Chapter 15

The paradox of autism: why does disability sometimes give rise to talent?

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Summary

We explore why people with autism spectrum conditions (ASC) not only show deficits but also areas of intact or even superior skill. The deficits are primarily social; the areas of intact or superior skill involve attention to detail and systemizing. Systemizing is the drive to analyse or build a system. We review the evidence related to systemizing in ASC and discuss its association with sensory hypersensitivity. We close by considering the evolution and adaptive features of systemizing and how – taken to an extreme – this can also give rise to disability.

Introduction

Paradoxes emanating from human brain functioning have long been noted – patients with amnesia who cannot *explicitly* recall information but who nevertheless reveal *implicitly* that they do recall information; patients with reported blindness who nevertheless demonstrate some 'unconscious' vision ('blindsight'); Brazilian street children who fail academic mathematics tests but who are lightening quick in performing calculations in the market place; and individuals who experience perceptions in one sensory modality when a different sensory modality is stimulated ('synaesthesia'). In some sense, paradoxes in brain functioning should perhaps not be so surprising given the number of different 'modules' and pathways in the brain, such that some functions may be impaired whilst others may simultaneously be either intact or even superior.

Whilst we are familiar with syndromes where most, if not all, cognitive functions are impaired (such as in certain forms of learning disability or dementia), this chapter focuses on what can be learnt from syndromes displaying uneven cognitive profiles. At the most general level, such syndromes may constitute evidence for neurological 'dissociations' and may reveal alternative strategies the brain can employ to solve a task. In this chapter, we focus on autism spectrum conditions (ASC) in which individuals characteristically show a mix of 'deficits' alongside 'intact' cognitive skills, and where in some individuals there are even 'islets of ability' that constitute talent – so-called 'savantism'.

Savantism describes a cognitive profile where an individual shows an area of skill that is significantly superior relative to their other skills. Savantism stands out most clearly in individuals who have a general developmental delay ('learning difficulties'), where IQ is in the below-average range, and this nicely sums up the idea of the 'paradoxical brain', since in such cases it is clear that IQ cannot explain the individual's level of functioning in all

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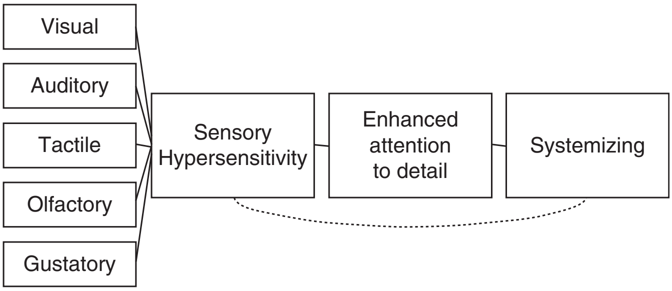

Figure 15.1 A proposed heuristic continuum suggesting how a multimodal, irregular profile of sensory hypersensitivity could lead to enhanced attention to detail. This, in turn, could lead to a drive for categorizing the external world on the basis of highly exact, perceptual details and a systemizing bias in cognition. An alternative model (dotted line) suggests that hyper-systemizing is also linked to sensory hypersensitivity, without necessarily being mediated through enhanced attention to detail (all lines represent a bidirectional flow). Current research in our lab is testing these two models. At top of first of four drawings (Figure 2) Taken from Myers *et al.* (2004).

areas. Savantism is found more commonly in ASC than in any other neurological group, and the majority of those with savantism have an ASC (Hermelin, 2002). ASC entails significant social and communication disability, alongside narrow and repetitive interests (APA, 1994). This 'co-morbidity' shows us that these two profiles are associated well above chance. This forces us to ask: why the link between talent and autism? And how is this paradox (a disability at times associated with talent) to be explained (cf. Treffert, 2010)? In this chapter we argue that whilst savantism, defined as prodigious talent, is only seen in a subgroup of people with ASC (e.g. Baron-Cohen *et al.*, 2007), a universal feature of the autistic brain is *excellent attention to detail* (Shah and Frith, 1993; Jolliffe and Baron-Cohen, 1997; O'Riordan, *et al.*, 2001). Further, we argue that excellent attention to detail exists in ASC because of evolutionary forces positively selecting brains for *strong systemizing*, a highly adaptive human ability (Baron-Cohen, 2008).

