**Experiencing hallucinations in daily life: The role of metacognition.**

Abigail C. Wright[1,2], Emma Palmer-Cooper[3], Matteo Cella[4,5], Nicola McGuire[6], Marcella Montagnese[4], Viktor Dlugunovych[7], Chih-Wei Joshua Liu[8], Til Wykes[4,5], & Corinne Cather[1,2]

[1] Center of Excellence for Psychosocial and Systemic Research, Department of Psychiatry, Massachusetts General Hospital, Boston, MA, USA

[2] Harvard Medical School, Boston, MA, USA

[3] Centre for Innovation in Mental Health, School of Psychology, University of Southampton, UK

[4] Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK

[5] South London & Maudsley NHS Foundation Trust, Maudsley Hospital, London, UK

[6] Institute of Health and Wellbeing, University of Glasgow, Glasgow, UK

[7] Walden University, USA

[8] Physics of Living Systems Group, Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

## Abstract

**Background**: Hallucinations have been linked to failures in metacognitive reflection suggesting an association between hallucinations and overestimation of performance although the cross-sectional findings are inconsistent. This may relate to the fluctuating hallucinatory experiences that are not captured in cross-sectional studies. Ecological Momentary Assessment (EMA) captures in-the-moment experiences over time so can help identify causal relationships between variables such as the associations between metacognition and hallucinatory experience in daily life and overcome problems in cross-sectional designs. **Methods**: Participants (N=41) experiencing daily hallucinations completed baseline questionnaires and smartphone surveys 7 times a day for 14 days. They were prompted to identify a task they would complete in the next four hours and to make metacognitive predictions around the likelihood of completing the task, the difficulty of the task, and how well they would complete it (standard of completion). **Results**: 76% finished the 14-days of assessment with an average of 41.5% survey completion. Less accurate metacognition was associated with more hallucinations, but less accurate likelihood and standard of completion was associated with fewer hallucinations. Using a cross-lagged analysis, metacognitive predictions around the likelihood of completion ($p<.001$) and standard of completion ($p=.01$) predicted hallucination intensity at the following timepoint, and metacognitive predictions regarding likelihood of completion ($p=.02$) predicted hallucination control at the following timepoint. **Discussion**: Interventions that aim to improve metacognitive ability in-the-moment may serve to reduce the intensity and increase the control of hallucinations.

**Keywords**: Metacognition, Hallucinations, Psychosis, Cognitive-affective processing, EMA, ESM, Mobile Health.

## INTRODUCTION

Hallucinations have been reported to exist on a continuum (van Os et al., 2000) from subclinical (fleeting experiences with minimal distress) to clinical experiences (experienced at a higher frequency and intensity, which can be distressing and require care, Reininghaus et al., 2016). Hallucinations across the continuum have been hypothesized to stem from failures in metacognitive processes (Powers, Mathys, & Corlett, 2017). Metacognition is the ability to "think about thinking" or the way one thinks about one's experience (Dimaggio, Vanheule, Lysaker, Carcione, & Nicolò, 2009). More broadly, metacognition involves forming an integrated representation of oneself, others, and the world and using these representations for appraisal of events and behaviors (Semerari et al., 2003); it also involves cognitive processes that regulate and monitor other cognitive processes (Efklides, 2006). Metacognition is often poor in those who have experienced psychosis, and metacognition has been associated with symptom severity, poorer functional outcomes, and self-esteem in clinical and non-clinical groups (Wright, et al., 2019; Lysaker et al., 2018; McLeod, Gumley, MacBeth, Schwannauer, & Lysaker, 2014; Palmer, Gilleen, & David, 2015; Cella, Swan, Medin, Reeder, & Wykes, 2014; Varese & Bentall, 2011; Rouault et al. 2018).

Although evaluations of the association between metacognition and hallucinations have been carried out (Gawęda et al., 2018; Gaweda, Woodward, Moritz, & Kokoszka, 2013), they use different metacognition definitions, measures, and samples and have produced inconsistent findings. Metacognition is traditionally measured using retrospective self-report which is vulnerable to recall bias (Lepage, Sergerie, Pelletier, & Harvey, 2007). Metacognition can also change over time either through natural fluctuation or in response to interventions (de Jong et al., 2018; O' Connor, Nelson, Cannon, Yung, & Thompson, 2017; Bora et al., 2007). The changes also impact the cross-sectional or retrospective assessments in previous studies.

Ecological Momentary Assessment (EMA) methodology overcomes the cross-sectional and retrospective report problem by asking participants to record experiences, thoughts, and behaviors in real-time several times a day. Momentary assessments of hallucinations are associated with conventional clinical assessments in people with schizophrenia (Wright et al., 2021), highlighting their validity. EMA can also test for causality between metacognition and hallucinations, bridging gaps in understanding results from cross-sectional and longitudinal studies.

EMA studies have investigated the frequency, intensity, and distress associated with hallucinations (Kimhy et al., 2017) and explored their association with emotions and other clinical factors (Van Os, Lataster, Delespaul, Wichers, & Myin-Germeys, 2014; Wigman et al., 2013). Few have investigated metacognition in relation to hallucinations (Harvey, Pinkham, Depp, & Granholm, 2020; Gard et al., 2014; Edwards et al., 2018) and suggest hallucinations and delusions are associated with overestimation of functioning (Gohari et al. 2022). None have assessed metacognition in relation to predicting future hallucinations which would allow some causal modeling. In addition to assessing the acceptability and feasibility of a novel momentary assessment of metacognition, this study explored the association between metacognition and hallucinations in people with daily hallucinations, across the continuum of psychotic experiences and thus irrespective of clinical diagnosis. We hypothesized that poorer momentary metacognitive expectancies (e.g., larger discrepancy between predicted and actual measures of the likelihood and standard of task completion as well as the difficulty of a task) will be associated with presence of a hallucinatory experience. We also hypothesized that when hallucinatory experiences were more intense, distressing, of longer duration, negative, and associated with a feeling of less control then they would be preceded by poor metacognitive expectancies.

## METHODS

### Design

This was a longitudinal EMA study including a baseline assessment of questionnaires and 14 days of EMA surveys with 7 surveys per day. The study design and analysis plan were pre-registered on https://aspredicted.org/8rc8g.pdf.

### Procedure

All participants provided informed consent. Participants screened to confirm eligibility and completed the baseline questionnaires. Participants downloaded mindLAMP to their smartphone and entered an access key provided via email. Over 14 days, participants were prompted 7 times per day to complete EMA surveys and at the end of the study completed a questionnaire about their participation experience.

## Participants

Participants were aged between 18 and 65 years of age, experienced hallucinations daily (see Appendix A for screening measures), able to read and communicate in English, and had daily access to a smartphone. Participants were recruited irrespective of diagnosis. Those with organic neurological impairment were excluded. Participants were recruited through online advertisement, including MoodNetwork online platform, recovery listservs, clinics, and advertising in the community. Recruitment information was reviewed by peer consultants with lived experience. The study was approved by the Massachusetts General Brigham (MGB) Institutional Review Board. Data were collected between July 2020 to March 2021. Participants were reimbursed for their involvement.

## Measures

All data were collected online using HIPAA compliant data management software, Partners RedCAP and MindLAMP (Torous et al., 2019). Data on demographics, clinical diagnoses, medication, and enrollment in psychiatric services were collected via self-report. Baseline questionnaires included unusual experiences and metacognition to compare assess validity against the momentary metacognition measures. A measure of negative symptoms was used as a covariate to control for the reported effects on metacognition (McLeod et al., 2014).

