Learning to infer transitively: ranking symbols on a mental line in premotor cortex

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Abstract:
Transitive inference (TI) is a form of deductive reasoning that allows to infer unknown relations among premises. It is believed that the task is cognitively solved resorting to a mental linear workspace, namely the mental line, in which the stimuli are mapped according to their arbitrary assigned rank. This means that, if one experiences that A>B and B>C, the relationship A>C can be transitively inferred as after learning the items A, B and C are properly located on adjacent positions along such linear workspace. An open question is whether this mental line is encoded somewhere in the brain and if so where and how.
Here, we investigated the possible role of the dorsal premotor cortex (PMd) in representing the hypothesized mental line during the acquisition of the relations between items, eventually leading to successfully perform a TI task. Two rhesus monkeys were tested requiring selecting the higher ranked item, presented alternatively on the left or right position of a computer monitor while the neural activity of the PMd was recorded simultaneously by 96 probes.
We analyzed the multi-unit neural activity (MUA) by relying to a mathematical framework in which it is possible to carry out the needed mental line as a linear combination of the representations of the stimuli/items in the neural state space. The applicability of this theoretical model relies on the hypothesis that both the identity and the spatial position of the stimuli are encoded in the probed network. As a first result, we found that PMd represents such information in its neural activity together with a correlate of the difficulty in motor decision. According to the model, we found that the PMd representations of the stimuli, once projected on the theoretical mental line (a linear neural subspace), are predictive of the motor decision.
Finally, we found striking evidence that representations of both the stimuli and the motor plan are plastic, as they change in time according to the behavioral output. A realignment of the mental line thus results leading to an increasing overlap with the axis decoding the motor responses.
Our results then provide evidence that a TI task can be solved as a linear transformation of the neural representations of arbitrarily ranked stimuli. PMd appears to have a leading role in manipulating such representations, efficiently transforming the ordinal knowledge of the stimuli relations into the motor output decision.