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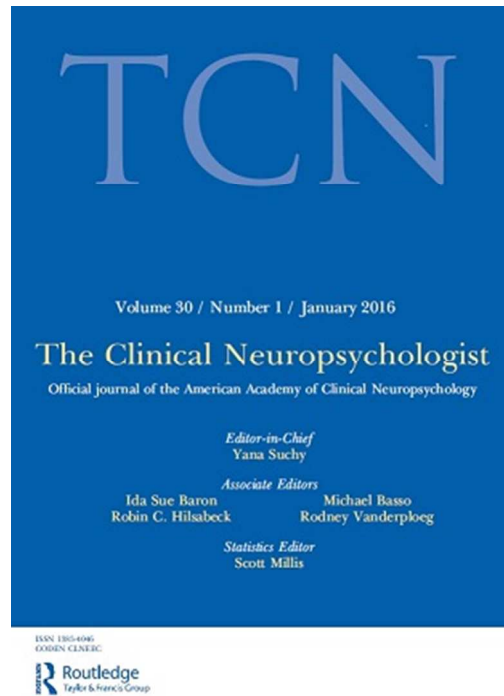
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For Peer Review Only

When synesthesia and savant abilities are mistaken for hallucinations and delusions: contribution
of a cognitive approach for their differential diagnosis

Short title: Synesthesia, savant syndrome, and schizophrenia

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3 Abstract
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6 Objective: Schizophrenia is characterized by hallucinations, delusions, disorganized speech and
7 behavior, and other symptoms that cause social or occupational dysfunction. However, some of
8 these symptoms, such as hallucinations and delusions, can be indicative of other phenomena such
9 as synesthesia and savant abilities. The aim of this paper is to highlight how neurological and
10 psychiatric conditions can be confused and how formal neuropsychological evaluations can be
11 necessary to distinguish them.
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21 Method: We report the case of a young woman, VA, who perceived sounds as colors and claimed
22 to have elaborated complex astrophysical reasoning, despite having experienced difficulties at
23 school, especially in mathematics. VA also had difficulties to orient herself, to develop social
24 relationships, and often became confused by daily life situations. These elements were considered
25 as symptoms of schizophrenia
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34 Results: Evaluations revealed that VA exhibited savant abilities in astrophysics and colored-
35 hearing synesthesia. We also found evidence of higher-than-average cognitive functioning.
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39 Conclusions: In complex cases, neuropsychological and formal evaluations are necessary to
40 establish a differential diagnosis. Moreover, the case highlights the link between synesthesia and
41 savant abilities.
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51 Keywords: schizophrenia, synesthesia, savant abilities, differential diagnosis
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Introduction

Neurological and psychiatric symptoms are sometimes difficult to dissociate. Indeed, many neurological diseases cause psychiatric symptoms, and, conversely, some psychiatric illnesses such as schizophrenia and autism involve neuropsychological impairment (Reichenberg, 2010; Wilson et al., 2014). Additionally, some neurological conditions, such as dementia with Lewy bodies or Parkinson's disease, can be confused for psychopathological conditions such as psychosis, especially due to the presence of hallucinations (Weintraub & Hurtig, 2007). The aim of this paper is to demonstrate how neurological and psychiatric conditions can be sometimes confused, and that neuropsychological and formal evaluations could be important for a differential diagnosis. For this, we report the case of a woman who presented as schizophrenic but whose objective and neuropsychological assessments rather revealed synesthesia and savant abilities.

It is well known that schizophrenia is a psychiatric disorder characterized by hallucinations (hearing voices or seeing things that are not there), delusions (false beliefs, grandiose ideas), negative symptoms (affective and emotional exhaustion), and disorganized speech and motor behavior (APA, 2013). Different forms of schizophrenia have been described (disorganized, catatonic, paranoid, and undifferentiated), and these are diagnoses assigned according to the dominant symptom. In addition to these symptoms, schizophrenia is often accompanied by cognitive deficit (Fioravanti, Carlone, Vitale, Cinti, & Clare, 2005; Heinrichs & Zakzanis, 1998; Reichenberg, 2010). According to Reichenberg (2010), the incidence of cognitive deficit in patients with schizophrenia is 55% to 80%. For instance, a general impairment is observed, with an IQ score below the general population (specifically, the performance IQ score). Executive function and memory are also impaired in this pathology.

