Probabilistic inference in psychosis and autism
Which parameter is gone awry?

Isabel Kreis [1], Kristin Sandvik [2], Håkon Tjemeland [3], Robert Biegler [2], and Gerit Pfuhl [1,2]

[1] Department of Psychology, UiT – The Arctic University of Norway

[2] Department of Psychology, NTNU – Norwegian University of Science and Technology

[3] Department of Mathematics, NTNU – Norwegian University of Science and Technology

/ BACKGROUND

Within the predictive coding framework the brain is defined as an inference machine that continuously tries to predict its sensory inputs on the basis of beliefs about the world and updates those beliefs in the presence of contradictory sensory data (i.e. prediciton errors; Friston, 2005). Neurobiologically, the weighting and further processing of those prediction errors is thought to be influenced by the gain of neuronal error units (Friston, 2010).

When explaining the aberrant cognitive processes in patients with psychosis and autism, models based on this account have generated contradictory predictions.
One main question is if the patients' beliefs are *too imprecise*, *too precise*, or if *the weighting of prediction errors* is aberrant.
In our study we are trying to test these hypotheses directly, using two different tasks that measure the precision of the prior belief and the weighting of the prediction error.

/ AIM

Our aim is to first determine the *cognitive markers* of autism and psychosis and to then identify their *neurobiological markers* .
In this first step we tested if our tasks are suitable to identify those markers and to differentiate between groups.

In a second step we want to test the neural gain assumption of the predictive coding framework (see *conclusion & future plans*). Are the identified cognitive markers accompanied by changes in neural gain?

/ METHODS

We adminstered two experimental tasks: a probabilitsic inference task (beads task) and a metacognitive task (precision task). With both tasks we *measure a certain belief* and the *change of that belief in the presence of contradictory evidence*.

SAMPLE
We tested so far N = 24 patients diagnosed with schizophrenia (from St. Olavs Hospital, Trondheim), N = 16 persons diagnosed with autism spectrum disorders, and N = 32 healthy controls.
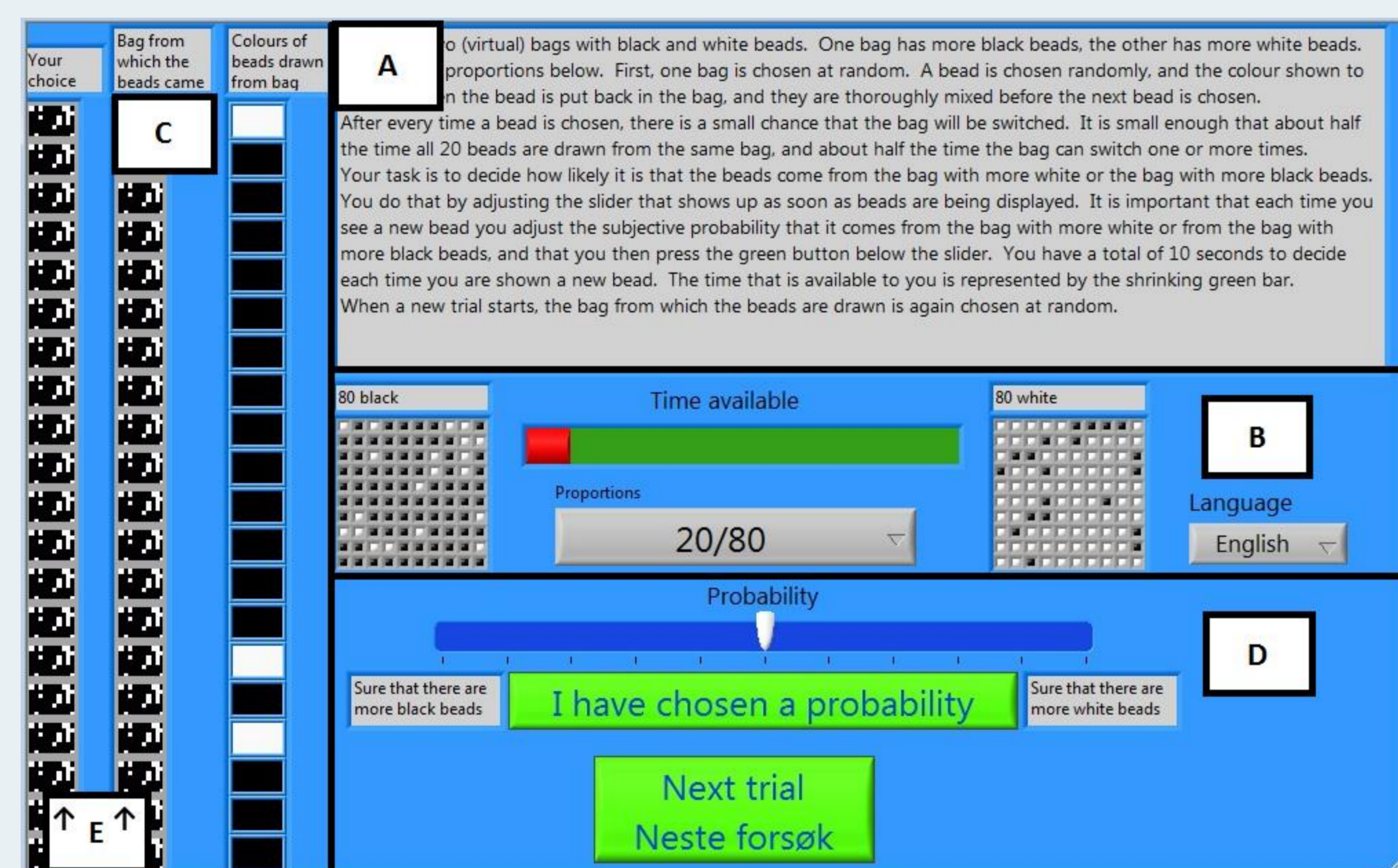
BEADS TASK

