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Enhanced perception in savant syndrome: patterns, structure and creativity

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According to the enhanced perceptual functioning (EPF) model, autistic perception is characterized by: enhanced low-level operations; locally oriented processing as a default setting; greater activation of perceptual areas during a range of visuospatial, language, working memory or reasoning tasks; autonomy towards higher processes; and superior involvement in intelligence. EPF has been useful in accounting for autistic relative peaks of ability in the visual and auditory modalities. However, the role played by atypical perceptual mechanisms in the emergence and character of savant abilities remains underdeveloped. We now propose that enhanced detection of patterns, including similarity within and among patterns, is one of the mechanisms responsible for operations on human codes, a type of material with which savants show particular facility. This mechanism would favour an orientation towards material possessing the highest level of internal structure, through the implicit detection of within- and between-code isomorphisms. A second mechanism, related to but exceeding the existing concept of redintegration, involves completion, or filling-in, of missing information in memorized or perceived units or structures. In the context of autistics' enhanced perception, the nature and extent of these two mechanisms, and their possible contribution to the creativity evident in savant performance, are explored.

Keywords: autism; savant syndrome; perception; creativity; pattern recognition; redintegration

1. ENHANCED PERCEPTION: FROM AUTISM TO SAVANT SYNDROME

Autism is characterized by enhanced perceptual processing (Happé & Frith 2006; Mottron *et al.* 2006*a*). The superiority of autistics in low-level cognitive operations (e.g. discrimination) is a widely replicated finding in both the visual and auditory modalities (Dakin & Frith 2005; Samson *et al.* 2006). At least at the group level, this advantage can be observed in most operations involving perceptual material. For example, superior discriminative performance co-occurs in the same autistic individuals with enhanced abilities in a variety of target detection tasks involving mnemonic, attentional or visuospatial operations (Caron *et al.* 2006). In the auditory modality, superior pitch discrimination, labelling and memory also co-occur (Bonnel *et al.* 2003; Heaton 2003). Mechanisms involved in these perceptual skill superiorities are not yet fully understood, but a more extensive and atypical involvement of primary and associative perceptual areas during perceptual tasks (Gaffrey *et al.* 2007; Manjaly *et al.* 2007; Milne *et al.* 2009), atypical lateral inhibition in both modalities (Bertone *et al.* 2005; Vandenbroucke *et al.* 2008) and functional autonomy of perceptual operations from top-down processing influences (Caron *et al.* 2006) are complementary and promising physiological explanations.

The collection of empirical findings and associated putative partial mechanisms related to autistic perception has been combined under the label of enhanced perceptual functioning (EPF), a behavioural and physiological model that has recently been updated in the form of a short list of principles (Mottron *et al.* 2006*a*). These principles can be considered variously as descriptive and/or explicative. For example, one principle is that top-down influences on perceptual systems are optional in autism and mandatory in non-autistics. This assertion may act not only as a unifying description for the dominant and extended role of perception in autistic strengths, but also as an explanatory mechanism for the autonomy of perception with respect to various higher level cognitive processes. The wide variety of atypical mechanisms involved in EPF principles suggests that autistic cognitive atypicalities are more accurately described as an entirely different processing system, rather than as a collection of negative cascade effects resulting from one or many major impairments (excesses or deficits) impeding typical processing and development.

The extensive support for EPF in autism is strongly suggestive that perception as a whole should be viewed as an integral part of the mechanisms of savant abilities, in as much as these unexpectedly strong skills are intrinsic manifestations of autistic behaviour, learning

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One contribution of 18 to a Discussion Meeting Issue 'Autism and talent'.

and intelligence. However, it is not yet clear to what extent basic perceptual mechanisms are associated with autistic ability peaks and *a fortiori* with savant abilities. Multiple intervening variables (e.g. nature, age and intensity of exposure to relevant material) may intercede between superior low-level processing and superior visual and auditory cognitive abilities, impeding any affirmation that, for example, enhanced visual discrimination directly produces visuospatial ability peaks, or that enhanced auditory discrimination produces superior musical ability in savant or non-savant autistics.