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3 Nonetheless, the diagnosis of schizophrenia can be difficult given that there is no known etiology
4 and no universally accepted test. Hallucinations and delusions are key symptoms of this
5 psychiatric disease, the main criterion being the distortion of reality. For most patients,
6 inappropriate thoughts and distorted perception are easy to diagnose. However, some patients
7 may report unusual perceptions and abilities that, while being exceptional and disconcerting, are
8 not necessarily the same as hallucinations and delusions. We will now discuss how two such
9 exceptional phenomena, synesthesia and savant abilities, may be mistaken for schizophrenia
10 symptoms, hallucinations and delusions.
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23 Synesthesia can be described as a subjective phenomenon where the perception of one particular
24 stimulus automatically elicits an idiosyncratic perception in the same or a different sensory
25 modality. Synesthesia is additive, whereby the triggered perception is added to the sensory
26 perception rather than replacing it (Simner, 2012). More than 60 types of synesthesia have been
27 described (Day, 2014), including time-space synesthesia (e.g., months are associated to specific
28 spatial localizations), grapheme-color synesthesia (e.g., letters are associated to specific colors),
29 and colored-hearing synesthesia (e.g., sounds are associated to specific colors) (Ward, 2013).
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40 Because multiple forms of synesthesia exist, it has been difficult to estimate its prevalence among
41 the general population. Some forms are quite rare: grapheme-color and sound-color are estimated
42 to have a prevalence of 0.2% to 2.8% in the general population. More frequent forms, such as
43 time-space synesthesia, are estimated to be prevalent in 9% to 14% of the general population
44 (Chun & Hupé, 2013). Synesthesia is thought to be neurological in origin (Hupé & Dojat, 2015),
45 and is not related to drug use (even if synesthesia can be in certain cases drug induced), or to
46 psychological, psychiatric, or to a specific neurological disease. However, recent studies have
47 reported a higher prevalence of synesthesia in the autistic population (Baron-Cohen et al., 2013;
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3 Neufeld et al., 2013). We will now consider the potential links between synesthesia and
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5 hallucinations, and how these could result in a misdiagnosis.
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8 After noting the crossover between synesthesia and hallucinations, Sagiv et al. (2011)
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10 reported the similarities between the two phenomena. Indeed, both are subjective, occur in the
11
12 absence of an appropriate stimulus, and are not under voluntary control. At first glance, therefore,
13
14 synesthesia is similar to hallucinations in that both involve the perception of something that is not
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16 physically present. However, the main difference between these experiences is the trigger. In
17
18 synesthesia, the perception is elicited by a stimulus in the same or a different modality, and in
19
20 hallucinations there is no obvious external trigger. Moreover, the correspondence between the
21
22 stimulus and the elicited perception is consistent in synesthesia, and the synesthetic experience is
23
24 thus predictable. This predictability helps a synesthete make sense of their environment. On the
25
26 contrary, the unpredictability of hallucinations means that they can be disruptive, and those
27
28 experiencing them can have trouble making sense of their environment. Consequently, the
29
30 consistency of the association has become the gold standard in evaluating the genuineness of
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32 synesthesia (Ward, 2013).
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39 The cognitive profile associated with synesthesia is still unclear, and is made more
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41 complicated by the identification of different forms of synesthesia. Synesthesia has been
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43 associated with superior cognitive abilities: enhanced mental rotation in time-space synesthesia
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45 (Brang, Miller, McQuire, Ramachandran, & Coulson, 2013), and visual memory for simple
46
47 abstract pattern in grapheme-color synesthesia (Rothen, Meier, & Ward, 2012). Using the
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49 Intelligence Structure Test, one large-scale survey study found synesthetes to have a superior
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51 capacity for reasoning and general knowledge (Rouw & Scholte, In Press). In exploring the
52
53 different sub dimensions of intelligence, another large survey adopted the Wechsler Adult
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3 Intelligence Scale, and showed that synesthetes only possessed superior verbal comprehension
4 compared to the general population (Chun & Hupé, 2015). Interestingly, there is also preliminary
5 evidence for a diminished performance in some tasks, which may reflect competitions between
6 brain regions in synesthesia (McCarthy & Caplovitz, 2014). For instance, while grapheme-color
7 synesthetes show enhanced color perception they also display a higher motion-coherence
8 threshold (i.e., an impaired ability to detect coherent motion; Banissy, Tester, et al., 2013) and
9 reduced audio-visual integration (Sinke et al., 2014). This latter result can be related to an
10 impaired motion perception (Safran & Sanda, 2015). This illustrates how perception can
11 influence cognition, and can lead to superior performance in specific tasks and diminished
12 performance in other tasks. However, as far as we are aware, these are the only studies that have
13 explored this apparent dichotomous performance. After defining synesthesia and its potential link
14 to hallucinations, we will now consider savant abilities and how they can be confused with
15 delusions.
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35 Savant abilities can be defined as exceptional abilities in a specific domain that contrast
36 with the general functioning of a person, often marked by intellectual or developmental
37 disabilities (Bouvet et al., 2014). Many savant abilities can be objectively assessed, as has been
38 reported in music production (Sloboda, Hermelin, & O'Connor, 1985), drawing (Wallace, Happé,
39 & Giedd, 2009), and calendrical calculation (Neumann et al., 2010). In some cases, savant
40 abilities can be observed in specialized domain requiring high levels of knowledge and reasoning,
41 such as mathematical and astrophysical reasoning. In these cases, a differential diagnostic
42 between savant abilities and delusion (especially grandiose ideas) may be difficult to carry out
43 without the help of expert. This was true for the case of Jacob Barnett, a young mathematical
44 prodigy, whose own mother could not tell if he was a genius or delusional (Barnett, 2013). Thus,
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3 for very specialized domains of expertise such as this, the genuineness of savant ability can be
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5 difficult to evaluate.
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9 Savant syndrome is quite rare, and only case studies have been published (e.g., Mottron &
10 Belleville, 1993; Sloboda et al., 1985; Soulières et al., 2010; Young & Nettelbeck, 1995).
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12 Consequently, little is known about the cognitive functioning of savant individuals. Saying this,
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14 savant abilities are most often reported in individuals with autism, with an estimated prevalence
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16 of 0,5% of population with autism (Hermelin, 2001). Despite a wide heterogeneity, a specific
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18 cognitive profile is observed in those with autism, and is characterized by superior performance
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20 in some domains and diminished performance in others. A well-established result is the enhanced
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22 performance in tests that require the processing of local elements, such as the block design test of
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24 the Wechsler scale and the embedded figures test (Muth, Hönekopp, & Falter, 2015). Diminished
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26 performance is observed in tasks involving theory of mind (Senju, 2012) and executive
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28 functioning (Russo et al., 2007). Thus, similarly to synesthesia, savant abilities are commonly
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30 accompanied by both **enhanced** and diminished cognitive abilities.
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38 In summary, it can be difficult to distinguish psychiatric symptoms such as hallucinations
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40 and delusions from phenomena such as synesthesia and savant abilities. A differential diagnosis
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42 can be further complicated by the fact that synesthesia and savant abilities are more prevalent in
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44 some psychiatric conditions. Indeed, autism is associated with a higher prevalence of synesthesia
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46 (Baron-Cohen et al., 2013; Neufeld et al., 2013) and savant abilities (Hermelin, 2001). Moreover,
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48 a particular personality type has been associated with synesthesia. For instance, synesthetes have
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50 been shown to have an increased openness to experience and fantasizing, a decreased
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52 agreeableness (Banissy, Holle, et al., 2013; Chun & Hupé, 2015; Rouw & Scholte, In Press), and,
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3 in grapheme-color and colored-hearing synesthesia, schizotypy (positive and disorganized signs)
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5 (Banissy et al., 2012).
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9 In the present paper, we present the rare case of VA. VA possesses synesthesia and savant
10 abilities, but was believed to be schizophrenic due to her reports of seeing localized sound in
11 colors, of having developed a complex mathematical reasoning, and talking about the origin of
12 the big bang. These were misinterpreted as hallucinations and delusions. This case report
13 highlights the importance of neuropsychological evaluations in the disentanglement of
14 neurological and psychopathological conditions in complex cases, and illustrates how special
15 abilities can interact.
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29 I- Case history