Strong systemizing requires excellent attention to detail, and in our view the latter is in the service of the former. Attention occurs at an early level of cognition, whilst systemizing is a fairly high-level aspect of cognition. Next, we argue that one can trace excellent attention to detail to its basis in *sensory hypersensitivity* in ASC (see Figure 15.1). Finally, we review our research programme exploring this in different sensory modalities. But first, what is systemizing?

Systemizing

Talent in autism comes in many forms, but a common characteristic is that the individual becomes an expert in *recognizing repeating patterns* in stimuli. We call this systemizing, defined as the drive to analyse or construct systems. These might be any kind of system. What defines a system is that it follows *rules*, and when we systemize we are trying to identify the rules that govern the system, in order to predict how that system will behave (Baron-Cohen, 2006). These are some of the major kinds of system:

- *collectible* systems (e.g. distinguishing between types of stones or wood),
- *mechanical* systems (e.g. a video-recorder or a window lock),
- *numerical* systems (e.g. a train timetable or a calendar),
- *abstract* systems (e.g. the syntax of a language, or musical notation),
- *natural* systems (e.g. the weather patterns, or tidal wave patterns),

- *social* systems (e.g. a management hierarchy, or a dance routine with a dance partner),
- *motoric* systems (e.g. throwing a Frisbee or bouncing on a trampoline).

In all these cases, you systemize by noting regularities (or structure) and rules. The rules tend to be derived by noting if p and q are *associated* in a systematic way. The general formulation of what happens during systemizing is one looks for laws of the form *'if p, then q'*. If we multiply 3 by itself, then we get 9. If we turn the switch to the down position, then the light comes on. When we think about the kinds of domains in which savants typically excel, it is those domains that can be readily systemized.

Examples might be from numbers (e.g. spotting if a number is a prime number), calendrical calculation (e.g. telling which day of a the week a given date will fall), drawing (e.g. analysing space into geometric shapes and the laws of perspective; and perfecting an artistic technique), music (e.g. analysing the sequence of notes in a melody, or the lawful regularities or structure in a piece), memory (e.g. recalling long sequences of digits or lists of information), or even learning foreign languages (e.g. learning vocabulary, or the laws of grammar). In each of these domains, there is the opportunity to repeat behaviour in order to check if one gets the very same outcome every time. Multiplying 3 by itself *always* delivers 9, the key change in this specific musical piece *always* occurs in the 13th bar, throwing the ball at this particular angle and with this particular force *always* results in it landing in the hoop.

Systemizing the Rubik's Cube

Let's take a real, cardinal example of savantism: a non-conversational child with autism who can solve the Rubik's Cube 'problem' in 1 minute and 7 seconds. This is a nice example because it illustrates several things. First, that the child's non-verbal ability with the Rubik's Cube is at a much higher level than either his communication or social skills, or indeed what one would expect of his age. Second, it prompts us to ask: what are the processes involved in solving the Rubik's Cube? At a minimum, it involves analysing or memorizing the sequence of moves to produce the correct outcome. It is a series of 'if p, then q' steps. This child with autism appeared to have 'discovered' the layer-by-layer method to solve the $3 \times 3 \times 3$ Rubik's Cube problem, which takes a minimum of 22 moves. (Note he was not as fast as the current 2008 World Champion Erik Akkersdijk who in the Czech Open championship solved the Rubik's Cube in 7.08 seconds!)

Systemizing in autism spectrum conditions

What is the evidence for intact or even unusually strong systemizing in ASC? First, such children perform above the level that one would expect on a physics test (Baron-Cohen *et al.*, 2001). Children with Asperger Syndrome (AS) as young as 8–11 years scored higher than a comparison group who were older (typical teenagers). Second, using the Systemizing Quotient (SQ), people with high functioning autism or AS score higher on the SQ compared to general population controls (Baron-Cohen *et al.*, 2003). Third, children with classic autism perform better than controls on the picture sequencing test where the stories can be sequenced using physical–causal concepts (Baron-Cohen *et al.*, 1986). They also score above average on a test of how to figure out how a Polaroid camera works, even though they have difficulties figuring out people's thoughts and feelings (Baron-Cohen *et al.*, 1985; Perner *et al.*, 1989). The Polaroid camera test was used as a mechanical equivalent to the False Belief test, since in the former all one has to do is infer what will be represented in a photograph given the 'line of sight' between the camera and an object, whereas in the latter one has to infer what belief (i.e. mental representation) a person will hold given what they saw and therefore know about. (A Polaroid camera was used because then the experimenter could state their prediction about the content of the photo, and have this verified within minutes.)

