

## **Delusions, illusions, and inference under uncertainty**

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### *Abstract*

Three challenges to a unified understanding of delusions emerge from Radden's *On Delusion* (2011). Here, I propose that to respond to these challenges, and to work towards a unifying framework for delusions, we should see delusions as arising in inference under uncertainty. This proposal is based on the observation that delusions in key respects are surprisingly like perceptual illusions, and it is developed further by focusing particularly on individual differences in uncertainty expectations.

### **1. Introduction**

Not only is it unclear what kind of malfunction in the brain gives rise to delusions, there also remain significant problems with providing a conceptual analysis and unequivocal categorization of delusions. This is argued very clearly by Jennifer Radden in her excellent *On Delusion* (2011): delusions cannot be understood in a one-eyed perspective but remains a multifaceted, unwieldy phenomenon.

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This presents a challenge because it is hard to believe that the set of neural mechanisms giving rise to delusions, though no doubt complex, is equally multifaceted and unwieldy. At a conceptual level, the challenge is to provide some unifying framework that would make it easier to look downwards to the neural mechanisms underlying delusions.

Here, I develop the view that such a unifying framework can be found in inferential, Bayesian approaches to perceptual and cognitive function (see (Hohwy, 2004; Hohwy and Rosenberg, 2005); see also (Fletcher and Frith, 2009) for a general approach to computational psychiatry, see (Montague et al., 2012)). Such approaches say we perceive and believe what has the strongest combination of both fitting the evidence and having a high prior probability, under expected levels of uncertainty. In particular, it is the notion of expected uncertainty that I will use to engage with the issues raised by Radden.

Section 2 uses Radden's challenges to set out three main constraints for a unified understanding of delusions. In Section 3 these constraints are used to argue that there are surprisingly substantial similarities between delusions and illusions. Inspired by this similarity, Section 4 proposes that the notion of uncertainty expectations in probabilistic inference might satisfy the constraints and thus point us towards a unified framework for delusions.

## **2. Three challenges to a unified understanding of delusions**

The first challenge concerns the categorization of delusions. A strong case has been made for the 'doxastic' view that delusions are on a par with other irrational beliefs

(Bortolotti, 2009): the reasons typically marshaled against the doxastic view either fail to apply to delusions or they unexpectedly apply to supposedly normal, paradigmatic instances of belief. Radden reasonably points out that, even so, theories of belief and of meaning in most cases simply are too broad and sweeping to enable firm judgment, especially for a class of states as heterogeneous as delusions (60). I agree with Radden's sentiment here, and provide some examples of delusions, from before the age of antipsychotic medicine, to illustrate the heterogeneity:

1. A woman...reports that...she is the Law and the Danish world mother...she has never had her own head, it has been held back...she has three snakes in her belly and speaks through soul telephones with 'resting members'.

2. A patient reports that his children have been killed, cut up and served hidden in the food.

3. A woman [reports that she] is plagued by wireless phones, the blue is put upon her. She has, under hypnosis had many children with 'astronomas'. Astronomas are different people, who are mutually identical...astronomas speak to her and can perform 'indications'. That is what one sees. If the doctor kills you, they can perform an indication.

4. A 34 year old male never goes out and people avoid him. He is in no doubt this is for good reason: he stinks of faeces. The reason for this, he says, is clearly that his 'deformed spine puts pressure on his belly such that the faeces cannot get out. There is a hole in the intestines and the faeces seeps into the abdomen.' At times he worries he will literally explode. He feels he is full of faeces and rot inside, and it is circulated through the entire organism in the blood. Brown sweat trickles through the

skin, and that of course causes a disgusting smell of faeces. He washes very frequently but the smell returns at once; he can also feel it in his nose and mouth, even though he tries to keep it down with chewing gum and sweets.

(Case 1-3: Strømgren, 1956(1939), 145; Case 4: Bjerg Hansen, 1976, 226.)

The subject matter of these delusions is very bizarre, strange or at least has incredibly low prior probability. It is rather difficult to see how these examples of delusional belief could arise just by some exacerbation of doxastic, rational tendencies and biases that are widespread in the healthy population.

At the same time, however, it is possible to see a measure of epistemic sensitivity to evidence even in some of these delusions. If someone has a constant taste of faeces in his mouth, then it is reasonable to look for an explanation of this unusual experience, and if no amount of washing and chewing gum gets rid of it, then something much more strange and unlikely may be afoot after all. Similarly, if you are uncertain about whether the doctors are out to kill you, then it may be quite rational to posit the existence of ethereal astronomas with the power to perform indications of such deeds.