30 *Developmental history*

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33 VA, a young woman, was 20 years old at the start of the study. Personal history was provided by
34 VA and was corroborated by her father. VA was born without any difficulties. Intellectual
35 precocity became apparent at an early age. At 16 months old, she started to speak with complete
36 sentences, yet she did not pronounce any single word before this age. During normal
37 development, children are expected to pronounce their first word at around 12 months and to start
38 to master syntax at 3 years old. VA learnt to read at 3 years old and was able to write texts one
39 year later (children usually start to read and write at 5-6 years old). At 3 years old, VA was able
40 to perform mental calculation (children usually acquire this ability at 5-6 years old), and, with a
41 calculator, she understood the concept of decimals and power numbers. She had very specific
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3 interests – dinosaurs and space – for which she had an encyclopedic knowledge, which is also
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5 unusual for a child.
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8 Despite her intellectual precocity, VA experienced motor and coordination difficulties.
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10 She started to walk at 24 months old, whereas children are expected to take their first steps at
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12 around 12 months old. She fell quite regularly and was unable to roller skate or to swim later in
13
14 childhood. She still has difficulties to orient herself and can become confused about everyday life
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16 situations. For example, VA explained that when she drops a pack of pasta on the floor, she is
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18 unable to work out how to pick it up. She also has issues with social relationships. At school, she
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20 was socially excluded, often a target of bullying, and had few friends.
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24 VA experienced global difficulties throughout her studies. When she started school, it was
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26 noticed that she found it difficult to understand ambiguous instructions. She performed quite well
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28 during primary school; while she had clear difficulties in mathematics, she performed quite well
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30 in biology. After high school, she enrolled in a course in astronomy that she gave up due to her
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32 difficulties with mathematics. She then enrolled at a university institute of technology, where she
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34 ranked as the lowest performing student on her course. Throughout her scholarship, VA had
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36 specific difficulties in mathematics and in formal comprehension.
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40 VA also has a familial history of psychiatric disorders: her half-sister and half-brother
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42 suffer from eating disorders (bulimia), her father suffers from paranoid personality disorder, and
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44 her mother was described as being psychologically and physically violent towards her daughters
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46 and her husband.
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50 51 52 53 ***Psychiatric diagnosis*** 54

