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NEUROSCIENCE 2012

Presentation Abstract

Program#/Poster#:	730.04
Presentation Title:	Decision and indecision on single trials of a monkey maze-reaching task
Location:	395
Presentation time:	Wednesday, Oct 17, 2012, 8:45 AM - 9:00 AM

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Abstract: To act, we must first decide. Choices may be 'forced' when only one action is available, or 'free' when multiple options are present. New information may also arrive mid-decision, prompting a change of mind. Changes of mind were observed behaviorally by Resulaj et al (Nature 2009). Here, we examined the neural processes that occur on single trials during decision making. We combined a novel 'decision maze' paradigm with large scale simultaneous neural recordings and single trial analytical tools. The task was a variant of the delayed-reach 'maze' task described previously (Kaufman et al, J Neurophys 2010; Churchland et al, Neuron 2010). Monkeys began each trial touching a central spot, then were presented with two targets and intervening virtual barriers. After a random delay, a go cue was given and the monkeys made curved reaches around the barriers to reach either target. The exact location and size of the barriers varied across trials, making each target easy, difficult or impossible to reach. In addition, a barrier could change size at a random point in the trial. This task thus included forced choices, free choices and mid-trial situation changes. In each of two monkeys, neural activity was recorded using dual 96 electrode Utah arrays implanted in primary motor and dorsal premotor cortex. Gaussian Process Factor Analysis (Yu et al, J Neurophys 2009) was used to extract low-dimensional single trial neural trajectories during the delay period (the time when the monkey made his decision, 200-1000 ms before movement onset). Using these trajectories, we could reliably decode which movement the monkey had chosen on a timescale of tens of milliseconds (~98%/94% accuracy for forced/free trials). Further, we observed 'changes of mind' in these single trial decodes, which could previously only be inferred by statistics of behavior. Some of these changes of mind were elicited by barrier changes, while others were spontaneous vacillations when both targets were viable (6-13% of free trials). We also examined how free choices differed from forced choices. Few neurons exhibited different mean firing rates for free vs. forced choices. However, reaction times (RTs) on these trials differed: when the go cue was given immediately upon onset of the maze, RTs were often slower for free vs. forced choice trials (~30 ms). This slowness suggests a 'moment of indecision' when choosing a target. However, it could also be due to simple hesitation initiating movement. We distinguished using the neural data: the decode often took longer to disambiguate for free trials than forced trials. This evidence supports the indecision model, and begins to reveal the decision making process on single trials.

Disclosures: **M.T. Kaufman:** None. **M.M. Churchland:** None. **S.I. Ryu:** None. **K.V. Shenoy:** None.

Keyword(s): DECISION MAKING

MOTOR CORTEX

MONKEY

Support: NIH Director's Pioneer Award 1DP1OD006409

DARPA REPAIR N66001-10-C-2010

NSF GRFP

[Authors]. [Abstract Title]. Program No. XXX.XX. 2012 Neuroscience Meeting Planner. Washington, DC: Society for Neuroscience, 2012. Online.