### *Baseline questionnaires*

#### *Hallucinations & depersonalization*

*Multimodal Unusual Sensory Experiences Questionnaire* (MUSEQ) (Mitchell, Maybery, Russell-smith, et al., 2017) is a 43-item 5-point Likert scale measuring anomalous perceptual/sensory experiences on 6 subscales: auditory, visual, smell, taste, bodily (e.g., touch or tactile) sensations, and sensed presence. The MUSEQ total score is the sum of the subscale scores (0-172) and higher scores represent more prominent anomalous experiences.

*Cardiff anomalous perceptions scale* (CAPS) (Bell, Halligan, & Ellis, 2006) is a 32-item questionnaire assessing anomalous perceptions (yes/no) as well the associated distress, intrusiveness, and frequency of those experiences. Four scores are calculated: total number of items endorsed (0-32), distress (0-160), intrusiveness (0-160), and frequency (0-160).

*Cambridge depersonalization scale* (CDS) (trait version) (Sierra & Berrios, 2000) is a 29-item scale assessing anomalous self-experiences over the last 6 months, with 4 subscales: *alienation from surroundings*, *anomalous subjective recall*, *emotional numbing* and *anomalous body experience* (Sierra et al., 2000). Four scores are calculated: number of items endorsed (0-29), average frequency (0-4), average duration (1-6), and a total score (0-290) with higher scores reflecting more unusual experiences.

***Metacognition***

*Metacognitive Self-Assessment Scale* (MSAS) (Pedone et al., 2017) is a self-report questionnaire measuring metacognitive capacity in four domains: i) monitoring, identification of feelings and thoughts, ii) differentiation, distinguishing between dreams, beliefs or assumptions, iii) integration, reflection on different mental states and rules governing them, and iv) decentration, describing the mental state of the other which is independent of their own view (Semerari et al., 2012). It has 18 statements rated on a 5-point Likert scale and the total score ranges from 18-90, with higher scores indicating better metacognition.

*The Beck Cognitive Insight Scale* (BCIS) (Beck, Baruch, Balter, Steer, & Warman, 2004). The 9 items self-reflectiveness scale was used (0 to 27), with higher scores representing higher self-reflectiveness.

***Covariate***

**Negative symptoms:** The Self-Evaluation of Negative Symptoms (Dollfus, Mach, & Morello, 2016) is a 20-item scale in five subscales: social withdrawal, diminished emotional range, avolition, anhedonia, and alogia and the total score is the sum of all items with higher scores indicating greater severity.

## Ecological Momentary Assessment (EMA)

This study used EMA-based assessment with 7 surveys to complete each day (9am-9pm) over 14-days. No additional prompts were provided after the first notification and each survey was open until the next survey was triggered. Voice-hearing studies have included up to 10 surveys per day with good completion rates (Hartley, Haddock, Vasconcelos Sa, Emsley, & Barrowclough, 2015; Oorschot et al., 2012) and one study reported no differences in completion rate between those with and without schizophrenia when asked to complete 7 surveys per day for six days (Edwards, Cella, Tarrier, & Wykes, 2016).

***EMA item development and response format***

**State metacognition** was assessed before a participant-nominated task was completed and then later to discover whether and how much the task had been completed. The participant provided an activity to complete over the next 4 hours, and asked twice per day about the: (1) ***likelihood*** ("How likely is it that you will complete the activity" from 1="Not likely" to 5="Extremely likely"); (2) ***difficulty*** ("How difficult do you think the activity will be?" from 1="Not difficult" to 5="Extremely difficult"); and (3) the ***standard of completion*** ("How well do you think you will complete the activity?" from 1="Very poorly" to 5="Very well"). The participant was asked to reflect on their previous tasks over the last few hours and answer the same questions on completion, difficulty, and standard of completion. Three state metacognition discrepancy scores were calculated (likelihood, difficulty, and standard of completion) by subtracting their initial pre-task prediction score from their post-task reflection score, and weighted average scores were calculated for each participant per day.

**State hallucinations** were rated for presence (i.e., Y/N), domain (i.e., Visual, touch, smell, taste, auditory), distress (i.e., 5-point Likert: 1= "Not distressing at all" to 5= "Extremely distressing"), positive-negative content (i.e., 5-point Likert: 1= "Very positive" to 5= "very negative), intensity (i.e., 5-point Likert: 1= "Not intense at all" to 5= "Extremely intense"), duration (i.e., 5-point Likert: 1= "Seconds" to 5= "Constant"), and controllability (i.e., 5-point Likert: 1= "No control" to 5= "Full control").

**State mood and self-esteem:** 5-point Likert items on happy, sad, self-esteem. Further description of the EMA items can be found in Appendix B.

**Qualitative feedback:** At the end of the study, participants were asked to complete a short questionnaire about their experiences taking part in the study. See Appendix C.

## Analysis plan

Power for mixed-effect analyses have used a ‘30/30 rule’ (Kreft, 1996) with 30 participants with at least 30 measurement occasions per participant (Ben-Zeev et al., 2014). To account for potential attrition, 10 additional participants were recruited.

Descriptive statistics were computed for drop-out rates and number of surveys completed. Variability was examined using intraclass correlation (ICC) which describes how strongly units in the same group (e.g., metacognition likelihood) resemble each other. Reliability was assessed by comparing metacognition scores from week 1 to 2, using a split-week reliability (Hektner, Schmidt, & Csikszentmihalyi, 2007). Convergent validity was examined by conducting mixed-effect regression analyses. The models were fit with random intercepts at the individual level. State metacognition discrepancy scores (likelihood, difficulty, and standard of completion) were the dependent variable, and predictors included: time, day, baseline metacognition (MSAS), and their interaction. All variables were included in the model and, using backward elimination, non-significant terms ($p<.05$) were removed one-by-one.

A series of mixed-effects regression analyses with random intercepts at the individual level were conducted to examine whether state metacognitive discrepancies predicted hallucinations (presence (logistic regression); distress; content; intensity; duration; controllability). Predictor variables assessed for inclusion in the final model using backward elimination were time, day, state metacognition (likelihood, difficulty, and standard of completion), and the interaction between metacognition, time, and day. The covariates were state mood, state self-esteem, trait negative symptoms (SNS). Models were re-run after removing non-significant predictors. To test whether metacognition predicted future hallucinations, time-lagged analyses were conducted using the same models, except hallucinations were at time t as the dependent variable and metacognition at the previous moment (t-1) was the independent variable. To assess differences between individuals who had a diagnosis of psychosis to those without a diagnosis, groups were compared on demographic/baseline variables and re-ran the mixed-effects analyses. Analyses were conducted using SPSS (Version 24) and R.

## RESULTS

Forty-two participants who experienced hallucinations daily were included in the analysis. On the baseline questionnaires, one participant reported "prefer not to answer" to most questions. As a result, this participant's data was not usable, and they were removed from the analysis (Final sample n=41). The sample was 54% male with a mean age of 31.9 (SD=8.8) years, and most were white (73%), were employed (63%), and living independently (81%). A third of the participants (34%) reported having a mental health diagnosis, and 71% of those reported schizophrenia diagnosis. (Table 1). There were no significant differences in demographic variables nor scores on baseline questionnaires between individuals who reported a schizophrenia diagnosis and those who did not ($p>.05$).

