

Decision-related activity & feature-selective attention: evidence for a common mechanism in macaque V2

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Abstract:

During perceptual decisions the activity of sensory neurons is often correlated with an animal's decision. These correlations with choice ("choice-probability", CP) are thought to reflect both feedforward and feedback sources (e.g. Clery et al., 2017). For a feature discrimination task, this implies that the feedback is feature-selective. One hypothesis is that the modulation of sensory neurons by feature-selective attention and the feedback source of CP reflect the same mechanism (Haefner et al., 2016). We combined this hypothesis with a classical finding of feature-selective attention – that it modulates the activity of feature-selective neurons globally, i.e. even when the attended stimulus is in the opposite hemifield to the receptive field of the modulated neuron (Treue & Martinez-Trujillo, 1999). This predicts that CP should also be observed globally, including for an ignored stimulus. We tested this prediction by recording in macaque V2, whilst the animal performed a disparity discrimination task, and either the task-relevant or task-irrelevant stimulus was inside the neurons' receptive fields. Consistent with our hypothesis, we found substantial CP for neurons representing ignored, task-irrelevant stimuli. Importantly, this would not be predicted by a feedforward account of CP, but is predicted if feature-selective attention and decision-related activity engage a common mechanism.

Keywords: decision-making; perception; feature attention.

Introduction

In a classic perceptual decision-making task, an observer is asked to discriminate a stimulus along a particular feature dimension, e.g. motion, orientation, disparity. When recording from sensory neurons selective for said feature while an animal performs such a perceptual task, one common observation is that the sensory activity is correlated with the animal's decision. This decision-related activity is often quantified as choice-probability (CP; Britten et al., 1996) and unexplained by the stimulus.

There are two classes of explanations put forth to account for this decision-related activity. The feedforward account suggested that decision-related activity reflects the causal effect of correlated sensory noise on the choice (e.g. Shadlen et al., 1996). However, there's a growing body of evidence for a feedback component to this activity (e.g. Nienborg & Cumming, 2009; Wimmer et al., 2015; Bondy et al., 2018). This idea can be formalized in an inference framework, which has recently been linked to the activity of sensory neurons (Haefner et al., 2016). In this framework, feedback reflects a task-specific belief about the stimulus. That means that in a feature-discrimination task, the feedback is feature-selective. This leads us to hypothesize that feature-selective feedback may engage the same mechanism as in the known modulation by feature-selective attention (e.g. Treue & Martinez Trujillo, 1999).

In order to test this hypothesis, we leveraged a classical finding from feature-selective attention. When an animal attends to a stimulus feature, the responses of neurons selective for this feature are modulated (Treue & Martinez Trujillo, 1999). Critically, this modulation is observed globally, i.e. even when the attended, task-relevant stimulus is in the opposite hemifield to the receptive field of the modulated neuron.

Together with the above hypothesis, this finding makes a strong prediction: choice-probabilities should also be observed globally, including for neurons representing a task-irrelevant, ignored stimulus. Here we sought to test this prediction.

Methods

One macaque performed a coarse disparity-discrimination task on one of two stimuli, only one of which was task-relevant. The task-relevant hemifield, and hence the locus of spatial attention varied blockwise (Fig. 1). Stimuli consisted of dynamic random-dot stereograms in which coherence was manipulated by varying the proportion of signal to

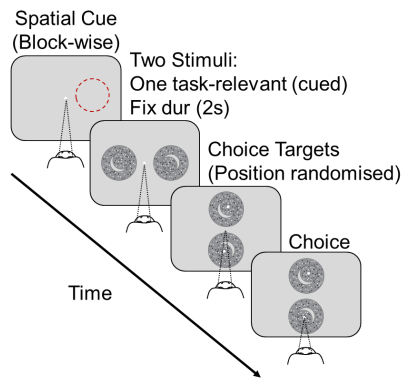


Figure 1: Task Outline

noise frames (measured in % signal). Both stimuli were statistically identical, but independent such that only the task relevant stimulus was informative about the correct choice. We carefully verified that the animal correctly ignored the task-irrelevant stimulus. First, psychophysical performance was independent of the signal strength of the task irrelevant but good for the relevant stimulus (Fig. 2A). Second, psychophysical reverse correlation revealed a pronounced kernel for the task-relevant stimulus and flat kernels for the task-irrelevant stimulus (Figure 2B).

