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Article

Dynamic Control of Response Criterion in Premotor Cortex during Perceptual Detection under Temporal Uncertainty

Highlights

- A template-matching algorithm detects neural correlates of false alarm events
- The subject's response criterion modulates over the course of a trial
- The response criterion is represented by the dynamics of a neural population
- A trained recurrent network unveils a mechanism for flexible response criterion

Authors

Federico Carnevale,
Victor de Lafuente, Ranulfo Romo,
Omri Barak, Néstor Parga

Correspondence

rromo@ifc.unam.mx

In Brief

Carnevale et al. explore how monkeys exploit previous knowledge to cope with temporal uncertainty in a perceptual detection task. The study demonstrates a neural mechanism by which prior information is intrinsically encoded in the dynamics of a neural population.

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Dynamic Control of Response Criterion in Premotor Cortex during Perceptual Detection under Temporal Uncertainty

Federico Carnevale,[1] Victor de Lafuente,[2] Ranulfo Romo,[3,4,*] Omri Barak,[5,6] and Néstor Parga[1,6]
[1]Departmento de Física Teórica, Universidad Autónoma de Madrid, Cantoblanco 28049, Madrid, Spain
[2]Instituto de Neurobiología, Universidad Nacional Autónoma de México, Querétaro 76230, México
[3]El Colegio Nacional, 06020 México DF, México
[4]Instituto de Fisiología Celular-Neurociencias, Universidad Nacional Autónoma de México, 04510 México DF, México
[5]Faculty of Medicine, Technion–Israel Institute of Technology, Haifa 32000, Israel
[6]Co-senior author
*Correspondence: rromo@ifc.unam.mx
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SUMMARY

Under uncertainty, the brain uses previous knowledge to transform sensory inputs into the percepts on which decisions are based. When the uncertainty lies in the timing of sensory evidence, however, the mechanism underlying the use of previously acquired temporal information remains unknown. We study this issue in monkeys performing a detection task with variable stimulation times. We use the neural correlates of false alarms to infer the subject's response criterion and find that it modulates over the course of a trial. Analysis of premotor cortex activity shows that this modulation is represented by the dynamics of population responses. A trained recurrent network model reproduces the experimental findings and demonstrates a neural mechanism to benefit from temporal expectations in perceptual detection. Previous knowledge about the probability of stimulation over time can be intrinsically encoded in the neural population dynamics, allowing a flexible control of the response criterion over time.

INTRODUCTION

One of the main challenges of cognitive neuroscience is to understand how external sensory stimuli and internal brain states interact to give rise to perception (Romo and de Lafuente, 2013). Internal states are believed to reflect acquired experience that can be used for making the best sense of sensory inputs (Gilbert and Sigman, 2007). During perceptual decisions, for example, the brain uses previous knowledge to transform noisy sensory evidence into percepts on which decisions are based (Forstmann et al., 2010; Hanks et al., 2011; Rao et al., 2012; Ratcliff and McKoon, 2008; Simen et al., 2009; Summerfield and Koechlin, 2008). In this study, we explore the dynamic nature of these internal states by asking how previous information about the timing of sensory evidence is incorporated in the decision-making process. We combine computational modeling with neurophysiological and behavioral data recorded while monkeys performed a somatosensory detection task (de Lafuente and Romo, 2005, 2006).

Subjects performing a decision-making task can benefit from the use of temporal expectations (Coull and Nobre, 2008) at multiple stages of the sensorimotor transformation (Nobre et al., 2007): (1) perception can be enhanced by increasing sensory accuracy at the relevant times (Correa et al., 2005; Ghose and Bearl, 2010; Ghose and Maunsell, 2002; Jaramillo and Zador, 2011; Rohenkohl et al., 2012); (2) the response criterion—the subject's internal rule to decide whether or not to report a stimulus—can be modulated to incorporate prior information without changes in the sensory representation (Katzner et al., 2012); and (3) motor readiness can be heightened, increasing the response speed in reaction-time tasks (Nobre, 2001; Scheibe et al., 2009). These studies have found neurophysiological evidence for the use of temporal information in the sensory and motor stages. However, little is known about the neural mechanisms that underlie the use of timing at intermediate stages of the sensorimotor transformation.

We address this intermediate step by analyzing recordings of premotor cortex neurons from monkeys performing a detection task with variable stimulus onset times (Figure 1A; see de Lafuente and Romo 2005, 2006). The task's temporal structure dictated that the stimulus only arrived within a 2 s temporal window but not before or after (Figure 1B). We asked whether monkeys can infer and take advantage of this temporal structure to increase performance. One possible way to incorporate this knowledge is to modulate the response criterion (the amount of sensory evidence required to produce a stimulus-present response) over the time course of the trial (Figure 1C). An efficient modulation of the criterion is to raise it outside the possible stimulation window to avoid false positive outcomes, and lower it within the window to allow correct detections. The exact shape of the response criterion within the possible stimulation window depends on the animal's inference about the underlying distribution of stimulus onset times (the subjective hazard function; Janssen and Shadlen, 2005; Luce, 1986; see Discussion).