**[INSERT TABLE 1 HERE]**

### Psychometric evaluation of momentary metacognition

#### *Feasibility*

A total of 76% (N=31) of participants completed the 14-day study period, defined as completing at least one survey per day over the 14-day duration of the study. Those who completed the 14-day EMA period were more likely to be working (74% vs 30%, $\chi 2$ (1, N=41)=6.37, $p$=.01) and had lower BCIS self-reflectiveness scores (M=15.84 [4.02] vs M=19.70 [2.45] respectively; $t(25.58)= -3.65$, $p=.001$). No other variables, including clinical diagnoses, were associated with completion. The total number of prompted surveys was 2253 and total number of answered surveys was 950, which equates to a 42.2% response rate. The median percentage of surveys completed per participant was 43.9% (IQR = 32.4% to 63.8%), and the median surveys completed per day was 53.3% (IQR = 42.0%-54.9%). Six individuals responded to fewer than 25% of surveys and were excluded from the main analyses (Edwards et al, 2018). Participants qualitatively reported that the application was easy to download and complete without face-to-face contact (see Appendix C).

#### *Consistency*

All momentary metacognition measures had high intraclass correlation coefficients, suggesting that responses to the same item by different participants are similar. Metacognition difficulty had excellent internal consistency (ICC = 0.99), standard of completion had very good consistency (ICC = 0.91), and likelihood had moderate consistency (ICC = 0.63).

***Split-Week Reliability***

There was no significant difference between week one and two for metacognition difficulty, t(1714.47)=1.03, p=.30, nor likelihood, t(1922.27)=1.49, p=.14. Individuals were more likely to underestimate the standard of completion in week two (M=-0.02, SD=0.50), compared to week one (M=0.07, SD=0.69), t(1489.46)=2.88, p=.004, suggesting lower reliability of this item across the two weeks.

***Validity: Predicting metacognition across time***

**Metacognition likelihood.** For the metacognition likelihood variable, there was a significant effect of day (p<.001), BCIS self-reflectiveness scale (p=.01), a significant interaction between day and BCIS self-reflectiveness scale (p<.001), and a significant interaction between day and MSAS total (p<.001) (Table 2). The interaction between day and BCIS self-reflectiveness scale reflected individuals with low self-reflectiveness at baseline were more likely to underestimate their likelihood of completing a task overtime (Figure 1). The interaction between day and MSAS scale showed that individuals with high MSAS scores at baseline were likely to become more accurate in their prediction of likelihood of completing a task compared to those with low MSAS scores were likely to overestimate their likelihood of completion (Figure 2).

**[INSERT TABLE 2 AND FIGURE 1 & 3 HERE]**

**Metacognition difficulty.** For the metacognition difficulty variable, there was a significant effect of day (p<.001) and BCIS self-reflectiveness (p<.001), and a significant interaction between day and BCIS self-reflectiveness (p<.001) (Table 3). The interaction demonstrated that individuals with a low baseline self-reflectiveness were likely to overestimate the difficulty of a task compared to those with high baseline BCIS self-reflectiveness score who were likely to become more accurate in their prediction of difficulty (Figure 3).

**[INSERT TABLE 3 AND FIGURE 3 HERE]**

**Metacognition standard of completion.** There were no significant effects nor interactions for this variable.

## Predicting hallucinations across time

When respondents reported any hallucination, 29.8% were auditory, 27% were tactile, 25.8% were visual, 11.5% were olfactory and 5.9% were gustatory.

### *Mixed-effects regression model*

No metacognitive variable had a significant effect on hallucination control, distress, content, intensity, or duration.

**Hallucination presence.** There was a significant effect of time ($p=.02$), metacognition: likelihood ($p=.04$), standard of completion ($p=.001$), difficulty ($p=.02$), and negative symptoms (SNS total). (Table 4). Less accurate metacognition difficulty was associated with an increase in hallucinations, but less accurate likelihood and standard of completion was associated with a decrease in hallucinations.

**[INSERT TABLE 4 HERE]**

### *Mixed-effects regression model with cross-lagged approach*

No baseline metacognitive variable had a significant effect on the following timepoint for hallucination presence, distress, content, or duration.

**Hallucination intensity.** There was a significant effect of day ($p<.001$), metacognition: likelihood ($p<.001$) and standard of completion ($p=.01$), sadness ($p<.001$), happiness ($p=.02$), and negative symptoms ($p=.02$) for predicting hallucination intensity (Table 5). Less accurate metacognition predicted more intense hallucinations.

**[INSERT TABLE 5 HERE]**

**Hallucination control.** There was a significant effect of day (p=.03), metacognition likelihood (p=.02), sadness (p=.01), and self-esteem (p=.01) for predicting hallucination control (Table 6). Less accurate metacognition likelihood predicted less control over hallucinations.

**[INSERT TABLE 6 HERE]**

Sensitivity analysis were conducted comparing those with psychosis (N=4 with usable EMA data) and those without psychosis. There were no apparent differences between the groups, except for those with psychosis who had less accurate metacognition (standard of completion) were likely to experience less hallucination intensity in the future.

## DISCUSSION

This was the first study to use a novel momentary metacognitive assessment to examine its temporal associations with hallucinations. Momentary metacognition likelihood and standard of completion predicted hallucination intensity at the following timepoint, and momentary metacognition likelihood predicted hallucination control at the following timepoint, demonstrating specific predictive associations between metacognition and hallucinations in daily life.

### Strength of evidence

Completion of the 14-day study period (76%) was comparable to other EMA studies measuring hallucinations (62%-87% [Granholm, Loh, & Swendsen, 2008; So, Peters, Swendsen, Garety, & Kapur, 2014]). However, the average number of surveys completed (42%) was lower (71%-90% [Kimhy et al., 2017; So, Peters, Swendsen, Garety, & Kapur, 2013; Edwards et al., 2018]), but participants were not necessarily experiencing daily hallucinations that may have affected their ability to engage with the surveys. A lower response could also be due to only providing one prompt per survey, as an EMA study in those with schizophrenia or bipolar reported that adherence to surveys was not correlated with the study length but that early nonadherence predicted later nonadherence (Jones et al., 2021). Encouraging early engagement through reminders and prompts may increase adherence.

The likelihood and difficulty measures demonstrated good reliability, and validity and both metacognition measures were predicted by baseline self-reflectiveness ability. This suggests that the EMA surveys were reasonably accurate in their assessment of metacognition.

Those with low baseline BCIS self-reflectiveness were likely to underestimate the likelihood of completing a task and overestimate the difficulty of that task over time. Participants with low baseline self-reflectiveness believed that the task would be difficult and they would not complete it. To improve momentary metacognition, training should introduce a feedback mechanism to provide information for the individual to incorporate into their beliefs such as the cognitive remediation software, CIRCuiTS (Reeder et al. 2015).

Individuals with high baseline metacognition (MSAS) were likely to become more accurate in their prediction of difficulty over time, suggesting that those with a higher ability to reflect on oneself at a global level were able to apply this ability in-the-moment to improve their metacognition. The practice embedded in EMA has an intervention-like quality that can encourage reflection on thinking patterns. However, those with low scores became less accurate by overpredicting the likelihood of completing a task. This contrasts with the interaction between momentary metacognition likelihood and BCIS self-reflectiveness. Each baseline measure of metacognition (MSAS and BCIS self-reflectiveness) may tap different metacognitive constructs (Palmer-Cooper, Mcguire, & Wright, 2021), and have nuanced associations with momentary metacognitive likelihood.