The key role of atypical perception in savant syndrome is not an entirely new story (see Heaton & Wallace 2004, for a review). For example, Treffert (1989) proposed that eidetic memory may be important in savant syndrome, but this view is contradicted by the transformations that savants consistently perform on their material of expertise. While Snyder & Mitchell (1999) elaborated on a privileged access to typical low-level perceptual processes, these authors do not explain why savant syndrome is so prevalent in autism or why particular abilities (e.g. calendar calculation) are disproportionately represented. Neither do they specify the details of the low-level operations responsible for savant performance. The aim of this paper is therefore to further explore the role of these aspects of perception and memory in the materials and cognitive operations commonly encountered in the investigations of savant syndrome.

2. SAVANT ABILITIES ENTAIL STRUCTURED MATERIAL

Materials involved in savant syndrome consist mainly of human codes (e.g. written language for hyperlexia and list memorizers, music for savant performers and composers, numeration for savant mathematical and calendar calculators, and complex three-dimensional graphic representations for savant artists). Human codes share the property of being structured and predominantly non-arbitrary. Emphasizing the role of pattern recognition is therefore in strong contrast with the idea that unstructured, eidetic-type, memory is a major mechanism underlying savant ability. A structured sequence (as opposed to noise) can be phenomenally defined by the recurrence of a finite list of elementary constituents (letters or ideograms, phonemes, digits, notes and geons). These constituents are spatio-temporally stable, in the sense that the shape of a letter, for example, remains roughly equivalent across its various occurrences. The constituents are also relatively simple forms, generally presented in homogeneous series (letters with letters or digits with digits).

The units composing most human codes are embedded in a hierarchy of recurrent patterns of increasing scale. In the case of written language, a finite series of letters forms a larger number of words, and these words are arranged in phrases and sentences with syntactic regularities. Each level contains elements that are intrinsically more similar within that level than they are across levels. Resemblance within letters defines the alphabet, resemblance among words defines lexicon and redundancy in the arrangement of words defines syntax. A similar structural regularity characterizes music (Jackendoff 1987), and could be used to encode the complexities of the three-dimensional perceptual world (Biederman 1987). Phenomenal resemblance or isomorphism is therefore at the centre of what describes a code, and the structured material composing human codes can be described as embedded organizations of isomorphisms, each class of isomorphism defining a particular level (e.g. phonological, lexical). We contend that the phenomenal redundancy of human perceptual and cognitive codes, in as much as they are processed by autistic perceptual mechanisms, grounds the key role these codes play in autistic strong interests and savant abilities.

3. PATTERN DETECTION IN SAVANT COGNITION

Structure being defined by the presence of repeating basic patterns, one possibility would be that pattern detection mechanisms are especially active in autism. This would explain the unique relationship between what phenomenally defines a structure, and perceptual mechanisms in autism. By especially active, we mean essential in achieving a high level of performance, guiding behaviour, detecting smaller or larger scale units, and being more independent from the influence of non-perceptual cognitive processes. Following this hypothesis, the detection of perceptual similarity between spatio-temporal recurrences of a pattern, whatever its scale, could result in the creation of a lexicon of units—and provide the perceptual root of savant ability. More generally, the detection of regions of the world possessing a high density of similarity among perceptual patterns would orient savants towards their principal materials of interest, i.e. towards commonly available human codes. For example, letters and digits presented in printed material belong to a finite list of visual patterns sharing overall shape and features, with multiple recurrences in the world, and are associated by largely non-arbitrary rules maximizing their salience as stimuli. In calendar calculation, the target information is commonly presented in the form of matrices where digits and letters occupy consistent places in the structure. Three-dimensional geometrical regularities (e.g. geons) are presented and available as two-dimensional representations structured and ruled by linear perspective, while pitches may be presented as locations on keyboards.

The same mechanism that detects intrinsic similarity among simultaneously presented units, or between presented and memorized units, could also detect higher scale isomorphisms by analysing the recurrent structures formed by redundant arrangement of these units, as well as their extrinsic similarities, i.e. recurrent figure–ground relationships between these structures and their context of occurrence. An enhanced role for pattern detection would therefore parsimoniously account both for the heightened interest in codes (characterized by their high level of structural redundancy), and for the detection of within-code, large-scale isomorphisms such as arithmetical structure, calendar structure, syntax and three-dimensional perspective rules.

