

# Using Smartphones to Identify Momentary Characteristics of Persecutory Ideation Associated With Functional Disability

Benjamin Buck<sup>1,\*</sup>, Mary Wingerson<sup>1</sup>, Justin S. Tauscher<sup>1</sup>, Matthew Enkema<sup>1</sup>, Weichen Wang<sup>2</sup>, Andrew T. Campbell<sup>2</sup>, and Dror Ben-Zeev<sup>1</sup>

<sup>1</sup>Department of Psychiatry and Behavioral Sciences, University of Washington, Seattle, WA; <sup>2</sup>Department of Computer Science, Dartmouth College, Hanover, NH

\*To whom correspondence should be addressed; BRiTE Center, Department of Psychiatry and Behavioral Sciences, University of Washington, 1959 NE Pacific Street, Box 356560, Seattle, WA 98195-6560, US; tel: 206-221-8518, fax: 206-543-9520

**Objectives:** Though often a feature of schizophrenia-spectrum disorders, persecutory ideation (PI) is also common in other psychiatric disorders as well as among individuals who are otherwise healthy. Emerging technologies allow for a more thorough understanding of the momentary phenomenological characteristics that determine whether PI leads to significant distress and dysfunction. This study aims to identify the momentary phenomenological features of PI associated with distress, dysfunction, and need for clinical care. **Methods:** A total of 231 individuals with at least moderate PI from 43 US states participated in a study involving 30 days of data collection using a smartphone data collection system combining ecological momentary assessment and passive sensors, wherein they reported on occurrence of PI as well as related appraisals, responses, and cooccurring states. Most ( $N = 120$ , 51.9%) participants reported never having received treatment for their PI, while 50 participants had received inpatient treatment (21.6%), and 60 (26.4%) had received outpatient care only. **Results:** Individuals with greater functional disability did not differ in PI frequency but were more likely at the moment to describe threats as important to them, to ruminate about those threats, to experience distress related to them, and to change their behavior in response. Groups based on treatment-seeking patterns largely did not differ in baseline measures or momentary phenomenology of PI as assessed by self-report or passive sensors. **Conclusions:** Smartphone data collection allows for granular assessment of PI-related phenomena. Functional disability is associated with differences in appraisals of and responses to PI at the moment.

**Key words:** schizophrenia/mobile health (mHealth)/sensing/ecological momentary assessment/mobile phones/psychosis

## Introduction

Persecutory ideation (PI)—persistent dysfunctional thought related to threats of intentional harm—is reported in up to 15% of the population.<sup>1</sup> While often associated with schizophrenia-spectrum disorders, PI is common in a range of presentations, including mood,<sup>2,3</sup> anxiety,<sup>4</sup> personality,<sup>5</sup> and neurodegenerative<sup>6</sup> disorders, as well as among individuals who are otherwise considered healthy. A growing body of evidence supports a continuum of PI,<sup>7</sup> ranging from more normative thoughts about potential danger to persistent, firmly held, disruptive beliefs based on little evidence<sup>8</sup> associated with impairments in work and social functioning.<sup>9,10</sup> Given the heterogeneous outcomes among individuals who experience PI, a growing emphasis of research has been to identify characteristics that distinguish more common PI from its more disruptive or disabling forms, including persecutory delusions.

Recent developments—for example, the NIMH Research Domain Criteria (RDoC<sup>11</sup>) initiative and Hierarchical Taxonomy of Pathology (HiTOP<sup>12</sup>) model—have increased attention to dimensional factors underlying symptoms as opposed to categorical diagnoses. These approaches aim to identify psychological or biological dimensions or constructs that vary in the general population and are linked with functional outcomes, and use assessment of these dimensions to tailor interventions more precisely. Central to a symptom-specific approach is identifying the factors that contribute to symptom's emergence, maintenance, and downstream negative impacts. Indeed, a robust body of literature has identified several such factors. Individuals with more severe PI are more likely to report high levels of worry or rumination,<sup>13</sup> negative beliefs about the self,<sup>14</sup> poor sleep,<sup>15</sup> and safety-seeking behaviors.<sup>16,17</sup> These findings have helped

contribute to the development of interventions that appear more effective than more generic or diagnosis-specific therapies.<sup>18,19</sup>

While extant work has identified traits of individuals who experience more severe PI, questions remain about the real-time, real-place responses to PI that determine the extent to which it causes dysfunction and disability. Most studies have assessed PI using retrospective measures, including self-report scales, surveys, or clinical interviews.<sup>20</sup> These approaches require respondents to summarize, estimate, or aggregate their experiences over long periods of time, away from the environmental influences that lead to their emergence.<sup>21,22</sup> In addition to being susceptible to memory inaccuracies, demand characteristics, and errors emerging from poor insight,<sup>23–25</sup> these tools are best suited to identify broader trends and do not assess momentary phenomenology. Identifying the momentary characteristics associated with dysfunction in PI can provide targets for emerging approaches that provide interventions directly to individuals at the moments they need them, for example, digital or just-in-time adaptive interventions. Such interventions are acceptable to individuals with serious mental illnesses<sup>26</sup> and achieve similar effectiveness to clinic-based care.<sup>27</sup>

