Prior-variance-dependent alterations in perceptual inference relate to hallucination severity in schizophrenia

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Abstract:

Bayesian models of hallucinations in psychosis posit that this symptom arises when people's perceptual representations are excessively biased towards prior expectations. But where do these variations in prior reliance come from? It is an open debate whether prior overreliance results from impaired sensory resolution arising from alterations at lower levels of processing or from alterations in the prior representation itself at higher levels. Following our work in healthy controls, we extended our investigation to a group of 36 patients with schizophrenia and 29 matched healthy controls. We aimed to disentangle the effects of hallucination severity and sensory resolution on prior biases in the perceptual estimation of time intervals. Among patients, we critically found that hallucination severity related to decreased ability to represent or use prior variance, but not to decreased sensory resolution or increased sensitivity to sensory noise.

Keywords: psychosis; psychophysics; interval timing estimation, sensory resolution, prior variance, prior bias

Introduction

Bayesian models posit that observers combine sensory evidence with prior expectations; these two sources of information are assumed to be weighted based on their respective reliability. In the psychosis literature, models of perceptual disturbances posit that hallucinations arise when perceptual representations of the world are excessively biased towards prior expectations (stronger priors, Fletcher and Frith, 2009, Corlett et al, 2019), a notion that has received some empirical support (Cassidy et al, 2018) but which has been challenged. Bayesian models accurately account for behavior in interval-timing and other magnitude-estimation tasks (Petzschner et al, 2015). Namely, the consistently observed regression effect in which the estimates are biased towards the mean of the presented distribution (referred to as "central tendency") can be explained as a prior bias. Prior biases can be larger either when sensory evidence is noisier (Jazayeri and Shadlen, 2010; Cicchini et al., 2012) or when context-derived predictions are more precise (narrow prior distributions or stronger priors, Cassidy et al., 2018). Here, we asked whether hallucinations are related to prior biases by examining prior biases in interval timing. Furthermore, we aimed to disentangle the effects of sensory resolution and hallucination severity on prior biases in interval timing.

Methods

Participants, tasks and metrics

Enrolled participants were diagnosed based on the SCID interview for DSM-IV. Participants performed several self-reported scales, and a clinician administered additional scales to patients, including a measure of auditory hallucination severity (HALL) based on the Psychotic Symptom Rating Scale (Haddock et al, 1999). After exclusions based on task performance below acceptable thresholds, our final sample had 65 participants (36 patients with schizophrenia and 29 healthy controls). Participants performed an interval timing paradigm (Jazayeri and Shadlen, 2010, Duhamel et al, 2023), varying in the width/variance (Wide vs Narrow) and length/mean (Medium vs Short) of the time intervals presented, for a total of three conditions: Wide-Medium (WM), Narrow-Medium (NM), Narrow-Short (NS). Participants' slopes of their reproductions of the interval times relative to the ones presented varied with the conditions; decreases in their slopes correspond to increases in central tendency, or stronger prior biases. Participants also performed a two-interval forced-choice task in which they evaluated which one of two intervals was longer, which allowed us to measure their sensory resolution via their Weber fraction (WF).

Linear mixed-effects (LME) models

We employed LMEs to be able to evaluate trial-by-trial responses and incorporate individual differences related to hallucination severity within the schizophrenia group:

$$Response \sim 1 + Sample * (HALL + WF + Length * HALL + Length * WF + Width * HALL + Width * WF) + GlobalMean + (1 + Sample \mid Subject)$$

Results

Across all 65 participants, we replicated previously observed prior biases due to length and width, in which either longer intervals (which are encoded with higher noise) or narrower distributions (which have less prior uncertainty) lead to decreases in the slopes (increased prior bias/central tendency, Figure 1). Patients and controls did not differ in their slopes or their modulation by condition, or their WF (z=-0.51, p=0.61).