At a still higher scale level, we propose that many savant abilities involve a one-to-one mapping process between two isomorphic series of elements, a veridical mapping between different codes involving the detection of structural similarity between the two series of units (e.g. written code/oral code). Accordingly, a significant proportion of savant ability involves between-code mapping: hyperlexia maps graphic and oral codes; absolute pitch maps pitch labels or keyboard locations and pitches of the chromatic scale; calendar calculation maps days of the week with dates; and prime number detection maps series of numbers with their factor composition. In all cases, the mastering of these mappings is implicit, both in the way they are learned, and in the frequent difficulty or impossibility that savants have in verbalizing the strategies used to produce answers relying on these mappings.

A beneficial consequence of enhanced pattern detection is that it allows stabilizing associations between labels and precise values within continuous dimensions, which non-autistics are poorly able to memorize. In a significant number of savant abilities, the equivalent ability in non-autistics is only poorly or rarely, if at all, represented. This may be because one series of representations cannot be anchored on the other, as in the example of relative rather than absolute pitch. For pitch perception, non-autistics are able to easily discriminate two distinct pitches as well as to maintain an absolute pitch value in short-term memory, but the pitch is generally lost in long-term memory. Similarly, the three-dimensional regularities of the real word are easily manipulated in three-dimensional visual perception but cannot be maintained even in short-term memory and *a fortiori* cannot be accessed through high-level processes. Recently, we have described prodigious abilities in weight estimation (Mottron *et al.* submitted), which are achieved through the stabilization of a veridical mapping mechanism. GT, who estimates the weight of objects below 500 g with a precision within approximately 5 per cent, proceeds by mentally comparing each object to a 35 g reference unit (the weight of a cereal bar).

Pattern recognition cannot be dissociated from grouping processes. Accordingly, pattern detection could be defined as the capacity to detect organization in the phenomenal aspects of the world. This may be done within the perceptual field, by the detection of relative properties of a series of features (e.g. proximity), or between two series of features (e.g. symmetry and similarity). It has been proposed that in autistics, some mechanisms involved in detecting relational feature properties such as grouping are less efficient (Dakin & Frith 2005). However, as demonstrated in Caron *et al.* (2006), grouping process are, at least under some experimental conditions, intact or even superior, but not mandatory in autism. Likewise, locally oriented graphic construction, resulting from the non-mandatory nature of grouping principles, produces a global figure that respects the relative proportions of each of its elements—demonstrating the integrity of these principles, as has been repeatedly demonstrated in autistic graphic arts (Selfe 1983). Similarly, musical performance in savants encompasses both superior local perception (absolute pitch) and the ability to perceive, perform, transpose, improvise on and enhance global aspects of musical structure (Sloboda *et al.* 1985; Hermelin *et al.* 1987, 1989; Miller 1989; Young & Nettlebeck 1995). Finally, autistics' more independent cognitive processes result in regularities within and among patterns being detected, manipulated and generated at the scale of very large structures (e.g. the 28- or 400-year regularity in calendar calculation)—while still retaining their perceptual nature.

4. PATTERN COMPLETION AT A DIFFERENT SCALE

We have proposed elsewhere (Mottron *et al.* 2006*a*) that the concept of redintegration, as applied to pattern completion tasks, may play an important role in the enhanced cognitive operations characterizing savant syndrome. Redintegration in its current use (Schweickert 1993) consists in completing a cue identical to a part of a larger configuration previously encountered. This completion is multidirectional, such that any part of a configuration can prompt recall of its missing parts. In the case of words, the recalled parts have been encountered as such and the cue and response form a unit in long-term memory. This concept is therefore close to that of pattern completion or of multidirectional cued recall, i.e. the ability to recognize an incomplete figure, a well-documented function of implicit memory (e.g. Toth *et al.* 1994). Its application to autistic production is related to the task support hypothesis first put forward by Bowler *et al.* (1997), in which cues perceptually identical to a part of the remembered material disproportionably aid autistics during recall. Redintegration-related mechanisms could describe savant abilities that are characterized by providing an answer to a closed question (e.g.: what day of the week was…; what is the square root of…; can you sing a C flat…), as well as bidirectional access to some calendar information, which allows the autistic savant DBC to answer with the same facility questions, such as 'what are the months beginning by a Friday?' and 'what day of the week was the 30th of April, 1998?' (Mottron *et al.* 2006*b*). In addition, with some latitude, this account may help explain the ability of savant artists to complete three-dimensional representations starting from any part of a figure, if one considers the state of the drawing at time 1 as a cue for its completion at time 2 (e.g. Mottron & Belleville 1994, fig. 2).

