**Central contribution:** Monkeys and humans use similar strategies for multisensory causal inference.

6/10/19 working on an outline: 1 informal sentence per section, then 1 informal sentence per paragraph, then fill in.

Context-content-conclusion

**Abstract**

**Intro – We need monkeys to do this kind of task, so we can poke into their brains and see what’s going on**

Information from multiple senses can be combined to improve accuracy of sensory inference, but this is only useful if all combined sensory streams reflect information about the same source.

Humans solve this problem in a Bayes optimal manner, which has been thoroughly explored in the literature.

Understanding of this phenomenon at the level of individual neurons has been challenging, because to date only human subjects have been used to look at CI, and we can’t easily record single neuron activity from them.

Here we create a behavioral paradigm that requires both implicit and explicit causal inference, which can be used in both monkeys and humans, and find that monkeys appear to apply the same type of Bayesian causal inference strategy seen in humans. (validating them as a potential model organism for the study of causal inference at the single neuron and neural circuit level)

**Results – Monkeys can do it, and seem to be basically doing it like humans with some caveats**

We have created a dual causal inference task, one which requires that subjects report both the number and unique stimuli as well as their position, which relies on both auditory and visual stimulus information. (figure 1, behavioral paradigm description)

Because of this dual task design, subjects are essentially performing two tasks simultaneously: 1 to identify whether it is more likely that there are one or two targets; and one where they must localize the source of both the auditory and visual stimuli. (schematic CI description?)

We have modeled this by adapting several forms of ideal observer models that have been previously applied to human behavioral experiments, including both optimal and heuristic decision rules. Because it is not strictly necessary that subjects use the same causal inference strategy for both localization and unity judgement, we combined models in a factorial manner. (fig 2, model descriptions and predictions)

We compare the predictions of various models fit to both human and monkey subjects, first for the **unity judgement case**, then for the **localization case**, and finally for the **joint condition** (which more exactly represents the task subjects are being asked to perform) figs 3-5

We find that both humans and monkeys are well fit by models of causal inference which have the following features:

Some differences are apparent between human and monkey subjects, in particular it seems like monkeys have more pronounced bias. These might be associated with learned priors over actual stimulus distributions.

**Discussion – We demonstrated that monkeys can do this task, and have some speculation about neural implementation**

Here we demonstrate that monkeys can be trained to perform a multisensory causal inference task, and do so in a manner consistent with human models of Bayesian observers.

In particular, these results are consistent with xxx result from the human literature, and extend that result to apply to macaque monkeys as well.

Some advantages of this dual task design are that it allows for rapid data collection that simultaneously captures implicit and explicit features of causal inference. This is critical for single unit recording as it is practically impossible to combine data across multiple recording sessions and ensure that the same units are being recorded.

This work is important because it will allow us to link our understanding of multisensory processing at the neuronal level with our deepening understanding of causal inference at the behavioral level. For instance we might make these predictions for what is happening at the neural level.

**Methods**

The behavioral paradigm is like this, with this kind of measurement for responses.

The stimulus properties are like this

The math is covered thoroughly elsewhere, but here is a cursory description of each of the model properties.