This is of course not to claim that all delusions are fully rational; Case 1, for example, is much more difficult to analyze. It is merely to point out that even bizarre delusions quite easily can be described such as to encompass elements of rational or irrational engagement with uncertain experiential evidence and updating of belief systems in response.

One possible way to go in response to the first challenge, about heterogeneity and the categorization of delusions, is then to simply set aside the distinction between belief

and non-belief and let other concerns, such as evidence-sensitivity, drive analysis of mental events.

People can disagree reasonably about whether delusions are truly beliefs or not but it would be unreasonable to deny that delusions implicate unusual or pathological patterns of dealing with evidence. It could be, then, that the way the deluded person deals with evidence convinces some theorists but not others to place delusions outside of the class of beliefs – but this would reflect people’s respective theories of belief more than the nature of delusions (see Gerrans, this volume, for similar considerations). Probabilistic approaches to perception and cognition can be used to bear out this strategy of focusing on evidence-processing, and bypass more conceptually involved theories of belief and other mental states.

The second challenge relates to the large but often rather ignored class of more florid, polythematic delusions, exemplified above (and discussed further by Coltheart, this issue). Radden points out that, when making the case (as above) that delusions sometimes look like rational or irrational responses to unusual experiences, there is a tendency to focus on monothematic delusions and set aside this much larger class of delusions. Specifically, there is little reason to think that polythematic delusions begin with well specified anomalous experiences to which a rational response is warranted; rather they appear to begin with more vague disquieting experiences, say, which are merely ‘ambiguous and open to interpretation’ (Radden, 2011, 56). Radden’s point here is important because it goes beyond the more detailed debate for and against ‘one factor’, Maher-style (Maher, 1974) accounts of delusions that have dominated the

debate about monothematic delusions. It is a challenge to not ignore polythematic delusions.

One possible way to respond to this challenge is to seize on Radden's apt description of the more polythematic cases as beginning from experiences that are ambiguous and open to interpretation, rather than downright unusual in their content. Certainly, some texts give patient descriptions consistent with this idea: in the initial phase, 'there is uncertainty about the meaning of what is experienced', 'feelings of insecurity, being perplexed, detached wondering about events'; 'there is something in the world I do not understand, it is all so wrong, I don't know whether it is me or the others'; 'so many strange things are happening – it is all like a picture book of illusions' (Wimmer, 1936, 304-6). There is a 'loss of meaning from everyday perceptions [attributed] to the "cob-webby veil" that [hangs between the patient's mind] and the external world of sensory impressions' (Freedman, 1974).

Perhaps there is then a way to jointly classify unusual and ambiguous experiences, which makes sense of how the former may lead to monothematic delusions and the latter to polythematic delusions. In particular, there is a need for a model where different impairments to the same perceptual mechanism can lead to one or the other type of delusion. This would be facilitated if, instead of having a distinction between delusions that have an unusual experience at their core and delusions that begin with less well-defined feelings of disquiet and ambiguity, there were a unifying notion of perceptual and cognitive *uncertainty*, where this uncertainty can take different shapes. Once again, probabilistic approaches to neural functioning can be useful in bearing

out this strategy because their overarching motivation is to enable systems to make inferences under uncertainty.

The third challenge relates to the difficult notion of privacy in delusional experience. In amongst these discussions, there are some related themes Radden often returns to. Delusions under almost any description contravene epistemic values, where these values are identified intersubjectively; it is then the ‘solipsistic and idiosyncratically ‘private’ nature of some mental states that makes us think of them as delusional’ (Radden, 2011, 9, 78, Ch. 4). Radden is sympathetic to the Kantian element here, where normal reasoning is associated with the ‘sensus communis’ and delusional reasoning is somehow a ‘sensus privatus’ – ideas that are peculiar to ourselves (2011, 8; Murphy, this volume, discusses the role that public expectations for reasoning and belief formation may have for delusion ascription). I think the four examples of florid delusions given above also accentuate this sense of privacy: there is something unapproachable and inherently private in the experiences and beliefs of the delusional person – one gets the sense that there is a kernel of desperate loneliness in patients’ battles with their delusional experiences.