However, a more general concept of pattern or information completion is required in order to encompass the creative scope of savant performance, which clearly exceeds memory and the limitations of redintegration in non-autistics. In addition, autistics' atypical perception would result in pattern or information completion occurring both at a more local level, as well as within structures much larger, than those used to demonstrate the equivalent mechanism in non-autistics. A greater independence among encoded levels of information would also be involved. For example, a non-autistic expert musician with absolute pitch is far more limited than DP, an autistic savant musician, in disembedding and reproducing (that is, completing or filling-in the pattern of) the individual notes in large chords (Pring 2008). Pattern or information completion may also act in combination with typical, conscious cognitive processes. In the case of a response to a question such as 'is this a prime number?', the limited concept of redintegration would be unable to account for factorization of never-encountered numbers or the detection of primes within very large numbers. It is therefore conceivable that the rapid decomposition of the target number into multiple subcomponents can return it to a state of memorized equivalence (e.g. $4\times3=12$) where pattern completion can occur. A similar mechanism could participate in the production of future dates, as in the case of the autistic calendar calculator Donny (Thioux *et al.* 2006) who exhibited a distance effect for future dates, implying the use of some kind of computational procedure.

5. SAVANT CREATIVITY: A DIFFERENT RELATIONSHIP TO STRUCTURE

Savant performance cannot be reduced to uniquely efficient rote memory skills (see Miller 1999, for a review), and encompasses not only the ability for strict recall, requiring pattern completion, but also the ability to produce creative, new material within the constraints of a previously integrated structure, i.e. the process of pattern generation. This creative, flexible, albeit structure-guided, aspect of savant productions has been clearly described (e.g. Pring 2008). It is analogous to what Miller (1999, p. 33) reported on error analyses in musical memory: 'savants were more likely to impose structure in their renditions of musical fragments when it was absent in the original, producing renditions that, if anything, were less 'literal' than those of the comparison participants'. Pattern generation is also intrinsic to the account provided by Waterhouse (1988).

The question of how to produce creative results using perceptual mechanisms, including those considered low-level in non-autistics, is at the very centre of the debate on the relationship between the nature of the human factor referred to as intelligence and the specific cognitive and physiological mechanisms of savant syndrome (maths or memory, O'Connor & Hermelin 1984; rules or regularities, Hermelin & O'Connor 1986; implicit or explicit, O'Connor 1989; rhyme or reason, Nettlebeck 1999). It also echoes the questions raised by recent evidence of major discrepancies in the measurement of autistic intelligence according to the instruments used (Dawson *et al.* 2007).

A combination of multiple pattern completions at various scales could explain how a perceptual mechanism, apparently unable to produce novelty and abstraction in non-autistics, contributes in a unique way to autistic creativity. The atypically independent cognitive processes characteristic of autism allow for the parallel, non-strategic integration of patterns across multiple levels and scales, without information being lost owing to the automatic hierarchies governing information processing and limiting the role of perception in non-autistics.

An interest in internal structure may also explain a specific, and new, interest for domains never before encountered. For example, a savant artist newly presented with the structure of visual tones learned this technique more rapidly and proficiently than typical students (Pring *et al.* 1997). In addition, the initial choice of domain of so-called restricted interest demonstrates the versatility of the autistic brain, in the sense that it represents spontaneous orientation towards, and mastering of, a new domain without external prompts or instruction. How many such domains are chosen would then depend on the free availability of the kinds, amounts and arrangements of information which define the structure of the domain, according to aspects of information that autistics process well. Generalization also occurs under these circumstances, for example, to materials that share with the initial material similar formal properties, i.e. those that allow 'veridical mapping' with the existing ability. In Pring & Hermelin (2002), a savant calendar calculator with absolute pitch displayed initial facility with basic number–letter associations, and was able to quickly learn new associations and provide novel manipulations of these letter–number correspondences.

