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ORIGINAL PAPER

Impaired semantic memory in the formation and maintenance of delusions post-traumatic brain injury: a new cognitive model of delusions

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Abstract This paper proposes a new cognitive model to explain the aetiology of delusions irrespective of diagnosis and/or phenomenology. The model hypothesises the influence of two processes in the formation and maintenance of delusions; (i) impaired perceptual abilities, particularly affect perception, which fosters the encoding of (ii) idiosyncratic semantic memories, especially those with an affective/self-referential valence. Previous research has established that schizophrenia patients with delusions have impaired semantic memory function. In the current paper we sought to provide evidence for (ii) abnormal semantic processing in persons with delusions with an alternative aetiology. Performance of four cases with a significant delusion post a traumatic brain injury was examined on a broad range of semantic memory tests. Overall semantic processing was impaired in the four cases relative to a normative healthy control sample. Cases performed better on tasks which required categorical identification, relative to the novel production of semantic information, which was poor in all four of the cases. These data offer preliminary evidence for our hypothesis of impaired semantic processing in persons with delusions. Findings will need to be empirically verified in larger sample groups and in those with alternative aetiologies.

Keywords Delusions · Psychosis · Traumatic brain injury · Semantic memory and perception

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Background

Delusions have traditionally been viewed as the defining characteristic of insanity. As Karl Jaspers observed "Since time in memorial … to be mad was to be deluded" [25]. In spite of this and the recognition of the prominence of delusions within psychopathology, until the last 20 years, there has been little empirical investigation into the aetiology of delusions [6]. As well as occurring in disorders such as schizophrenia, bipolar affective disorder, and delusional disorder, delusions are also present in a number of medical conditions, for example, dementia (16–70% incidence rate in Alzheimer's type; [4]), temporal lobe epilepsy (7–23% [12]), and in up to 9% of individuals who sustain traumatic brain injury (TBI) [12]. Delusions also vary dramatically in terms of their associated phenomenology. In psychiatric cases, delusions can be widespread and multi-thematic or they can be circumscribed and monothematic. The same holds for organic delusions. Delusional symptoms associated with temporal lobe damage can be widespread and co-occur with other psychotic symptoms, whereas right hemisphere brain damage tends to result in monothematic delusions.

The multiplicity of conditions and the variable phenomenology associated with delusions are clinically important and theoretically challenging. Exploring what is common and what is different about delusions in varying conditions, independent of phenomenology, is critical to the development of a comprehensive cognitive model of how individuals with delusions generate, evaluate, and then accept and reject (usually if implausible) candidate beliefs, and how those beliefs are then maintained. Such a comprehensive model will have practical applications. For example, common cognitive features of delusions can be used to improve and extend cognitive therapy models applicable to any delusion, rather than those that exist for paranoia only [8]. Thus, such therapy will be more diagnostically inclusive and cost-effective.

Cognitive models

There is no encompassing cognitive model to explain all delusions, independent of aetiology or phenomenological characteristics. It may be that all types of delusions, regardless of differences in associated condition and/or phenomenology, arise from a common cognitive impairment. Alternatively, it may be that schizophrenia, affective delusions, and 'organic' delusions are qualitatively distinct, not only at a psychopathological level but also at a cognitive level. To date, at least four explanations have been put forward to explain delusions occurring in psychiatric disorders [20]: (a) an overconfident "jumping to conclusions" style of belief formation manifesting in abnormal performances on probabilistic reasoning tasks [20, 24], although, there are some failures to replicate [49]; (b) a self-defensive attributional style biasing individuals towards blaming other people, rather than any aspect of themselves, for negative events, especially prominent in individuals with paranoid/persecutory delusions but not other delusional types [30]; and (c) a theory of mind deficit resulting in an inability to represent the beliefs, thoughts, and intentions of other people [11, 18, 32, 33]. However, even though theory of mind deficits are highly replicable in patients with schizophrenia, there is less convincing evidence to suggest such a deficit is a factor in delusion formation or maintenance. The last approach has stated that delusions are the consequence of (d) a normal response to an anomalous experience, for example, experiencing hallucinations [34]. However, this does not account for delusions in the absence of anomalous experiences (i.e. delusional disorder and many organic delusions [9]).

New cognitive model

This paper proposes an alternative cognitive model to explain the aetiology of all delusions in all conditions. This innovative model hypothesises that delusions are the consequence of impaired perceptual abilities, visual and auditory, particularly affect perception. This results in the encoding of unusual ideas, which leads to the formation of idiosyncratic semantic memories, especially memories with an affective/self-referential valence. In deluded individuals there is continual confirmatory evidence for delusional ideas from anomalous perception, but also feedback from semantic memory that the belief concurs with previously held beliefs and past experiences. It is not within the scope of this paper to examine both aspects of this model. Thus, this current work will focus on the proposal that persons with delusions have abnormal semantic processing. Anomalous sensory processing and perception has been discussed in substantial detail in previous work [34, 47, 48].