It is not easy to explicate the notion of privacy, however. As Radden notices, even though some theories of meaning begin to approach it, such theories seem too sweeping to apply to the multidimensional nature of clinical delusions (2011, 60). Moreover, some delusions, notably, *folies à deux*, are not obviously private (see Radden, 2011, Ch. 5; see also Langdon, this volume).

One possible way to respond to this third challenge is to attempt to explain the hunch that privacy is involved without appeal to the philosopher's traditional notions of privileged introspection of self, private language and asymmetry between first-person and third-person access to mental states. Instead, the idea would be to take an epistemic approach and consider the role of more contingent partitions in the flow of information, where these partitions create a kind of privacy by inducing a degree of evidential insulation, which need not align with bodily or individual boundaries. Here it is again attractive to appeal to probabilistic inference under uncertainty, which is helped and hindered in different ways by the available sources of evidence and their probabilistic independence (see Gerrans, this volume, for considerations in the same vein).

### **3. Delusions and illusions**

A probabilistic notion of inference can, I suggested, be brought to bear on each of the three challenges to a unified conception of delusions. Such a probabilistic notion has been applied with success to perceptual illusions, so we should expect more substantial similarities between illusions and delusions than normally assumed. This section explores this similarity. Though there are of course differences between delusions and illusions, the degree of similarity is a clue that the probabilistic frameworks that incorporate perceptual inference under uncertainty might be candidates for incorporating delusions too (see also Hohwy and Rajan, 2011).

First, delusions mostly do not have a mere 'as if' feel. Similarly, the perceptual content of most illusions is not 'as if'. In perceiving the Müller-Lyer illusion it is not *as if* one line is longer than the other, the experience is 'as of' one line being longer



than the other. Of course, in some (but not all) contexts, we might have background knowledge that the lines are really of the same length and then adopt the ‘de dicto’ attitude that our experience of the illusion is ‘as if’, but this belies the perceptual phenomenology itself, which does not carry its illusory nature on its sleeve.

Second, delusional individuals are mostly unaware that some of their beliefs are delusional; at best there is a vacillating suspicion, which fails to penetrate the delusional belief itself, that the general content of the delusion cannot be true, (for discussion of this, see Radden, 2011 and Gerrans, this volume). Similarly, illusions often go unnoticed, for example we are mostly completely unaware of the ventriloquist effect we experience when watching TV, and of the constant exposure to Müller-Lyer style stimuli in the built environment, and of the perplexing degree of inattentional blindness we may occasionally have (*i.e.*, when attention to something makes us utterly blind to otherwise salient events (Chabris et al., 2011)). Often it takes clever experiments to illustrate how pervasive illusory perceptual content actually is in our daily experience.

Third, there is a complex relation between delusions and action. For example, in some instances, delusional belief can lead to violence but in other cases delusional beliefs seem curiously circumscribed from the delusional person’s other beliefs and behavior. Neither is the relation between illusions and behavior straightforward. Illusions can fail to influence behavior directly (Aglioti et al., 1995; Kammers et al., 2009), yet be more subtly involved in action (Kammers et al., 2010; Skewes et al., 2011). Illusions also often fail to infiltrate the wider belief system (for example, we do not believe the

moon actually changes in size even though it seems different when low vs. high on the horizon).

Fourth, illusions are perceived as tenaciously as delusions are believed. In the rubber hand illusion a visible rubber hand is touched in synchrony with touch on one's real but hidden hand; most people cannot help but strongly experience that the touch is felt on the rubber hand, even if they know full well it cannot be so. There might even be cases where we refuse to accept that something is in actual fact an illusion, even if we are presented with overwhelming evidence to the contrary. This might be the case for illusions of conscious will, when people feel they are agents when in fact they are not, and *vice versa* (Wegner, 2002). The experience of making consciously willed decisions is so strong that we display at best mock acceptance if not downright disbelief about the claim that we conscious control is illusory.

Fifth, the previous point about tenacity relates to how delusions seem impervious to reality testing. There is a more involved point of comparison with illusions here. Though getting additional, independent evidence against an illusion doesn't abolish it, it can make us fully believe it is not veridical. This doesn't seem to happen for delusions. However, two points soften this point of apparent difference between illusions and delusions. First, some illusions are recalcitrant to independent evidence. We may know full well that when we watch TV we are subject to the ventriloquist effect but we fully forget this when immersed in the watching experience. Second, any difference between delusions and illusions may at least in some cases be down to the mere contingent fact that for delusions there are no independent sources of evidence that are deemed relevant for the situation at hand. To illustrate, when

experiencing the Müller-Lyer illusion you can take out a ruler and directly measure the length of the lines but in delusions of alien control it is hard to conceive of a direct, independent measure of the sense of being in control of one's movement, and patients must rely on much more indirect, general evidence to the effect that other people don't have those sorts of experiences.

