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Data gathering ability contributes to visual organization and probabilistic reasoning

Tyler Bernadyn [a,b], **Keith A. Feigenson** [a,*]

[a] *Psychology Department, Albright College, 1621 N. 13th Street, Reading, PA 19612, USA*

[b] *Pharmacology and Physiology, Drexel University College of Medicine, 2900 W. Queen Lane, Philadelphia, PA 19129, USA*

[*] Corresponding author.

E-mail address: kfeigenson@albright.edu (K.A. Feigenson).

Abstract

Individuals use data gathering methods to inform judgments and behaviors. Effective interaction with the environment depends on these having high accuracy and low noise, but when they become abnormal, aberrant thoughts and perceptions can occur. In this study, we examined if data gathering methods were consistent across tasks that relied on different cognitive abilities, specifically visual perception and probabilistic reasoning. Thirty-four non-clinical participants engaged in the Ebbinghaus Illusion and the Jumping to Conclusions tasks, while also completing questionnaires concerning aspects of delusion formation. A significant, positive correlation was observed between performance on the Ebbinghaus Illusion and the Jumping to Conclusions tasks. Both tasks were negatively correlated with the General Conspiracy Belief Scale. The results suggest an underlying mechanism for data gathering that is consistent across behavioral domains and exists on a continuum in the general population.

Keyword: Psychology

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1. Introduction

An essential mechanism contributing to complex human cognition is the ability to adapt and learn with new information. Some mental processes use Bayesian functions when gathering data to alter or maintain hypotheses about the external world, relying on an interplay between the environment and the organism (English et al., 2016; Fawcett and Frankenhuis, 2015). As new data is incorporated, hypotheses are reevaluated, allowing individuals to adjust to changing circumstances. Therefore, the ability to accurately gather data and process coherent stimuli from the environment is instrumental to the proper development of multiple cognitive faculties.

1.1. Prediction error and behavior

Experiential learning in the manner described above is exemplified through the development of an individual's worldview. Thoughts, manners, and social norms inform future behavior based on patterns of responses and consequences of actions (Jozefowiez and Staddon, 2008). Learning and behavior may not be guided strictly by rewards and consequences, however, but also by Bayesian reasoning (Zhang, 2009). Under this framework, individuals develop hypotheses about their environments from expected outcomes, but continually update their expectations based on the actual outcomes (i.e. adjusting for prediction error). At the neurobiological level, this type of adaptive learning occurs as neural connections strengthen or weaken depending on the outcomes of cellular interactions (Friston, 2005; Schultz and Dickinson, 2000). Highly active synapses form additional dendrites and receptors, increasing the overall efficacy of existing connection and contextual inputs. Likewise, synapses with seldom used connections will degrade, decreasing their efficacy. Because these individual nodes comprise larger networks feeding into conscious processes and behaviors, deficiencies can result in mental health disorders, such as schizophrenia, in which improperly weighted salience placed on stimuli can result in delusions, perceptual aberrations, and other positive symptoms of psychosis (Clark, 2013; Corlett et al., 2009; Hemsley and Garety, 1986; Kapur, 2003; Phillips and Silverstein, 2013; Roiser et al., 2009).

To form and update probabilistic inferences of the outside world, data need to be effectively gathered and analyzed. If prediction errors are not correctly applied, cellular networks may not adjust synaptic integrity appropriately based on contextual inputs, and probabilities of expected outcomes may not generate accurately. When the probabilistic outcomes of certain events or stimuli are inappropriately weighted, salience can be placed on perceptions or thoughts that are not representative of the actual environment. This can result in delusional ideation, in which maladaptive beliefs are strongly held in the absence of supporting evidence, and not

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necessarily limited to a clinical diagnosis (Corlett and Fletcher, 2012). While most individuals require a certain amount of information before adjusting behaviors, thoughts, or opinions, some may require substantially less, and there is evidence for such a distribution in the general population (Ross et al., 2015; Warman et al., 2007). Even in the absence of clinical illness, however, this type of cognitive mindset can have deleterious manifestations. For example, subscribing to conspiracy theories has been linked to delusional ideation and abnormal scoring on cognitive-perceptual measures (Dagnall et al., 2015). Understanding the extreme levels of this spectrum could therefore help identify individuals at risk for developing mental health issues and develop treatments for addressing aberrant thinking.