Digital technologies provide new tools to address each of these limitations. A number of technologies—pagers (with accompanying journals<sup>28–31</sup>), palm pilots or PDAs,<sup>32</sup> and more recently mobile phones<sup>33,34</sup> have all been used to assess PI phenomenology with ecological momentary assessment (EMA) or passive mobile sensors—eg, light, sound, accelerometer, and GPS sensors—built into standard smartphones. These studies reduce reliance on retrospective recall, or—in the case of passive sensors—on self-report altogether. Studies using digital technologies have suggested several factors associated with dysfunction: cognitive appraisals (e.g. conviction around certain persecutory beliefs<sup>32</sup>), affective experiences (eg, increased fear, depression or defeat in response to PI<sup>35,36</sup>), and behavioral responses (eg, staying home and avoiding contact with others to seek safety<sup>37</sup>). Few studies using EMA have included individuals along the full PI continuum or examined relationships of momentary PI phenomenology to psychiatric disability. None to the best of our knowledge have done so with passive behavioral sensing strategies. Taken together, these technologies provide remarkable opportunities to identify momentary factors that contribute to and maintain the distress and dysfunction associated with PI.

Our team previously used a multimodal smartphone data collection system to better understand the real-time, real-place characteristics associated with dysfunction resulting from another cross-diagnostic symptom indicative of psychosis risk: Auditory verbal hallucinations, or voices.<sup>38</sup> To identify cross-diagnostic factors associated with distress and dysfunction, we compared real-time experiences across 3 groups representing clinical

severity: (1) those who had received inpatient services for their voices, (2) those who had received outpatient services for their voices only, and (3) those who had never received care. We found that individuals with a help-seeking history described their voices at the moment as louder and more powerful than those who had never received care. They also spent significantly more time at home and less near other people. These findings provided support for a dimensional approach to understanding PI, and provided evidence of real-time affective and behavioral differences predicted from existing models of AVH.

This study builds on that initial work by deploying EMA and passive sensors in an exploratory approach to identifying the cross-diagnostic cognitive, affective, and behavioral characteristics of PI associated with functional disability. We took an overall exploratory approach. First, we aimed to characterize overall frequency of various aspects of momentary PI-related phenomenology – including cognitive appraisals, affective experiences, and behavioral responses. Second, we examined the relationship of these factors to levels of clinical severity as defined by levels of treatment received. Consistent with our team's previous work focused on AVH, we expected that individuals with PI that had received treatment for it would on average present with a profile consistent with greater clinical severity, including reporting more problematic appraisals of PI, more frequent impacts of PI on one's functioning, greater levels of general distress, and behavior patterns consistent with increased social withdrawal (eg, less time spent around others, less phone activity). Third, we sought to examine whether individuals with greater functional disability presented with this same general profile. These analyses aim to extend the literature on PI by providing more granular information on the phenomenology of and responses to PI that determine whether it causes distress and dysfunction. Identifying these attributes can help symptom-specific intervention approaches to assessment and intervention.

## Methods

### *Participants*

Two hundred and thirty-one individuals with PI completed data collection. Inclusion criteria included being (1) at or over the age of 18 years; (2) an English speaker; (3) an Android smartphone user (to enable deployment of the study's specialty software) with an active data plan, and (4) providing responses consistent with moderate PI (ie,  $\geq 11$ ) on the ideas of persecution subscale of the Revised Green Paranoid Thoughts Scale.<sup>39</sup> The R-GPTS is 10-item scale of persecutory ideation derived from the full-length Green Paranoid Thoughts Scale; previous psychometric work validating this instrument provided guidance for this clinical cutoff for inclusion in the study. Exclusion criteria included (1) living outside of the United States,

(2) lack of availability for the 30-day timeframe of data collection, or (3) previous study participation.

### Procedures

Study procedures were based on our team's previous study studying the antecedents and consequents of auditory verbal hallucinations (or "voices"), described elsewhere.<sup>38,40</sup> All participants were recruited remotely using Google Ads. These ads were designed to appear in prospective participants' online search results when they used terms were consistent with medical (eg, *psychiatric help*, *bipolar disorder*), or non-medical descriptions of illness (eg, *spied on*, *conspiracy*) terms. Ads also appeared for users whose search terms matched one of the additional keywords generated automatically by Google Ads "broad match" algorithm. Participants who clicked on a Google Ad were taken to the study website, which provided detailed information about the study, including a video, text, and infographic describing details of study procedures and the smartphone data collection system. Interested participants followed a link to questions verifying their phone and email address, the study consent form, as well as a screening questionnaire (including the R-GPTS) to confirm their understanding of study details. Once participants completed identity verification and the consent questionnaires, they could provide informed consent, complete all baseline study questionnaires, and download the study mobile app. Participants were asked to keep their smartphones with them for the 30-day data collection period and respond to prompts to complete brief questionnaires. While engaging in data collection, participants could reach out to a research coordinator for technical support or troubleshooting by phone or email. A member of the research team would reach out to participants to address technological issues when participants' devices did not provide information for 3 days. When participants completed data collection, the application no longer collected information from their device, they were instructed to uninstall the app, and they were provided \$125 as compensation for participating (\$75 for participation, and \$50 to defray any additional data processing or transmission costs).