Sixth, delusional content and structure is, as Radden emphasises, very heterogeneous. Similarly, illusions are very varied in content, structure and modality. To mention just a few examples of substantially heterogeneous illusions: Troxler fading where peripheral stimuli fade from consciousness, the Ebbinghaus illusion, the ventriloquist illusion, inattention blindness, change blindness, temporal illusions (Haggard et al., 2002), the rubber hand illusion, the body swap illusion (Petkova and Ehrsson, 2008) and illusions of agency and conscious free will. There is also variability in the extent of illusions: everyone seems to experience the Ebbinghaus illusion but the Colavita effect, where visual input extinguishes auditory input, occurs only on about 30% of trials (Spence and Narayanan, 2009) and not everyone experiences inattention blindness (Simons and Chabris, 1999) or the full body illusion (Lenggenhager et al., 2007). In our own experiments with the rubber hand illusion (Hohwy and Paton, 2010), it is clear that people have very different degrees of experience of the illusion. They also seem to have very idiosyncratic routes towards their experience, where they focus on very different things like visual characteristics of the hand, felt textures, radiated heat from the experimenter's hand, location or timing of the tapping. Similarly, in the full body illusion there are differences in how different people experience out-of-body illusions under the same stimulus conditions (Ionta et al., 2011).

Of course, concerning heterogeneity, there are dissimilarities between delusions and illusions. For example, delusional content is sensitive to cultural and historical context, whereas illusions seem less so. It bears mentioning, however, that culturally sensitive explanations can in fact be elicited during multisensory illusions. Thus, in our own study of the rubber hand illusions, a ‘supernatural touch’ version of the illusion prompted participants to describe their experience in distinctly modern terms of ‘a spectral gun’, ‘opposed magnets in the skin’, ‘an invisible, upright, Newton’s cradle’ (Hohwy et al., 2010)

Seventh, delusions can be difficult to discern precisely in introspection and to express succinctly in public reports. Similarly, some (but not all) illusions are difficult to pin down introspectively – they can be frustratingly private. For example, many find it very difficult to describe the touch sensation in the rubber hand illusion and must be guided by the questionnaires that are now standard in the field. Another example can be seen in the uncertainty about whether people fail to experience or fail to report the auditory stimulus during visual capture in the Colavita effect (Spence et al., 2009).

Eight, as suggested a number of times above, it appears that many delusions tend to arise when the perceptual system is dealing with different forms of uncertainty.

Similarly, illusions arise for ambiguous and noisy stimuli. For example, the ventriloquist illusion is sensitive to the variance (uncertainty) about the individual estimates of the visual and auditory stimuli (Alais and Burr, 2004), and is based on a choice between different causal models of the world (Körding et al., 2007). In the rubber hand illusion, the sensory input is ambiguous between a touch felt on a rubber

hand and a touch felt on one's own unseen hand, and the synchronous tapping on the two hands is then processed as a disambiguating signal in favour of the illuded hypothesis.

This last similarity may extend further. Illusions arise as reasonable but false perceptual responses to ambiguous or uncertain evidence. For example, given the context of the wings in the Müller-Lyer illusion, it is reasonable to perceive one line as longer than the other; similarly, given the proximity of the ventriloquist to the doll, and the precisions of the auditory and visual inputs, it is reasonable to perceive the speech as coming from the doll. This raises the question whether delusions too arise as reasonable responses to ambiguous or uncertain evidence, that is, whether a Maher-style account can be expanded and generalized so it doesn't just concern very salient experiences that are uncertain because they are unusual (Maher, 1974) but all situations in which there are unexpectedly high or low levels of uncertainty, noise or ambiguity?