1.2. Perceptions and delusions

There is evidence that aspects of delusional ideation can arise from discrepancies and aberrations in perceptual experiences and post-hoc explanations to rationalize their existences (Maher, 2005; Uhlhaas and Mishara, 2007). This alteration in the integration of visual data could explain the co-occurrence of schizophrenia and disruptions in visuo-perceptual functioning (Silverstein and Rosen, 2015). Recently, this same link has been observed in people at high risk for schizophrenia (Mittal et al., 2015), suggesting the relationship between cognitive and visual symptomology may not be a state related factor of the disorder. Rather, there may be a similar biological mechanism contributing to both domains. As many visual processes have sensitive periods relying on precise windows to collect stimuli to develop properly (Lewis and Maurer, 2005), an inherent biological ability to collect and interpret data would affect this development.

1.3. Jumping to conclusions

One data gathering paradigm is the Jumping to Conclusions (JTC) task (Garety et al., 1991; Huq et al., 1988). Participants make probabilistic decisions concerning beads picked from jars based on the number of beads chosen to be observed. It has been widely used as a measure of probabilistic reasoning in schizophrenia studies to show delusional ideation may be associated with placing disproportionate import on prematurely gathered data (Dudley et al., 2016; Fine et al., 2007; Garety and Freeman, 2013; Speechley et al., 2010). In non-schizophrenia populations, however, a JTC bias has been shown to exist on a spectrum (Catalan et al., 2015) and correlate with levels of paranoia (Moritz et al., 2012), suggesting an individual differences factor, the extreme end of which may represent a risk factor for delusional psychosis. This fits with the concept that symptoms of psychosis, notably hallucinations and delusions (Freeman, 2006; Linscott and van Os, 2013; Peters et al., 1999; Strauss, 1969; van Os et al., 2009; van Os and Reininghaus, 2016), and sensory integration

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disturbances (Carter et al., 2017) exist on a continuum in the general population. Further supporting this concept is the empirical evidence that non-clinical individuals who nonetheless subscribe to conspiracy theories tend to make hastier or statistically inaccurate decisions in probabilistic reasoning tasks, suggesting they differentially weight stimuli in order to avoid uncertainty (Brotherton and French, 2014; Moulding et al., 2016).

1.4. Data gathering mechanisms

To investigate the idea that data gathering ability is sensitive to visual input, participants took the JTC task, along with the Ebbinghaus Illusion task, which assesses perceptual organization, specifically examining how relative sizes of shapes are misinterpreted based on surrounding shapes appearing larger or smaller. The illusion develops over time: it is weaker in young children who perceive the stimuli more veridically (Doherty et al., 2010; Kaldy and Kovacs, 2003), suggesting not all of the necessary neural connections are present during childhood. The visual system learns through Bayesian processing from repeated experience about size constancy: a smaller circle suggests the image is further away, therefore any nearby objects would be considered larger in the context. Another group resistant to the illusion is individuals with schizophrenia (Horton and Silverstein, 2011; Silverstein et al., 2013), especially those with a disorganized presentation, suggesting the Ebbinghaus Illusion might be a biomarker for impaired Bayesian processing.

The purpose of this study was to examine data gathering across multiple domains. We hypothesized that performance on tasks depending on a shared data gathering mechanism will be consistent, so there will be a positive correlation between Ebbinghaus Illusion strength and the number of beads observed in the JTC task. A secondary hypothesis was that personality components of delusional ideation will negatively correlate with both the Ebbinghaus Illusion strength and the number of beads observed in the JTC task.

2. Method

2.1. Participants

Thirty-eight participants were recruited for this study (see Table 1 for demographic information). To identify participants who were guessing or randomly answering questionnaires, quality control items were inserted into questionnaires. Four participants were excluded for incorrectly answering 3 or more quality control items. This study was approved by the Albright College Institutional Review Board. All participants provided written informed consent.

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Table 1. Demographic information.

Characteristic	Mean
Total Participants	34
Age (Years)	19.74 ± 1.763
Sex (# Female)	16
Race (#)	
White	22
Black	4
Hispanic	5
Other/Multiple	3