55 Two years prior, VA was referred to a psychiatrist who diagnosed social phobia and
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57 schizophrenia. These conclusions were based on severe disturbances of social behavior (mainly
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3 fear and avoidance of social groups) and on a misinterpretation of what VA reported as ‘special
4 competences’. VA claimed that she had the special ability to see forms and colors when hearing
5 sounds, and even images ‘turning around her or going through her’, especially when listening
6 music. She also claimed that she was working on a theory of the ‘big bang’. She explained she
7 was trying to develop a mathematical reasoning based on visual representations from 2 to 6
8 spatial dimensions in order to describe black holes, white holes, and worm holes. The psychiatrist
9 considered VA to be experiencing multimodal hallucinations and delusions of scientific
10 aptitudes. Combined with her family history of psychiatric disorders, this logically led to the
11 diagnosis of schizophrenic disorder.
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28 **II- Neuropsychological evaluation**

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30 VA came to the neurological department for vocational guidance. We first conducted a
31 neuropsychological assessment. **The main objective of this assessment was to evaluate the**
32 **general functioning of VA by exploring general intelligence, memory, executive functioning, and**
33 **visuo-spatial abilities. The second objective was to evaluate if VA exhibited a deficit in executive**
34 **function and working memory, as has been found in schizophrenia (Reichenberg, 2010).**
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43 ***General intelligence***

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46 An assessment of intelligence was made using the Wechsler Adult Intelligence Scale III (WAIS -
47 III ; Wechsler, 2000) . The results of this evaluation indicated a superior verbal quotient
48 compared to the general population (see Table 1). Although VA showed high abilities in verbal,
49 perceptual, and working memory domains, her index of speed processing was within the normal
50 range. The difference between VA’s verbal/perceptual intelligence and her speed processing
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3 could be suggestive of difficulties to rapidly process information. Despite her reported difficulties
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5 in math, no difficulty in the arithmetic subtest was observed. However, her reasoning was
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7 sometimes unusual. For example, for the problem ‘A person buys the third of a building plot and
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9 another person a quarter of the same plot. Which proportion remains to buy?’, VA answered very
10
11 quickly ‘42%’; she explained that she counted the cubes within a 3D structure but was unable to
12
13 convert her mathematical reasoning into fractions to give the expected response ‘5/12’.
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16 17 18 **Memory**

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20 Specific evaluation of memory was also carried out using the Wechsler Memory Scale III (WMS
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22 - III ; Wechsler, 2001). This evaluation highlighted VA’s superior memory abilities for auditory
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24 information as well as a high working memory capacity (see Table 1).
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29 [Table 1]
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32 33 **Executive functions**

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35 Executive functioning was also assessed with normed tests. The first part of the Trail
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37 Making Test (TMT ; Tombaugh, 2004) involves connecting numbers in ascending order, and in
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39 the second part involves linking letters and numbers in alternation in an ascending order. In the
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41 Wisconsin Card-Sorting Test (WCST ; Heaton, Chelune, Talley, Kay, & Curtis, 2007), cards
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43 must be sorted as a function of one criterion, which then switches. The verbal fluency test
44
45 evaluates the capacity to generate words with a phonetic or semantic link within two minutes
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47 (Cardebat, Doyon, Puel, Goulet, & Joannette, 1990). VA’s results revealed no particular difficulty
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49 regarding capacity of mental flexibility and fluency. The TMT indicated slow reaction times,
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51 which corroborated VA’s specific difficulty to rapidly process information (see Table 2).
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Visuo-spatial abilities

Visuo-spatial abilities were also investigated (Table 2) using normed tests. The Hooper visual organization test measures the capacity to recognize a shape from puzzled elements (Hooper, 1983). In the 15 objects test, the task is to denominate as many perceived objects as possible in a figure composed of 15 objects (Pillon et al., 1989). In the bell's test, 35 bells among 280 distractors must be detected (Gauthier, Deahault, & Joannette, 1989). The Rey complex figure involves reproducing a drawing of a complex figure by copy and then by memory (Rey, 1959). Regarding VA's performance, some difficulties were noticed in the bell's test and in the copy task of the Rey complex figure test. These results suggest a specific difficulty in the visual domain.

[Table 2]

Mathematical abilities

To evaluate VA's difficulty in formal calculation, she was asked to solve written mathematical problems with the application of a formula (simple operations, calculation of power number, fractional number, and Thales and Pythagorean Theorem). This evaluation revealed her difficulty to master formal calculation. It appears that while VA was able to easily perform mental operations, writing these operations down was a challenge. In addition, VA showed difficulties to generalize formulas and to understand code correspondence between letters and numbers.

