A few remarks on "uncrowding" in visual stimuli

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ABSTRACT

Visual crowding occurs when a target stimulus is presented along with flanking stimuli. These tend to reduce the visibility of the target. It has been found that adding additional flanking stimuli may reduce the crowding effect. This has been termed "uncrowding". It has previously been demonstrated that interference in the stimuli may have effects similar to visual crowding. Interference takes place in the stimuli and is unrelated to vision. The question is then: Can adding additional flanking stimuli reduce the interference effect of initial flanking stimuli in a manner consistent with uncrowding. The present simple calculations indicate that this is very much a possibility.

Key words: Visual crowding; Fourier Transform; interference; amplitude; phase; disinhibition.

When presenting a stimulus along with other stimuli its visibility may be reduced. This is sometimes referred to as "visual crowding" (Levi, 2008). It has been shown that it may be possible to counteract this effect by introducing additional stimuli (Choung et al., 2021). In the words of Choung et al. (2021, p. 1): "Surprisingly, perception can be rescued from crowding if additional flankers are added (uncrowding)". And, they continue: "Uncrowding is a major challenge for all classic models of crowding ...".

Crowding has typically been interpreted in terms of factors in the visual system (e.g., Freeman & Simoncelli, 2011; Herzog et al., 2015; Jastrzebowska et al., 2021; Levi, 2008; Motter, 2018; Whitney & Levi, 2011). However, it has become clear that interference in the stimuli may have an effect similar to that of crowding (Skottun, 2021a, b, c; 2020). This raises the question of whether or not the counteracting effect of additional stimuli, as observed in uncrowding, could be consistent with interference. It should be pointed out that interference takes place in the stimuli and is unrelated to vision. That is, interference takes place even if the stimuli are not being seen.

Interference can be most easily understood in terms of amplitude spectra. [FOONOTE 1] The amount of interference in the combination of two stimuli may be quantified by calculating the *Relative Amplitude Sum* (Skottun, 2018a, b, c; 2020). For two stimuli f_1 and f_2 we may designate their Fourier Transforms by F_1 and F_2 , respectively. The sum of amplitudes in the transforms then becomes $\sum |F_1|$ and $\sum |F_2|$, where $|\cdot|$ denotes the amplitude operator. The *Relative Amplitude Sum* is calculated as $\sum |F_1 + F_2| / (\sum |F_1| + \sum |F_2|)$. In words, it is the sum of amplitudes in the combined stimulus ($\sum |F_1 + F_2|$) relative to the sum of amplitudes in the first stimulus ($\sum |F_1|$) plus the sum of amplitudes in the second ($\sum |F_2|$). A *Relative Amplitude Sum* = 1.0 entails there is no interference (i.e., the amplitude of the sum equals the sum of amplitudes) a value below 1.0 indicates the presence of interference. The amount by which the *Relative Amplitude Sum* falls below 1.0 can be taken as a measure of interference. [FOOTNOTE 2]

The stimuli used in the present very simple demonstration to simulate "uncrowding" are shown in Fig. 1. A target stimulus is shown in the top row (Stim1). The second row shows a pair of flanking stimuli (Stim2). The third row shows a pair of "uncrowding" stimuli that fit outside of the flanking stimuli (Stim3). And finally, in the last row is shown the flanking stimuli together with the "uncrowding" stimuli (Stim2 + Stim3). (Numerical analyses were carried out using *GNU Octave*.)

Fig. 1. The simulated stimuli. Top row shows the target stimulus (*Stim1*) in which all but one out of 11 elements have been set to zero. The element not set to zero, which is the central element (position 6), has been set to one. In the second row are shown the flanking stimuli (*Stim2*). In this stimulus positions 4, 5, 7, and 8 have been set to one with the remaining elements set to zero. The third row shows the "uncrowding" stimuli (*Stim3*). In this stimulus locations 2, 3, 9, and 10 have been set to one. Again, the remaining elements have been set to zero. The bottom row shows the flanking stimuli together with the "uncrowding" stimuli (i.e., *Stim2 + Stim3*).

For the target stimulus (*Stim1*) and the flanking stimuli (*Stim2*) we have the *Relative Amplitude Sum* = $(\sum |F(Stim1 + Stim2)|) / (\sum |F(Stim1)| + \sum |F(Stim2)|) = 0.626$ (where $F(Stim1 + Stim2)$, $F(Stim1)$, and $F(Stim2)$ denote the Fourier Transforms). That is, interference caused a reduction of 37.4 % of the amplitudes in the combined stimulus relative to the amplitudes in the individual stimuli. For the target stimulus (*Stim1*) plus the flanking stimulus (*Stim2*) and the uncrowding stimulus (*Stim3*) we have that *Stim2+Stim3* together make up the flanking stimulus giving us a *Relative Amplitude Sum* = $\sum |F(Stim1 + Stim2 + Stim3)| / (\sum |F(Stim1)| + \sum |F(Stim2 + Stim3)|) = 0.660$ (with $F(Stim1 + Stim2 + Stim3)$, $F(Stim1)$, and $F(Stim2 + Stim3)$ denoting the Fourier Transforms). Thus, in this case there was only a reduction of 34.0 % in the amplitudes of the combined stimulus. Therefore, if we accept the *Relative Amplitude Sum* as a measure of interference we have that there can be reduced interference when additional flanking stimuli are added. This would be consistent with "uncrowding" as has been observed in actual experiments (Choung et al., 2021).

