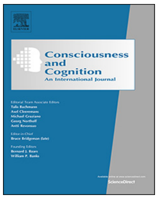
ARTICLE IN PRESS

Consciousness and Cognition xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog



Review article

# Visual masking: Contributions from and comments on Bruce Bridgeman

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ARTICLE INFO

*Keywords:*
Masking
Metacontrast
Visual processing
Consciousness
Psychophysiology
Models

ABSTRACT

When about half a century ago masking research emerged as one of the hot topics in psychophysics, cognitive psychology and psychophysiology, Bruce Bridgeman was among the leaders in this domain. His studies and papers on masking must not be overlooked also today. This article brings to the readers a brief review of Bridgeman's contributions to the field and directly related research from other laboratories, with an eye on the implications for consciousness studies.

## 1. Introduction

For consciousness researchers, experimental methods allowing precise manipulation of reportability of target stimuli are an obvious necessity. Visual masking is a prominent example. Masking in general can be defined as "The blocking or suppression of the perception of a stimulus, often called the *test stimulus*, by the presentation of another stimulus, called the *masking stimulus*." (Colman, 2001). In the case of vision, a wide variety of the types of stimuli can be used as tests or targets – small spatially localized luminance increments or decrements, simple geometrical shapes, visual gratings, alphanumeric symbols, images of natural objects, etc. Similar stimuli can be presented as masks, but it may be advisable to use visual noise or meaningless pattern as a masking stimulus instead. If the mask follows the target in time, it is called backward masking; if the mask precedes the target we deal with forward masking; in sandwich-masking forward and backward types of presentation are combined. When in backward masking target and mask do not overlap in space, but are closely adjacent, it is termed metacontrast.

Back in 1989 our University published my book on visual masking and consciousness, featuring a review of the most influential research findings and theories (Bachmann, 1989). There was no blurb on it, but inside the cover there was the first page depicting small photoportraits of the main players in the field, especially the ones whose research had produced important results for theoretical approaches to consciousness mechanisms. There were Heinz Werner, Bruno Breitmeyer, Naomi Weisstein and a few more staring at you, among them also Bruce Bridgeman. What fascinated me perhaps the most was his approach whereby psychophysical masking phenomena were explained as the outcome of neural interactions known from the studies of sensory and perceptual neurophysiology. This kind of liaison between subjective and objective was by no means an invention of Bruce Bridgeman, but the way he used this approach included many original ideas and findings. The approach where psychological subjective processes were to be grounded on precise scientific knowledge of the underlying brain mechanisms was characteristic to most of his scientific and academic work (e.g., Bridgeman, 1979, 1986, 1988a; Bridgeman, Van der Hejiden, & Velichkovsky, 1994). He also insisted on the importance of modeling besides pure psychological or psychophysiological experiments, which direction he himself of course followed (Bridgeman, 1971, 1977, 1978, 2001, 2006a, 2006b, 2007). Although Professor Bridgeman was versatile in many subfields of research, the share of studies of (metacontrast) masking and sensorimotor (afference/efference) interactions was prevailing among

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https://doi.org/10.1016/j.concog.2018.04.013
Received 4 January 2018; Received in revised form 26 March 2018; Accepted 24 April 2018
1053-8100/

Please cite this article as: Bachmann, T., Consciousness and Cognition (2018), https://doi.org/10.1016/j.concog.2018.04.013

other topics. As a colleague who thinks he also belongs to the "masking camp“ I will briefly review the contributions from Bruce to the field of visual masking. This review will be focused in the sense that masking research from other labs will be invoked, provided it is more or less directly related to the masking issues dealt with by Bridgeman.

## 2. Bridgeman's interpretation and modeling of the masking effects

Metacontrast is a variety of visual backward masking where visibility of a brief target stimulus (which, when presented alone is well and veridically perceived) becomes suppressed as a result of presenting a masking stimulus spatially adjacent to the target (e.g., Piéron, 1925; Werner, 1935). The effect of metacontrast depends on the delay of onset of the mask after the onset of the target (stimulus onset asynchrony, SOA). Depending on the target and mask parameters such as their luminance, contrast and duration, magnitude of the masking effect can be either a monotonic function of SOA or a nonmonotonic function of SOA (the so-called J-shaped or U-shaped function). For the researchers of consciousness the effect of metacontrast is quite useful as it allows to manipulate perceptibility of a target or test stimulus by precisely dosing out the spatial and temporal variables of stimuli presentation. However, despite its known effects and usefulness as a method (e.g., in priming studies and research on nonconscious processing), the very mechanisms of metacontrast have remained poorly understood up to the present day. Therefore, every effort at disclosing the nature of the metacontrast effect is valuable also for the consciousness science. This is both, in terms of revealing the very mechanisms of conscious experience as well as in terms of knowing the limits and pitfalls of using masking as the method of research. The upsurge of masking research took place between 1960ies and 1990ies and Bruce Bridgeman was one of the main participants in that.