Strong systemizing is a way of explaining the non-social features of autism: the narrow interests, repetitive behaviour and resistance to change/need for sameness. This is because when you systemize, it is best to keep everything constant, and to only vary one thing at a time. That way, you can see what might be causing what, and with repetition you can verify that you get the very same pattern or sequence ('if p, then q') every time, rendering the world predictable. One issue is whether hyper-systemizing only applies to the *high*-functioning individuals with ASC. Whilst their obsessions (with computers or maths, for example) could be seen in terms of strong systemizing (Baron-Cohen *et al.*, 1999), when we think of a child with *low*-functioning autism, many of the classic behaviours can be seen as a reflection of their strong systemizing, if looked at through this theoretical framework. Some examples are listed in Box 1.

Systemizing and Weak Central Coherence

Like the Weak Central Coherence (WCC) theory (Frith, 1989), the hyper-systemizing theory is about a different cognitive style (Happe, 1996). Like that theory, it also posits *excellent attention to detail* (in perception and memory), since when you systemize you have to pay attention to the tiny details. This is because each tiny detail in a system might have a functional role leading to new information of the form 'if p, then q'. Excellent attention to detail in autism has been repeatedly demonstrated (Shah and Frith, 1983, 1993; Jolliffe and Baron-Cohen, 2001; O'Riordan *et al.*, 2001; Mottron *et al.*, 2003; Baldassi *et al.*, 2009; Joseph *et al.*, 2009).

One difference between these two theories is that the WCC theory sees people with ASC as drawn to detailed information (sometimes called a local processing bias) either for *negative* reasons (an inability to integrate was postulated in the original version of this theory), or because of stronger local processing (in the later version of this theory). In contrast, the hyper-systemizing theory sees this same quality (excellent attention to detail) as being highly purposeful; it exists in order to understand a system. Attention to detail is occurring for *positive* reasons: in the service of achieving an ultimate understanding of a system, however small and specific that system might be.

We can return to the Rubik's Cube problem to see the difference between these two theories more clearly. At one level, the Rubik's Cube is a 3D Block Design Test but where the cubes are all connected. Recall that the Block Design Test is the subtest on Weschler IQ tests on which people with autism perform at their best (Shah and Frith, 1993; Happe, 1996). The Rubik's Cube contains 21 moveable connected cubes (since the 5 central cubes do not move) with different coloured faces in the $3 \times 3 \times 3$ version. According to WCC theory, the reason why people with autism show superior performance on the Block Design Test is that their good local processing enables them to 'see' each individual cube even if the design to be copied is not 'pre-segmented' (Shah and Frith, 1983). It is clear how good local processing would lead to faster 'analysis' of the whole (design) into constituent parts (the individual cubes), but to solve the Rubik's

Box 1 Systemizing in classic autism and/or Asperger Syndrome

Type of systemizing	Classic autism	Asperger Syndrome
Sensory systemizing	Tapping surfaces, or letting sand run through one's fingers	Insisting on the same foods each day
Motoric systemizing	Spinning round and round, or rocking back and forth	Learning knitting patterns or a tennis technique
Collectible systemizing	Collecting leaves or football stickers	Making lists and catalogues
Numerical systemizing	Obsessions with calendars or train timetables	Solving maths problems
Motion systemizing	Watching washing machines spin round and round	Analysing exactly when a specific event occurs in a repeating cycle
Spatial systemizing	Obsessions with routes	Developing drawing techniques
Environmental systemizing	Insisting on toy bricks being lined up in an invariant order	Insisting that nothing is moved from its usual position in the room
Social systemizing	Saying the first half of a phrase or sentence and waiting for the other person to complete it	Insisting on playing the same game whenever a child comes to play
Natural systemizing	Asking over and over again what the weather will be today	Learning the Latin names of every plant and their optimal growing conditions
Mechanical systemizing	Learning to operate the VCR	Fixing bicycles or taking apart gadgets and reassembling them
Vocal/auditory/verbal systemizing	Echoing sounds	Collecting words and word meanings
Systemizing action sequences	Watching the same video over and over again	Analysing dance techniques