A pure Maher-style account would require just experiential unusualness coupled with normal reasoning abilities to generate delusions. A main argument against such an account is that there are cases where people have the unusual experience but do not form the delusion. Therefore a second factor involving a reasoning bias or deficit in addition to the experiential factor seems necessary (Coltheart et al., 2011; see also McKay 2012). It is worth noticing that a similar argument has less traction for illusions. There are cases, for instance in the rubber hand illusion, where participants have an unusual experience of vaguely displaced touch but fail to experience the illusion. The best explanation of this is not that a second factor involving reasoning

biases or deficits is needed to make the illusion arise but that these participants differ in their estimation of the precisions of the sensory input. This explanation operates purely in terms of probabilistic sensory processing. If a similar explanation applies for delusions it is less clear that it would be an independent second factor rather than an integral part of the sensory process.

There are thus indeed surprisingly substantial similarities between illusions and delusions. This predicts systematic differences in how illusions are experienced in delusional individuals. Accordingly, there is a sizeable literature investigating just this, with a relevant general finding being that in schizophrenia ‘impairment in perceptual organization [needed for normal illusion perception] is most pronounced when processing novel, fragmented stimuli within noise, and therefore where top-down input is required to produce grouping in the absence of strong stimulus-driven cues.’ (Silverstein and Keane, 2011).

#### **4. Inference and expectations of uncertainty**

Of course there remain important differences between delusion and illusion.

However, the similarities described in the previous section suggest that rather than looking at categorical differences, it may be fruitful to look at circumstantial, context-bound differences, or different ways in which the same kind of probabilistic (Bayesian) representational mechanism might go wrong for different kinds of sensory input. At their core, such Bayesian approaches say we perceive and believe what has the strongest combination of both fitting the evidence and having a high prior probability, given expected levels of uncertainty.

This probabilistic approach immediately softens the distinction between belief and perception, which speaks to one of the three constraints discussed above. On this approach, belief and perception are governed by the same fundamental probabilistic principles and may differ only in how responsive they are to occurrent sensory input. From this perspective there would be nothing amiss in saying that delusions fall somewhere between having perceptual and conceptual content, or that delusions are belief-like but are subject to deficits or biases in the way they are updated in the light of new evidence, or that they are atypical in how they relate to behavior.

As suggested above, the probabilistic approach can also be used to accommodate the privacy constraint: 'privacy' might be just a contingent matter of the available sources of evidence and their probabilistic independence of each other. Many delusions seem to occur in 'inner' domains characterised by lack of independent sources of evidence for reality testing (here I elaborate a point made by William James; see Coltheart, this volume; see also Hohwy & Rosenberg, 2005). Consider, for example, affective (made emotions), bodily (taste of faeces in the mouth), and agential (alien control) domains – it is difficult to assign other sensory avenues for testing these beliefs about inner states. Similarly, some delusions with spiritual and supernatural content are akin to the philosopher's traditional skeptical scenarios, which are difficult to falsify because they are beyond independent sources of evidence (e.g., 'astronomers who can perform indications'; 'in a previous life I was a butterfly in Spain'). This point about skeptical scenarios also holds for our access to other minds ('the doctor might want to kill me'). In these kinds of cases, inference is 'private' in the sense of being relatively inaccessible to other, independent sources of evidence. In all of these cases, privacy

arises as a matter of probabilistic inference and only contingently aligns with bodily or subjective boundaries.

This conception of privacy is crucial to delusion formation because good probabilistic inference is helped more by having independent sources of evidence than by repeated sampling from the same perhaps unreliable source (for discussion, see Bovens and Hartmann, 2003). To illustrate, if a certain state of affairs is accessible through the evidence of only one sensory modality (as might be the case for a taste of faeces) and there is uncertainty about this evidence, then it is like a court case for an alleged crime where the verdict must rely on testimony from one questionable witness only. (See Gerrans, this volume, for an argument that delusions arise when default processes are not modulated sufficiently by decontextualized processing providing, as I would put it, independent sources of evidence).

Radden discusses *folie à deux* and it is evident that these types of delusions, which are shared between individuals, do not immediately fit with the constraint that delusions are inherently private (2011: Ch. 5). However, *folie à deux* can be accommodated if privacy is dealt with in my suggested terms of the availability of independent sources of evidence. As a pair, the *folie à deux* sufferers exclude other sources of evidence so the delusion is 'private' relative to them (and indeed, as noted by Langdon, this volume, the delusional pair is very often socially isolated). Moreover, in *folie à deux* one sufferer tends to be the primary source of the delusion, spreading it to the secondary partner. This means that the sources of evidence for the two individuals are not independent, which strengthens the privacy aspect. The situation is like two



witnesses in a court case where one has been unduly influencing the other before each giving their testimony.