In a review, McKenna [36] suggested that a natural link between abnormal semantics and psychopathology is the delusion; that is, they both involve aspects of meaning and belief, and the belief is equated with their knowledge-base. Delusions are commonly defined as abnormal beliefs, but could also be construed as statements and inferences based on a faulty knowledge-base or semantic system. All semantic memories are acquired, stored, and may be retrieved; if these processes were interfered with, or go unchecked, this could lead to erroneous semantic memories or false knowledge, i.e. delusions. Interestingly, impaired semantic processes have long been recognised as being central to cognitive deficits in patients with schizophrenia (e.g. [2, 10, 22, 35, 38, 44–46]). However, more recent data have established that a person's store of knowledge—facts about the world, and the meanings of words—appears to be especially corrupt in schizophrenia patients with delusions [28, 41–43]. A semantic priming experiment showed reduced direct semantic priming but intact indirect priming in patients with prominent delusions, especially when the material had a negative valence [43]. Semantic fluency production was significantly reduced in schizophrenia, and especially so in those with delusions; the deluded patients showed more idiosyncratic word associations [42]. Finally, analysis of sentence verification errors demonstrated a bias in the deluded patients with schizophrenia to accept improbable sentences congruent with their delusional ideas [41]. The results of these three studies were interpreted as showing that the organisation of semantic information in schizophrenia patients with delusions is different from controls. In such individuals semantic information is shown to be idiosyncratically and illogically organised: some normal logical relationships between concepts are not present and some abnormal associations are present [42]; illustrated in the prototypical semantic network in Fig. 1. Thus, individuals with delusions are more prone to generating idiosyncratic, implausible ideas (the delusion) influenced by anomalous perceptions. As their semantic network is corrupt, the process of checking beliefs against information in their semantic network does not result in error detection, and is therefore accepted, in the same way

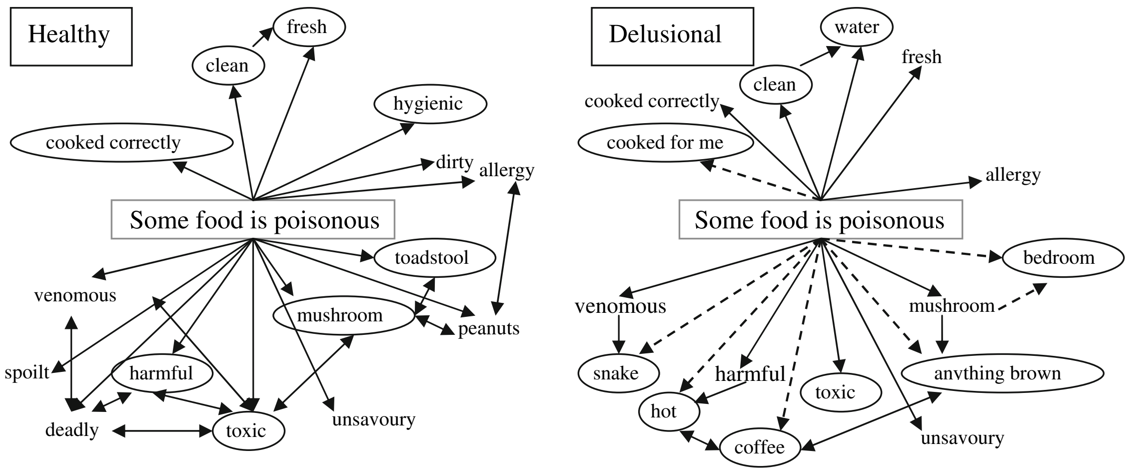

Fig. 1 A schematic diagram of the semantic network for the proposition 'some food is poisonous' in healthy and deluded individuals. Shown is a network of concepts permanently held in semantic memory relating to this proposition. *Circled items* are temporarily activated concepts and *un-circled items* are not activated upon activation of the proposition. Activation of the proposition occurs if it is heard or thought about. Temporary activation of particular concepts depends on the context of the proposition (in this example in the forest), and their frequency of use. → show accurately related concepts, ⇢ show idiosyncratically related concepts. In healthy persons activation of the proposition may lead to other thoughts, i.e. 'some mushrooms are poisonous/toxic, they may be harmful' Deluded individuals have (1) less accurately related concepts available to them and (2) more idiosyncratic relations available. In all individuals some relations do not reach activation (i.e. food poisonous-allergy; mushroom-bedroom formed via clanging; food poisonous-venomous) as the context may not be appropriate or alternatively stronger relations may have been formed between other concepts (via frequency use) (i.e. food poisonous-clean; food poisonous-bedroom; food poisonous-snake)

as a plausible belief, and is also maintained. Data from this author is now confirming that it is indeed the store of information and ideas, and not the access of information that is the critical impairment [40].