However, we do not need to rely upon the Fourier Transform. For a vector $A = \{a_1, a_2, \dots, a_n\}$ we

define the norm as $\|A\| = \sqrt{\sum_{i=1}^n a_i^2}$. We can then define the *Relative Norm* in a manner similar to *Relative Amplitude Sum*. For two vectors A and B the *Relative Norm* = $\|A + B\|/(\|A\| + \|B\|)$. Since the norm is the length of the vector in an n-dimensional Euclidean vector space the *Relative Norm* gives the length of the vector representing the combined stimulus relative to the lengths of the vectors representing the two individual stimuli. For *Stim1* and *Stim2* we have the *Relative Norm* = $\|(Stim1 + Stim2)\|/(\|Stim1\| + \|Stim2\|) = \sqrt{5}/(\sqrt{1} + \sqrt{4}) = 0.745$. For *Stim1*, *Stim2* and *Stim3* we have (since *Stim2* and *Stim3* together make up the flanking stimulus) the *Relative Norm* = $\|(Stim1 + Stim2 + Stim3)\|/(\|Stim1\| + \|Stim2 + Stim3\|) = \sqrt{9}/(\sqrt{1} + \sqrt{8}) = 0.784$. Thus, if we take the amount by which the *Relative Norm* falls below 1.0 as measure of interference we get less interference for *Stim1 + Stim2 + Stim3* than for *Stim1 + Stim2*. Again, this would be consistent with "uncrowding". (For some comments on the use of norms in this context see Skottun, 2018c)

These observations ought to be of relevance for the study of visual crowding and particularly for the issue of uncrowding. However, they may also have relevance for the study of disinhibition, an area of research which was pioneered back in the 1950s by Hartline and Ratliff (1957). The idea behind disinhibition is that if one neural unit is inhibited by a second unit the inhibition may be reduced if the second unit in turn is inhibited by a third. This will then result in less inhibition by the second unit upon the first causing the excitation in the first unit to be enhanced. If the three units are stimulated by separate stimuli interference between the stimuli needs to be taken into account.

The present results do not mean, and should not be taken to mean, that they *explain* the findings of Choung et al. (2021). It is not clear what is to be meant by "explanation" in the context of visual science. If one requires that all aspects of some phenomenon be accounted for by a single mechanism it may be difficult to identify such a mechanism since particular results are likely to reflect a number of influences many of which are likely to be specific to the particular cases. The purpose of the present calculations is to explore principles which, it is hoped, may have some degree of generality. (The pitfall to be avoided is, of course, to focus so intensely on particulars so as to fail to appreciate general principles.)

What the present observations do show are the kinds of considerations that need to be made when interpreting results such as those of Choung et al. (2021). As was pointed out above, interference takes place in the stimuli and does not depend on vision or the visual system. It is, thus, a feature of the stimuli. The present observations, therefore, serve to underscore that in order to try to understand the responses to visual stimuli one ought first try to understand the stimuli.

FOOTNOTES

1. Note that while a transform of a signal into its Fourier spectrum is a linear transform the transform of a signal into its amplitude spectrum is (in general) not. If we denote the Fourier transforms of two signals by F_1 and F_2 and denote the Fourier Transform of their sum by $F_{(1+2)}$ we can write $F_{(1+2)} = F_1 + F_2$ but not (generally) $|F_{(1+2)}| = |F_1| + |F_2|$ (where $|\cdot|$ stands for the amplitude operator). Therefore, one must not confuse Fourier spectra and amplitude spectra. (However, because the Fourier Transform is a linear transform while the transform of a signal into amplitudes is not we can write $|F_{(1+2)}| = |F_1 + F_2|$ but neither $|F_{(1+2)}| = |F_1| + |F_2|$ nor $|F_1 + F_2| = |F_1| + |F_2|$.)

2. The Fourier Transform consists of a series of complex numbers having the form $z = a + b i$, where $i = \sqrt{-1}$ and a and b are real numbers. The amplitude of z is $|z| = \sqrt{a^2 + b^2}$. When adding two Fourier spectra one adds pairs of complex numbers $z_1 + z_2 = a_1 + a_2 + (b_1 + b_2)i$. We then have that $|z_1 + z_2| < |z_1| + |z_2|$ unless $a_1/b_1 = a_2/b_2$ (i.e., z_1 and z_2 having the same phase). Another way to express this would be to say that the Fourier Transform consists of a series of sine functions and that when adding two Fourier Transforms one is adding pairs of sine functions of the same frequency. The amplitude of a sine function can be written as $|e^{i\omega(x-\phi)}|$, where ω denotes frequency, x gives position, and ϕ the phase. Interference occurs when two sine functions having different phases, i.e. when $\phi_1 \neq \phi_2$, are added as one then ends up with a sine function with a smaller amplitude than the sum of amplitudes of the individual functions: $|e^{i\omega(x-\phi_1)} + e^{i\omega(x-\phi_2)}| < |e^{i\omega(x-\phi_1)}| + |e^{i\omega(x-\phi_2)}|$. When $\phi_1 = \phi_2$ we have $|e^{i\omega(x-\phi_1)} + e^{i\omega(x-\phi_2)}| = |e^{i\omega(x-\phi_1)}| + |e^{i\omega(x-\phi_2)}|$ which means no interference. Consequently, when there is no difference in the phase spectra (which corresponds to $a_1/b_1 = a_2/b_2$ above) we have a *Relative Amplitude Sum* $= \sum |F_1 + F_2| / (\sum |F_1| + \sum |F_2|) = 1.0$ (where F_1 and F_2 denote Fourier spectra). When the phase spectra differ resulting in interference we have $\sum |F_1 + F_2| < \sum |F_1| + \sum |F_2|$ making the *Relative Amplitude Sum* fall below 1.0. This makes the *Relative Amplitude Sum* a measure of interference. (For further discussions see Skottun, 2018a, b, c; 2020).

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