2.2. Materials and procedure

2.2.1. Ebbinghaus Illusion

All stimuli were presented and responses encoded and analyzed using a C++ program developed by Phillips et al. (2004). This task has been used effectively in multiple replications (Doherty et al., 2008, 2010; Feigenson et al., 2014; Horton and Silverstein, 2011; Silverstein et al., 2013). Subjects made a forced choice decision about which target circle, presented in the left or right side of the screen, was larger, when alone or surrounded by different arrangements of relatively larger or smaller circles in the context condition. On each trial, subjects pressed a key to indicate which target appeared larger. Circles were black, appearing on a white background. Length of presentation for each stimulus was until subjects responded, up to a maximum of 2 seconds. Responses labeled ‘correct’ were valued at 1 and ‘incorrect’ valued at 0. If time ran out before a response, it was recorded as 0.5 for guessing. On each trial, target circles were centered on their respective side of the screen, either with (context) or without (no context) surrounding circles. On every presentation, the target circles varied in physical size, with the difference varying across trials. One target circle was always 2.67° of visual angle in diameter, while the countering target circle would be 0.05°, 0.16, 0.27, 0.37, or 0.48° larger or smaller, depending on the condition. The side in which the larger circle appeared was randomized for each trial. Each size difference appeared in 3 conditions (Fig. 1): Misleading, helpful, and no-context (control). In the misleading condition, larger target circles were always surrounded by 8 large circles, arranged uniformly around the target in a square configuration (3 on top, bottom, left, and right). The smaller target circles were surrounded by smaller circles (1.33° in diameter). This arrangement biases subjects into perceiving the physically larger circle as smaller than the physically smaller circle, thus the size contrast impairs discrimination (Doherty et al., 2008). Each of the five size difference conditions were shown 16 times. In the helpful condition, the target circles in each condition were either 2.6°1 or 2.72°, presented 8 times each (equating to the 0.05° size difference of the previous condition). They were surrounded by the

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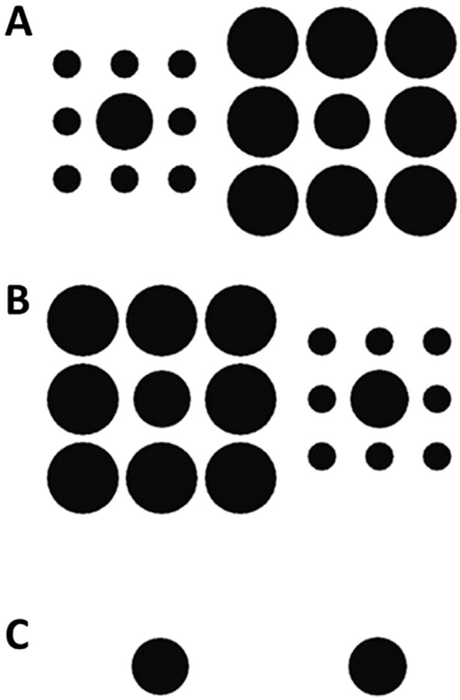

Fig. 1. Ebbinghaus Illusion conditions, in which the goal is to determine which central circle on the left or right is larger. A) Helpful condition. The center circle on the left is 2% larger than the central circle on the right. B) Example of the misleading condition. The central circle on the left is 2% larger than the central circle on the right, but the surrounding circles can misleadingly make it seem smaller. C) Control condition with no contextual circles.

same sets of larger and smaller context circles, only in this condition the smaller target circle was surrounded by the smaller (1.33° in diameter) circles, and the larger target circle surrounded by the larger (3.33° in diameter) circles. Here, size contrast facilitates accuracy, biasing the subject towards the correct selection. This set of trials also served as a control on understanding the directions: if subjects were making their selections based on total stimulus size (the targets and the surrounds), they would make the incorrect decision every time. There were 16 presentations of this condition, consistent with previous studies (Doherty et al., 2008; Feigenson et al., 2014; Phillips et al., 2004; Silverstein et al., 2013). The helpful and misleading conditions comprised the context conditions, and contained a total of 96 trials (80 in the misleading, and 16 in the helpful conditions), presented randomly. The no context condition also contained 96 trials, also presented randomly. They contained the same sets of size difference comparisons as the context conditions, only without contextual circles. The two blocks (context vs. no context) were counterbalanced across subjects. Individual trials were separated by 200 ms, and collectively took fewer than 10 minutes to complete.

Facilitation was operationalized as the proportion correct in the no-context condition subtracted from that in the helpful condition. This was done only for the 0.05° size

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difference difficulty trials. Contextual impairment was operationalized as the proportion correct in the no-context condition subtracted from the proportion correct in the misleading condition, for all trial conditions. The key value was context sensitivity, calculated by subtracting impairment from facilitation, with higher values corresponding to greater sensitivity (Table 2).

2.2.2. *Jumping to conclusions task*

Participants were given the instructions that they would be selecting the most likely jar from which an experimenter was picking a colored bead (each jar contained a specific ratio of black and yellow beads). They were told they could get one guess, but were allowed to see as many bead draws as they would prefer, draws to decision (DTD). Before starting, the experimenter asked the participant if they would like to guess from which jar the beads would be selected. After this, they would draw a bead, show it to the experimenter, place it back in the jar, and ask the participant if they would like to make a decision. There were two variations: the easy condition had high discriminability between jars (an 85:15 ratio in the amount of black: yellow beads and vice versa), and the hard condition had low discriminability between jars (60:40 ratio). The order of draws, and which draws were considered correct responses, were fixed (Fig. 2). This design was modeled after those of Garety et al. (2005) and Jolley et al. (2014).