Fig. 1 Beads task
A) The participants start the task by reading the instruction. *B)* Two bags with black and white beads are displayed. One bag contains 80 black and 20 white beads, the other bag the reverse. *C)* One after another, beads are drawn from one of the bags and put back immediately, so the distribution inside the bags does not change. There are 20 draws in each trial (N_{Trials} = 5), and the result of each draw (i.e. the color of the bead drawn) is displayed in the right one of the three vertical columns. The bag of origin is unbeknownst to the participants. *D)* The participants' task is to identify from which bag the beads are currently drawn from. They are informed that the bag of origin can change throughout a sequence of beads in 50% of the trials. After being shown the color of the current bead, the participants have 10 seconds to estimate a probability for the beads being drawn from either the bag with more black or more white beads. They do so by dragging the marker on a visual scale either to the left or the right side. *E)* At the end of each trial the participants receive a feedback on their own choices compared to the actual origin of the beads. This feedback is visualized in the two columns to the left.
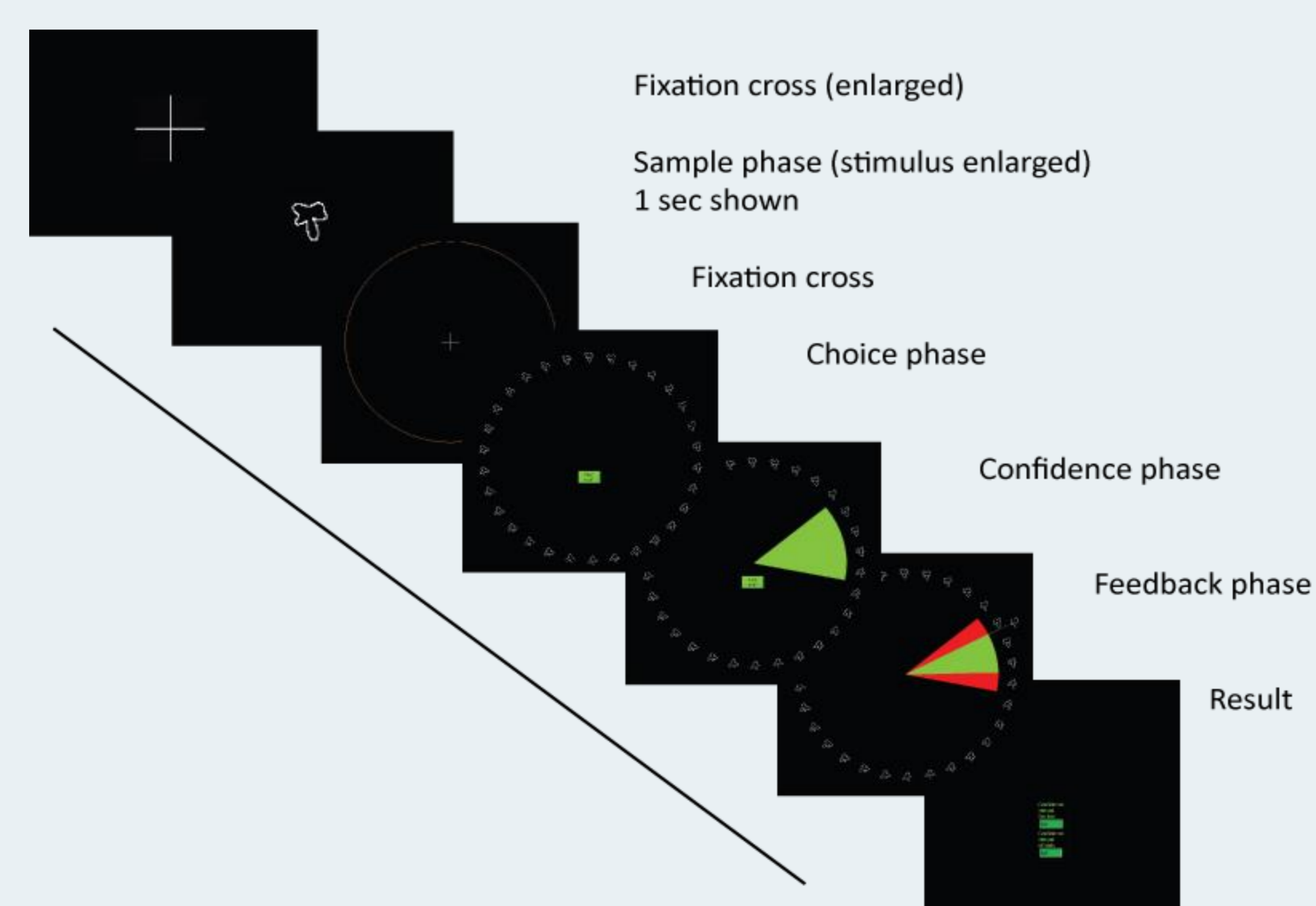
PRECISION TASK