Cube (or the Block Design problem), more than just good local processing is needed. A strength in 'if p, then q' type reasoning is also required. On the classic Block Design subtest you need to *mentally or manually rotate* the cube to produce the relevant output. That is, you need to *perform an operation* on the input to produce the relevant output. The same is true (but with more cubes and therefore more complexity) in the Rubik's Cube problem: 'If the red cube with the green side is positioned on the top layer on the right side and I rotate the top layer anticlockwise by 90°, then this will complete the top layer as all one colour'.

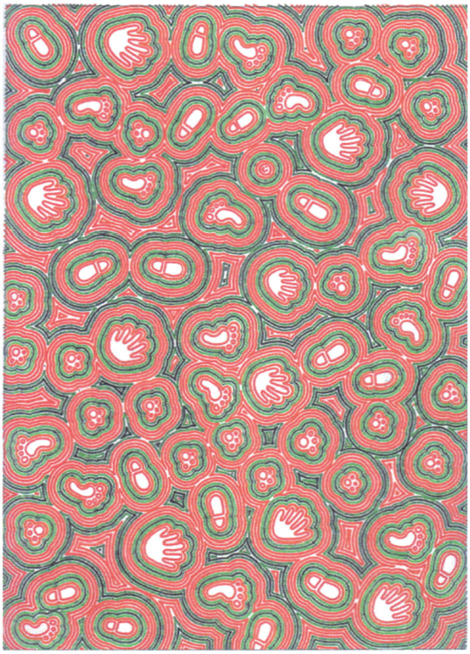

Figure 15.2 Symbolic impressions. MK-79.

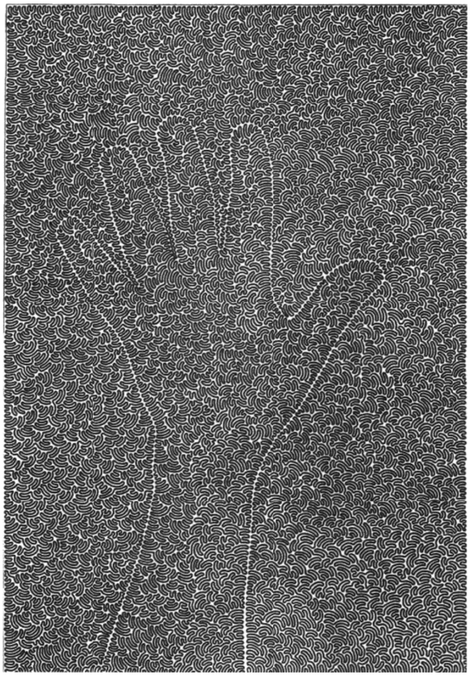

Figure 15.3 Peter's Hand. MK-VII.

In earlier formulations of systemizing, the key cognitive process was held to be in terms of [input–operation–output] processing (Baron-Cohen, 2002, 2006). In mathematics, if the input = 3, and the operation = cubing, then the output = 27. In the Rubik's Cube notional example above, the input = [the red cube with the green side is positioned on the top

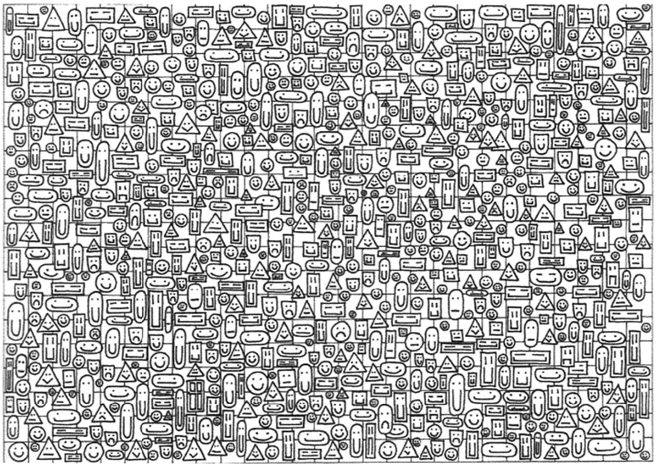

Figure 15.4 Untitled [Author's Note – 'A development of the well-known smiley face symbol/design'.]