Responses were deemed incorrect for decisions made when the evidence did not support the selected jar. Decisions made before a third bead draw were labeled hasty, or 'jumping to conclusions.' A hasty decision suggests a JTC bias (Garety et al., 2005; So et al., 2012). For analysis, participants were divided into groups if they jumped to conclusions, in addition to if they made the correct response on none, one, or both of the conditions. Our main metric of interest was DTD added across both conditions (Table 2).

Table 2. Task mean scores and percentages.

Scores on Measures			
Task	**Mean ± SD**	**% (n)**	**% (n)**
Ebbinghaus Illusion			
Facilitation	0.333 ± 0.181		
Impairment	−0.539 ± 0.165		
Context Sensitivity	0.872 ± 0.288		
Probabilistic Reasoning Task	Beads drawn	Jumped to Conclusions	Incorrect responses
Easy	3.41 ± 2.0	29.4% (10)	5.9% (2)
Hard	5.59 ± 3.23	20.6% (7)	29.4% (10)
Combined	7.59 ± 3.34	35.3% (12)	32.4% (11)

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	JTC		No JTC																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Easy	Y	Y	Y	B	Y	Y	Y	B	Y	Y	Y	B	Y	Y	B	Y	Y	Y	Y	Y
Hard	Y	B	B	Y	Y	B	Y	Y	Y	B	Y	Y	Y	Y	B	B	Y	B	B	Y

Fig. 2. Jumping to Conclusions (JTC) Task. There were two conditions in which participants had to guess from which jar the experimenter was picking. One way an 'easy' condition, with the jars containing beads in ratios of 15:85 black to yellow and yellow to black. The other was a 'hard' condition, in which the ratios were 60:40. The order in which the beads were picked are shown above for each condition (Y = yellow, B = black). Participants were allowed to see one bead at a time, and were allowed to make one decision at any point after they had observed a bead. A selection before the 3^{rd} bead picked was considered a jump to a conclusion.

2.2.3. *Questionnaires*

The MIS was developed to assess levels of magical ideation, or beliefs in causational phenomenon not based on generally accepted knowledge (Brotherton et al., 2013; Chapman et al., 1978; Eckblad and Chapman, 1983). These beliefs are a fixture of schizotypal personality disorder, in addition to being a prodromal marker for individuals at risk for schizophrenia (Chapman and Chapman, 1980, 1987). It is a 30 item True-False scale, where answers affirming magical ideation are rated a "1," otherwise a "0" (example: "I think I could learn to read other's minds if I wanted to."). Higher scores on the MIS indicate greater subjective experiencing of thoughts and ideas that have little basis in physical evidence or experience.

The 21item question PDI assesses aspects of delusional ideation in the general population along dimensions of distress, conviction, and preoccupation (Peters et al., 1999, 2004). Participants respond Yes-No if they experience any of the items (example: "Do you ever feel as if you had no thoughts in your head at all?"). If participants endorse one of the 21 items, they then rate it on a Likert scale of 1−5 describing the degree to which the item causes them stress, they are preoccupied by the item, and how strongly they believe it to be true. Higher vales indicate stronger delusional beliefs. For each participant, the total number of items endorsed was calculated, the summed values of the endorsed dimensions, and the summed value of all the dimensions.

The General Conspiracy Belief Scale (GCBS) was designed to measure conspiracy ideation, broken down across several subdomains: Government malfeasance, malevolent global conspiracy, personal well-being, extraterrestrial cover-up, and control of information (Brotherton et al., 2013). There are 15 total items, each answered on a 5 point Likert scale from "definitely not true" to "definitely true," where higher scores indicate an increased belief in the conspiracy represented in that subcategory (example: "The government uses people as patsies to hide its involvement in criminal activity").

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The PAS is a 35 item True/False questionnaire designed to assess self-reported alterations in perceptual experiences (Chapman et al., 1978). Higher scores on the PAS are typically associated with altered processing of sensory information and are associated with positive symptoms in schizophrenia and in individuals at high risk for schizophrenia (Cicero et al., 2014). Altered perceptual experiences in non-schizotypal people may reflect failures in the coordination of somatosensory signals (Feigenson et al., 2014), and as a result lead to abnormal experiences of body and environmental perception (example: "I have sometimes felt confused as to whether my body was really my own.").

