A MODEL OF VISUAL BACKWARD MASKING.

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ABSTRACT

Visual recognition of a target stimulus can be impaired when it is presented in close temporal proximity with another stimulus called the mask. Of particular interest is backward masking, where the mask is presented after the target. This raises several questions. For instance: 1. How can the presentation of a later stimulus affect the recognition of a stimulus that has entered the visual system earlier? 2. Why is the mask sometimes most effective when presented approximately 80-100ms after the stimulus (U-shaped behavioural response accuracy)? 3. How can the target have priming effects on subsequent stimuli even when it is so effectively masked that there is no conscious recollection of its presentation? Masking is a peculiar phenomenon that constitutes a test for any model of biological vision.

There are two families of models of backwards masking. The first introduces a temporary store of the target information in early visual areas that supplies information for time-consuming processing in later stages. The presentation of the mask does then interfere with the integrity of the store and prevents the identification of the target. The second assumes that masking information is somehow able to catch up with target information while it travels in the visual stream and is able to interfere with it.

The store model has received experimental support for instance from EMG data showing that masking correspond to the temporal overlapping of occipital responses to the target and the mask (Rieger et al., 2002). Electrophysiological data from Rolls and Tovee (1994) show that face selective neurons in IT exhibit a prolonged firing after the offset of the target, and that this firing is interrupted by the presentation of the mask. Such prolonged firing could reflect either a local storage mechanism, or persistent input from a store in lower visual areas.

The store concept underlies the recent “efficient masking” theory (Francis, 2000) that answers question 2 by assuming that the stimulus is stored in the form of a decaying trace that is available for processing as long as its activity exceeds a given threshold. The longer the duration of the supra-threshold phase, the better the “perceptual strength” of the stimulus and the more accurate the behavioural response. The mask would reduce the trace activity and would have a maximal effect on its duration when the activity is close to the threshold, hence some time after the stimulus onset. The “object substitution” theory of Enns and DiLollo (2000) also uses a decaying image of the target in early visual areas. The mask would then not inhibit the target, but “replace” it, thus effectively interrupting its processing. All the models above are conceptual that do not rely on details of neuronal information processing.

In contrast, in a model by Bugmann and Taylor (1994), stores took the form of sustained neuronal firing. These were integral components of each visual information processing stage, ensuring that information is kept available until recognised by neurons in the next layer. When such a scheme is modelled by a pyramidal network of spiking neurons, it is found that activity propagation is a stochastic process where activity “jumps” to the next layer at random times, and information

"stays" in source neurons for a random duration. The processing is purely feed-forward, but activity propagates with variables velocities in different branches of the pyramid. Part of the stimulus information can still be located in the first layer when the masking stimulus is presented. The mask activates lateral inhibitory mechanisms and interrupt the firing of neurons representing the stimulus. Thus part of stimulus information can be erased by the mask, so preventing, or degrading, stimulus identification. The advantage of such a detailed model is that the probabilistic response of subjects is a feature of the model and does not need to be introduced by hand as in other trace models. It should be noted that the only role of the store is to ensure loss-less feedforward information propagation. Thus the model is consistent with evidence that early responses in the visual stream result from purely feedforward processing (Mehta et al., 2000, Thorpe et al., 1996) and carry almost all information about the stimulus (Oram and Perret, 1992). This model answers question 1, but does not reproduce the U-shape of the response accuracy with SOA (Stimulus – Mask Onset Asynchrony).

The second family of model is exemplified by the work of Breitmeyer (1984) where an inhibitory signal is carried by the fast magnocellular pathway that allows the masking signal to "catch up" with the slower visual information in the parvocellular pathway. There are evidences for a temporary inhibition of neural response in V1 by the mask (Macknik and Livingstone, 1998), although it is unknown if the magnocellular pathway is involved. Such a model has been able to explain a number of peculiar perceptual phenomena (Breitmeyer and Ogmen, 2000). However, unconscious priming (question 3) remains a challenge.

Overall, the idea that the mask has the ability to interfere with ongoing activity is generally accepted. This can be in the form of more or less strong lateral inhibition due to the incompatibility of low level features of the mask and target, and sometime involve cross-stream inhibition (parvo- and magno-cellular). Target substitution could possibly also be describes in these terms (Francis and Hermes, 2002). However, most current models are rather vague on how later processing stages, important for priming effects, are affected by the mask.
To explore the effects of the mask on the dynamics of information propagation and recognition, the model of Bugmann and Taylor (1994) has been refined with more realistic models of neuronal integration, retinal persistence and memory processes along the visual information processing stream.

It is found that the U-shaped response curve could be explained by the properties of the prolonged response of retinal ganglion cells (see e.g. Levick, 1973). As long as cortical cells receive retinal/LGN inputs, the resetting of the sustained cortical firing by the mask has only a temporary effect and cortical cells can resume sending information to the next layer. However, towards the end of the retinal response, the input is weaker and looses is ability to re-initiate cortical firing. That is when the masking effect is maximal. For later presentations of the mask, in most cases, visual information will already have been picked up by higher cortical areas and the mask has no effect. Indeed, this mechanism cannot operate when the mask interrupts directly the retinal firing. Thus depending on the mask characteristics, the model produces a monotonic or U-shaped masking function.

In order to understand unconscious priming, special attention is given to the effect of the mask on speed and level of target activity propagation. It is found that, by reducing the level of activity in earlier areas, the mask can significantly reduce the speed of propagation of target information. Further, the level of activity is reduced in each traversed layer. If visual features of the mask are sufficiently different from those of the target, mask information propagates in a different sub-network of the visual system and can overtake the weakened target signal. This is consistent with *imaging* data by Dehaene et al. (2001) suggesting that the mask reduces the level of activation in successive layers in a gradual way, so that priming effects are still possible, but that activity reaching higher visual areas is below a "consciousness threshold". E.g. only 8% of normal activity remains in the fusiform gyrus where word priming effects are observed.

In summary, a physiologically plausible mechanism for the store model is proposed, using sustained firing that is supporting feedforward information propagation. Including accepted lateral inhibition schemes and prolonged retinal ganglion cell responses, the model reproduces monotonous and U-shaped behavioural responses and their probabilistic characteristics. However, to reproduce unconscious priming, a new “race mechanism” along parallel visual sub-networks has to be considered that determines which stimulus reaches awareness.

Keywords: Metacontrast masking, backward masking, visual latency, unconscious priming.

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