Fig. 2 Precision task
A sample shape is presented for one second, followed by 30 shapes in a circular arrangement. The participants point to the shape that most resembles what they remember, and estimate a confidence interval. They receive feedback by being shown the same shape as during the sample phase, correctly placed in the array of shapes. Deviation from that location (*real precision*) indicates the extent to which participants misremembered the shape. Participants can also see whether their confidence interval (*perceived precision*) included the sample shape or not.

/ RESULTS

As data acquisition is still ongoing, no statistical analysis has been conducted yet and the results presented here are solely descriptive.
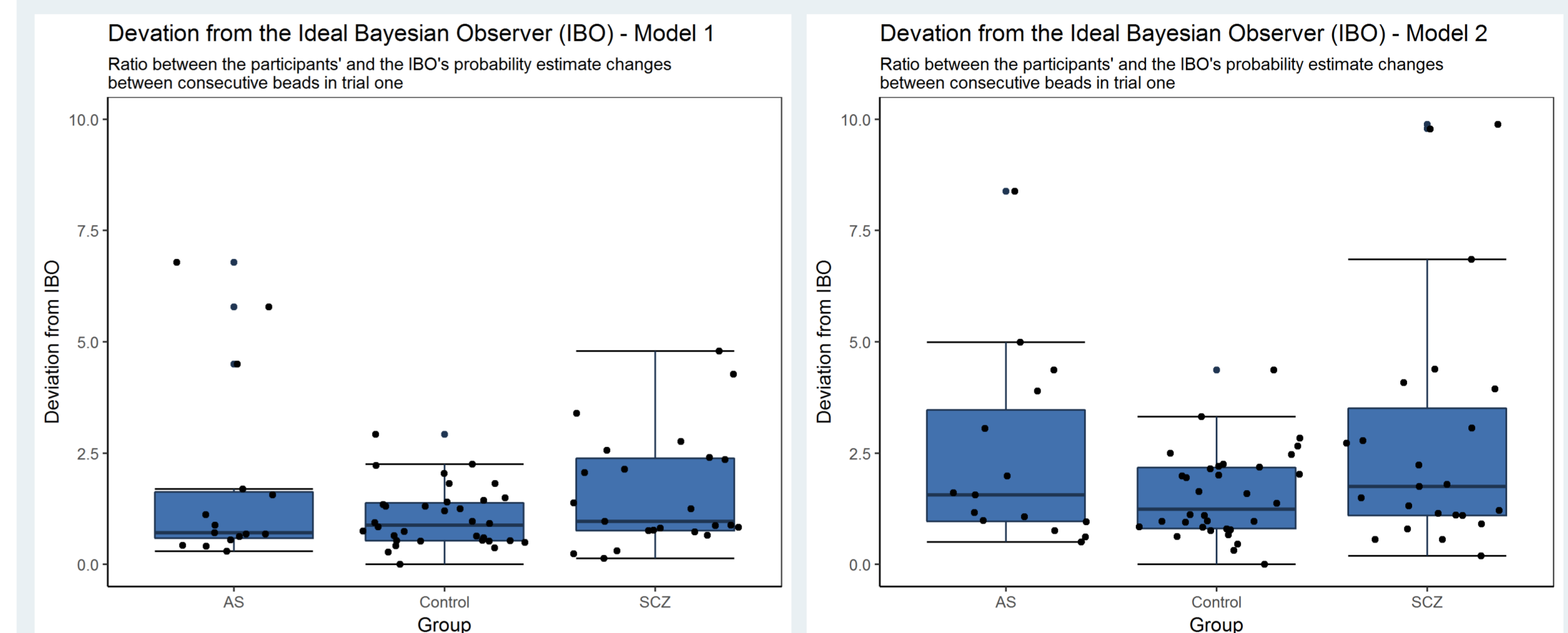
BEADS TASK

