HHS Public Access
Author manuscript
Trends Cogn Sci. Author manuscript; available in PMC 2019 January 01.

Published in final edited form as:
Trends Cogn Sci. 2018 January ; 22(1): 5–7. doi:10.1016/j.tics.2017.10.005.

Single-Neuron Correlates of Awareness During Attentional Blinks

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Abstract

A recent single-neuron study revealed an anatomical anterior-to-posterior gradient of awareness-related responses by 'concept neurons' within the human medial temporal lobe. Delayed and weaker responses were indicative of the failure of a stimulus to reach awareness, suggesting that reliable fast responses are a critical aspect of the neural mechanisms of consciousness.

Keywords

medial temporal lobe; amygdala; hippocampus

Although a vast amount of information is captured and processed by the nervous system, only a small subset of this information is consciously perceived. Many experiments have revealed this cognitive bottleneck, but the neural processes that elevate a processed sensory stimulus to a state of conscious perception remain largely unknown. Developing a better understanding of this process is critical to resolving one of the biggest remaining mysteries in neuroscience: the neural mechanisms of consciousness.

Recently, Reber and colleagues [1] used 'concept neurons' to investigate the neural mechanisms underlying conscious perception. A concept neuron is a visually responsive neuron in the human medial temporal lobe (MTL) that is tuned to a single specific concept [2]. For instance, some concept neurons increase their activity specifically to images that contain Jennifer Aniston [2]. In their study, Reber et al. [1] explored whether concept cells responded differently to the same stimulus when it was consciously perceived versus when it was not, with the goal of determining whether concept cells in different parts of the MTL would differentially correlate with conscious perception.

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The authors first identified images that elicited selective responses from different concept cells. They then embedded two of these images within a stream of distractors and asked participants to determine whether the sequence of images contained the targets (Figure 1a). Previous work has established that during this ‘Rapid Serial Visual Presentation’ task (RSVP), a target image that follows within about 500ms of another target image tends to fail to reach awareness. This phenomenon, known as ‘attentional blink’, possibly reflects limits in how fast attention can switch between targets. The key question was how would concept cells respond during attentional blinks.

Prior work has shown that activity of MTL concept cells remains unchanged when a target is not consciously perceived [3, 4]. By contrast, Reber et al. [1] have found that neurons in the anterior parts of the MTL (amygdala and part of hippocampus) still increased their firing rates when presented with unseen targets, albeit with less intensity and much later onset. Neurons recorded in the posterior MTL, however, responded the same way to seen and unseen targets. These differential response patterns reveal an anatomical gradient within the MTL (Figure 1b).

These findings raise important questions. First, what explains the difference between the new study [1] and prior work [3, 4]? Previous experiments relied on the disruption of low-level sensory processes using backward masking or binocular rivalry. Consequently, visual information about unseen stimuli likely never reached the MTL, explaining why responses to unseen stimuli were not observed in these paradigms. By contrast, in [1] stimuli failed to reach awareness due to dynamic limits of top-down attention instead of insufficient visual processing, as is evident from the response of posterior MTL concept cells. Interestingly, un-perceived stimuli triggered less intense but more variable response from the anterior MTL concept cells, suggesting that the timing of spikes is important for conscious perception.

Second, why are responses in the MTL, an area classically known for its role in memory, correlated with conscious perception? One explanation is that the RSVP task depends on working memory. Indeed, previous work has shown that concept cells within the MTL support working memory through persistent activity [5]. Interestingly, previous work has also shown that when stimuli are presented in succession with sufficient time for conscious perception (200ms), ongoing activity of some concept cells is terminated by the onset of the next stimulus [6]. This suggests that target images may not have been perceived because of a failure to initiate and terminate persistent activity in a timely manner. A second possibility is that persistent activity itself has a role in visual awareness, a hypothesis that posits that persistent activity supports the large-scale distributed synchronization necessary to provide the ‘ignition’ that lifts a stimulus into consciousness [7].

The results of Reber et al. [1] also speak to other aspects of the neural mechanisms of consciousness. The finding that the activity of anterior MTL (i.e. amygdala) neurons indicates visual awareness most reliably adds to the growing literature on the role of the amygdala in awareness [8]. A related proposal is that the amygdala's role is to enhance the likelihood that stimuli with affective value reach awareness. However, this hypothesis rests largely on work with fearful faces, whereas the stimuli used by Reber et al. [1] were not aversive. In addition, the findings of Reber et al. [1] do not support the view that a fast

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subcortical pathway enables amygdala neurons to rapidly respond to visual stimuli even when they are not consciously perceived [8]. Instead, the response to unperceived stimuli was delayed and weaker. A critical future experiment will be to repeat the RSVP experiment with emotional faces. Amygdala neurons differentiate between facial emotions [9], making it possible to test directly whether amygdala neurons signal emotions of unseen faces during the attentional blink.

Oscillations are thought to be critical for consciousness because they coordinate neural activity across large numbers of neurons. The study of concept cells in the MTL has already provided evidence for this proposal. Stimulus-triggered theta power in the MTL is indicative of awareness, and the activity of concept cells is coordinated by these theta oscillations [10]. Together with Reber et al. [1], this suggests that theta oscillations and the resulting coordination of conceptcell persistent activity might be a mechanism contributing to visual awareness. The robust but delayed responses to unseen stimuli during the RSVP task [1], which were absent from previous paradigms, might make it possible to examine this question directly from the perspective of spikefield coherence.

In sum, Reber et al. [1] reveal an anatomical anterior-to-posterior gradient of awarenessrelated response within the MTL and suggests that concept cells in the amygdala and hippocampus might support conscious perception through persistent activity. This is both a critical new insight into the neural mechanisms of consciousness as well as a demonstration of the powerful insights enabled by single-neuron recordings in humans.

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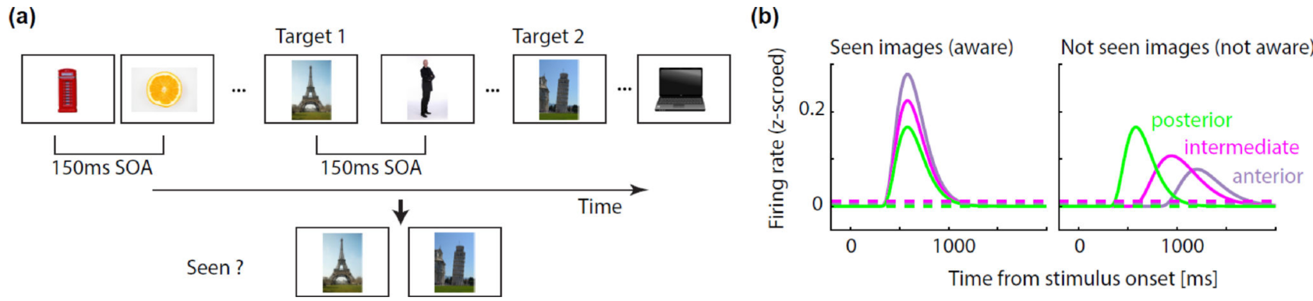

Figure 1.

Experimental setup and principal observation of Reber et al. [1]. (A) Illustration of the task. Two target images were embedded in a sequence of stimuli shown with a stimulus onset asynchrony (SOA) of 150ms. After each trial, subjects indicated for each target whether they had seen it or not (bottom). (B) Summary of the principal observation: the response of concept cells to their preferred stimulus (straight lines) was reduced in amplitude and occurred later when a stimulus was not seen. This difference between seen and unseen images was most pronounced in the anterior MTL (i.e. the amygdala). The neurons did not modulate their firing rate in response to non-preferred stimuli (dashed lines).