosis proneness in healthy individuals. *Frontiers in Psychology*, 12:583637. doi: 10.3389/fpsyg.2021.583637