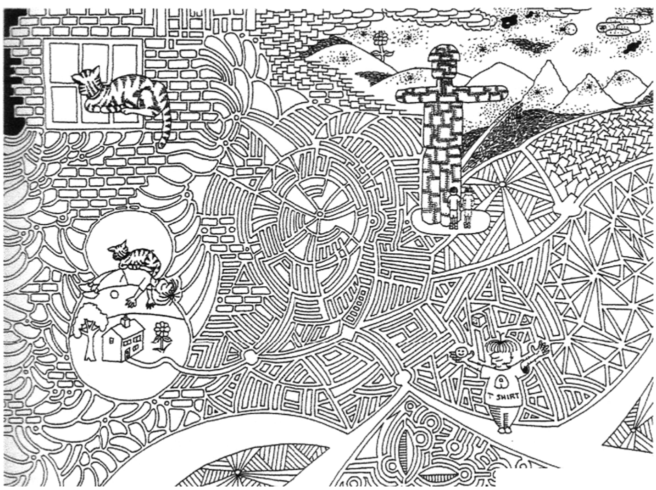

Figure 15.5 Mazewandering.

layer on the right side], the operation = [rotate the top layer anticlockwise by 90°], and the output = [complete the top layer as all one colour]. Notice that WCC makes no mention of the key part of this, that is *noting the consequences of an operation*. Simply seeing the parts in greater detail would not by itself lead to *understanding the operations* (the moves) needed to solve the Rubik's Cube.

Another difference between the WCC theory and the hyper-systemizing theory is that the latter (but not the former) predicts that, over time, the person may achieve an excellent understanding of a whole system, given the opportunity to observe and control all the variables (all the 'if p, then q' rules) in that system. WCC would predict that, even given all the time in the world, the individual will be forever lost in the detail. The existence of talented mathematicians with AS like Richard Borcherds is proof that such individuals can *integrate* the details into a true understanding of the system (Baron-Cohen, 2003). In the rule 'if p, then q', the terms 'if' and 'then' are how the details become integrated, albeit one small step at a time. The idea at the neurological level that ASC involves an abundance of local short-range connectivity (Belmonte *et al*., 2004) may explain this cognitive style of identifying one specific link between two details.

Hyper-systemizing: implications for education

Teachers, whether of children with autism or adults with AS, need to take into account that hyper-systemizing will affect not only how people with ASC learn, but also how they should be assessed. IQ test items, essays and exam questions designed for individuals who are 'neurotypical' may lead to the person with ASC scoring zero when their knowledge is actually greater, deeper and more extensive than that of most people. What can appear as a slow processing style may be because of the massively greater quantity of information that is being processed.

A man with AS reported recently: 'I see all information in terms of links. All information has a link to something and I pay attention to these links. If I am asked a question in an exam I have great difficulty in completing my answer within the allocated 45 minutes for that essay, because every fact I include has thousands of links to other facts, and I feel my answer would be incorrect if I didn't report all of the linked facts. The examiner thinks he or she has set a nice circumscribed question to answer, but for someone with autism or Asperger Syndrome, no topic is circumscribed. There is ever more detail with ever more interesting links between the details'.

When asked about the concept of apple, for example, he could not give a short summary answer such as 'an apple is a piece of fruit' (i.e. referring to the prototypical level 'apple' as linked to the superordinate level 'fruit'), but had to continue by also trying to link it to the 7500 different species of apple (the subordinate level concepts), listing many of each type and the differences in terms of the history of each species, how they are cultivated, what they taste and look like, etc. When asked about the concept of beetle, he could not just give a summary answer such as 'a beetle is an insect' but had to mention as many of the 350,000 species of beetle that he knew existed. If he was asked to be less long-winded, he could not do it, since all facts to him seemed important and it made him feel anxious to leave any out. If asked to just include the important facts and to exclude the unimportant facts, he could not decide which fell into the 'important' category.