The final constraint concerned the need to unify accounts of monothematic and polythematic delusions, which I suggested we might satisfy by describing these different delusions as different ways of responding to uncertainty. In monothematic delusions it would be responses to unusual sensory evidence (e.g., it is uncertainty induced by the inconsistency of the experience that ‘I know I moved myself but it feels just like when other people push me’). In polythematic delusions, it would, following Radden’s considerations and the argument made at the end of Section 3, be responses to ambiguous or hard to interpret sensory evidence. Thus, as illustrated in patient reports, ‘everything is mysterious, the hospital interiors could be ‘pictures’ from fifteen different places...the attendants could for example be roman slaves guarding prisoners of war’; ‘when I read I think the Danish language is so strangely put together, as if wrong words were put in, or there is something symbolic in it’ (Wimmer, 1936, 306).

Here the crucial Bayesian element concerns expectations for uncertainty. Levels of uncertainty in the environment vary and sometimes we are confronted with unexpectedly high or low levels of uncertainty. Uncertainty can also arise in different ways, for example due to internal noise in the neuronal system, or external noise in the world, and relatively non-noisy input may still be uncertain in the sense of being ambiguous between different interpretations. This tells us that we need to be able to assess levels of uncertainty and develop strategies for how to respond when uncertainty varies. In short, just as we need to model the world, we need to model the

uncertainties in the world (Feldman and Friston, 2010). Every time we engage in perceptual and conceptual inference we come into the situation with expectations for what the states of affairs in the world might be, and with expectations for what the level of uncertainty is going to be. Problems with optimizing these expectations would be entrenched and be difficult to rectify because rectifying them would require even higher orders of uncertainty processing – a statistical procedure that quickly becomes computationally unrealistic.

Two people with different expectations for uncertainty can thus respond to the same situation differently, even if they assign the same prior probability to their models of the world. On a Bayesian account, the bottom-up sensory input is explained away by top-down models. A good way to conceive this is in terms of top-down predictions attenuating sensory input and letting only the unpredicted part – the prediction error – through for processing at higher levels (Friston and Stephan, 2007). On this conception, bottom-up sensory signals are nothing but the prediction error.

A crucial part of this story is how the forward, bottom-up sweep of sensory input (prediction error) is regulated, independently of how well it is predicted top-down by models of the world. The candidate for regulating how much sensory input is passed up through the cortical hierarchy is just the expectations for uncertainty discussed above. The rationale is that the strength of the sensory input (that is, the prediction error) should be consummate with its expected certainty. That is, the inferential system should weight sensory input (prediction error) that is expected to have high precision (i.e., low variance or uncertainty). This is a way to ensure that perceptual

inference by and large is determined by the most reliable signals it receives from the world (Hesselmann et al., 2010).

This approach follows the same motivation as holds for standard statistical inference. In statistical inference one may need to assess measures of central tendency, such as the means of two distributions. But, for inference to be meaningful, the variability about the means must also be assessed. Otherwise, one cannot be confident that the two means differ (or not).

This gives an inkling of the Bayesian mechanism that drives perceptual inference. Not only are priors and likelihoods estimated, the precisions of the sensory input are estimated and this determines preferential processing of some parts of the sensory input over others (for a heuristic presentation, see Hohwy 2012).

An important aspect of these computations concerns what happens when sensory imprecision is expected and the sensory signal is therefore down-weighted. In such instances, top-down expectations are given more weight in determining the outcome of perceptual inference. In other words, if a perceptual decision needs to be made even when the evidence is deemed unreliable, then it makes sense to let one's preconceptions drive inference. In addition, if the perceptual input underdetermines models of the world, then, if an inference must be made, it makes sense to look for *any* cue that could determine the matter rather than let inference be random. That is, even in a poor field of evidence it can make sense to search vigorously for disambiguating clues.

Now we have a somewhat richer and multifaceted conception of uncertainty processing than just a simple application of Bayes rule. This opens possibilities of individual differences in our responses to different levels of uncertainty. For someone who expects much uncertainty, the sensory input will be weighted less and prior models of the world will be weighted more. If this is a relatively chronic state then those prior models will be poorly revised in previous learning. This set of circumstances could then be implicated in polythematic delusions: a general lack of impact on perceptual inference by the incoming sensory evidence and a disproportionate weighting of prior models, which are themselves not maintained by precise sensory input (of relevance here is findings from Khemlani and Johnson-Laird, 2012 that we explain away conflicting evidence by adopting models that makes it harder for us to spot inconsistencies).