In his seminal paper (Bridgeman, 1971) he described how the decaying oscillatory excitatory/inhibitory activity (as a trace of target information) becomes perturbed by a similar activity ignited by the masking stimulus in a two-layer lateral inhibition network of neurons. Masking is weak when cross-correlation between the activity caused by target alone and the activity caused by the target-plus-mask combination produces high value of correlation. Masking is strong when this computed value is low. This model produced a close fit to human psychophysical functions with SOA values less than 60 ms. As with longer SOA values the model output tended to produce oscillating masking functions typically unknown from human data, Bridgeman later improved it with results of modeling better fitting the human data (Bridgeman, 1977, 1978). This model works well for simulating the effect of spatial distance between target and mask on the magnitude of masking. (Metacontrast effect decreases with increase in the distance between the target outer contour and the contours of masking stimulus that are flanking the target.) The model can simulate also nonmonotonic functions of masking. Later on, when comparing his two-layer model with a six-layer model of Francis (1997), Bridgeman showed his model to be able to simulate monotonic masking in the low-criterion conditions (Bridgeman, 2001). Another two-layer lateral inhibitory model was presented by Supèr and Romeo (2012). Metacontrast simulations supported earlier Bridgeman's accounts on possible non-monotonicity of masking functions and presence of target-related neuronal ON-response despite well expressed masking. However, additional features of the dynamics of metacontrast were shown such as substantial effect of OFF-responses and after-discharges, consistent with some neurophysiological results on metacontrast masking (Macknik & Livingstone, 1998; Macknik & Martinez-Conde, 2004, 2007).

Though Bridgeman's works on modeling metacontrast masking were highly stimulating, there were understandably limitations, which is the very characteristic of virtually all current studies. Therefore, it is not surprising that in several experimental papers theoretical models and simulations were founded on postulates and architectures different from the Bridgeman's model of recurrent lateral inhibition. No recurrent activity was conceptualized in the works advocating for feedforward models of lateral inhibition in metacontrast (Macknik & Martinez-Conde, 2007; Supèr & Romeo, 2012). Bridgeman's model (1971) was also criticized from a different angle by Stewart, Purcell, and Pinkham (2011). They contended that once the Hartline–Ratliff equation used for describing primitive neural function in the compound eye, on which the Bridgeman's model is based, is applied to visual masking, it is no longer clear whether it represents a single level of processing or a network of several layers of processing. The mathematics of Bridgeman's model too weakly constrains the underlying neurophysiology. To avoid any possibly premature neural implementations, Stewart et al. (2011) stayed on the psychophysical level of theoretical unit impulse responses and developed their model as founded on the Broca-Sulzer effect (subjective brightness of a luminous flash is a nonmonotonic function of its duration, with a maximum at some intermediate values of duration). The more intense the light flash, the stronger the effect is. Interestingly, the minima of non-monotonic metacontrast functions (i.e., maxima of target suppression) have approximately the same SOA plus target duration value as the duration of unmasked flashes in the Broca-Sulzer phenomenon. Stewart and colleagues showed that nonmonotonic meta-contrast effect increases similarly to the increase of the Broca-Sulzer effect of brightness – with increase in luminance. Moreover, at higher luminous intensities of the white background of the black target, target detection not only dropped to non-detection level, but even showed below-chance performance in a two-alternative detection task. This means that due to the brightness reversal effect – the black target disc appears brighter than its surround – observers commit more to the target-absent responses than to the target-present responses. The SOA value of the optimal masking increases with increase in luminance, which is a known effect of meta-contrast. This is definitely a different explanation for metacontrast non-monotonicity compared to what Bridgeman proposed.

Tapia, Breitmeyer, and Jacob (2011) note that according to Bridgeman's lateral inhibition model metacontrast suppression is a low-level mechanism, neural correlates of which can be found early in the hierarchy of visual processing (e.g., V1). Tapia et al. (2011) carried out a successful metacontrast experiment with texture-defined second-order stimuli implying figure-ground segmentation processes at the higher levels of visual hierarchy in order to allow stimulus discrimination. These levels include extrastriate regions in the ventral stream. Consequently, low-level lateral-inhibition is unlikely to explain metacontrast suppression of texture-defined second-order stimuli.

In modeling information processing as it takes place in the human brain and mind, a model is valued highly if it shows at least