The CSS assesses cognitive disorganization (Miers and Raulin, 1987), a trait that tends to be high in individuals with schizophrenia and schizotypy (Loas et al., 2013; Osman et al., 1992). This 47 True-False questionnaire index was used as a way to assess if there were aspects of mental organization not related to clear data gathering processes that might be influencing other associations. Each endorsed question counts as a "1." Higher scores indicate a greater degree of cognitive slippage (example: "My thoughts are usually clear, at least to myself."). Scores for all measures are found in Table 3.

2.2.4. Analyses

All calculations were performed in SPSS V.23. Pearson correlation coefficients were used for all normally distributed measures (The PDI, MIS, and context sensitivity), and Spearman's rho used for measures skewed because of ceiling or floor effects (the CBI, CSS, PAS, and DTD). Planned *t*-tests were used when comparing individuals

Table 3. Scores on questionnaire items.

Task	Mean ± SD
Peters Delusional Inventory	
Endorsed	7.65 ± 3.09
Distress	16.85 ± 10.06
Preoccupation	19.5 ± 9.89
Conviction	24.0 ± 11.53
Total	61.09 ± 29.55
General Conspiracy Beliefs	
Government malfeasance	10.09 ± 9.87
Malevolent global conspiracy	7.79 ± 3.54
Personal well being	7.59 ± 3.34
Extraterrestrial cover-up	7.0 ± 3.75
Control of information	9.65 ± 3.25
Total GCB	40.26 ± 14.0
Magical Ideation Scale	8.21 ± 5.03
Perceptual Aberration Scale	4.12 ± 4.31
Cognitive Slippage Scale	7.5 ± 6.91

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who jumped to conclusions and those who did not, and when comparing individuals who made errors in the JTC task and those who did not. Planned *t*-tests were also used between individuals who made errors in the JTC task and those who did not for the task and personality measures.

2.2.5. Apparatus

Stimuli were presented on a 22" S22C450MW Series 4 LED Business Monitor with viewable dimensions of 47.5 by 29.8 cm. Viewing distance was 24 inches (60.9 cm). Screen resolution was 1680 × 1050. Viewable screen subtended 43° × 27° of visual angle.

3. Results

3.1. Relationship between DTD and Ebbinghaus Illusion strength

The main association was the correlation between DTD and context sensitivity (Table 4). There was a significant medium sized positive correlation between context sensitivity and combined DTD ($rs = .407$, $p < .05$) (Fig. 3). There was also a positive correlation between context sensitivity and DTD in the hard condition ($rs = .424$, $p < .05$), but no significant correlation was observed with the easy condition ($rs = .245$, $p = .163$). These data suggest that the size of the Ebbinghaus Illusion for each participant was moderately related to how many beads they observed before making a decision in the JTC task (the larger the illusion, the greater the context sensitivity). These correlations remain significant after using a false discovery rate correction for multiple comparisons.

3.2. Jumping to conclusions and making errors

To assess whether individuals who jumped to conclusions in either condition ($M = 0.78$, $SD = 0.187$) experienced the illusions differently from those who did not jump

Table 4. Correlations between task measures.

Variables	1	2	3	4	5	6
1. Total beads observed	–					
2. Beads observed (hard)	.976**	–				
3. Beads observed (easy)	.75**	.61**	–			
4. Facilitation	.224	.303	−.073	–		
5. Impairment	−.451**	−.38*	−.543**	−.391*	–	
6. Context sensitivity	.407*	.424*	.245	.85**	−.817**	–

Note: *p < .05, **p < .01 Spearman's rho used in correlations with the bead tasks, Pearson's *r* used for correlations between Ebbinghaus Illusion measures.