The standard of completion measure did not have such robust results as it was not associated with validated metacognition measures and performance varied across the weeks. While the variation in performance was likely due to the psychometric properties, it may also be due to a legitimate change in responding due to exposure.

Caution should be taken when interpreting the results of this item and research is warranted to understand whether the measure captures its construct.

### Hallucinations

The similar frequency of auditory (30%), visual (26%), and tactile hallucinations (27%) reported in this study may be a consequence of the EMA methodology to be able to detect more transient hallucinations that may otherwise not be reported, since auditory hallucinations are considered the most common hallucination in those with schizophrenia (Waters et al., 2014). However, multi-modal hallucinations in non-auditory modes are common in those who experience primary auditory hallucinations (Dudley et al. 2022), with over 50% reporting hallucinations in other domains (Toh et al., 2019). In this study, participants who reported experiencing hallucinations across several domains, reported on the most distressing hallucinatory experience. Future hallucinations studies should offer the options to select multiple domains to capture the variety of experiences.

Contrary to our hypothesis, individuals who were better able to predict whether they would complete a task (metacognition likelihood) and how well they would complete it (metacognition standard of completion) reported more hallucinations. Individuals with and without a clinical diagnosis were included in this study, such that some individuals may experience hallucinations but may be able to interpret them in a positive, or meaningful way. Palmer-Cooper, McGuire, & Wright (2021) found that healthy individuals who seek unusual experiences (such as Tulpamancy and Autonomous Sensory Meridian Response [ASMR]) reported comparable levels of metacognition to those without these experiences, and metacognition was also associated with unusual experiences. Higher metacognitive awareness may enable these individuals to feel less distress when experiencing hallucinations.

An individual's inability to accurately predict the likelihood of completing a future task or the standard of completion predicted increased hallucination intensity. Thus, poorer metacognition has causal effects on whether someone experiences more emotionally intense hallucinations, potentially influencing interpretations and maintaining hallucinatory experiences. Poorer momentary metacognition likelihood also predicted less hallucination control. Hallucination control is a clinically important construct as the impact of hallucinations is affected by the individual's perception of control over the experience (Bell, Raballo, Larøi, & Aleman, 2010). It is also critical for the level of distress experienced (Swyer & Powers, 2020) with treatment-seeking individuals with voice-hearing experiences reporting less control compared to non-treatment seeking individuals (Baumeister, Sedgwick, Howes, & Peters, 2017; Daalman, Weijer, & Blom, 2010). Brett et al. (2009) proposed that how individuals reflect on their thoughts (such as predicting the likelihood of completing a task) and hallucinations may interact with control over them, leading to the perception of less control of their thinking and experiences. Birchwood and colleagues (2014) conducted a trial using Cognitive Behavioral Therapy (CBT) techniques that reduced compliance with commanding voices via modifying conviction in beliefs linked to the power/control of a voice (Birchwood et al., 2018). CBT incorporates aspects of metacognitive training by encouraging the individual to consider alternative perspectives. This act of reinterpretation may improve metacognitive function and, thus, hallucination control.

For both hallucination intensity and control, a time lag between a change in metacognitive likelihood and increased hallucination intensity or control demonstrates a causal relationship and may be the result of the reinterpretation of the hallucinations over time. As this was the first study to examine the momentary association between metacognition and hallucinations, our cross-lagged analysis should be replicated to confirm the findings and the concept of re-interpretation empirically tested.

Momentary metacognition did not predict hallucination distress, content, or duration, highlighting the specificity of metacognition's role on hallucinatory experiences. Momentary metacognition items were also not associated with trait hallucination measure, consistent with cross-sectional studies (Gaweda et al., 2013; Moritz, Woodward, & Chen, 2006; Wright, Nelson, Fowler, & Greenwood, 2020), supporting the idea that momentary metacognition may not translate to global experiences of hallucinations.

## Limitations

Heterogeneity in diagnoses of participants may have led to heterogeneity in the data. When differences were examined between individuals with psychosis and those without psychosis, there were no differences in demographic variables nor scores on baseline questionnaires and minimal differences in the mixed-effects analyses which supported the use of the combined sample. The momentary metacognitive scores were averaged across the day due to the nature of the questions asking participants to reflect on an earlier activity and to prevent loss of data due to missed surveys. The study methodology did not allow for separate analyses of momentary versus cumulative judgements of competence, which may be determined by different contextual factors, such as time spent alone at home (Gohari et al. 2022). Increasing engagement and enabling broader questions on activities will allow for assessment of momentary associations.

## REFERENCES


Baumeister, D., Sedgwick, O., Howes, O., & Peters, E. (2017). Auditory verbal hallucinations and continuum models of psychosis : A systematic review of the healthy voice-hearer literature. *Clinical Psychology Review*, *51*, 125–141. https://doi.org/10.1016/j.cpr.2016.10.010

Beck, A. T., Baruch, E., Balter, J. M., Steer, R. a., & Warman, D. M. (2004). A new instrument for measuring insight: The Beck Cognitive Insight Scale. *Schizophrenia Research*, *68*, 319–329. https://doi.org/10.1016/S0920-9964(03)00189-0

Bell, V., Halligan, P. W., & Ellis, H. D. (2006). The Cardiff Anomalous Perceptions Scale (CAPS): A New Validated Measure of Anomalous Perceptual Experience. *Schizophrenia Bulletin*, *32*(2), 366–377. https://doi.org/10.1093/schbul/sbj014

Bell, V., Raballo, A., Larøi, F., & Aleman, A. (2010). *Assessment of hallucinations. In Hallucinations: A guide to treatment and management*.

Bell, Vaughan, Halligan, P. W., & Ellis, H. D. (2015). *Explaining delusions : a cognitive perspective*. (July). https://doi.org/10.1016/j.tics.2006.03.004

Ben-Zeev, D., Brenner, C. J., Begale, M., Duffecy, J., Mohr, D. C., & Mueser, K. T. (2014). Feasibility, acceptability, and preliminary efficacy of a smartphone intervention for schizophrenia. *Schizophrenia Bulletin*, *40*(6), 1244–1253. https://doi.org/10.1093/schbul/sbu033

Birchwood, M., Michail, M., Meaden, A., Tarrier, N., Lewis, S., Wykes, T., ... & Peters, E. (2014). Cognitive behaviour therapy to prevent harmful compliance with command hallucinations (COMMAND): a randomised controlled trial. *The Lancet Psychiatry*, *1*(1), 23-33.

Birchwood, M., Dunn, G., Meaden, A., Tarrier, N., Lewis, S., Wykes, T., ... & Peters, E. (2018). The COMMAND trial of cognitive therapy to prevent harmful compliance with command hallucinations: predictors of outcome and mediators of change. *Psychological medicine*, *48*(12), 1966-1974.