### Baseline Measures

**Self-Report.** Functional disability was assessed with the Sheehan Disability Scale (SDS<sup>41</sup>), a brief self-report measure of symptom-related impairments in work/school activities, family relationships, and social functioning. Depressive and anxiety symptoms were assessed with the Patient Health Questionnaire (PHQ-9<sup>42</sup>) and Generalized Anxiety Disorder Questionnaire (GAD-7<sup>43</sup>), respectively, 2 commonly used questionnaires each summed for an overall score. Insomnia was assessed with the Insomnia Severity Index (ISI<sup>44</sup>), a 7-item assessment

of participants' satisfaction with their sleep and degree of difficulty with sleep patterns. Three subscales of the endorsed and anticipated stigma inventory—including the Beliefs about Mental Illness, Beliefs about Mental Health Treatment, and Beliefs About Help-Seeking subscales—were administered to assess participants' stigmatizing attitudes related to mental health. Each subscale comprises 8 items, rated on a 5-point Likert scale, and summed to generate a total.

Participants also provided data on their current and lifetime experiences with treatment across a range of formal and informal care settings (eg, outpatient care, partial program, and online interventions). Based on their responses, participants were grouped based on treatment intensity in one of 3 groups: (1) inpatient hospitalization ( $N = 50$ , 21.6%), (2) outpatient treatment ( $N = 61$ , 26.4%), and (3) no-treatment history ( $N = 120$ , 51.9%).

### Mobile data collection

**Ecological Momentary Assessment.** Data were collected via a smartphone application deployed in our team's previous studies.<sup>36-38</sup> Participants agreed to carry their smartphone device with them and complete brief questionnaires—ie, EMAs—in response to prompts sent 4 times semi-randomly between the hours of 9 AM and 9 PM. Participants could also self-initiate an EMA entry; however, given the potential for reporting biases (eg, self-initiating data collection because one is experiencing an increase in PI), we only assessed prompted responses in this study. Questionnaires had 12 items, all assessed on a 4-point Likert scale (0 = not at all, 3 = very much). The first items pertained to PI occurrence, or whether participants were currently experiencing thoughts related to others wanting to harm them ("Are you currently feeling that someone or something wants to harm you?"). Participants who endorsed this item with any response greater than 0 ("not at all") were provided 3 items related to cognitive appraisals or reactions and 2 items related to affective and behavioral impact. Cognitive response items included (1) conviction ("How certain are you that this is true?"), (2) importance ("How much does the threat matter to you?") and (3) rumination ("How much are you thinking about the threat?"). Impact items focused on (1) distress (i.e. "How much is this distressing you?") and (2) behavior change (ie, "How much are you changing your behavior right now because of the threat?"). At every EMA (ie, regardless of whether they endorsed PI), participants also completed items related to (1) anxiety ("How anxious do you feel right now?"), (2) self-esteem ("How self-confident do you feel right now?"), (3) sadness ("How sad do you feel right now?"), (4) sociality ("How much do you want to be around people right now?"), (5) energy ("How well-rested do you feel right now?"), and (6) presence of others ("Are you alone?"; rated dichotomously as "yes" or "no").

*Passive Sensing.* The study application simultaneously collected data passively by recording data from existing sensors on the device, including accelerometers, light and audio sensors, GPS, and logs of call and SMS activity. Detailed information related to development and optimization of the smartphone data collection system can be found in previous published work.<sup>45-47</sup> In the present analysis, we examined 5 variables, including (1) time spent in primary one's primary location (ie, time spent at home), (2) distance traveled, (3) time spent around speech, (4) time sitting still (ie, inactivity), (5) SMS messages sent and received, and (5) outgoing and incoming phone call duration. To derive geospatial activity data, the study application recorded estimated locations every 10 minutes through GPS, WiFi, and cellular tower location services. Time spent around speech was derived through samples of ambient sound collected every 3 minutes and run through a speech detection algorithm. To protect participant privacy, the app collected no raw audio, but simply categorized whether the algorithm detected speech. Time sitting still was recorded using Google Activity Recognition API. This system uses an algorithm to approximate physical activity based on physical movement of the device.