To summarize, the neuropsychological profile of VA indicates cognitive abilities in the superior norm. A very efficient working memory was also observed, as well as intact executive functions. The auditory modality was particularly efficient, but to the detriment of the visual modality, as

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3 evident by difficulties in visuo-spatial abilities (copy task of the Rey Figure test, Embedded
4 Figure Test, Bell's test). Difficulties to rapidly process information and to master formal
5 calculation were also found.
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12 This cognitive profile is not consistent with the one typically observed in schizophrenia, which is
13 characterized by a deficit in executive function and working memory (Reichenberg, 2010). Given
14 this, we performed a psychometric exploration of her auditory visual perception in order to
15 evaluate whether VA's profile could be related to the phenomenon of synesthesia. Moreover, we
16 sought an expert's opinion to assess the veracity of her astrophysical reasoning abilities.
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24 25 26 27 28 **III – Psychometric evaluation of synesthesia**

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31 **Description.** VA reported possessing this particular association for as long as she could
32 remember. She perceives colors for any acoustic stimuli (verbal and non verbal). Colors vary
33 according to timbre, loudness, and frequency. Moreover, these colors are organized in a dynamic
34 form. For verbal sounds, each phoneme is associated to a specific color, and thus, on hearing a
35 word, VA perceives a succession of colors. In turn, for words or sentences, the color is rapidly
36 replaced by a visual dynamic image that represents the word or the sentence. She reported that
37 this image has often caused her to lose the thread of a conversation. For nonverbal sounds, colors
38 are more intense and are localized all around her (360°). High-pitched sounds are localized at the
39 top of her visual field and low-pitched sounds at the bottom. She also reported that she feels the
40 spectrogram of a sound and that certain frequencies can 'pierce' her. She compared this to the
41 unpleasant sensation experienced on hearing the noise of a piece of chalk on a blackboard. VA
42 explained that her sound-color associations had helped her to learn foreign languages; she is a
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3 bilingual French-English speaker and fluent in German, which she described as easy to learn. To
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5 conclude, the description of VA's auditory-visual perception is very detailed and each perception
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7 seems to be elicited by a specific trigger, which fits more with the definition of synesthesia than
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9 hallucination. Because one key feature of synesthesia is the predictability/consistency of the
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11 perception, a psychometric evaluation of the consistency of her auditory-visual associations was
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13 made.
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18 **Evaluation of the consistency of VA's perceptions.** To evaluate the stability of VA's
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20 perception, we first tested her associations between phonemes and colors. Thirty-seven phonemes
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22 present in French were orally presented once at the time of assessment and again 2 months later
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24 (see Figure 1). Each phoneme was presented twice in order to avoid confusion: one alone and
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26 once in the context of a word. VA was then asked with the software *Paint*© to create the color
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28 associated to the phoneme by adjusting 3 parameters (hue, saturation, and luminosity). A color is
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30 a combination of red, green, and blue (when all these values are set at 0, the color is white and
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32 when they are all 255, the color is black). The hue matches the x-axis of the rainbow while
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34 saturation matches the y-axes. The luminosity (lightness/darkness) ranges from 0 to 240. VA's
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36 results were consistent across the two sessions. VA reported that there was more sunshine on the
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38 retest session, and so the colors reported were a little brighter than those of the first session. For
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40 some sounds, she reported two colors.
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48 We then tested the stability of VA's sound-color associations for non-verbal sounds. The
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50 consistency of these associations was tested using the online Synesthesia Battery (Eagleman,
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52 Kagan, Nelson, Sagaram, & Sarma, 2007). VA performed the Piano Scale Color Picker Test and
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54 the Instrument Color Picker Test. In the first test, 13 pitches (from C4 to C5, piano timbre) are
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56 played at least three times in a random order. In the second test, one identical tone is played by 18
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3 instruments (guitar, trombone, violin, cymbal, etc.) in a random order. In both tests, participants
4
5 must choose a corresponding color after hearing each sound, from a palette of $256 \times 256 \times 256$
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7 colors. These tests evaluate the consistency of responses across trials by calculating the color
8
9 variation between different trials. VA obtained a score under 0.5 (a non-synesthetic person scores
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11 above 2, which indicates a variation between the chosen colors across trials). This score indicated
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13 that she was consistent across the reported colors, which is specific to synesthesia.
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21 [Figure 1]
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26 To summarize, VA clearly showed consistent color associations between verbal and non-verbal
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28 sounds and colors. Considering that the gold standard of synesthesia is the consistency of
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30 associations, this indicates that VA possesses colored-hearing synesthesia.
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37 **IV- Astrophysical reasoning**