Bora, E., Erkan, A., Kayahan, B., & Veznedaroglu, B. (2007). Cognitive insight and acute psychosis in schizophrenia. *Psychiatry and Clinical Neurosciences*, *61*(6), 634–639. https://doi.org/10.1111/j.1440-1819.2007.01731.x

Brett, C. M. C., Johns, L. C., Peters, E. P., & McGuire, P. K. (2009). The role of metacognitive beliefs in determining the impact of anomalous experiences: a comparison of help-seeking and non-help-seeking groups of people experiencing psychotic-like anomalies. *Psychological Medicine*, *39*(6), 939–950. https://doi.org/10.1017/S0033291708004650

Cella, M., Swan, S., Medin, E., Reeder, C., & Wykes, T. (2014). Metacognitive awareness of cognitive problems in schizophrenia: Exploring the role of symptoms and self-esteem. *Psychological Medicine*, *44*(3), 469–476. https://doi.org/10.1017/S0033291713001189

Daalman, K., Weijer, A. De, & Blom, J. D. (2010). *The Same or Different? A Phenomenological Comparison of Auditory Verbal Hallucinations in Healthy and Psychotic Individuals*. (October 2017). https://doi.org/10.4088/JCP.09m05797yel

de Jong, S., van Donkersgoed, R. J. M., Timmerman, M. E., aan het Rot, M., Wunderink, L., Arends, J., … Pijnenborg, G. H. M. (2018). Metacognitive reflection and insight therapy (MERIT) for patients with schizophrenia. *Psychological Medicine*, 1–11. https://doi.org/10.1017/S0033291718000855

Dimaggio, G., Vanheule, S., Lysaker, P. H., Carcione, A., & Nicolò, G. (2009). Impaired self-reflection in psychiatric disorders among adults: A proposal for the existence of a network of semi independent functions. *Consciousness and Cognition*, *18*(3), 653–664. https://doi.org/10.1016/j.concog.2009.06.003

Dudley, R., Watson, F., O'Grady, L., Aynsworth, C., Dodgson, G., Common, S., ... & Fernyhough, C. (2022). Prevalence and nature of multi-sensory and multi-modal hallucinations in people with first episode psychosis. *Psychiatry Research*, 114988.

Edwards, C. J., Cella, M., Tarrier, N., & Wykes, T. (2016). The optimisation of experience sampling protocols in people with schizophrenia. *Psychiatry Research*, *244*, 289–293. https://doi.org/10.1016/j.psychres.2016.07.048

Edwards, C. J., Cella, M., Emsley, R., Tarrier, N., & Wykes, T. H. (2018). Exploring the relationship between the anticipation and experience of pleasure in people with schizophrenia: An experience sampling study. *Schizophrenia Research*, *202*, 72-79.

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review*, *1*, 3–14. https://doi.org/10.1016/j.edurev.2005.11.001

Eisner, E., Bucci, S., Berry, N., Emsley, R., Barrowclough, C., & Drake, R. (2019). Feasibility of using a smartphone app to assess early signs, basic symptoms and psychotic symptoms over six months: a preliminary report. *Schizophrenia Research*, (xxxx). https://doi.org/10.1016/j.schres.2019.04.003

Gard, D. E., Sanchez, A. H., Cooper, K., Fisher, M., Garrett, C., & Vinogradov, S. (2014). Do people with schizophrenia have difficulty anticipating pleasure, engaging in effortful behavior, or both? *Journal of Abnormal Psychology*, *123*(4), 771–782. https://doi.org/10.1037/abn0000005

Gawęda, L., Li, E., Lavoie, S., Whitford, T. J., Moritz, S., & Nelson, B. (2018). Impaired action self-monitoring and cognitive confidence among ultra-high risk for psychosis and first-episode psychosis patients. *European Psychiatry*, *47*(2018), 67–75. https://doi.org/10.1016/j.eurpsy.2017.09.003

Gaweda, L., Woodward, T. S., Moritz, S., & Kokoszka, A. (2013). Impaired action self-monitoring in schizophrenia patients with auditory hallucinations. *Schizophrenia Research*, *144*(1–3), 72–79. https://doi.org/10.1016/j.schres.2012.12.003

Gohari, E., Moore, R. C., Depp, C. A., Ackerman, R. A., Pinkham, A. E., & Harvey, P. D. (2022). Momentary severity of psychotic symptoms predicts overestimation of competence in domains of everyday activities and work in schizophrenia: An ecological momentary assessment study. *Psychiatry Research*, *310*, 114487.

Granholm, E., Loh, C., & Swendsen, J. (2008). Feasibility and validity of computerized ecological momentary assessment in schizophrenia. *Schizophrenia Bulletin*, *34*(3), 507–514. https://doi.org/10.1093/schbul/sbm113

Hartley, S., Haddock, G., Vasconcelos e Sa, D., Emsley, R., & Barrowclough, C. (2015). The influence of thought control on the experience of persecutory delusions and auditory hallucinations in daily life. *Behaviour Research and Therapy*, *65*, 1–4. https://doi.org/10.1016/j.brat.2014.12.002

Harvey, P., Pinkham, A., Depp, C., & Granholm, E. (2020). Immediate Accuracy of Judgments of Memory Performance Examined With Ecological Momentary Assessment Across Variable Levels of Objective Difficulty: Context and Symptom Correlates. *Biological Psychiatry*, *87*(9), S184–S185.

Hektner, J. M., Schmidt, J. A., & Csikszentmihalyi, M. (2007). *Experience Sampling Method: Measuring the Quality of Everyday Life. Experience Sampling Method Measuring the Quality of Everyday Life. California: Sage.*

Jones, S. E., Moore, R. C., Pinkham, A. E., Depp, C. A., Granholm, E., & Harvey, P. D. (2021). A cross-diagnostic study of adherence to ecological momentary assessment: Comparisons across study length and daily survey frequency find that early adherence is a potent predictor of study-long adherence. *Personalized Medicine in Psychiatry*, *29*, 100085.

Kelleher, I., Connor, D., Clarke, M. C., Devlin, N., Harley, M., & Cannon, M. (2012). Prevalence of psychotic symptoms in childhood and adolescence: a systematic review and meta-analysis of population-based studies. *Psychological Medicine*, *42*(09), 1857–1863. https://doi.org/10.1017/S0033291711002960

Kimhy, D., Wall, M. M., Hansen, M. C., Vakhrusheva, J., Choi, C. J., Delespaul, P., … Malaspina, D. (2017). Autonomic Regulation and Auditory Hallucinations in Individuals with Schizophrenia: An Experience Sampling Study. *Schizophrenia Bulletin*, *43*(4), 754–763. https://doi.org/10.1093/schbul/sbw219

Kreft, I. (1996). *Are multilevel techniques necessary? An overview including simulation studies. Unpublished Manuscript*.

Kumar, S., Nilsen, W. J., Abernethy, A., Atienza, A., Patrick, K., Pavel, M., … Swendeman, D. (2014). *Mobile Health Technology evaluation: The mHealth Evidence Workshop*. *45*(2), 228–236. https://doi.org/10.1016/j.amepre.2013.03.017.Mobile

Lepage, M., Sergerie, K., Pelletier, M., & Harvey, P. (2007). Episodic Memory Bias and the Symptoms of Schizophrenia. *La Revue Canadienne de Psychiatrie*, *52*(11).