We can even see how uncertainty expectations may be implicated in other, perplexing aspects of schizophrenic phenomenology. If there is a general expectation for low precision input, then input which in fact turns out to be precise will generate prediction error, perhaps giving rise to reported feelings of enhanced sensory awareness where ‘perceptions become more vivid, direct, acute’. This may be reflected in patient reports too. For example, a patient describes her visual experiences as ‘my eyes became markedly oversensitive to light. Ordinary colors appeared to be much too bright, and sunlight appeared dazzling in intensity’; similarly, ‘some patients reported that they felt suddenly opened up to a wealth of perceptual stimuli of which they had not been aware previously (Freedman, 1974).

In addition, such an individual who turns down the weighting on sensory evidence in a fairly wholesale fashion will also be more inclined to search frantically for any cue that would allow disambiguation. For example, if the dampened down sensory signal is unable to decide between two models of the world and a salient but unrelated event happens just at that point, then the salient event could be taken as evidence that can break the probabilistic deadlock. Irrelevant pieces of evidence may then be brought to bear on the generation of a bizarre belief and subsequent disconnected delusional elaborations.

The story about uncertainty expectations also cuts the other way. In instances where there is unexpectedly high precision, the perceptual system will be determined more by the bottom-up sensory signal and less by the corrective factor (or control parameter) of top-down prior expectations. Unexpectedly high precision could be a matter of a fairly simple increase in signal strength, which normally goes with increased signal-to-noise ratio. The idea is then that, if the incoming signal is unexpectedly strong, say because of neurological insult, and if it is also insulated from other sources of evidence, then perceptual inference under these conditions could lead to monothematic delusions. In brief, a single, perceptual content is singled out for belief due to its unexpectedly high strength, which intrinsically dampens down top-down, rational control.

Uncertainty expectations are thought to be implemented neurally in synaptic gain and this process is likely to be a matter of degree such that some people are strongly driven by the expected high strength input and others less so. Intermediate cases of this would then be those who report the unusual experience but fail to develop the

delusion. Such differences would also interact with different types of neurological insult producing bottom-up signal of different strengths. In combination, we should expect a heterogeneous range of perceptual inference in different individuals with different neurological insults.

On this account of monothematic delusions, the deficit or bias lies in the setting of uncertainty expectations. This deficit may be domain general or domain specific. If it is domain general, then there should be evidence of it across many contexts, which presents a challenge to the fact that these are monothematic delusions. If it is domain specific, then the challenge is to explain why such a specific deficit should arise and why it appears to arise in just a small class of sensory contexts. In both cases one can appeal to the system's opportunity for optimizing its uncertainty expectations.

Perhaps uncertainty expectations are more difficult to optimize in areas of perception where there are not many independent sources of evidence (sense of agency, bodily awareness, etc.), leading to selective impairment (see Coltheart, this issue, for discussion of explanations of monothematic vs. polythematic delusions).

Thus, by wielding the different ways in which a Bayesian inferential system processes and responds to levels of uncertainty it is possible to identify different ways this system can be pathological. Polythematic delusions arise when low precision expectations cause one to be driven by poorly shaped prior expectations, and monothematic delusions arise when unexpectedly high precision content in evidentially insulated areas cause one to be in the thrall of spurious sensory input. This is speculative, of course, but it is worth considering these kinds of ideas because they begin to unify the different aspects of monothematic and polythematic delusion

formation, which Radden focuses on. Much more needs to be said to substantiate this, but it is noteworthy that there are studies of delusions pointing in this general direction (Corlett et al., 2009; Fletcher et al., 2009; Corlett et al., 2010; Synofzik et al., 2010).

Underlying this probabilistic approach to pathological belief formation is a picture of human beings as condemned to make sense of our uncertain sensory input using only our prior learning. There is an imperative to make sense of the world and this forces us to do whatever we can even when uncertainty mounts. Under uncertainty, we cast about frantically for cues and prior knowledge to force a winner. If this happens in contexts of relative evidential insulation and where expectations of precision are suboptimal, then it seems plausible that different kinds of delusion could arise. Part of the picture Jennifer Raden paints in *On Delusions* should therefore motivate a focus on perceptual and cognitive inference under uncertainty, with special attention to individual differences in precision expectations.

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