Abnormalities in semantic processing have also been reported in individuals experiencing delusions more frequently associated with an organic origin, for example head trauma, dementia, or cerebral vascular disease. Edelstyn and Oyebode [15] have reviewed the Capgras Syndrome; the belief that a person, usually closely related to the patient, has been replaced by an impostor with a close resemblance to the original. They discuss how this delusion is postulated to result from a discrepancy between old stored representations, or semantic memories, and new information. Patients fail to update physical changes in their relatives, ending up with idiosyncratically stored information on these individuals. The cases they examined had mixed organic aetiology. Abe et al. [1] described a peculiar form of delusional misidentification due to Alzheimer's disease. The patient misidentified her daughters as her sisters. The authors speculated that the misidentification was the failure to update semantic memory with new episodic and perceptual information. Finally, Feinberg et al. [16] reported a case of Fregoli delusion in a 61-year-old man after a TBI. The Fregoli delusion is the belief that a person, often a persecutor, has disguised themselves as someone known to the patient. In this case the patient misidentified 13 people around him in the hospital as family members or co-workers. This individual had marked loosening of associations and semantic processing deficits, and the authors proposed his over-misidentification may have resulted from a tendency to select frequently inappropriate associations because of their personal salience, as well as an acceptance of inaccurate information. Failure to modify his beliefs in the face of disconfirmatory evidence suggests that there was damage to his semantic networks involving family members and friends.

In a theoretical review, Davies et al. [13] dismissed the notion that delusions are the consequence of a deficient semantic memory. They suggested that such a theory does not account for patients being able to appreciate that other people will find their belief implausible and why individuals end up with specific delusions, and not a whole store of delusions. However, the model presented by this manuscript addresses such criticism. Patients with delusions do seem to appreciate that their ideas are idiosyncratic, and thus they are different from others beliefs. Current data from Rossell and Batty [44] established that patients with schizophrenia with multiple delusional themes have more severe semantic memory abnormalities. Those with four or more delusional themes scored 80 out of a maximum of 240 on a word definition task, whereas those with few or monothematic delusions (e.g. those with one or two delusional themes) scored 136/240 on the same task, suggesting a specific breakdown of semantic information related to the themes of one's delusions or particularly self-referential/affective information (i.e. the more widespread the delusions the more extensive the semantic memory corruption).

Current study

Given that the previous literature has established a link between semantic processing deficits and delusion in schizophrenia, the current study sought to examine whether such deficits exist in individuals with delusions with an alternative aetiology. Thus, the current study examined four individuals with a significant delusion post a traumatic brain injury in comparison to a normative healthy control sample. It was expected that these individuals would show deficits across the range of semantic memory tasks, especially a marked loosening of/disordered associations within their semantic network, as previously shown in psychiatrically deluded individuals: for example, in deluded schizophrenia patients [41, 43]. This would serve as additional evidence for the model being proposed.

Materials and methods

Participants

Normative data

The control data consisted of 32 healthy controls from the general public. This sample was recruited for the study by advertisement in two local Sydney job centres. All participants tested were between the ages of 18 and 55 years and had an estimated pre-morbid IQ as scored by the National Adult Reading Test (NART) of >90 (see Table 1). No participant reported any psychiatric illness, confirmed by a current assessment using the Brief Psychiatric Rating Scale (BPRS [37]), a first-degree relative with a psychiatric illness, a neurological illness or a history of ECT.

Case studies background

Four cases with delusions post-traumatic brain injury were recruited from the South Western Sydney area. Prior to the TBI none of the cases had reported any history of psychiatric illness. In addition, no participant had any relative with a psychiatric illness. In each of the four cases described below psychopathology was rated using the Schedule of Negative Symptoms (SANS), and the Schedule of Positive Symptoms (SAPS) [3] (see Table 2). IQ in the four cases was determined by the NART.