Lysaker, P. H., Gagen, E., Wright, A., Vohs, J. L., Kukla, M., Yanos, P. T., & Hasson-Ohayon, I. (2018). Metacognitive Deficits Predict Impaired Insight in Schizophrenia Across Symptom Profiles: A Latent Class Analysis. *Schizophrenia Bulletin*, *45*(1), 48–56. https://doi.org/10.1093/schbul/sby142

McLeod, H. J., Gumley, A. I., MacBeth, A., Schwannauer, M., & Lysaker, P. H. (2014). Metacognitive functioning predicts positive and negative symptoms over 12 months in first episode psychosis. *Journal of Psychiatric Research*, *54*, 109–115. https://doi.org/10.1016/j.jpsychires.2014.03.018

Mitchell, C. A. A., Maybery, M. T., Russell-Smith, S. N., Collerton, D., Gignac, G. E., & Waters, F. (2017). The structure and measurement of unusual sensory experiences in different modalities: The Multi-Modality unusual sensory experiences questionnaire (MUSEQ). *Frontiers in Psychology*, *8*(AUG), 1–18. https://doi.org/10.3389/fpsyg.2017.01363

Moritz, S., Woodward, T. S., & Chen, E. (2006). Investigation of metamemory dysfunctions in first-episode schizophrenia. *Schizophrenia Research*, *81*(2–3), 247–252. https://doi.org/10.1016/j.schres.2005.09.004

Moritz, S., Woodward, T. S., Whitman, J. C., & Cuttler, C. (2005). Confidence in errors as a possible basis for delusions in schizophrenia. *The Journal of Nervous and Dental Disease*, *193*(1), 9–16. https://doi.org/10.1097/01.nmd.0000149213.10692.00

Newton, E., Landau, S., Smith, P., & Monks, P. (2005). *Early Psychological Intervention for Auditory Hallucinations: An Exploratory Study of Young People's Voices Groups*. *193*(1), 58–61. https://doi.org/10.1097/01.nmd.0000149220.91667.fa

O’ Connor, K., Nelson, B., Cannon, M., Yung, A., & Thompson, A. (2017). Perceptual abnormalities in an ultra-high risk for psychosis population relationship to trauma and co-morbid disorder. *Early Intervention in Psychiatry*, (May), 1–10. https://doi.org/10.1111/eip.12469

Oorschot, M., Lataster, T., Thewissen, V., Bentall, R., Delespaul, P., & Myin-Germeys, I. (2012). Temporal dynamics of visual and auditory hallucinations in psychosis. *Schizophrenia Research*, *140*(1–3), 77–82. https://doi.org/10.1016/j.schres.2012.06.010

Palmer-Cooper, E., Mcguire, N., & Wright, A. (2021). Unusual experiences and their association with metacognition : investigating ASMR and Tulpamancy metacognition: investigating ASMR and Tulpamancy. *Cognitive Neuropsychiatry*, *0*(0), 1–19. https://doi.org/10.1080/13546805.2021.1999798

Pechey, R., & Halligan, P. (2012). Prevalence and correlates of anomalous experiences in a large non-clinical sample. *Psychology and Psychotherapy: Theory, Research and Practice*, *85*(2), 150–162. https://doi.org/10.1111/j.2044-8341.2011.02024.x

Pedone, R., Semerari, A., Riccardi, I., Procacci, M., Nicolò, G., & Carcione, A. (2017). Development of a self-report measure of metacognition: The metacognition self-assessment scale (MSAS). instrument description and factor structure. *Clinical Neuropsychiatry*, *14*(3), 185–194.

Powers, A. R., Mathys, C., & Corlett, P. R. (2017). Pavlovian conditioning–induced hallucinations result from overweighting of perceptual priors. *Science*, *357*(6351), 596–600. https://doi.org/10.1126/science.aan3458

Reeder, C., Pile, V., Crawford, P., Cella, M., Rose, D., Wykes, T., ... & Callard, F. (2016). The feasibility and acceptability to service users of CIRCuiTS, a computerized cognitive remediation therapy programme for schizophrenia. *Behavioural and Cognitive Psychotherapy*, *44*(3), 288-305.

Reininghaus, U., Kempton, M. J., Valmaggia, L., Craig, T. K., Garety, P., Onyejiaka, A., ... & Morgan, C. (2016). Stress sensitivity, aberrant salience, and threat anticipation in early psychosis: an experience sampling study. *Schizophrenia bulletin*, *42*(3), 712-722.

Rouault, M., Seow, T., Gillan, C. M., & Fleming, S. M. (2018). Psychiatric symptom dimensions are associated with dissociable shifts in metacognition but not task performance. *Biological psychiatry*, *84*(6), 443-451.

Semerari, A., Carcione, A., Dimaggio, G., Falcone, M., Nicolò, G., Procacci, M., & Alleva, G. (2003). How to evaluate metacognitive functioning in psychotherapy? The metacognition assessment scale and its applications. *Clinical Psychology and Psychotherapy*, *10*(4), 238–261. https://doi.org/10.1002/cpp.362

Semerari, A., Cucchi, M., Dimaggio, G., Cavadini, D., Carcione, A., Battelli, V., … Smeraldi, E. (2012). The development of the Metacognition Assessment Interview: Instrument description, factor structure and reliability in a non-clinical sample. *Psychiatry Research*, *200*, 890–895. https://doi.org/10.1016/j.psychres.2012.07.015

Sierra, M. Y., & Berrios, G. E. (2000). The Cambridge depersonalization Scale: A new instrument for the measurement of despersonalization. *Psychiatry Research*, *93*(2), 93¸153-164. Retrieved from http://www.sciencedirect.com/science/article/pii/S0165178100001001%0Ahttp://dx.doi.org/10.1016/S0165-1781(00)00100-1

Smelror, R. E., Bless, J. J., Hugdahl, K., & Agartz, I. (2019). Feasibility and acceptability of using a mobile phone app for characterizing auditory verbal hallucinations in adolescents with early-onset psychosis: Exploratory study. *JMIR Formative Research*, *3*(2), e13882.

So, S. H. wai, Peters, E. R., Swendsen, J., Garety, P. A., & Kapur, S. (2013). Detecting improvements in acute psychotic symptoms using experience sampling methodology. *Psychiatry Research*, *210*(1), 82–88. https://doi.org/10.1016/j.psychres.2013.05.010

Swyer, A., & Powers, A. R. (2020). Voluntary control of auditory hallucinations : phenomenology to therapeutic implications. *Npj Schizophrenia*. https://doi.org/10.1038/s41537-020-0106-8

Toh, W. L., McCarthy-Jones, S., Copolov, D., & Rossell, S. L. (2019). Have we overlooked the significance of multinodal hallucinations in schizophrenia?. *Psychiatry Research*, *279*, 358-360.

Torous, J., Wisniewski, H., Bird, B., Carpenter, E., David, G., Elejalde, E., … Keshavan,

M. (2019). Creating a Digital Health Smartphone App and Digital Phenotyping Platform for Mental Health and Diverse Healthcare Needs: an Interdisciplinary and Collaborative Approach. *Journal of Technology in Behavioral Science*, *4*(2), 73–85. https://doi.org/10.1007/s41347-019-00095-w

Van Os, J., Hanssen, M., Bijl, R. V., & Ravelli, A. (2000). Strauss (1969) revisited: a psychosis continuum in the general population?. *Schizophrenia research*, *45*(1-2), 11-20.

Van Os, J., Lataster, T., Delespaul, P., Wichers, M., & Myin-Germeys, I. (2014). Evidence that a psychopathology interactome has diagnostic value, predicting clinical needs: An experience sampling study. *PLoS ONE*, *9*(1). https://doi.org/10.1371/journal.pone.0086652

Varese, F., & Bentall, R. P. (2011). The metacognitive beliefs account of hallucinatory experiences: a literature review and meta-analysis. *Clinical psychology review*, *31*(5), 850-864.