#### *Data Analytic Plan*

First, we aimed to characterize the sample according to their momentary experiences of PI. We qualitatively examined the frequencies of responses to each of the EMA items, as well as mean scores on baseline questionnaires. Second, we examined whether treatment intensity groups differed on baseline, EMA, and passively sensed variables. Following our group's previous approach to examining auditory verbal hallucinations,<sup>38</sup> we created contrast variables for each participant to isolate 2 comparisons. These contrast variables compared (1) the inpatient group to the no-treatment group, as well as the (2) outpatient group to the no-treatment group. For baseline variables, linear regression models were conducted using a single contrast variable as a predictor. For longitudinal EMA variables, mixed models were used. In these models, observations were nested within individuals, and intercepts were allowed to vary. The group contrast variables were entered as fixed effects, and appropriate distributions were selected based on dispersion of responses. Finally, to examine the relationship between momentary PI characteristics and functional disability, we conducted mixed-effects models using participants' total scores on the SDS provided at baseline as predictors. These models—which also allowed intercepts to vary at random—examined the extent to which levels of psychiatric disability reported at baseline were associated with differences in momentary PI-related cognitive responses or distress. For analyses examining passively sensed variables, analyses are based on measures aggregated by the day of data collection. These analyses were also

conducted using generalized mixed-effects models, with appropriate distribution family and link function chosen based on each variable's characteristics. For variables with high numbers of zeroes (eg, SMS messages and phone calls), we conducted 2 models, one predicting the occurrence of an SMS or phone call that day (ie, binary model) and another predicting the count or scale values on days when each occurred (ie, continuous model).

#### **Results**

After removing duplicate and test entries,  $N = 1701$  participants verified their phone number on the study landing page. Of those,  $N = 522$  (30.7%) did not continue through the informed consent pipeline, and  $N = 600$  (35.3%) were screened for ineligibility. Of the remaining participants who were sent links to download the study app ( $N = 579$ , 34.0%), 181 did not install the app (31.3%), 41 dropped from the study or were lost to follow-up (28.2%), and 4 (0.7%) were excluded for being discovered to be ineligible after completing automated screening procedures. This left  $N = 231$  study completers.

Participants' average age was 38.08, ( $SD = 11.60$ ), and most participants identified as white ( $N = 163$ , 70.9%), non-Hispanic ( $N = 213$ , 92.2%), and cisgender women ( $N = 164$ , 71.0%). Participants resided in 43 US states and the District of Columbia. Full participant demographics can be found in [table 1](#). With regard to EMA engagement, 2 participants who began the study period did not provide any prompted EMA entries (these participants provided self-initiated entries, but these are excluded in the present analysis). Of those that provided responses to prompts, participants typically provided responses to about half of approximately 120 prompt opportunities ( $M = 63.53$ ,  $SD = 32.20$ ).

*Baseline Measures.* Treatment intensity groups did not significantly differ on baseline measures. Pairwise comparisons revealed that only on one baseline measure were there significant differences between any 2 of the 3 groups. Participants with a history of inpatient treatment had higher scores on the GPTS-R,  $t(168) = 2.25$ ,  $P = .03$ , relative to the participants with no history of treatment. None of the other comparisons between treatment and no-treatment groups were significant (see omnibus models and means in [table 2](#)).

*Response Frequencies.* First, we aimed to describe typical patterns in the experience of PI. For simplicity, we focus reporting here on the proportion of responses where participants reported each phenomenon at a moderate or extreme level; however, full-item response frequencies can be found in [table 3](#) and correlations between PI occurrence and cognitive response variables can be found in [supplementary material](#). Of 14 549 EMA responses, most ( $N = 7748$ , 53.3%) instances involved participants reporting

