



Readout of the intrinsic and extrinsic properties of a stimulus from un-experienced neuronal activities: Towards cognitive neuroprostheses

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ABSTRACT

While sensory and motor systems have attracted most of the research effort in the field of neuroprosthetics, little attention has been devoted to higher order cortical processes. Here, we propose a first step in the direction of applying neural decoding to the study and manipulation of visuospatial attention, an endogenous process at the interface between sensory and motor functions. To this aim, we investigate whether the offline activity of a population of non-human primate frontal eye field neurons (FEF) in response to an endogenous cue can be readout *on a trial by trial basis* to provide a precise description of the cue's attributes, namely, its location and identity, but also the allocation of attention following its interpretation. Using a linear decoder, we reach up to 86% correct predictions for the different decoded variables, including the spatial allocation of endogenous attention. We show that the decoding performance drops on incorrect trials, indicating that cue encoding participates to the animal's behavioral performance. Last, we show that the temporal resolution of the decoding influences readout performance. These results are a strong indication of the feasibility of the readout of endogenous variables by standard decoding algorithms, on a suboptimal dataset. However, its validity remains to be proved in a real-time situation.

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1. Introduction

The field of neural prosthetics is rapidly developing in the larger field of neuroscience (Lebedev and Nicolelis, 2006; Nicolelis and Lebedev, 2009; Green and Kalaska, 2010; Fetz, 2007; Hatsopoulos and Donoghue, 2009). Its general aim is to use preserved electrophysiological nervous activities in order to counter specific functional dysfunctions or deficits by driving external palliative devices. One of the most representative examples of its applications is the use of the neuronal activity of the motor cortex in a tetraplegic patient to control a computer driven environment, thus allowing him a certain degree of mobility and independence (Hochberg et al., 2006; Donoghue et al., 2007). Another important advance in the field is the demonstration that other regions than the motor cortex can be used to drive neural prostheses, such as parietal cortex (Musallam et al., 2004), or dorso-lateral prefrontal cortex (Vansteensel et al., 2010) hence providing a potential substitute for motor cortex activities when these are not available, following for example an acute injury of this region. This field holds the potential to improve the life of thousands of patients and the research effort is directed to alleviate a diversity of pathological

conditions including injuries of the motor system (e.g. lesions of the motor cortex, cortico-spinal pyramidal tract or spinal cord), certain types of neurodegenerative conditions (e.g. cerebral palsy, amyotrophic lateral sclerosis) or distal limb injuries (e.g. amputations).

However, while most of the research effort in neural prosthetics has concentrated on the use of motor signals to drive external devices, new directions in the field of neuroprostheses are also emerging. For example, a recent study has demonstrated that incorporating sensory feedback to a motor neural prosthesis improves its performance (Suminski et al., 2010). On another line, Musallam et al. (2004) have shown, in the context of a motor behavior, that cognitive signals such as the expected value of a reward, i.e. the subject's motivation, can be decoded from parietal neural activity. The work of Jerbi and collaborators also demonstrates that such signals as attention orientation signals and mental calculation signals can be used to drive a cognitive brain-machine interface (Jerbi et al., 2009).

Our scope in the present work is to test whether other types of cognitive variables in relation with visuospatial processing can be decoded from neuronal populations and thus serve to enhance the functions of neural prostheses. We will specifically focus on endogenous spatial attention which guides the active selection of sensory information based on cognitive priors (for example when looking for the phone, the likelihood of it being on the table is higher than

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on the ceiling, as a result, most visual resources will be focused on the table). This process, which is distinct from subsequent perceptual processes, is a key cortical function. Following parietal acute lesions, hemineglect patients develop the inability to attend and thus to perceive and interact with their contralesional environment (Husain and Nachev, 2007; Riddoch et al., 2010). In order to address this question, we use a database of neurons recorded from the frontal eye fields (FEF) while monkeys were engaged in a variant of a cued target detection which allows to dissociate in time the processes related to the orientation of attention from processes related to target detection (Ibos et al., 2009). The FEF is a prefrontal area that plays a crucial role in the control of eye movements and visual attention (Ibos et al., 2009; Schall et al., 2004; Bruce and Goldberg, 1985), as assessed both from its neuronal response profiles (Bruce et al., 1985) and the effect of its perturbation on behavior (Moore and Armstrong, 2003; Wardak et al., 2006; Bruce et al., 1985). Collecting neuronal data from non-human primates allows a precise targeting of the cortical area of interest over several recording sessions. On the opposite, the electrodes used for intracortical recordings in humans are primarily placed to identify epileptogenic foci and are therefore not optimal to address specific cognitive processes such as those described in the present paper. Here, we provide a quantification of how efficiently the allocation of spatial attention following cue presentation can be readout on a trial by trial basis. We contrast this readout performance with that achieved in reading out the physical attributes of the cue known to be represented in the FEF, such as its position. We also describe several parameters that affect the final prediction of the classifier.