Waters, F., Collerton, D., Ffytche, D. H., Jardri, R., Pins, D., Dudley, R., ... & Larøi, F. (2014). Visual hallucinations in the psychosis spectrum and comparative information from neurodegenerative disorders and eye disease. *Schizophrenia bulletin*, *40*(Suppl_4), S233-S245.

Wells, A., & Cartwright-Hatton, S. (2004). A short form of the metacognitions questionnaire: Properties of the MCQ-30. *Behaviour Research and Therapy*, *42*, 385–396. https://doi.org/10.1016/S0005-7967(03)00147-5

Wigman, J. T. W., Collip, D., Wichers, M., Delespaul, P., Derom, C., Thiery, E., … van Os, J. (2013). Altered Transfer of Momentary Mental States (ATOMS) as the Basic Unit of Psychosis Liability in Interaction with Environment and Emotions. *PLoS ONE*, *8*(2). https://doi.org/10.1371/journal.pone.0054653

Wright, A.C., Fowler, D., & Greenwood, K. E. (2019). Influences on functional outcome and subjective recovery in individuals with and without First Episode Psychosis: A metacognitive model. *Psychiatry Research*.

Wright, A. C., Browne, J., Skiest, H., Bhiku, K., Baker, J. T., & Cather, C. (2021). The relationship between conventional clinical assessments and momentary assessments of symptoms and functioning in schizophrenia spectrum disorders :

A systematic review. *Schizophrenia Research*, *232*, 11–27. https://doi.org/10.1016/j.schres.2021.04.010

Wright, A., Nelson, B., Fowler, D., & Greenwood, K. (2020). Perceptual biases and metacognition and their association with anomalous self experiences in first episode psychosis. *Consciousness and Cognition*, *77*(October 2019), 102847. https://doi.org/10.1016/j.concog.2019.102847

## TABLES

**Table 1**: Demographic and baseline variables for 41 participants.

| **Categorical variables** | **% (N)** |
|---|---|
| Male (% yes) | 54% (22) |
| Hispanic (% yes) | 20% (8) |
| Race | |
| American Indian or Alaska Native | 5% (2) |
| Asian | 10% (4) |
| Black or African American | 22% (9) |
| White | 73% (30) |
| Highest education level | |
| Completed college or higher | 56% (23) |
| Some college | 39% (16) |
| High school graduate | 5% (2) |
| In employment (% yes) | 63% (26) |
| Full-time employment (% yes) | 61% (16) |
| Part-time employment (% yes) | 39% (10) |
| In education (% yes) | 17% (7) |
| Housing situation | |
| Independent housing (% yes) | 81% (33) |
| Supportive housing (% yes) | 15% (6) |
| Not listed (% yes) | 5% (2) |
| Health insurance | |
| Private | 37% (15) |
| Public | 54% (22) |
| Uninsured | 7% (3) |
| Prefer not to answer | 2% (1) |
| Enrolled in psychiatric services (% yes) | 42% (17) |
| Medication (% yes) | 42% (17) |
| Diagnosis (% yes) | 34% (14) |

| | |
|---|---|
| Schizophrenia or psychosis spectrum disorder (%) | 71% (10) |
| Bipolar (%) | 21% (3) |
| PTSD (%) | 21% (3) |
| OCD (%) | 21% (3) |
| Autism spectrum disorder (%) | 21% (3) |
| **Continuous variables** | **Mean (SD); Range** |
| Age | 31.85 (8.83); 19-50 |
| MUSEQ total (0-172) | 92.46 (32.76); 40-157 |
| MUSEQ auditory (0-28) | 20.85 (5.60); 8-28 |
| MUSEQ visual (0-32) | 20.42 (7.60); 7-32 |
| MUSEQ smell (0-32) | 14.46 (8.73); 2-30 |
| MUSEQ taste (0-32) | 11.47 (8.55); 0-29 |
| MUSEQ bodily senses (0-32) | 17.05 (8.66); 0-30 |
| MUSEQ sensed presence (0-16) | 8.58 (4.60); 0-16 |
| CAPS | |
| CAPS number of experiences endorsed (0-32) | 15.29 (7.91); 5-32 |
| CAPS distress (0-160) | 37.46 (22.08); 8-117 |
| CAPS distraction (0-160) | 40.51 (23.35); 0-103 |
| CAPS frequency (0-160) | 39.24 (23.61); 0-95 |
| CDS total (0-290) | 65.63 (44.08); 5-169 |
| MSAS total (18-90) | 70.30 (14.14); 44-90 |
| BCIS self-reflectiveness (0-27) | 16.78 (4.03); 8-25 |
| SNS total (0-60) | 17.03 (7.56); 3-32 |

Note: PTSD = post-traumatic stress disorder; OCD= obsessive compulsive disorder; MUSEQ= Multimodal Unusual Sensory Experiences Questionnaire; CAPS = Cardiff anomalous perceptions scale; CDS = Cambridge depersonalization scale; MSAS= Metacognitive Self-Assessment Scale; BCIS= Beck Cognitive Insight Scale; SNS = Self-Evaluation of Negative Symptoms. Data were within normal limits of skewness and kurtosis, except CAPS distress was positively skewed so we used Spearman correlation for CAPS distress.

**Table 2**: Fixed effects from mixed-effect regression model for predicting metacognition likelihood.

| *Fixed effects* | *Estimate* | *St. Error* | *t-value* | *p value* |
|---|---|---|---|---|
| Intercept | -1.25 | 0.46 | -2.72 | .01 |
| Day | 0.08 | 0.01 | 5.75 | **<.001** |
| BCIS S-R | 0.05 | 0.02 | 3.03 | **.01** |
| MSAS total | 0.01 | 0.01 | 1.90 | .07 |
| Day*BCIS S-R | -0.00 | 0.00 | -3.20 | **<.001** |
| Day*MSAS total | -0.00 | 0.00 | -5.19 | **<.001** |

NOTE: **Bold** is significant at p<.05. BCIS S-R=Beck Cognitive Insight Scale self-reflectiveness subscale. MSAS=Metacognitive Self-Assessment Scale.

**Table 3**: Fixed effects from mixed-effect regression model for predicting metacognition difficulty.

| *Fixed effects* | *Estimate* | *St. Error* | *t-value* | *p value* |
|---|---|---|---|---|
| Intercept | -0.65 | 0.31 | -2.11 | .04 |
| Day | 0.11 | 0.02 | 5.78 | **<.001** |
| BCIS S-R | 0.06 | 0.02 | 3.00 | **<.001** |
| Day*BCIS S-R | -0.01 | 0.00 | -6.65 | **<.001** |

NOTE: **Bold** is significant at <.05. BCIS S-R=Beck Cognitive Insight Scale self-reflectiveness subscale.

**Table 4**: Fixed effects from mixed-effect regression model for predicting hallucination presence.

| *Fixed effects* | *Estimate* | *St. Error* | *z-value* | *p value* |
|---|---|---|---|---|
| Intercept | 0.70 | 0.22 | 3.20 | **.001** |
| Time | -0.09 | 0.04 | -2.37 | **.02** |
| Metacognition likelihood | -0.31 | 0.15 | -2.04 | **.04** |
| Metacognition standard of completion | -0.43 | 0.13 | -3.28 | **.001** |
| Metacognition difficulty | 0.24 | 0.11 | 2.26 | **.02** |
| SNS total | -0.04 | 0.01 | -3.69 | **<.001** |

NOTE: **Bold** is significant at p<.05. BCIS S-R=Beck Cognitive Insight Scale self-reflectiveness subscale, SNS=Self-Evaluation of Negative Symptoms.