Fig. 3 & 4 Deviation from the Ideal Bayesian Observer (IBO)
We calculated the mathematical optimal solution (IBO) of probability estimates for all beads in trial one and compared the probabilty changes of participants to the changes of the IBO. *Model 1*: the probability of the bag changing is ignored, *Model 2*: the probability of the bag changing is incorporated in the probability estimates. *Note*: one extreme outlier (Group: AS) with a value of 14.19 is excluded in both figures.
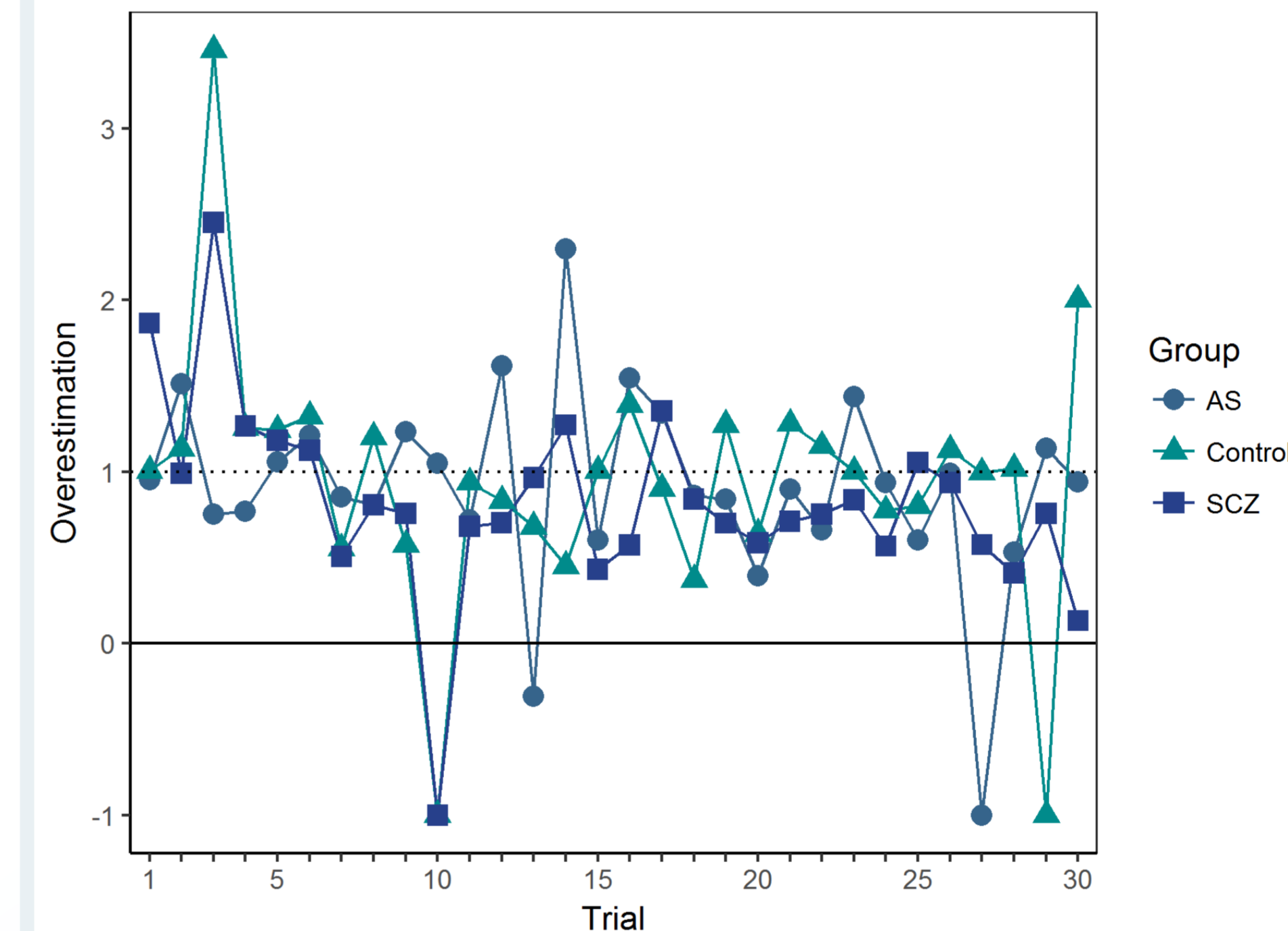
PRECISION TASK

Fig. 5 Overestimation of precision
Overestimation of precision is the logarithmic ratio of real precision to perceived precision.

The closer the value is to 1 (dotted line), the better is the self-assessment, i.e. accurate estimation of one's own precision.
If it is <1 the participants are judging themselves as less precise (i.e. lower confidence) than they should according to their real precision.
If it is >1 they are judging themselves to be more confident than they actually should (given their comparably lower precision).

Notes: -1 represents a skipped trial, *AS* = Autism Spectrum Disorder, *SCZ*= Schizophrenia, *Control* = Healthy Control

/ CONCLUSIONS & FUTURE PLANS

No test statistics have been conducted yet so that no conclusions can be drawn at the moment. For the beads task it seems like participants in all groups generally ignored the probability of change of the bags when making their probability ratings in a sequence of beads. And though the medians look similar for all groups, the variance is visibly higher in the patients groups. For the precision task it has to be tested if the trend of the overestimation over the 30 trials differs between groups. Further, correlations of the parameters of both tasks shall be investigated.