2. Methods

2.1. Description of the neurophysiological database

2.1.1. Behavioral task

The activity of 142 frontal eye field (FEF) neurons was recorded from two macaque monkeys, while performing a cued target detection task (Ibos et al., 2009). The experimental design of this task allows to dissociate in time the processes related to the orientation of attention from those related to target detection. In particular, the cue is an abstract cue whose joint identity and position information need to be combined by the monkey in order to know towards which hemifield he should direct his attention. Briefly, the monkeys had to fixate a central point on the screen (Fig. 1a). Two streams of visual objects were presented, one in the visual receptive field of the neuron being recorded and the other in the contralateral side. One of the streams included a cue which instructed with a certain probability the position of the target. The cue could be green (resp. red), predicting that the target would appear in the same (resp. other) stream. Therefore, the monkey had to combine the information related to both physical attributes of the cue (its location and identity) to find out its instruction. This instruction is thus a cognitive cue eliciting a cognitive response in the brain. The monkey had to release a lever to report the presence of the target. In 67% of the trials, the target appeared in the instructed stream (valid trials), in 17% of the trials, it appeared on the opposite stream (invalid trials), and in 16% of the trials it did not appear at all (catch trials) to discourage systematic responses. The monkey was rewarded for releasing the lever 150–750 ms following target

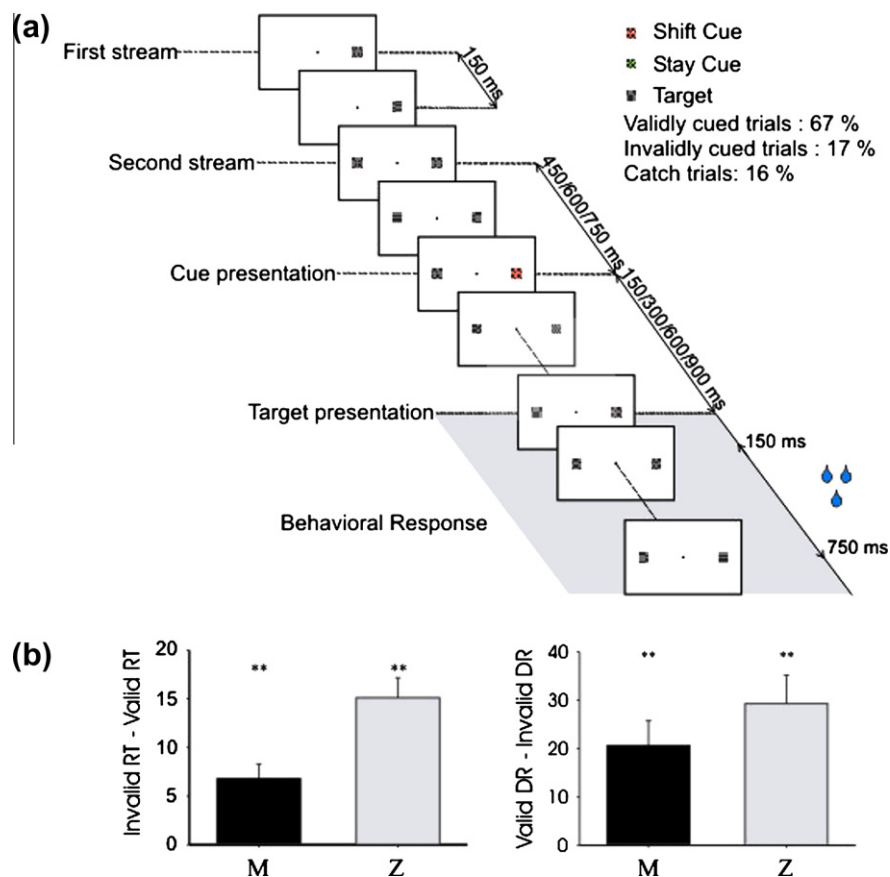


Fig. 1. (a) Example of an RSVP trial for a valid shift cue condition. This trial being a valid trial, the target is presented in the stream opposite to the cue. On target detection, monkeys have to release the lever between 150 ms and 750 ms following target presentation. They are rewarded for successful detections. (b) Behavioral validity effects of both monkeys M and Z as measured on reaction times (RT) and detection rates (DR).

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