Table 1 Demographics

	Controls $N = 32$	ERL	DEN	JL	BS
Male/Female	21/11	F	M	M	M
Age	36.6 (12.3)	56	23	39	30
No. of years of education	13.8 (2.2)	13	10	12	12
NART IQ	115 (10.9)	103	80	110	75

Table 2 Clinical ratings using SANS and SAPS

Global rating	ERL	DEN	JL	BS
Affective flattening	0	3	0	2
Alogia	0	0	0	2
Avolition–Apathy	0	3	0	3
Anhedonia–Asociality	0	4	3	4
Attention	0	3	0	3
Hallucinations	0	?	0	0
Delusions	2	5	0	2
Bizarre behaviour	0	3	2	2
Positive FTD	0	2	3	2

FTD formal thought disorder

Case one: ERL

ERL was a 56-year-old married woman, who worked for a bank prior to her accident. In 1995 she was involved in a car accident that resulted in a head injury. No specific lesion information was available but a right frontal pathology was implicated in case notes. During her hospital stay, she developed signs of paranoia, but returned to work 6 months after the accident, however, this was when the paranoia became prominent. The nature of ERL's psychotic symptoms involved paranoia and delusional ideas that others were conspiring against her and her thoughts were being broadcasted. She had experienced a few episodes of auditory hallucinations. She had also experienced OCD concurrent with her paranoia, where her neurotic symptoms consisted of a cleanliness obsession and a compulsion to wash everything. ERL had a series of in and out patient admissions, and received pharmacological treatment. On the day of testing she was mildly paranoid.

Case two: DEN

DEN was a 23-year-old single male, who is the father of a young boy. He was Australian born but his family originated from Vietnam prior to his birth. He completed his schooling until age 16 and went on to complete fencing and concreting courses at Technical and Further Education College (TAFE), where he subsequently worked as a concrete labourer. In January 2000, DEN was involved in a motor vehicle accident that resulted in a head injury. A CT scan suggested a lesion within the left frontoparietal region. Since the brain injury, DEN developed the belief that he is dead and his penis has shrunk (a Koro delusion). His psychotic symptoms included hallucinations where he talks to people he believes are in his roof and paranoid delusions where he believes that his accident was the result of a conspiracy involving his brother and sister, and believes that there is a woman in his head influencing his life. He had also become more aggressive since his accident and the onset of his delusions. DEN received pharmacological treatment for his pain and delusions. On the day of testing he had moderate to severe negative psychotic symptoms, including affective flattening, avolition, anhedonia, and poor attention. He was also experiencing a range of positive psychotic phenomenon including very severe delusions, moderate bizarre behaviour, and mild thought disorder.

Case three: JL

JL was a 39-year-old single male. He completed his schooling until age 18 and went on to complete a 2-year Diploma in accountancy. JL worked as a bank teller before his accident. In January 1990, JL was hit by a car and sustained a right frontal haematoma, cerebro-spinal fluid leak, and lower fracture of the face and fracture of the hip. As a result of his injuries he lost his sense of smell. JL returned to work in late 1990 but began to develop psychotic symptoms approximately one year later where he developed concerns that he smelt. As a consequence, JL left the bank for an outdoor job to escape this problem. He had been diagnosed with bipolar disorder where he experiences periods of mania. The nature of JL's psychotic symptoms included olfactory hallucinations where he felt that he emitted a "dead body" smell, somatic delusions that involve himself as "Mr Smell", and thought disorder. His monothematic delusion of smell and decay was not mood-congruent, occurring independently of his mania. JL had received pharmacological treatment and commented that his psychotic symptoms were mostly under control; on the day of testing he was experiencing moderate thought disorder and mild bizarre behaviour.

Case four: BS

BS was a 30-year-old single male. BS moved to Australia from Fiji with his family at the age of 10 years. He and his family are Hindus. He completed his schooling until age 18 and then went on to study bookkeeping and office duties courses and worked as a train maintenance person for the Railways. The seven years leading up to his injury, BS worked full time in various positions in a bank and more recently in accounting. In May 2002, BS was involved in a motor vehicle accident that resulted in multiple trauma to his head (right temporal subarachnoid and subdural haemorrhage, and lacunar infarct) and body (damage to ribs, thorax, liver, and right brachial plexus), with residual memory and cognitive problems. Since his accident, BS had become excessively religious and attributed his survival to special magical powers due to his connection with God; he had experienced visual hallucinations of the God he prays to (Shiva) and had developed some beliefs in telepathic abilities. Subsequent to his head injury and delusions, BS experienced depression and some anxiety symptoms, such as obsessive checking, and was taking medication. On the day of testing he was experiencing mild delusions, thought disorder, and bizarre behaviour.

Cognitive tasks

The following tasks were approved by South Western Sydney Area Health Service ethics and were carried out in accordance with the latest version of the Declaration of Helsinki. Informed consent was obtained from them after the study procedures had been explained to the participants. The semantic task battery is described briefly below, more detail on each task can be found in Rossell and David [40].