**Table 5**: Fixed effects from mixed-effect regression model for predicting hallucination intensity (T1).

| *Fixed effects* | *Estimate* | *St. Error* | *t-value* | *p value* |
|---|---|---|---|---|
| Intercept | 1.30 | 0.30 | 4.34 | **<.001** |
| Day | -0.03 | 0.01 | -2.60 | **.01** |
| Metacognition likelihood | -0.46 | 0.15 | -3.14 | **<.001** |
| Metacognition standard of completion | -0.22 | 0.08 | -2.77 | **.01** |
| Sadness | 0.31 | 0.05 | 6.35 | **<.001** |
| Happiness | 0.13 | 0.05 | 2.45 | **.02** |
| Negative symptoms | 0.03 | 0.01 | 2.73 | **.02** |

NOTE: **Bold** is significant at p<.05

**Table 6**: Fixed effects from mixed-effect regression model for predicting hallucination control (T1).

| *Fixed effects* | *Estimate* | *St. Error* | *t-value* | *p value* |
|---|---|---|---|---|
| Intercept | 2.27 | 0.23 | 9.98 | **<.001** |
| Day | -0.02 | 0.01 | -2.12 | **.03** |
| Metacognition likelihood | 0.27 | 0.11 | 2.41 | **.02** |
| Sadness | 0.11 | 0.04 | 2.79 | **.01** |
| Self-esteem | -0.11 | 0.04 | -2.72 | **.01** |

NOTE: **Bold** is significant at p<.05.

**FIGURES**

**Figure 1**: Line graph for two-way interaction for metacognition likelihood discrepancy score for day (1-14) and baseline BCIS-SR score (high vs. low). Note: Metacognition likelihood discrepancy score below 0 represents under-estimation of likelihood of completing a task, whereas a score above 0 suggests over-estimation of likelihood of completing a task.

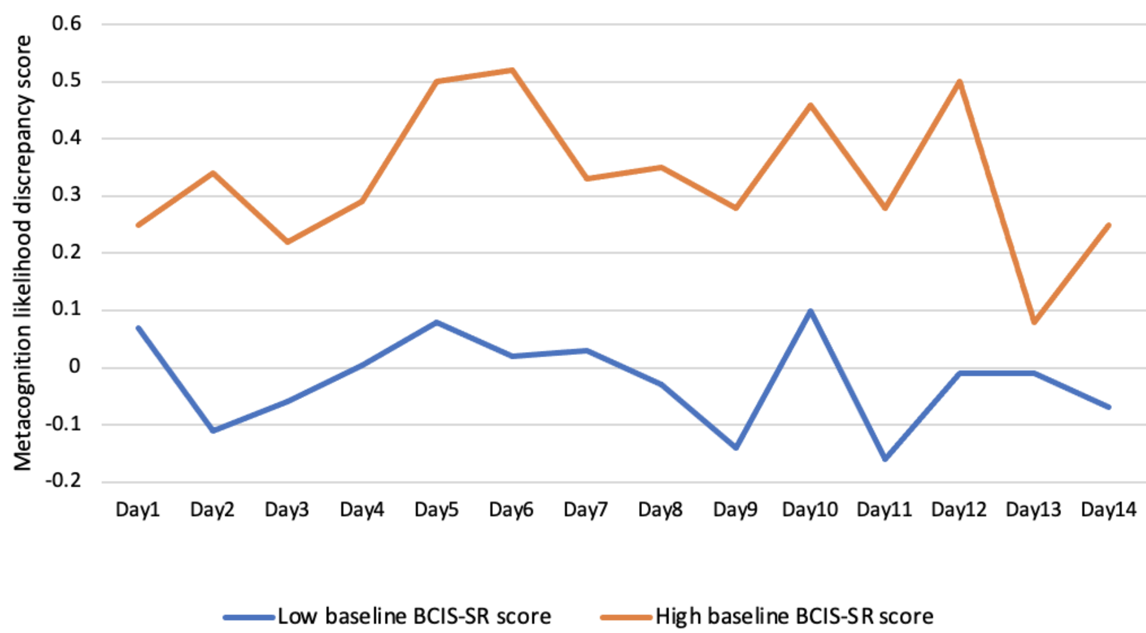


**Figure 2**: Line graph for two-way interaction for metacognition likelihood discrepancy score for day (1-14) and baseline MSAS score (high vs. low).

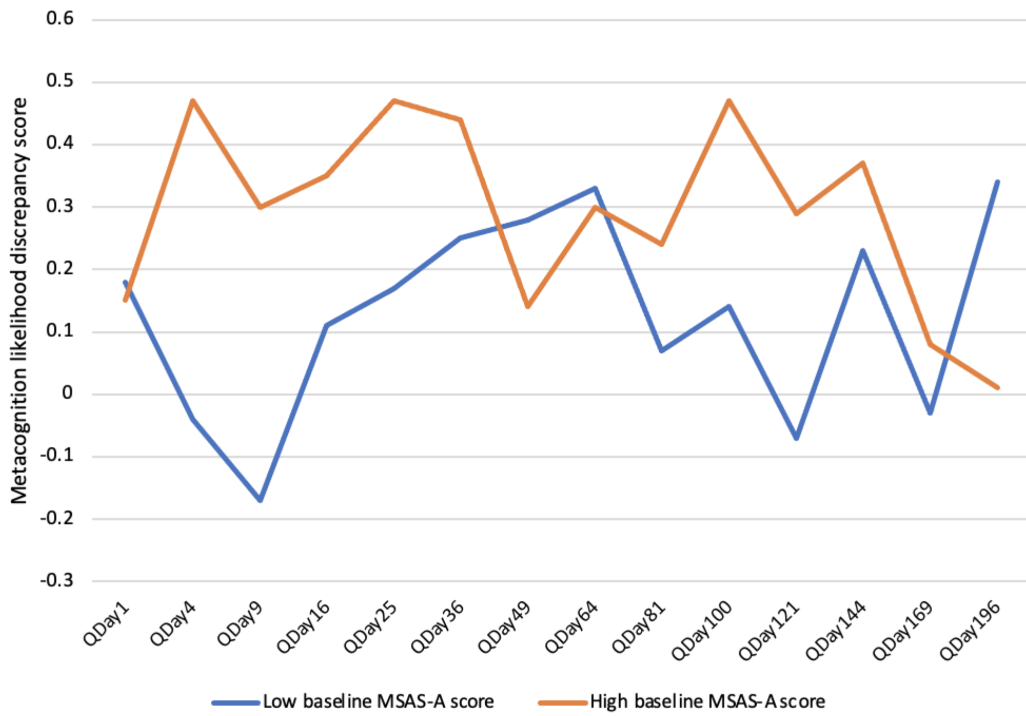


**Figure 3**: Line graph for two-way interaction for metacognition difficulty discrepancy score for day (1-14) and baseline BCIS-SR score (high vs. low). Note: Metacognition difficulty discrepancy score below 0 represents under-estimation of the difficulty of a chosen task, whereas a score above 0 suggests over-estimation of difficulty of a task.