OUTLOOK

To test the neural gain assumption of the predictive coding framework, we are going to administer an isoluminant modified version of the beads task in combination with pupillometry measures to patients and healthy participants. Pupil dilation measures can serve as a proxy for noradrenergic neural gain modulation (Joshi et al., 2016) and allow to infer attention and learning about the task stimulus (Yu & Dayan, 2005).
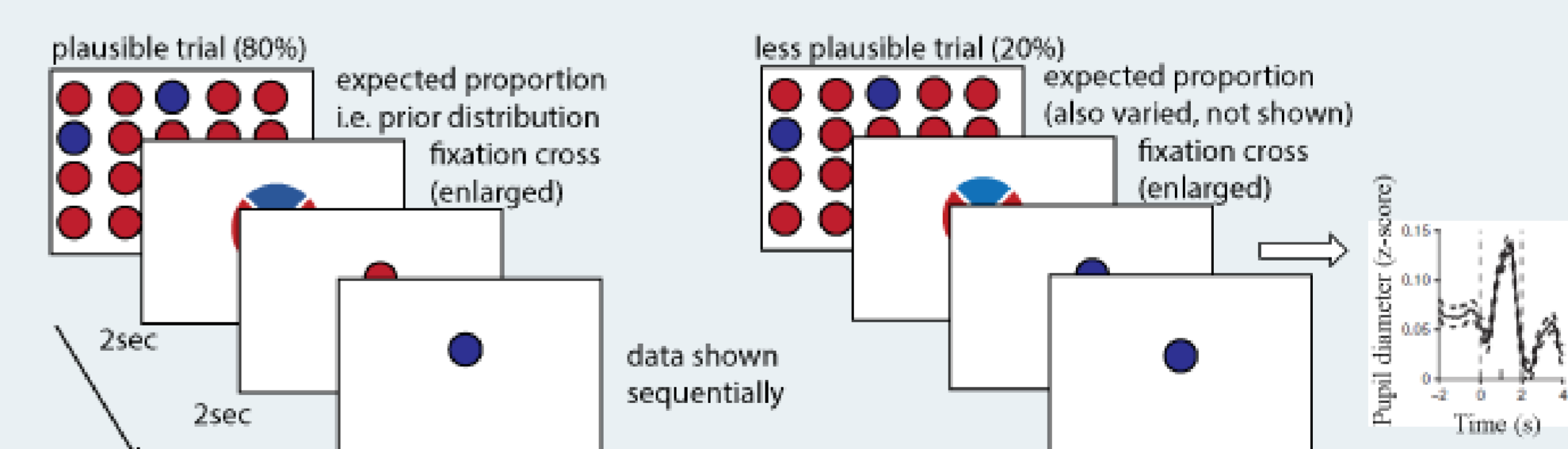

Fig. 6 Modified beads task
In this version the beads will be presented sequentially to get a direct measure of surprise for every single belief confirming and belief contradicting piece of evidence. At the same time we will measure pupil dilations (figure to the right, by Nassar et al., 2012) as a measure of neural gain, which is assumed to be higher for surprising stimuli.

We want to test if neural gain (reflected in pupil dilations as reactions to prediction errors) is higher in people with psychotic and/or with autistic traits than healthy controls and if those measures correlate with aberrant probabilistic inference, namely an overweighting of the prediction error.

REFERENCES

Friston, K. (2005). A theory of cortical responses. *Philos Trans R Soc Lond B Biol Sci*, 360(1456), 815-836.

Friston, K. (2010). The free-energy principle: a unified brain theory? *Nat Rev Neurosci*, 11(2), 127-138.

Joshi, S., Li, Y., Kalwani, R. M., & Gold, J. I. (2016). Relationships between pupil diameter and neuronal activity in the locus coeruleus, colliculi, and cingulate cortex. *Neuron*, 89(1), 221-234.

Nassar, M. R., Rumsey, K. M., Wilson, R. C., Parikh, K., Heasly, B., & Gold, J. I. (2012). Rational regulation of learning dynamics by pupil-linked arousal systems. *Nature neuroscience*, 15(7), 1040-1046.

Yu, A.J., & Dayan, P. (2005). Uncertainty, neuromodulation, and attention. *Neuron*, 46(4), 681-692.