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40 **Description.** VA reported a deep interest in astronomy and claimed to have the ability to
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42 calculate ephemeris (i.e., sunsets and the rising of stars) using a method that she had developed
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44 when she was 16 years old. VA also claimed that she elaborated astrophysical theory using
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46 graphical reasoning. Her thinking was that black holes could create a big bang, in the sense that
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48 white holes are the opposite of black holes. She also theorized that the gravitation of black holes
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50 could have an impact on the formation of galaxies. She reported that her ability to form a mental
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52 image of infinity helped her to develop this reasoning and to understand that the positive and
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3 negative infinities are one. As we were unable to dissociate delusions from genuine abilities in
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5 astrophysics, an expert was asked to test the veracity of VA's reasoning.
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9 ***Evaluation of the veracity of VA's reasoning by an expert.*** Marc Lachièze-Rey, astrophysicist
10 and researcher, and head of a French CNRS laboratory at that time (Astroparticule et
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12 Cosmologie, UMR 7164, Paris 7 University), agreed to meet VA and to evaluate her theories.
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14 After a two-hour meeting, Prof. Lachièze-Rey confirmed that VA's theory about the big bang
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16 was scientifically correct and original. He also reported that some other researchers had proposed
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18 an alternative method to calculate ephemeris based on calculation and not on visuo-spatial
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20 reasoning, and that their method was more time consuming than VA's. Prof. Lachièze-Rey also
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22 confirmed that VA possessed exceptional geometric abilities, but that her difficulties to turn them
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24 into formal calculation make it hard to share with the scientific community.
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31 In sum, the evaluation of VA's reasoning by an expert revealed the presence of savant
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33 abilities in the field of astrophysics.
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40 **V- Links between cognition, synesthesia, and savant abilities**

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43 Given VA's atypical cognitive profile, her auditory-visual synesthesia, and her savant abilities for
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45 astrophysical reasoning, we can wonder to what extent they might be linked or be part of the
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47 same phenomenon. In VA's case, it seems that her ability to form a visual representation might
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49 be involved in the development of her savant abilities. Indeed, in addition to her colored-hearing
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51 synesthesia, her advanced ability for visual representations apply to quantity value, whereby she
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53 automatically visualizes a quantity when hearing or reading about it: little dots for small
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55 quantities and a string of squares for larger quantities. Her representation of quantity helps her to
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3 calculate power numbers. For squared numbers, she creates a two dimensional representation and
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5 counts each square of the representation. The volume can grow or shrink according to the number
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7 value and is modified according to the calculation being performed. For instance, she adds
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9 another dimension (3D) for cube numbers. For higher power numbers, she adds even more
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11 dimensions to her visual representation. Beyond power 6 – a representation with 6 spatial
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13 dimensions – VA found this uncomfortable. Even though VA knew that these multi-dimensional
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15 representations cannot be real, she described them to be as vivid as 2D and 3D representations.
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17 VA reported that this ability to form a mental image of not only a number, but also infinity,
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19 helped her to develop her astrophysical reasoning. This further exemplifies the potential link
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21 between her savant abilities and synesthesia. Interestingly, this capacity might also explain her
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23 difficulty to master formal calculation, whereby her inability to understand mathematical formula
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25 may be a result of her difficulty to visualize them.
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36 **Discussion**