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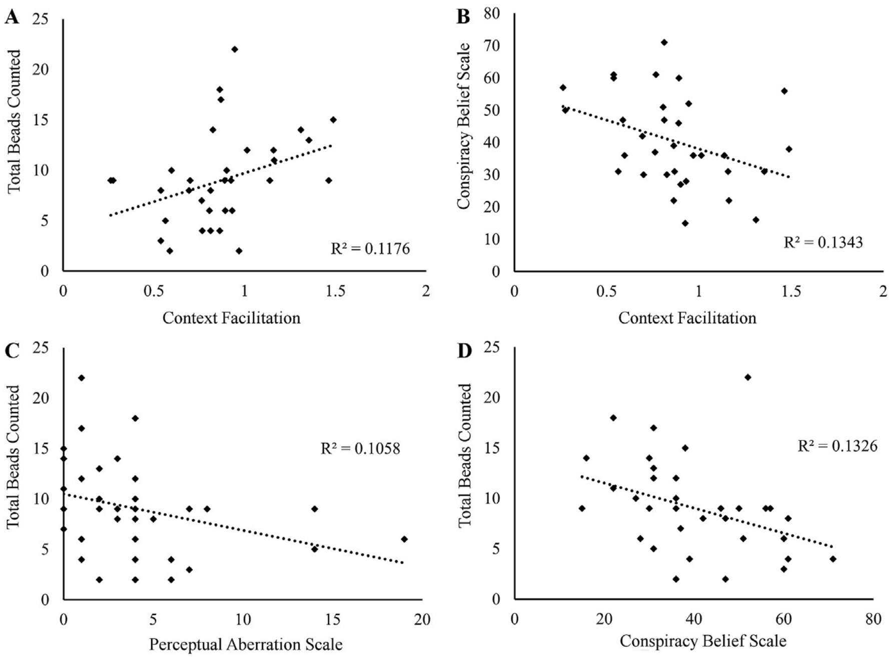

Fig. 3. Correlations between tasks and questionnaire items. A) A positive, medium sized correlation was observed between the total number of beads observed in the JTC task and context facilitation in the Ebbinghaus Illusion task. B) A negative, medium sized correlation was observed between self-report scores on the General Conspiracy Belief Scale and context facilitation in the Ebbinghaus Illusion task. C) A negative, medium sized correlation was observed between the total beads observed in the JTC task and the Perceptual Aberration Scale. D) A negative, medium sized correlation was observed between the total number of beads observed in the JTC task and the General Conspiracy Belief Scale.

to conclusions ($M = 0.921$, $SD = 0.323$), independent subjects *t*-tests for context sensitivity showed no significant differences between groups [$t(32) = 1.38$ $p = .18$]. The difference between the JTC group ($M = -0.473$, $SD = 0.137$) and the non-JTC group ($M = -0.574$, $SD = 0.17$) approached significance for the impairment value of the Ebbinghaus Illusion [$t(32) = 1.76$, $p = .088$]. There was no difference between the JTC ($M = 0.307$, $SD = 0.158$) and non-JTC ($M = 0.347$, $SD = 0.194$) groups for the facilitation value [$t(32) = 0.606$, $p = .549$]. There were no significant differences when these analyses were rerun for whether participants jumped to conclusions in the easy task or the hard task independently. These results suggest there were no categorical distinctions between individuals who jumped to conclusions and those who did not on Ebbinghaus Illusion size. When divided into groups based on if they made a statistical error in making decisions, there were no significant differences using any Ebbinghaus measures as dependent variables [$t(32)$s < 1.081, ps $> .288$]. Nor were there any differences when participants were divided into groups depending on if they committed errors in the easy or hard conditions independently [$t(32)$s < 1.202, ps $> .238$]. These data suggest that individuals who made errors in guessing the correct jar were not perceiving the Ebbinghaus Illusion differently from those who did not commit errors.

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3.3. Differences between groups that made errors or jumped to conclusions

The differences in questionnaire responses were examined when participants were divided into groups based on whether they jumped to a conclusion in either the easy or hard conditions. There were no significant differences between the group that jumped to conclusions and those that did not for any questionnaire item [$t(32)$s < 1.585, ps $> .12$]. When groups were divided based on whether or not they made an incorrect guess based on the evidence they had viewed, there were significant differences between the group that made an error ($M = 11.18$, $SD = 5.69$) and the group that did not make an error ($M = 6.78$, $SD = 4.08$) on the MIS [$t(32) = 2.585$, $p < .05$]. There was also a significant difference between the group that did not make an error ($M = 5.74$, $SD = 5.63$) and the group that made an error ($M = 11.18$, $SD = 8.11$) on the CSS. No other tests were significant [$t(32)$s < 1.633, ps $> .112$)].

3.4. Personality measures

Our second objective was to determine if there were correlations between personality characteristics and these psychophysics tasks (Table 5). The total score on the GCBS was significantly negatively correlated with both combined DTD ($rs = -.454$, $p < .01$) and context sensitivity ($rs = -.415$, $p < .05$), indicating the more likely participants were to endorse conspiracy beliefs, the fewer beads they observed in the JTC task, and the less context sensitivity they experienced in the Ebbinghaus Illusion (Fig. 3). The PAS was also negatively correlated with combined DTD ($rs = -.416$, $p < .05$), suggesting the more perceptual aberrations individuals reported,

Table 5. Correlations with task measures and questionnaire scores.