(A) Synonyms

Using the stimuli from Psycholinguistic Assessment of Language Processing in Aphasia (PALPA [26]) task 49 we examined the participant's ability to correctly identify synonyms. 60 word pairs (30 synonyms and 30 non-synonyms) of which 50% were high- and 50% were low-frequency, were randomly presented centrally on a computer screen. The first word in the pair was presented for 200 ms, there was a 550 ms blank screen followed by the second word for 200 ms. There was a blank screen between trials of 2,500 ms and the subjects were able to respond for up to 2,000 ms after the second word presentation. Participants were asked to indicate whether or not the pair was a synonym using a two-button press. Accuracy was recorded for high- and low-frequency conditions separately.

(B) Word associations

Using the stimuli from PALPA [26] task 51 we examined the subject's ability to correctly identify word associations. 30 key words (15 high- and 15 low-frequency) were compared to 4 other words; one related, one semantic foil and two unrelated (Example: key word-*fog*, related-*mist*, semantic foil-*steam* and unrelated-*bolt*, and *lock*). This was a paper and pencil task with key words on the left-hand side of the page in bold followed by the four possible associates on the same line. The participant was asked to indicate, by underlining, which of the 4 other words were related/associated by meaning to the key word. Accuracy was recorded for high- and low-frequency conditions separately.

(C) Definitions

As much as 42 words, between 4 and 8 letters long were used (see [44]). They were taken from the MRC Oxford Psycholinguistic Database. From these words two task versions were created; generate and forced choice. Participants always performed generate first and then, after approximately 90 min, the forced choice. (1) Generate: after hearing and seeing each word, the participant was required to generate a definition, i.e. what each word meant. The participant's performance was monitored for the first 5 words. If they were not completing the task correctly the instructions were repeated and an example of a correct definition was given. For each word the participant's definition was compared against Oxford Concise English Dictionary entries, and was awarded between 2 and 0 points depending on its accuracy and completeness. When an answer scored 0 points it was further rated as one of 5 possibilities for an incorrect answer: (a) an association i.e. army–navy, (b) an opposite response i.e. shallow–deep, (c) no obvious sense in the definition i.e. dusk–not finished 1,000 years to go, (d) an incorrect answer, may be for an alternative spelling of the word i.e. lain = small narrow road, and finally, (e) missing or no response. Total accuracy as well as % of errors to each of the five categories above was recorded. (2) Forced choice: the same 42 words were presented with four definitions: two foils, one incorrect and one correct answer (for example, GREEN: foil1 = the colour between red and yellow; foil2 = the colour of the sun; incorrect = solid, firm or rigid material; and correct = the colour between blue and yellow). The foil answers were created using a thesaurus and finding definitions of similar words or concepts. The participants were required to indicate the correct definition. The % of correct, incorrect, and foil answers were recorded for each participant.

(D) Categories

We used a revised version of the category task reported in Chen et al [10]. 18 categories were selected from the norms of Battig and Montague [5] and Hampton and Gardiner [21], e.g. VEHICLES. For each category 5 different exemplar words were selected to provide different degrees of relatedness, resulting in 90 trials. These exemplar words were either: (1) high frequency (VEHICLE—bus), (2) low frequency (VEHICLE—ferry), (3) borderline (VEHICLE—ski), (4) related but outside the category (VEHICLE—horse), and (5) unrelated (VEHICLE—banker). Stimuli were presented in random order centrally on a computer screen. First, category names appeared in capital letters for 1,000 ms. After a delay of 550 ms exemplar words appeared in lower case for 200 ms followed by a 2,000 ms response window. After the exemplar word was shown, participants were asked to indicate whether it belonged to the category or not by pressing one of two buttons, YES or NO. For four of the categories there was clearly a single obviously correct answer, 'YES' for high frequency and low frequency, and 'NO' for the related and unrelated categories. This was not the case for the borderline condition where classification of category membership was supposed to be ambiguous. For simplicity when calculating accuracy 'YES' was taken as the correct answer. Accuracy for the five categories is reported.

(E) Pyramids and palm trees (PPT)

The PPT [23] is a test of semantic associative knowledge. The participants viewed 3 pictures, a prime and two targets. They were asked to indicate which of the targets was related to the prime. Accuracy was recorded.

(F) Fluency

Category fluency was examined using the category animals. Participants were asked to give as many category exemplars as they could over 60 s. The total number of words generated for the category was calculated minus errors (i.e. category inappropriate words) and perseverations.

Results

Data for the seven semantic memory tasks for the four case studies and the healthy control group are presented in Table 3. If the case study demonstrated deficient performance on any of the measures this was noted in terms of the number of standard deviations (SD) difference from the healthy control groups performance (* = 1SD ** = 2SD and *** = 3SD). A summary of performance of each case study is described below and the salient deficits are presented in Table 4.