**Table 1.** Sample Descriptive Statistics

	No Lifetime Treatment ( <i>n</i> = 120)		Outpatient Treatment ( <i>n</i> = 61)		Inpatient Treatment ( <i>n</i> = 50)		F or $\chi^2$	<i>P</i>
	M or <i>N</i>	( <i>SD</i> or %)	M or <i>N</i>	( <i>SD</i> or %)	M or <i>N</i>	( <i>SD</i> or %)		
Age	38.48	12.40	37.51	11.04	37.80	10.39	0.16	.85
Race							10.85	.37
White/ Caucasian	80	66.7%	41	68.3%	42	84.0%		
Black/ African American	25	20.8%	10	16.7%	4	8.0%		
Pacific Islander	0	0.0%	1	1.7%	0	0.0%		
American Indian/ Alaskan Native	2	1.7%	0	0.0%	0	0.0%		
Asian	3	2.5%	1	1.7%	1	2.0%		
More than one race	10	8.3%	7	11.7%	3	6.0%		
Ethnicity							0.57	.75
Non-Hispanic/ Non-Latino	112	93.3%	55	90.2%	46	92.0%		
Hispanic/ Latino	8	6.7%	6	9.8%	4	8.0%		
Gender							5.62	.69
Female	87	72.5%	44	72.1%	33	66.0%		
Male	27	22.5%	14	23.0%	15	30.0%		
Transgender man	3	2.5%	0	0.0%	0	0.0%		
Transgender woman	1	0.8%	1	1.6%	0	0.0%		
Other/ Non-binary	2	1.7%	2	3.3%	2	4.0%		
Diagnoses (self-report) <sup>^</sup>								
Alzheimer's or Parkinson's	1	0.8%	0	0.0%	0	0.0%	0.95	.62
Bipolar disorder	39	33.1%	31	50.8%	26	52.0%	<b>7.88</b>	.02*
Depressive disorder	69	58.5%	45	73.8%	40	80.0%	<b>8.99</b>	.01*
Borderline PD	19	16.1%	8	13.1%	11	22.0%	1.61	.45
Paranoid PD	4	3.4%	7	11.5%	7	14.0%	<b>6.96</b>	.03*
Schizoaffective Disorder	7	5.8%	10	16.4%	18	36.0%	<b>24.60</b>	<.001***
Schizophrenia	11	9.3%	11	18.0%	10	20.0%	4.47	.11
Post-traumatic stress disorder	48	40.7%	34	55.7%	36	72.0%	<b>14.38</b>	<.001***
Substance use disorder	24	20.3%	18	29.5%	18	36.0%	4.93	.09 <sup>^</sup>
Schizotypal PD	2	1.7%	0	0.0%	2	4.0%	2.56	2.77
Anxiety disorder	57	48.3%	48	78.7%	44	88.0%	<b>31.13</b>	<.001***
None of the above	26	22.0%	0	0.0%	1	2.0%	<b>24.67</b>	<.001***
Living status							8.50	.20
Independent	63	52.5%	35	57.4%	25	50.0%		
Living with family	44	36.7%	20	32.8%	19	38.0%		
Assisted/supported housing	2	1.7%	5	8.2%	3	6.0%		
Homeless	11	9.2%	1	1.6%	3	6.0%		
Employment status							3.56	0.47
Unemployed	81	68.6%	34	55.7%	35	70.0%		
Working part-time	20	16.9%	15	24.6%	8	16.0%		
Working full-time	17	14.4%	12	19.7%	7	14.0%		
Education							5.43	.71
Less than high school diploma	15	12.5%	3	4.9%	4	8.0%		
High school diploma/ GED	71	59.2%	35	57.4%	30	60.0%		
Associate's degree	20	16.7%	14	23.0%	8	16.0%		
Bachelor's degree	10	8.3%	6	9.8%	4	8.0%		
Graduate degree	4	3.3%	3	4.9%	4	8.0%		

\**P* < .05, \*\**P* < .01, \*\*\**P* < .001, <sup>^</sup>*P* < .10;

Note: Percentages and totals based on valid, non-missing responses. <sup>^</sup>Non-mutually exclusive codes so total > 231, one participant that described their diagnosis as “Other” and their provider’s “diagnostic impression of schizoaffective” was coded as such.

that they were not currently experiencing PI, and only approximately a quarter (*N* = 4259, 29.3%) of responses involved an experience of moderate or extreme PI. This differed from other symptoms assessed, for example, sadness and anxiety, where participants endorsed some level of each in most EMA questionnaires. At the same time, most participants that provided EMA responses did—at

some point during the study period—provide a response consistent with at least moderate (*N* = 220, 91.3%) or extreme PI (*N* = 168, 73.4%). Participants also reported some variability regarding cognitive responses to PI. In nearly 80% of all responses where the participant reported some level of PI, the participant also reported feeling that the threat involved in their PI was either moderately (*N*

**Table 2.** Mean Values of Baseline Assessments, and Results of One-Way ANOVAs Examining Omnibus Group Differences Between all 3 Groups

	No Lifetime Treatment ( <i>N</i> = 120)	Outpatient Treatment ( <i>N</i> = 61)	Inpatient Treatment ( <i>N</i> = 50)	<i>F</i>	<i>df</i>	<i>P</i>
R-GPTS (total)	30.86 (6.90)	31.59 (6.83)	33.44 (6.63)	<b>2.53</b>	<b>2, 228</b>	.08 <sup>^</sup>
PHQ-9 (total)	21.16 (4.66)	20.39 (5.22)	20.38 (4.62)	0.74	2, 228	.48
GAD-7 (total)	16.12 (4.50)	15.73 (4.39)	17.10 (3.61)	1.46	2, 227	.24
ISI (mean)	2.54 (0.81)	2.55 (0.93)	2.61 (0.85)	0.12	2, 228	.89
SDS-3 (total)	24.97 (5.98)	26.05 (5.45)	26.16 (5.12)	1.13	2, 221	.33
EASI-MI (total)	18.03 (6.37)	16.36 (5.87)	16.51 (6.08)	1.94	2, 228	.15
EASI-TR (total)	21.80 (6.72)	20.41 (6.75)	21.45 (6.31)	0.90	2, 228	.41
EASI-TS (total)	20.68 (7.18)	20.08 (7.05)	19.42 (7.35)	0.56	2, 228	.57
EASI-3 (mean)	20.17 (5.36)	18.95 (5.36)	19.13 (5.51)	1.29	2, 228	.27

\* $P < .05$ , \*\* $P < .01$ , \*\*\* $P < .001$ , <sup>^</sup> $P < .10$ ;

Note: For measures where scores are typically reported as sum totals, mean imputation was used to account for missing values.

R-GPTS, Revised Green Paranoid Thoughts Scale; PHQ-9, Patient Health Questionnaire; GAD-7, Generalized Anxiety Disorder Questionnaire; ISI, Insomnia Severity Index; SDS-3, Sheehan Disability Scale, 3-item total; EASI-MI, Endorsed, and Anticipated Stigma Inventory, Mental Illness Scale; EASI-TR, EASI, Treatment subscale; EASI-TS, EASI, Treatment-Seeking Subscale; EASI-3, Mean of the 3 administered EASI subscales.