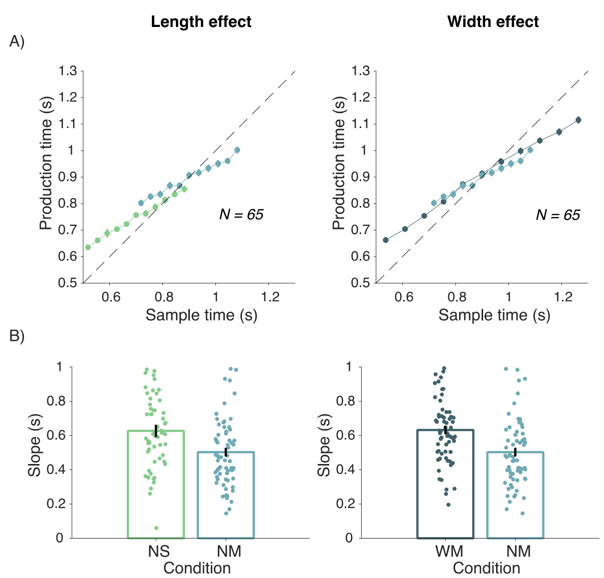

Figure 1. Length and width effects across all the 65 participants. Slopes are decreased / prior bias is increased either with increases in sensory noise (NS to NM) or with decreases in the width of the prior distribution (WM to NM).

Individual differences with LMEs

Next, we leveraged individual differences to investigate hallucination severity in patients. Here, the sensory resolution (WF) and hallucination severity (HALL) scores were not significantly correlated across all 36 patients (rho=0.100, p=0.575), suggesting their independence. An LME considering individual participants' WF and HALL fit the data better than one without these participant-level parameters. As expected and visible in Figure 1, this model also found significant effects for the length effect ($Length \times Sample$, t_{19971}=3.73, p=1.9*10^{-4}) and width effect ($Width \times Sample$, t_{19971}=5.57, p=2.6*10^{-8}). We found no significant effect of sensory resolution on central tendency ($Sample \times WF$, t_{19971}=-0.811, p=0.417). Critically, we found a significant effect of hallucination severity where higher hallucination severity related to a decrease in the width effect ($Width \times Sample \times CAPS$, t_{19971}=-2.161, p=0.031, Figure 2).

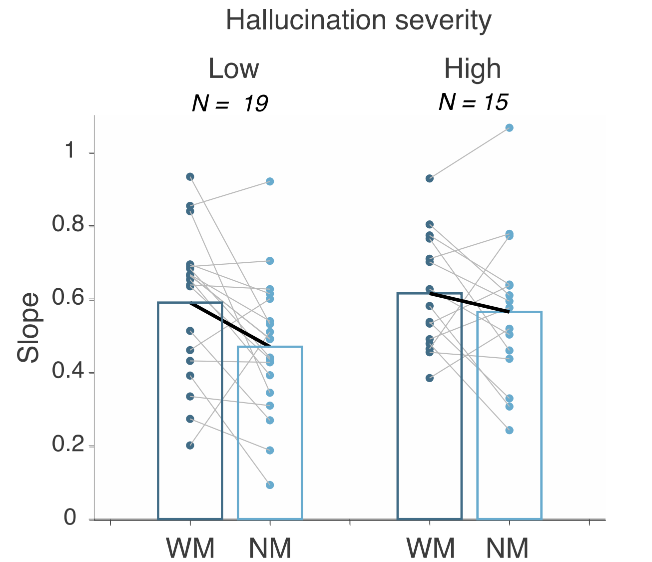

Figure 2: Patients with high HALL (HALL>0) show smaller differences in their slopes as the prior width decreases from WM to NM. Bars represent means. Lower slopes for WM imply stronger priors.

Conclusions

Consistent with our previous findings in a non-clinical group (Duhamel et al, 2023), we observed increased prior biases with greater clinical hallucination severity. Patients with higher hallucination severity were less able to effectively use the contextual information provided by the prior variance but had similar sensory resolution and adapted normally to sensory noise. Altogether, our findings support the view of prior overweighting as a driver of hallucinations and further suggest this overweighting may result from a primary alteration in the representation or use of prior beliefs.

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