Case studies

Case one: ERL

ERL demonstrated intact *synonym* performance. Alternatively, she produced less correct responses (2SDs) on the *word association* task to the low-frequency stimuli only. This was due to her greater selection of semantically related responses. She generated fewer definitions on the *definition* task (1SD from the norms). Of note within the definitions generate task is that ERL made more associative errors (two SD's from the norm). Her performance on the definitions forced choice component was comparable to the

Table 3 Task data across the four cases and the control group

Task	Condition	Variable	Controls $N = 32$	ERL	DEN	JL	BS
(A) Synonyms	High frequency	% Correct	94.2 (5.6)	93.3	70.0***	100.0	53.3***
	Low frequency	% Correct	88.2 (9.0)	86.7	30.0***	80.0	63.3***
(B) Word associations	High frequency	% Correct	89.9 (7.1)	86.6	53.3***	86.6	60.0***
		% Semantic errors	9.5 (7.1)	6.7	6.7	6.7	40.0***
		% Unrelated responses	0.6 (2.0)	6.7	33.3***	6.7	0.0
	Low frequency	% Correct	83.4 (11.4)	66.6**	71.3*	93.3	13.3***
		% Semantic errors	13.9 (8.5)	26.7*	20	6.7	20.0
		% Unrelated responses	2.6 (5.6)	6.7	6.7	0.0	53.3***
(C) Definitions	(1) Generate	% Correct	80.9 (23.8)	50*	18**	49*	39*
		% Associative errors	26.9 (12)	57.1**	38.7*	81.8***	47.6*
		% Opposite errors	4 (6.8)	7.1	3.2	0.0	0.0
		% Nonsense errors	6.9 (9.9)	7.1	38.7***	0.0	4.8
		% Incorrect	38 (31.3)	7.1	3.2	9.1	4.8
		% No response	20.8 (26.6)	21.4	12.9	9.1	42.8
	(2) Forced choice	% Correct	61.5 (21.7)	92.9	64.3	88.1	59.5
		% Incorrect	25.3 (19.9)	0.0	7.1	0.0	9.5
		% Foils	13.2 (5.5)	4.8	28.6***	11.9	31.0***
(D) Categories	Total	% Correct	78.7 (7.5)	84.4	70.0*	81.1	70.0*
	High	% Correct	94.9 (5.2)	94.4	94.4	88.9*	94.4
	Low	% Correct	86.4 (10.1)	77.7	72.2*	88.9	77.8
	Borderline	% Correct	70.7 (6.6)	72.2	88.9	50.0***	83.3
	Related	% Correct	72.7 (9.8)	88.9	33.3***	77.8	27.8***
	Unrelated	% Correct	89.4 (7.2)	88.9	61.1***	100	61.1***
(E) Pyramid and palm trees		% Correct	92.3 (5.8)	90.4	94.2	90.4	94.2
(F) Category fluency	Animals	Words produced	20.3 (5.1)	11*	12*	20	13*

* ><1SD the health controls, ** ><2SD the health controls, *** ><3SD from the health controls

Table 4 Summary of salient semantic deficits in the four case studies

Task name	Task type (I vs. P)	ERL	DEN	JL	BS
Synonyms	I	✔	×	✔	×
Word association high-frequency correct	I	✔	×	✔	×
Word association low-frequency correct	I	×	×	✔	×
Definitions generate correct	P	×	×	×	×
Definitions generate associative errors	P	×	×	×	×
Definitions forced choice foils	I	✔	×	✔	×
Categories total correct	I	✔	×	✔	×
Category fluency	P	×	×	✔	×

✔ intact, × impaired, *I* identification, *P* production

NB: × at least ><1SD from norm

healthy controls. On the *categories* task ERL was able to correctly identify the categories to which words belonged. No impairment was shown on the *pyramid and palm trees* task. ERL produced fewer words on the *category fluency* task, 1SD below controls.

Case two: DEN

DEN showed deficits across all semantic tasks (the majority of his scores were more than three standard deviations from the healthy control group), with the exception of the *pyramid and palm trees* task. Notable were his responses on the *word association* task; while his performance was poor to both high- and low-frequency words, his errors were confined to making unrelated responses and his semantic errors were comparable to the controls. Similar to ERL, DEN made a high number of associative errors when asked to define words (*definitions generate* task), and a high number of nonsense errors. The *definitions forced choice* component of this task reflected that DEN was distracted by foil definitions, and he was only able to identify word categories to high-frequency and borderline words on the *category* task. DEN produced fewer words on the *category fluency* task, 1SD below controls.