The apparently 'restricted' aspects of restricted interests are at least partly related to pattern detection, in that there are positive emotions in the presence of material presenting a high level of internal structure, and a seeking out of material related in form and structure to what has already been encountered and memorized. Limitation of generalization may also be explained by the constraints inherent in the role of similarity in pattern detection, which would prevent an extension of isomorphisms to classes of elements that are excessively dissimilar to those composing the initial form. In any case, there is no reason why autistic perceptual experts would be any less firm, diligent or enthusiastic in their specific preferences for materials and domains than their non-autistic expert counterparts. However, it must also be acknowledged that the information autistics require in order to choose and generalize any given interest is likely to be atypical in many respects (in that this may not be the information that non-autistics would require), and may not be freely or at all available. In addition, the atypical ways in which autistics and savants learn well have attracted little interest and are as yet poorly studied and understood, such that we remain ignorant as to the best ways in which to teach these individuals (Dawson *et al.* 2008). Therefore, a failure to provide autistics or savants with the kinds of information and opportunities from which they can learn well must also be considered as explaining apparent limitations in the interests and abilities of savant and non-savant autistics (see also Heaton 2009).

6. STRUCTURE, EMOTION AND EXPERTISE

While reliable information about the earliest development or manifestations of savant abilities in an individual is very sparse, biographies of some savants suggest a sequence starting with uninstructed, sometimes apparently passive, but intent and attentive (e.g. Horwitz *et al.* 1965; Selfe 1977; Sacks 1995) orientation to and study of their materials of interest. In keeping with our proposal about how savants perceive and integrate patterns, materials that spontaneously attract interest may be at any scale or level within a structure, including those that appear unsuitable for the individual's apparent developmental level.

For example, Paul, a 4-year-old autistic boy (with a presumed mental age of 17 months), who was found to have outstanding literacy, exceeding that of typical 9-year olds, intently studied newspapers starting before his second birthday (Atkin & Lorch 2006). It should not be surprising that in savants, the consistent or reliable availability of structured or formatted information and materials can influence the extent of the resulting ability. For example, the types of words easily memorized by NM, proper names, in addition to being redundant in Quebec, share a highly similar structural presentation in the context where NM learned them, including phone books, obituaries and grave markers (Mottron *et al.* 1996, 1998). However, a fuller account of why there is the initial attraction to and preference for materials with a high degree of intrinsic organization, and for specific kinds of such structured materials in any particular individual, is necessary.

Positive emotions are reported in connection with the performance of savant abilities (e.g. Selfe 1977; Sloboda *et al.* 1985; Miller 1989). Therefore, it is possible that a chance encounter with structured material gives birth to an autistic special interest, which then serves as the emotional anchor of the codes involved in savant abilities, associated with both positive emotions and a growing behavioural orientation towards similar patterns (Mercier *et al.* 2000). Brain structures involved in the processing of emotional content can be activated during attention to objects of special interest in autistics (Grelotti *et al.* 2005). So-called repetitive play in autism, associated with positive emotions, consists of grouping objects or information encompassing, as in the codes described above, series of similar or equivalent attributes. In addition, in our clinical experience, we observe that repetitive autistic movements are often associated with positive emotions.

One possibility worth further investigation would be that patterns in structured materials, in themselves, may trigger positive emotions in autism and that arbitrary alterations to these patterns may produce negative emotions—a cognitive account of the insistence on sameness with which autistics have been characterized from the outset (Kanner 1943). Individuals who excel in detecting, integrating and completing patterns at multiple levels and scales, as we propose is the case with savants, would have a commensurate sensitivity to anomalies within the full array of perceived similarities and regularities (e.g. O'Connell 1974). In Hermelin & O'Connor (1990), an autistic savant (with apparently very limited language skills) known for his numerical abilities, including factorization, but who had never been asked to identify prime numbers, instantly expressed—without words—his perfect understanding of this concept when first presented with a prime number. The superior ability of autistics to detect anomalies—departures from pattern or similarity—has accordingly been reported (e.g. Plaisted *et al.* 1998; Baron-Cohen 2005).