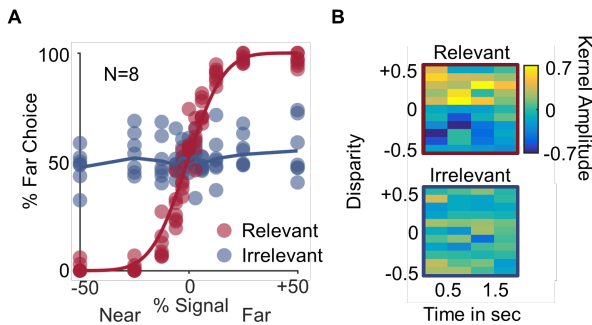


Figure 2: A) Psychophysical performance across all sessions (N=8). B) Psychophysical kernel for 0% signal trials as a function of time. The color bar depicts amplitude of the kernel, with positive values denoting amplitude for near decisions, and negative for far.

Whilst the animal performed the task, multiunit and single unit activity was measured in area V2 using multi-channel laminar probes (8 sessions). Only units that discriminated high-signal disparity signals (typically 50% signal stimuli, $d' > 0.2$, mean $d' = 1.9$, $n = 77$ units) were included. Trials were divided into those where the task-relevant stimulus was inside or outside of the receptive field (RF). As expected for manipulations of spatial attention, this resulted in a substantial response modulation by spatial attention (Fig. 3), quantified as the following spatial attention

index: $(R_{in} - R_{out}) / (R_{in} + R_{out})$ where R_{in} and R_{out} refers to the mean firing rate of the neuron when the task-relevant stimulus was inside or outside the neuron's receptive field. Choice-probabilities (CP) were computed as described previously (Britten et al., 1996) and corrected for stimulus-induced effects as in Nienborg & Cumming (2009).

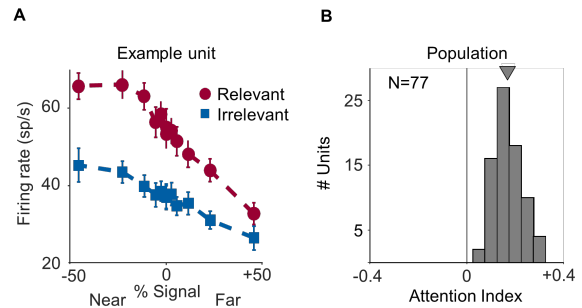


Figure 3: Modulation of firing rates by spatial attention A) in one example unit and B) across the population

Results

Once the animals successfully ignored the task-irrelevant stimulus, we performed multichannel recordings from disparity selective units in area V2. Figure 4 shows the results for one example unit. In support of the hypothesis, we find substantial choice-probabilities for the ignored, task-irrelevant stimulus (Fig. 4B). This is highly consistent across the population (Fig. 5A) and correlated with those found in the task-relevant condition ($r = 0.5$, $p < 10^{-5}$). Further, there was no significant difference between the choice-probability distributions across the relevant (mean CP=0.62) and irrelevant (mean CP=0.62) task conditions (Fig. 3C).

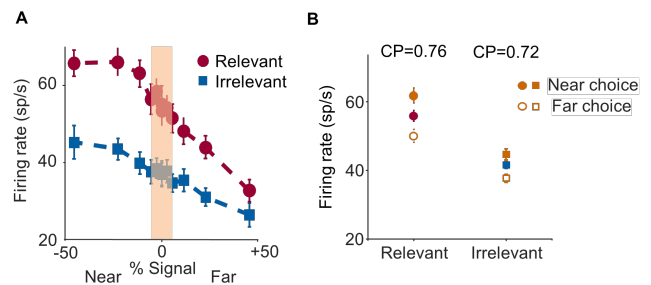


Figure 4: Decision-related activity in one example unit. A) Firing rates for relevant and irrelevant conditions. The 0% signal trials from these conditions (highlighted in orange) are taken to compute decision-related activity as seen in B).

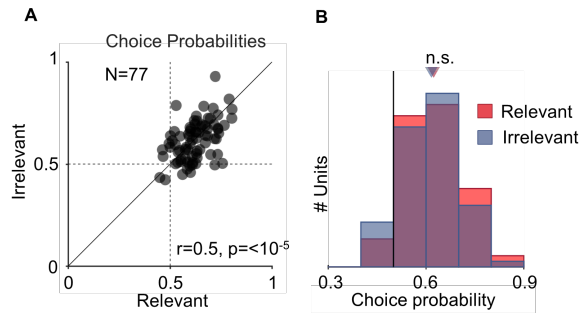


Figure 5: Decision-related activity across the population.

Conclusions

We found significant choice-probabilities for neurons representing an ignored, task-irrelevant stimulus, which is incompatible with a feedforward account, in which choice-probabilities reflect the read-out of the information used by the animal. These results therefore provide a novel, but predicted, link between feature-selective attention and decision-related activity in sensory neurons, compatible with an inference framework of perceptual-decision making (e.g. Haefner et al., 2016).

Acknowledgments

This work was supported by an ERC starting grant and the DFG.

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