The only significant paired comparison (ie, comparing each treatment condition with no treatment) was between those with no lifetime PI treatment and those with inpatient PI treatment, which significantly differed  $t(168) = 2.25$ ,  $P = .03$ . No other head-to-head comparisons were significant.

= 1795, 27.8%) or extremely ( $N = 3436$ , 53.3%) important to them. Most respondents rated their current level of rumination as moderate ( $N = 1924$ , 29.7%) or extreme ( $N = 2894$ , 44.6%), and most reported feeling moderate ( $N = 1968$ , 30.6%) or extreme ( $N = 2993$ , 46.5%) levels of conviction. A similar number reported feeling moderate ( $N = 1779$ , 27.5%) or extreme ( $N = 2978$ , 46.0%) levels of distress. Responses were more divided with regard to behavior change in response to the persecutory threat, as a little over half of the sample ( $N = 3627$ , 56.0%) reported moderate or extreme changes to behavior, and slightly less than half reported not at all ( $N = 940$ , 14.5%) or a little behavior change ( $N = 1917$ , 29.6%). With regard to other factors associated with PI, participants most commonly reported low levels of self-confidence, desire to socialize, and low levels of energy (see table 3).

**Ecological Momentary Assessment.** EMA-assessed ratings of PI occurrence, cognitive responses, or impact were not found to differ significantly between the treated and untreated groups. In only one comparison pertaining to affect, individuals from the outpatient group were less likely to report feeling sad than those from the no-treatment group,  $\beta = -0.23$ ,  $SE = 0.11$ ,  $P = .04$ .

A second set of models examined the relationship between functional disability and momentary characteristics of PI. Increased disability was associated with an increased likelihood of appraising threats as important,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .02$ , ruminating about those threats,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .005$ , changing one's behavior in response to the threat,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .003$ , experiencing distress related to the threat,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .007$ . Disability was also associated with levels of anxiety ( $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .035$ )

and sadness ( $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .048$ ) experienced during the 30-day data collection period. Notably, while these phenomenological features were associated with disability levels, frequency of PI was not,  $\beta = 0.01$ ,  $SE = 0.01$ ,  $P = .25$ . Significant models are reported in table 4.

#### Sensing and Device Use

Across all participants, average days involved around 4 hours in settings that devices logged as near speech ( $M = 3.78$ ,  $SD = 3.50$ ), and about 18 hours per day at the participant's primary location ( $M = 18.27$ ,  $SD = 6.16$ ). Participants traveled on average around 29 miles per day on average ( $M = 41\,424.01$  meters,  $SD = 529\,144.16$ ), sent and received around 30 text messages ( $M = 27.46$ ,  $SD = 44.99$ ), and were on the phone for about 17 minutes ( $M = 0.29$  hours,  $SD = 0.50$ ). With regard to primary analyses, treatment groups did not differ with regard to passively sensed variables, with one exception. On days that a text message was either sent or received, individuals who had received outpatient services exchanged fewer messages than those who had not received treatment,  $\beta = -0.31$ ,  $SE = -0.15$ ,  $P = .04$ . With regard to baseline psychiatric disability, similarly only one model was significant, as higher levels of psychiatric disability were associated with higher number of text message exchanges on days texts were exchanged at all,  $\beta = 0.02$ ,  $SE = 0.01$ ,  $P = .03$ .

#### Discussion

This study provides granular insights into the momentary characteristics that are associated with poorer functional outcomes. Individuals with greater functional disability

**Table 3.** Frequencies of Persecutory Ideation EMA Items

	Not at All	A Little	Moderately	Extremely	Total Responses <sup>^</sup>
<b>PI occurrence</b>					
<b>Persecutory ideation:</b>	7748	2542	1847	2412	14 549
Are you currently feeling that someone or something wants to harm you?	(53.3%)	(17.5%)	(12.7%)	(16.6%)	
<b>PI cognitive responses</b>					
<b>PI conviction:</b>	360	1119	1968	2993	6440
How certain are you that this is true?	(5.6%)	(17.4%)	(30.6%)	(46.5%)	
<b>PI importance:</b>	169	1050	1795	3436	6450
How much does the threat matter to you?	(2.6%)	(16.3%)	(27.8%)	(53.3%)	
<b>PI rumination:</b>	208	1457	1924	2894	6483
How much are you thinking about it?	(3.2%)	(22.5%)	(29.7%)	(44.6%)	
<b>PI impact</b>					
<b>PI distress:</b>	268	1448	1779	2978	6473
How much is this distressing you?	(4.1%)	(22.4%)	(27.5%)	(46.0%)	
<b>PI behavior change:</b>	940	1917	1555	2072	6484
How much are you changing your behavior right now because of the threat?	(14.5%)	(29.6%)	(24.0%)	(32.0%)	
<b>Affect / Environment</b>					
<b>Anxiety:</b>	3250	4077	3342	3219	13 888
How anxious do you feel right now?	(23.4%)	(29.4%)	(24.1%)	(23.2%)	
<b>Self-esteem:</b>	4489	4400	3440	1549	13 878
How self-confident do you feel right now?	(32.3%)	(31.7%)	(24.8%)	(11.2%)	
<b>Sadness:</b>	4164	4575	2691	2459	13 889
How sad do you feel right now?	(30.0%)	(32.9%)	(19.4%)	(17.7%)	
<b>Sociality:</b>	6409	3962	2360	1157	13 888
How much do you want to be around people right now?	(46.1%)	(28.5%)	(17.0%)	(8.3%)	
<b>Energy:</b>	6409	3962	2360	1157	13 888
How well-rested do you feel right now?	(46.1%)	(28.5%)	(17.0%)	(8.3%)	
<b>Alone:</b>	7329 (No)		6648 (Yes)		13 977
Are you alone?	(52.4%)		(47.6%)		