Case three: JL

JL had mostly intact semantic processing performance with some notable exceptions. He had poor *definition generation*, due to a large number of associative errors. Interestingly his performance on the *definitions forced choice* component was comparable to the norms. On the *categories* task his overall accuracy matched the norm data, however, he showed an unusual pattern of performance on the borderline condition, only selecting 50% yes responses in comparison to 70% in the healthy controls. JL had intact *synonym* recognition, *word association* recognition*, category fluency,* and *pyramid and palm trees* performance.

Case four: BS

Similar to DEN, BS showed deficits across all semantic tasks except for the pyramid and palm trees task. His performance too, was in general three SD's from the norms. He demonstrated poor *synonym* and *word association* identification. BS made a large number of semantic errors when identifying *word associations* for high-frequency words, but a large number of unrelated responses when identifying low-frequency words. When attempting to *generate word definitions* his poor performance was split between making associative errors and no response, and similar to DEN, the forced choice component of this task reflected that BS was distracted by foil word definitions. BS again showed a pattern of performance similar to DEN when identifying word categories; he was only able to correctly categorise high-frequency and borderline words.

Results summary

All four cases showed impairments when asked to *generate definitions* for words. Furthermore, the errors made on the *definitions generate* task were predominantly errors of association. Three out of the four cases had poor *category fluency*. Conversely, all cases were able to identify which target was related to the prime on the *pyramid and palm trees* task. Cases two and four (DEN and BS, respectively) were unable to identify *synonyms*, *word associations*, *forced choice definitions* and *word categories* (see Table 4).

Discussion

Deficits in semantic processing were shown by all of our cases. These results support our proposal that individuals with delusions have abnormal semantic processing (some individuals were more extensively impaired than others i.e. DEN and BS versus JL and ERL; this will be discussed below), and is congruent with evidence of disordered semantic networks in deluded schizophrenia patients [41, 43], and one previous study of delusions post a traumatic brain injury [17]. As such, these cases provide additional evidence for the relationship between delusions and abnormal semantic processing, independent of aetiology.

An interesting behavioural pattern emerged during the analysis, that is, all cases were particularly impaired on tasks that required the individual to *produce* or generate semantic information (*definitions generate and category fluency*). Whereas the remainder of tasks, which required categorical *identification* were, overall, more successfully completed (by at least two of the four cases on any given task, see Table 4). Rossell has previously postulated that individuals with delusions have (i) idiosyncratically and illogically organised semantic information, where some typical logical relationships between concepts are present but some abnormal associations are also present [41] (see Fig. 1), and (ii) that these idiosyncrasies and abnormalities are represented by inaccurate storage of information and ideas rather than the access to this information [44]. In this study the existence of some typical logical associations or relationships between concepts may have been sufficient to generally allow the correct categorical identification of words when the correct response, acting as a prompt or memory cue, is offered amongst a group of alternatives. This would allow for supported performance on the *synonyms, words association, definition forced choice, categories, and pyramids and palm trees tasks*. However, when required to *produce* semantic information unaided, cues or alternative choices are not available. Thus, resulting in the inability of all cases to perform the *definition generate* task within normal ranges, and three out of four cases showing poor *category fluency*.

Another important behavioural pattern is with regard to the errors produced on the tasks. When the cases were asked to *generate definitions* their incorrect responses were predominantly classified as ‘associative errors’. This is a further indication of the loose associative links inherent within an idiosyncratically organised semantic network (as previously shown in a deluded brain injured patient [16]). Thus, deluded individuals have (i) less accurately related concepts available to them and (ii) more idiosyncratic relations available. For example, when asked to define the word ‘army’ an associated response would be ‘navy’, this illustrates that stronger relations may have been formed between these two concepts in the deluded individual than the association of ‘army’ with its correct definition ‘the military force of a nation’. We argue that these idiosyncratic associations are formed during the encoding of new information, although clearly this needs experimental testing. DEN additionally showed an increased rate of nonsense errors; again this can be used as evidence for a severe disruption in the semantic information held for the concepts tested on this task. Significantly, the errors produced by the four cases are very different from the healthy controls. The healthy controls had the greatest percentage of incorrect responses, that is, defining a word with a similar spelling. Idiosyncratic semantic organisation may also explain the increased rate of ‘foil’ responses on the *definitions forced choice* task, especially in DEN and BS. That is, the cases had some general understanding of the concept but were not able to be specific. Although this study did not directly test the access-store dichotomy, that is, whether semantic memory is abnormal because of impaired storage versus impaired access, the pattern of findings, especially the pattern of errors, suggests that the deficits in semantic processing are due to the manner in which semantic information is stored and not with the access and retrieval of semantic information [see 40].