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38 The aim of this paper was to present the case of an individual described as suffering from
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40 schizophrenia, but for whom neuropsychological and formal evaluations revealed synesthesia and
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42 savant abilities. We will now discuss elements of the differential diagnosis and the link between
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44 synesthesia and savant abilities.
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49 Some elements of VA's personal history are congruent with the diagnosis of
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51 schizophrenia, including social withdrawal and difficulties at school. Moreover, the multiple
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53 cases of mental illness observed in her family may have also biased the diagnosis of
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55 schizophrenia. Given this context, it is understandable why VA's reports concerning her ability to
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3 perceive sound in color and to perform high astrophysical reasoning were interpreted as auditory
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5 hallucinations and delusions. However, VA exhibited a superior cognitive profile and exceptional
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7 memory for auditory information with no deficit in executive functions. The only difficulty
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9 observed was the processing of visuo-spatial information. Thus, this cognitive profile is not
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11 consistent with the one typically observed in schizophrenia, characterized by a deficit in
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13 executive function and working memory (Reichenberg, 2010). Furthermore, the genuineness of
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15 her synesthesia and astrophysical reasoning also discredits this diagnosis of schizophrenia.
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17 Indeed, without these elements, the only symptom in favor of a diagnosis of schizophrenia is
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19 social withdrawal; this alone is not specific enough for a diagnosis and can be observed in other
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21 psychiatric pathologies (such as autism), in specific neuronal lesions, or even in the general
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23 population (preference for solitude).
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30 The investigation of VA's auditory associations revealed her hearing-color synesthesia to be
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32 authentic. However, her synesthetic associations are atypical. Indeed, the description made by
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34 VA indicates that her synesthesia is disruptive. Generally, the synesthetic triggered sensation
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36 does not replace the original perception but it is added to it (Ward, 2013). In the case of VA, the
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38 triggered perception replaces the original perception in memory. This means that she can be
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40 overwhelmed by her synesthesia and often unable to keep track of a conversation. This is quite
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42 atypical for synesthesia and, furthermore, is a factor used to dissociate between hallucinations
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44 and synesthesia. This raises the question as to what extent hallucinations and synesthesia may be
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46 part of the same continuum, and whether these phenomena may rely on the same mechanisms.
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48 This idea has already been mentioned in the literature (Pearson & Westbrook, 2015; Sagiv,
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50 Ilbeigi, & Ben-Tal, 2011), but there is no research that further illustrates the distinctions between
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52 synesthesia and hallucinations. At the cognitive level, synesthesia is characterized by superior
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3 performance in some tasks (such as mental rotation or visual memory in certain forms of
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5 synesthesia) as well as diminished performance in other tasks (such as higher motion-coherence
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7 threshold or audio-visual integration in some forms of synesthesia). While the present results
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9 highlight a cognitive profile for synesthesia that is characterized by peaks and troughs in
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11 cognitive functioning, further research is needed to better determinate a specific cognitive profile
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13 in synesthesia.
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18 Can VA's astrophysical reasoning be considered a savant ability? Savant abilities contrast
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20 with the general functioning of the individual in terms of developmental and/or intellectual
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22 abilities (Bouvet et al., 2014). In the case of VA, her reasoning capacity contrasts with her
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24 difficulties to master formal calculation, which points to the presence of savant abilities. Her
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26 savant abilities are also quite atypical from those reported in the literature (e.g., music, drawing,
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28 memory). In the literature, there are few reports of co-occurring synesthesia and savant syndrome
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30 (Bor, Billington, & Baron-Cohen, 2007; Bouvet et al., 2014) and few authors have explored the
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32 potential link between them. Simner et al. (2009) proposed that synesthesia might be a foundation
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34 of savantism. In this study, the authors observed that individuals with visuo-spatial synesthesia
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36 exhibited superior abilities in visuo-spatial tasks. In the case of VA, her capacity to visualize
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38 quantity forms the basis of her power number calculation and astrophysical reasoning. Moreover,
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40 the rapid forgetting of the verbal code, once this is converted into a visual format, might play a
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42 role in VA's difficulties to understand formulas, theorems, and the symbolic status of letters in
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44 formulas. It can be hypothesized that her 'overwhelming' synesthesia might be caused by an
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46 exceptional mental imagery. Indeed, studies have found that synesthetes possess superior mental
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48 imagery (Chun & Hupé, 2015) and some authors related synesthesia to the phenomenon of
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50 'phantom perception' involved in mental imagery (Pearson & Westbrook, 2015). We propose
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3 that this vivid and atypical imagery helped VA to develop an atypical form of savant ability, that
4 is, abstract astrophysical reasoning. This ability might also be involved in her difficulty in the
5 social domain. Indeed, VA's synesthesia meant that she often lost the thread of conversations,
6 and her multi-dimensional representations are difficult for other people to visualize. This raises
7 the question as to what extent synesthesia and savant abilities impact at the social level despite
8 the absence of pathological disease in persons with no pathological disease. As of yet, no studies
9 have directly addressed this question in the field of synesthesia.
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24 To conclude, this clinical case illustrates how neuropsychological investigation may be
25 required for complex behavioral diagnosis. The neuropsychological evaluation allowed us to
26 evaluate if VA's cognitive profile was in line with the one typically observed in schizophrenia,
27 and to formally evaluate the non-psychiatric origin of her specific abilities (see Table 3). In
28 addition, the systematic and the complete evaluation of patients helps us to understand how the
29 same phenomenon can lead to superior abilities and simultaneously diminished performance. In
30 the case of VA, we believe that her vivid mental imagery is related to her overwhelming
31 synesthesia and atypical savant abilities. Moreover, we believe that VA's difficulty with visuo-
32 spatial tasks and formal calculation are also a result of vivid mental imagery. This kind of
33 dichotomous performance is poorly described in the literature. The study of complex cases like
34 VA highlight the fact that systematic evaluations of difficulties should be made and, more
35 generally, uncover the links between perception and cognition.
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4
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7 comments on the manuscript.
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Table 1. VA's intellectual efficiency and memory

<i>Tests</i>	<i>Standard</i>		<i>Tests</i>	<i>Standar</i>	
	<i>/ Scale</i>	<i>Percentile</i>		<i>d/ Scale</i>	<i>Percentile</i>
	<i>score</i>			<i>score</i>	
WAIS-III			WAIS-III		
Verbal IQ	132	98	Performance IQ	115	84
Verbal comprehension index	125	95	Perceptual organization index	126	96
Similarities	13	84	Picture completion	16	98
Vocabulary	15	95	Block design	13	84
Information	15	95	Matrix reasoning	13	84
(Comprehension)	15	95	(Picture arrangement)	10	50
			(Objet assembly)	12	75
Working memory index	130	98			
Digit Span	17	99	Processing speed index	97	42
Arithmetic	14	91	Digit symbol-coding	9	37
Letter number sequencing	14	91	Symbol search	10	50
WMS III			WMS III		
Immediate memory index	126	96	General delayed memory index	99	47
Auditory immediate memory index	140	>99	Auditory delayed index	110	75
Visual immediate memory index	106	66	Visual delayed index	97	42
			Auditory recognition delayed index	91	17
Working memory index	123	94			

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Notes : WAIS III: Wechsler Adult Intelligence Scale (french version ; Weschsler, 2000) ; WMS III : Wechsler Memory Scale (french version ; Wechsler, 2001).