Note: <sup>^</sup>Responses excluded if participants chose to “SKIP” the item or if they did not complete the questionnaire.

are more likely to describe threats as important to them, to ruminate about those threats, to experience distress related to them, and to change their behavior in response. Functional disability was not associated, however, with the frequency with which individuals experienced PI. Clinical and nonclinical groups with PI largely did not differ with one another in regard to either momentary or baseline characteristics. In our team’s previous work examining characteristics associated with treatment intensity among individuals with AVH, we found that individuals who had received inpatient or outpatient treatment differed in predictable ways from those who had never received care. The results of the present study suggest that PI may have a more complex relationship to help-seeking behaviors. Last, a general lack of significant differences in passively sensed variables deviates from our team’s prior work examining AVH, and suggests that passively sensed data may be better suited to identify changes occurring within individuals rather than distinguish across groups.

Descriptive results provide a snapshot of typical cross-diagnostic PI phenomenology. Results were consistent with previous findings<sup>29</sup> that PI and its negative momentary effects appear episodic. This contradicts traditional views of persecutory delusions, wherein individuals with PI are thought to hold consistent and inflexible beliefs about threats. Though all participants enrolling in the study screened positive for moderate PI using a retrospective measure, at most data collection time points, participants reported not experiencing PI. When experiencing PI; however, they were likely to report moderate or severe appraisals of the PI as important, certain, and causing them to ruminate. This suggests that disruptions caused by PI may most often result from momentary exacerbations. Identifying and reducing individual risk factors—eg, poor sleep, stress—likely reduces the frequency of these episodes, as has been suggested in studies using retrospective measures.<sup>19</sup>

**Table 4.** Mixed Models Demonstrating Significant Relationships of Psychiatric Disability at Baseline to Momentary Persecutory Ideation Factors

	<b>Importance</b> How Much Does the Threat Matter to You?			<b>Rumination</b> How Much are You Thinking About the Threat?			<b>Behavior</b> Are You Changing Your Behavior in Response to the Threat?		
	Est	SE	t	Est	SE	t	Est	SE	t
	Fixed effects								
Intercept	1.68	0.19	8.93***	1.45	0.19	7.74***	0.89	0.21	4.23***
Psychiatric Disability (SDS)	0.02	0.01	2.40*	0.02	0.01	2.86**	0.02	0.01	2.96**
Random effects									
$\sigma^2$	0.42			0.45			0.61		
$\tau_{00\ id}$	0.34			0.33			0.41		
ICC	0.45			0.42			0.40		
$N_{\ id}$	219			219			219		
Observations	6234			6267			6269		
AIC	12 868.34			13 451.14			15 278.55		
	<b>Distress</b> How much is this distressing you?			<b>Sadness</b> How sad do you feel right now?			<b>Anxiety</b> How anxious do you feel right now?		
	Est	SE	t	Est	SE	t	Est	SE	t
	Fixed effects								
Intercept	1.44	0.19	7.55***	0.89	0.21	4.22***	1.08	0.21	5.05***
Psychiatric Disability (SDS)	0.02	0.01	2.71**	0.02	0.01	1.99*	0.02	0.01	2.12*
Random effects									
$\sigma^2$	0.49			0.67			0.66		
$\tau_{00\ id}$	0.34			0.45			0.46		
ICC	0.41			0.40			0.41		
$N_{\ id}$	219			222			222		
Observations	6258			13 360			13 358		
AIC	13 896.66			33 341.02			33 198.70		

\* $P < .05$ ; \*\* $P < .01$ ;

Several factors were identified as associated with functional disability in PI, including perceived importance of the threat, rumination, associated distress, and changing one’s behavior in response. The use of dimensional factors to better predict PI-related outcomes aligns with models that acknowledge continuum of psychiatric phenomena. There exist identifiable factors that determine the functional impact of PI, and these factors are not specific to individuals who have received services. These results are also broadly consistent with cognitive models of PI, according to which an individual’s appraisals and behavioral responses determine the extent to which psychiatric phenomena result in distress or dysfunction.<sup>48</sup> This was particularly clear in light of findings that PI frequency on its own was not associated with functional disability. In addition to reinforcing the logic of the cognitive model, this finding also cautions against relying entirely on frequency of PI as a metric of symptom severity. These findings also align with acceptance and commitment models recently applied to psychosis,<sup>49</sup> according to which it is not unwanted thoughts that result in impairment, but rather responses to unwanted thoughts that increases their perceived

importance (eg, changing one’s behavior because of a thought, ruminating).