Variable	1	2	3	4	5	6	7	8	9	10
1. Total beads drawn	–									
2. Beads drawn (hard)	.976**	–								
3. Beads drawn (easy)	.75**	.61**	–							
4. Context sensitivity	.407*	.424*	.245	–						
5. GCBS (total)	−.454**	−.439**	−.288	−.415*	–					
6. CSS	−.21	−.236	−.117	−.179	.234	–				
7. PAS	−.416*	−.479**	−.163	−.163	.319	.627**	–			
8. PDI (total endorsed)	.015	−.001	.146	.147	.034	.313	.286	–		
9. PDI (summed scores)	−.194	−.214	.023	−.152	.304	.527**	.527**	.731**	–	
10. MIS	−.338	−.363*	−.121	−.015	.418*	.628**	.767**	.299	.618**	–

Note: *p < .05, **p < .01, Pearson's *r* used between context sensitivity, MIS, and PDI, Spearman's rho used in correlations with all other measures. PDI = Peters Delusional Inventory, MIS = Magical Ideation Scale, CSS = Cognitive Slippage Scale, PAS = Perceptual Aberration Scale, GCBS = General Conspiracy Belief Scale.

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the fewer beads they were likely to observe. The MIS approached a significant negative correlation with the combined DTD ($rs = -.338$, $p = .051$), but was significantly correlated with DTD in the hard condition ($rs = -.363$, $p < .05$). The hard bead draw condition was significantly correlated with the same variables as the total bead draw condition. To specifically examine if distress from delusional ideation related to task performance, we ran correlations using the total distress score from the PDI and distress per endorsed item, but there were no significant correlations. No other correlations were significant with the measure of context sensitivity or DTD. The significant correlations remained borderline significant after using a false discovery rate correction for multiple comparisons (ps = .055).

3.5. Controlling for demographic variables

Correlations between age and the task scores were performed to examine if demographic variables were potential confounds. Age was not significantly correlated with context sensitivity ($rs = -.033$, $p = .851$) or any of the total bead draws ($r = .075$, $p = .673$). No One-Way ANOVAs showed any significant differences between races on any of the tasks (Fs < 1.84, ps $> .162$). Planned t-tests showed no effects of gender on the combined DTD [$t(32) = .071$, $p = .944$] or context sensitivity [$t(32) = .321$, $p = .75$]. These results suggest demographic variables did not significantly affect the observed relationships between tasks and personality measures.

4. Discussion

4.1. Data gathering, perceptual organization, and personality

Our hypothesis that there would be a positive correlation between context sensitivity to the Ebbinghaus Illusion and DTD in the JTC task was supported. There was also a significant positive correlation with DTD in the hard, but not easy, condition in the JTC task, implying this drove the relationship. Our secondary hypothesis that elements of personality would correlate with both measures was partially supported. While both tasks were negatively correlated with the GCBS, the PAS and MIS were negatively correlated with DTD. When groups were divided into those who jumped to conclusions and those who did not, there were no differences on the context sensitivity or the personality measures. This suggests an ability to gather data may inform aspects of perception, decision making, and personality, and that, in the general population, data gathering ability may exist on a spectrum.

4.2. Data gathering as an individual difference factor

These results argue for a common data gathering mechanism informing discrete domains of behavior and cognition. One possibility is the degree to which individuals use Bayesian reasoning: in the Ebbinghaus Illusion, individuals are more context

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sensitive because their visual systems are drawing on stored information of size contrast. This type of perceptual inference is guided by learning over the lifetime, as continual interaction with the environment necessitates updates of visual expectations (Aggelopoulos, 2015), learning, for example, that an object's size can be inferred by relative sizes of nearby objects. Similarly, individuals who choose to observe more beads in the JTC task are relying on, or are more comfortable with, continually updating their expectations to interpret present circumstances. In both cases, Bayesian reasoning is used to make decisions (whether consciously or unconsciously). Therefore, if individuals are slow to update prior expectations, their visual systems might not learn contextual rules effectively, and when making a conscious decision (such as in the bead counting task) will rely more heavily on preliminary stimuli (Moritz and Woodward, 2006; Woodward et al., 2008). In this latter case, additional beads would be less likely to change a decision and thus not need to be observed.

Under this framework, data gathering ability could vary across individuals, influencing how they view the world, make decisions, and update hypotheses. In our study, task scores were negatively correlated with increased belief in conspiracy theories. In our view, people who would be slow to update hypotheses would be less likely to have their opinions changed about bizarre and strange thoughts to which they subscribe, even when exposed to new evidence. This bias against discomfirmatory evidence has been found in schizophrenia (Woodward et al., 2006), at-risk (Eisenacher et al., 2016), and delusion prone, non-clinical populations (Woodward et al., 2007), and correlates with delusional ideation in the general population (Orenes et al., 2012; Zawadzki et al., 2012). Our study adds support to this idea.