Overexposure to material highly loaded with internal structure plausibly favours implicit learning and storage of information units based on their perceptual similarity, and more generally, of expertise effects. Savants benefit from expertise effects to the same extent as non-autistic experts (Miller 1999). Among expertise effects is the recognition of units at a more specific level compared with non-experts and the suppression of negative interference effects among members of the same category. Reduced interference has been demonstrated between lists of proper names in a savant memorizer (Mottron *et al.* 1998). Another expertise effect is the 'frequency effect', the relative ease with which memorization and manipulation of units, to which an individual has been massively exposed, can be accomplished (Segui *et al.* 1982). For example, Heavey *et al.* (1999) found that calendar calculators recalled more calendar-related items than controls matched for age, verbal IQ and diagnosis, but exhibited unremarkable short- or long-term recall of more general material unrelated to calendars. These two aspects of expertise would favour the emergence and the stabilization of macrounits (e.g. written code in a specific language, or set of pitches arranged by harmonic rules), which are perceptually the spatio-temporal conjunctions of recognizable patterns related by isomorphisms. Conversely, pattern detection may be unremarkable or even diminished in the case of arbitrarily presented unfamiliar material (Frith 1970).

Identifying savant syndrome as aptitude, material availability and expertise, combined with an autistic brain characterized by EPF, is also informative on the relationship between savant syndrome and peaks of ability in non-savant autistics. Perceptual peaks are largely measured using materials with which the participant has not been trained, whereas savant syndrome encompasses the effects of a life spent pursuing the processing of specific information and materials. We therefore forward the possibility that the range and extent of autistic abilities may be revealed only following access to specific kinds, quantities and arrangements of information. However, we do not expect savant abilities to differ from non-savant autistic peaks of ability in their basic mechanisms. According to this understanding of differences between savant and non-savant autistics, the fact that not all autistics are savants is no more surprising than the fact that not all non-autistics are experts.

7. BEHAVIOURAL AND BRAIN IMAGING SUPPORT FOR ENHANCED PERCEPTION IN SAVANT SYNDROME

The proposals in this paper lack sufficient empirical support from savant studies, but are consistent with the well-established role of enhanced perception in autistic cognitive abilities. This is evident in a large variety of tasks studied in non-savant autistics, ranging from visuospatial peaks of ability such as the hidden figure task (Manjaly *et al.* 2007) to high-order tasks such as the N-back task (Koshino *et al.* 2005). In the latter study, the authors report that whereas non-autistics exposed to series of letters that can be either linguistically or perceptually processed exhibit activation of left frontal regions, consistent with the occurrence of mandatory linguistic processing, autistics exhibit mainly extrastriate activation, consistent with their optional use of a more perceptual mechanism. The ability to engage perception in this task did not disadvantage the autistics who performed as well as their controls, and were more flexible in rapidly adjusting to different N-back conditions. Nor does the optional ability of autistics to perceive letters as images hamper their ability to comprehend sentences, a task in which a group of autistics performed dramatically faster than typical individuals (Just *et al.* 2004).

Similarly, hyperlexic children display 'acute visual registration mechanisms for written language' (Goldberg & Rothermel 1984, p. 759; see also, Cobrinik 1982), but this superior perceptual ability does not impinge on their skill in reading visually distorted words or pseudowords (Goldberg & Rothermel 1984; Atkin & Lorch 2006); and these children are not impeded, as are typical children, by the notorious complexity and difficult orthography of written English (Seymour *et al.* 2003). An extrastriate pattern of activation has also been observed in a 9-year-old boy with limitations in oral skills in the presence of decoding skills 6 years in advance of his chronological age (he began his interest for printed material at 13 months). He showed greater activity than reading age-matched controls in the right posterior inferior temporal sulcus, an extrastriate region belonging to the right ventral stream known to be important in visual form recognition. This area is activated in early stages of reading acquisition, but its activity disappears with age. Interestingly, these areas were activated in addition to typical left hemisphere phonological decoding systems (Turkeltaub *et al.* 2004), which is indicative of an important role for perception in exceptional reading ability in autistics.

Future research should explore the role of enhanced perception across the development of expertise, as well as in the entire range of exceptional abilities in savants and autistics. Particular consideration should be given to domains in which, given the opportunity, these individuals perform with proficiency, flexibility and creativity.

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