Interestingly, neither real-time or retrospective measures of PI differed across groups defined by their level of treatment intensity. This was the case both with baseline measures and in momentary data collection. This pattern of results differed from our team’s previous work examining differences between groups by treatment intensity among people who experience auditory verbal hallucinations (or voices), where individuals with higher levels of care intensity reported higher levels of distress and dysfunction related to their voices. While the precise cause of this is unclear, several factors could be relevant. There are numerous factors that determine whether an individual is going to receive mental health services, including distance from clinics,<sup>50</sup> available resources,<sup>51</sup> as well as attitudes toward help-seeking,<sup>52</sup> although importantly, controlling for stigma did not change overall patterns in findings related to help-seeking groups. Further, it is possible that PI severity has a complex relationship with help-seeking. Its associated distress might both make help-seeking more likely, while at the same time, associated fear of disclosure might discourage it.<sup>53</sup>



Given the fact that PI may itself constitute a barrier to accessing care, these findings indicate intervention delivery strategies that circumvent these barriers, including telemedicine, or even guided self-help.

Baseline functional disability did not appear to predict passive sensor values consistent with social withdrawal. This overall trend differs some from our team's previous work examining AVH. In that study, individuals with clinical AVH appeared to engage in a number of behaviors consistent with social withdrawal: Spending more time at home and less time around other people. The reduced magnitude of effects in a population of individuals with PI could be attributed to several factors. First, the present study involved a sample that was about 60% the size of that of our prior work focused on AVH; greater statistical power could be needed to detect true population differences. Second, it might be the case that the behavioral disruptions caused by PI are less observable. While participants with greater functional disability were more likely to report changing their behavior in response to threats, these changes may have been more covert or internal. Third, our findings might support different and more personalized uses of passively sensed data. These data may be most useful to detect changes within participants rather than between them, as has been suggested by our team's work examining PI in schizophrenia,<sup>37</sup> as well as others using these tools alongside more sophisticated personalized estimates to better understand depression,<sup>54</sup> anxiety,<sup>55,56</sup> or other psychotic symptoms.<sup>57</sup>

Our study is not without limitations. First, the study was conducted entirely remotely and online. The population from which our sample was drawn might overrepresent attributes specific to individuals more likely to participate in online studies, including access to digital technologies or technological literacy. For example, in a manner consistent with other online research, our sample overrepresented females. Second, measures of disability were not assessed longitudinally. We cannot conclude then whether real-time attributes of PI are the result of disability, a cause of it, or concurrently associated with a shared underlying variable. The SDS also is a brief measure that provides a rough overall estimate of self-perceived functional disability; a more thorough assessment may have revealed slightly different results. Third, we did not engage in purposive sampling to represent individuals across PI severity levels. While application of our inclusion criteria resulted in a reasonable distribution of severity levels and varied diagnoses, it is possible that certain forms of PI were overrepresented relative to others. It is particularly notable that a small subset of the sample reported a history of schizophrenia-spectrum disorders. It is unclear whether this reflects the fact that most people who experience PI present with other diagnoses or that our study recruitment insufficiently engaged individuals with this diagnostic history. There is

a dearth of epidemiological studies to help answer this question. Fourth, interpretation of passive sensor data is challenging without grounding in individual patterns. In other words, it might be the case that an elevation on a particular sensor could indicate dysfunction for one individual and adaptive resilience for another. Our study provides an important first step to understand broad patterns in differences in activity detected by these sensors, but future studies should take such a person-centered approach, or seek to validate how passive sensors might be used nomothetically.<sup>58,59</sup> Fifth, the exploratory approach of our study prevents more targeted assessment of the synergistic interactive effects that result from the co-occurrence of PI and other psychotic and non-psychotic symptoms.

These results provide support for the importance of real-time, real-place responses to PI in determining functional disability across the continuum of PI. PI is episodic, and varies according to important phenomenological attributes. Further, individuals who have not received treatment for these experiences do not appear overall to experience fewer functional disruptions from these symptoms. Intervention approaches that transcend barriers to individuals with PI, and provide them support in real-time appear better suited to reduce their negative impact and may reduce the likelihood that they evolve into disabling psychiatric conditions.

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## Conflicts of Interest

Dr. Ben-Zeev has financial interests in FOCUS technology, CORE technology, and Merlin LLC. He has an intervention content licensing agreement with Pear Therapeutics and has provided consultation services to Trusst Health, K Health, Boehringer Ingelheim, eQuility, Deep Valley Labs, and Otsuka Pharmaceuticals. The other authors have no conflicts to disclose.

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