4.3. Limitations

A departure from the literature is that our tasks were not correlated with the PDI, which is associated with jumping to conclusions in clinical (Peters et al., 1999, 2004) and non-clinical (Colbert and Peters, 2002; So and Kwok, 2015) groups (Ross et al., 2015). However, this is not universally consistent, as other studies have not found correlations between the PDI and DTD (Lincoln, 2010; Ziegler et al., 2008). Interestingly, there was no correlation between the GCBS and the PDI, suggesting that DTD in our sample was related to a willingness to believe in conspiracy theories (which may have some basis in reality), but not necessary endorse delusional ideas (which tend to have little basis in reality). Therefore, it may not be delusional ideation, per se, that is an individual difference factor. Rather, data gathering ability could confer risk towards developing clinical delusions at extreme levels, which were not present in our sample. While aspects of delusion formation may exist in the general population (Peters et al., 1999; van Os et al., 2009; van Os and Reininghaus, 2016), delusional ideation might only start to covary with other symptoms once an individual develops psychosis.

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We also did not control for negative affect and any influence it might have on attention in either task. It is well established that fearful or anxious personality characteristics can alter attentional focus (Easterbrook, 1959), and bias individuals towards inappropriately weighting salience based on perceived aversive outcomes (Wiemer and Pauli, 2016a,b). This suggests a similar cognitive mechanism as that expressed in delusional ideation. Indeed, while the literature is mixed, studies have shown that anxiety may influence probabilistic reasoning (Garety et al., 2005; Johnstone et al., 2017; Lincoln, 2010; Mujica-Parodi et al., 2002), and can be directly linked to belief in conspiracy theories (Green and Douglas, 2018). This relationship has been explained as a drive to collect information in order to reduce cognitive uncertainty at the cost of accuracy when making decisions (Bensi and Giusberti, 2007). Furthermore, there is empirical evidence that individuals self-reporting higher levels of fear tend to hold more conservative opinions (Hatemi et al., 2013), and that extreme ideology is explicitly linked to endorsing conspiracy theories (Krouwel et al., 2017; Van Prooijen et al., 2015). It is therefore possible that anxiety or fearful personality could mediate the association of our measures and tasks. While we examined the distress component of the PDI, it did not have significant relationships with performance on either task. This, however, is far from a comprehensive construct for anxiety or stress, and other established measures, such as the State-Trait Anxiety Inventory (Spielberger et al., 1983) or the fear and anxiety components of the Symptom Checklist 90 revised (Derogatis, 2000), would offer better construct validity when revisiting these relationships.

Additionally, we did not screen participants for IQ, previous history of mental illness, or drug use beyond verbal confirmation that participants had not engaged in drug or alcohol prior to three days before participating in the study. IQ can mediate performance on jumping to conclusions tasks (Falcone et al., 2015; Garety et al., 1991; Moritz et al., 2010) and certain drugs of abuse, such as ketamine, can impair perception up to 3 days after consumption (Curran and Morgan, 2000). Furthermore, since our study is assessing performance in the general population, it is possible that some individuals had a prior history of mental illness, which could skew results towards the extreme end of functioning. However, the majority of participants were college aged and thus less likely than the general population to have experienced episodes of schizophrenia or bipolar disorder (Blanco et al., 2008; McGrath et al., 2016). Nevertheless, all of these factors should be considered limitations and should be considered in future adaptations of this paradigm.

5. Conclusions

Our results suggest a mechanism contributing to data gathering ability pertaining to perceptual organization and probabilistic reasoning. Deconstructing this relationship could lead to better understanding of delusional etiology and how it overlaps with or

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influences psychosis. The next step would be to extend this to clinical studies to determine if the relationship between Ebbinghaus Illusion strength and DTD is similarly correlated in schizophrenia. The hypothesis is that schizophrenia patients who jump to conclusions will have significantly higher resistance to the illusion than those who do not, and this will correlate with their delusion strength. This would support our findings in the general population that jumping to conclusions bias and Ebbinghaus Illusion resistance share a common mechanism that is distributed on a continuum, the extreme ends of which may confer risk for delusional ideation.

Declarations

Author contribution statement

Both Tyler Bernadyn and Keith Feigenson conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, contributed materials, analysis tools, and data, and wrote the paper.

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