For Peer Review Only

Table 2. VA's executive and visuo-spatial functions

<i>Tests</i>	<i>Score</i>	<i>Score according to norms</i>
<u>Executive functions</u>		
<i>Trail making test</i>		
A	23s	40th percentile
B	49s	40th percentile
<i>Wisconsin Card Sorting Test</i>		
<i>Number of categories achieved</i>	6	>16 percentile
<i>Total errors</i>	8	96th percentile
<i>Perseverative errors</i>	4	96th percentile
<i>Verbal fluency</i>		
<i>Phonetic (R)</i>	14 words	- 0.6 SD
<i>Semantic (fruits)</i>	22 words	+ 0.7 SD
<u>Visuo-spatial domain</u>		
<i>Hooper visual organization test</i>	25/30	T score: 41-55
<i>15 objects test</i>	12/15	NA
<i>Bell's Test</i>		
<i>Number of correct answers</i>	34/35	NA
<i>Number of auto corrections</i>	5	- 2.5 SD
<i>Rey Complex Figure</i>		
Copy	31/36	-2.7 SD
Immediate recall	23.5/36	0.5 SD
Delayed recall	18/36	0.7 SD
Recognition	22/24	NA

Notes : Trail making Test : canadian norms (Tombaugh, 2004) ; Wisconsin Card Sorting Test : french norms (Heaton et al., 2007) ; Verbal fluency : french norms (Cardebat et al., 2000) ; Hooper visual organization test : US norms (Hooper, 1983) ; 15 objects test : french norms (Pillon et al., 1989) ; Bell's test : french norms (Gauthier et al., 1989) ; Rey Complex Figure : french norms (Rey, 1960).

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Table 3. Different manifestations observed in schizophrenia, synesthesia, and savant abilities

	Schizophrenia	Synesthesia	Savant abilities
Extraordinary ability	Belief in extraordinary abilities that are not real	None	Genuine superior ability in one specific domain (art, memory, mathematics)
Unusual perception	Perception of something that is not there, with no obvious trigger. The perception is not automatic and can be different each time.	Perception of something that is not there resulting from one particular trigger stimulus that is physically present: the perception is automatically elicited and similar each time.	None
Atypical social personality	<ul style="list-style-type: none"> - Emotional exhaustion - Social withdrawal 	<ul style="list-style-type: none"> - Signs of positive schizotypy - Increased openness to experiences - Decreased agreeableness 	When reported in co-occurrence with autism: <ul style="list-style-type: none"> - social withdrawal
Cognitive profile	<ul style="list-style-type: none"> - Deficit in executive functions - Deficit in working memory - Difficulties of attention 	<ul style="list-style-type: none"> - Higher general cognitive abilities - Grapheme-color synesthesia: diminished motion coherence 	When reported in co-occurrence with autism: <ul style="list-style-type: none"> - Enhanced performance for the block design and embedded figures tests - Diminished performance for tasks involving theory of mind, executive functions

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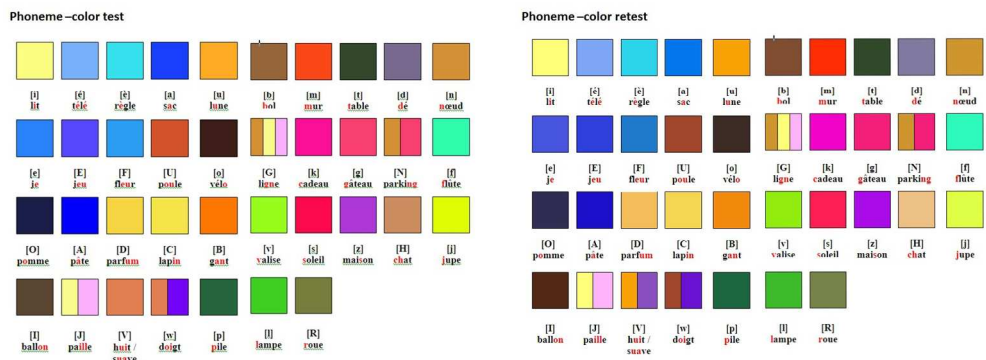


Figure 1. VA's phoneme-color associations

152x57mm (300 x 300 DPI)

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