Importantly, increased associative errors and reduced incorrect errors on the *definitions generate* task, replicates the response pattern previously shown in patients with schizophrenia [44]. Further, reduced *category fluency* has been reported in schizophrenia, particularly in patients with delusions who produce more idiosyncratic word associations on this task [41]. In this study, some of the responses recorded for *category fluency* task were idiosyncratic, for example; one of DEN’s responses was ‘alpaca’, while JL named both an Indonesian elephant and an African elephant, as well as a sloth. ‘Teddy bear’ was generated in amongst the responses by BS, which is a further example of loose and uniquely organised semantic networks. Together this data provides evidence for the proposal that abnormal and idiosyncratic organisation of the semantic network is a common feature in individuals with delusions, irrespective of diagnosis and phenomenology.

Ceiling performance on the *pyramid and palm trees* task by all our cases is postulated to be the consequence of the simple requirements of this task, which are to indicate a semantic match, and also the simple nature of the stimuli, common pictures. Thus, this task was unable to tap into the uncued semantic processes we are arguing to be impaired.

Word frequency influenced task performance for both the cases and healthy controls; high-frequency words were generally correctly identified at higher rates than low-frequency words (*synonyms, word associations, and categories* tasks). The ‘commonality’ of words has been shown to promote more expedient encoding [7, 44]. On two occasions however, a higher rate of correct responses were shown to the *low*-frequency words relative to the high; BS and DEN on the *synonyms and word association* tasks, respectively. This reverse pattern is predicted to reflect subtle differences specific to the semantic organisation of these two individual cases.

Lesion location and severity may have also influenced semantic memory performance. Three patients had a frontal pathology; ERL, DEN, and JL. The two patients with some intact semantic abilities both had a right frontal lesion. BS had a temporal lobe pathology. Interestingly, DEN and BS had more extensive injuries that ERL and JL. Further group studies are needed to confirm the role of brain region on delusions and semantic processing. Interestingly, recent MRI studies have implicated both temporal and frontal involvement in delusion formation [30].

Limitations

The cases DEN and BS warrant closer inspection. Both revealed greater deficits across all tasks relative to the other two case studies, commonly scoring more than three standard deviations below the norm. Both experienced multi-thematic delusions; DEN was identified with four delusional themes and BS with three, which was more than the other two cases that had one or two delusional themes. This is further evidence for the proposal that individuals with multiple delusional themes have more severe semantic memory abnormalities, shown previously in schizophrenia patients with delusions [44]. Interestingly, both of these cases also had delusions congruent with their cultural identities. However, low pre-morbid IQ estimates were obtained for these cases, which is a limitation of these findings, as low IQ would have impinged on language and reading abilities necessary for the tasks. Importantly, the other two cases had IQs within the normal range and still exhibited semantic processing problems. Pre-morbid IQ would need to be matched in any further investigations to elucidate and remove its effect on semantic memory performance.

There are a number of limitations to this research that should be mentioned. Due to time restrictions we were unable to assess other neuropsychological abilities. Thus, it is not known whether the patients also showed similar attention, executive function and other memory difficulties; and whether these other neuropsychological abilities were related to psychotic psychopathology. However, previous research in delusion formation in schizophrenia suggests that finding such a relationship between these other neuropsychological abilities and delusions is unlikely, and was not the rationale for completing this project. Further, the cases did exhibit other positive symptoms of psychosis, for example thought disorder and hallucinations. Hallucinations have not been linked to a semantic processing pathology but some authors (but not all) argue that semantic processing is involved in thought disorder. However, in all four cases the predominant psychotic symptom was delusions, with thought disorder being mild. Future studies may also benefit from comparing TBI psychosis patients with TBI patients with no history of psychosis. These patient groups will need to be closely matched for lesion location and extent.

Conclusions

We have shown atypical semantic processing in deluded individuals who have sustained a TBI. Importantly, the pattern of semantic performance recorded by our cases is consistent with schizophrenia patients with delusions, although in some cases they did not show such global semantic processing impairments. Taken together, we consider this as preliminary evidence for consistent abnormal semantic processing in persons with delusions, irrespective of diagnosis and phenomenology. This finding will need to be verified in larger sample groups of persons with delusional beliefs across a range of diagnoses, and matched for pre-morbid IQ. Group-based studies will allow for correlational analysis with other positive symptoms to examine whether semantic processing abnormalities are unique to delusions. The new distinction shown between the production and identification of semantic information warrants further investigation, and the extent of anomalous affect perception in deluded individuals needs to be determined before this new cognitive model of delusions can be confirmed.

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