This cognitive style is understandable in terms of the hyper-systemizing theory because a concept is a system. A concept is a way of using an 'if p, then q' rule to define what to include as members of a category (e.g. if it has scales and gills, then it is a fish). Furthermore, concepts exist within a classification system, which are rules for how categories are related to one another. So, the question 'what is a beetle?' is trivial for a neurotypical individual who simply answers in terms of a crude, imprecise and fuzzy category: 'it is an insect'. It may, however, require a very long, exhaustive answer from someone with autism: 'beetles are members of the category of animal (kingdom), arthropods (phylum), insects (class), pterygota (sub-class), neoptera (infra-class), endopterygota (super-order), coleoptera (order), and could be in one of 4 sub-orders (adephaga, archostemata, mycophaga and polyphaga), each of which has an infra-order, a super-family and a family'. Even the previous sentence would, for this man with AS, be a gross violation of the true answer to the question because so much important factual information has been left out. But for the hyper-systemizer, getting these details correct matters, because the concept – and the classification system linking concepts – is *a system for predicting* how this specific entity (this specific beetle) will behave or will differ from all other entities.

Hyper-systemizing theory vs. Executive Dysfunction theory

The Executive Dysfunction (ED) theory (Rumsey and Hamberger 1988; Ozonoff *et al*., 1991; Russell, 1997) is the other major theory that has attempted to explain the non-social features of ASC, and particularly the repetitive behaviour and narrow interests that characterize ASC. According to this theory, aspects of executive function (action control) involved in flexible switching of attention and planning are impaired, leading to perseveration. The ED theory, like the WCC theory, has difficulty in explaining instances of good understanding of a whole system, such as calendrical calculation, since within the well-defined system (calendar) attention can switch very flexibly. The ED theory also predicts perseveration (so-called 'obsessions'), but does not explain why in autism and AS these should centre on systems (Baron-Cohen and Wheelwright, 2004). Finally, the ED theory simply re-describes repetitive behaviour as an instance of executive dysfunction without seeing what might be positive about the behaviour.

So, when the low-functioning person with classic autism has shaken a piece of string thousands of times close to his eyes, whilst the ED theory sees this as perseveration arising from some neural dysfunction which would normally enable the individual to shift attention, the hyper-systemizing theory sees the same behaviour as a sign that the individual 'understands' the physics (i.e. recognizes the patterns) behind the movement of that piece of string. He may be able to make it move in exactly the same way every time. Or, to take another example, when he makes a long, rapid sequence of sounds, he may 'know' exactly that acoustic pattern, and get some pleasure from the confirmation that the sequence is the same every time. A mathematician might feel an ultimate sense of pleasure in the 'golden ratio' (that $(a + b)/a = a/b$ and that this *always* comes out as 1.61803399). Similarly, a child – even one with low-functioning autism – may produce the same outcome every time with their repetitive behaviour, and appear to derive some emotional pleasure at the predictability of the world. This may be what is clinically described as 'stimming' (Wing, 1997), where an individual's attention is wholly focused on their current actions or thoughts and they lapse into a trance-like state and may experience a surge of excitement that manifests as a sudden 'explosion' of movement. Autism was originally described as involving 'resistance to change' and 'need for sameness' (Kanner, 1943), and here we see that important clinical observation may be the hallmark of strong systemizing. Recent neuroimaging studies suggest that there might be aberrant processing of rewards in people with ASC (Schmitz *et al*., 2008; De Martino *et al*., 2008) and it will be important for future neuroimaging studies to test if the reward systems in the brain (e.g. the dopaminergic or cannabinoid systems) are active during such repetitive behaviour.

If we return to the Rubik's Cube example, an executive dysfunction would predict that an inability to 'plan' should make solving a Rubik's Cube impossible for a savant with autism. In contrast, as we saw earlier, the hyper-systemizing theory has no difficulty in explaining such talent.

Sensory hypersensitivity

Rather than assuming that the strong systemizing in ASC is ultimately reducible to excellent attention to detail, in this section we pursue the idea that the excellent attention to detail is itself reducible to sensory hypersensitivity. In 2001, Mottron and Burack postulated the 'enhanced perceptual functioning' (EPF) model of ASC, characterized by superior low-level perceptual processing (Mottron and Burack, 2001). To what extent is this a feature of basic sensory physiology?

Studies using questionnaires such as the Sensory Profile have revealed sensory abnormalities in over 90% of children with ASC (Leekam *et al*., 2001; Kern *et al*., 2006; Tomchek and Dunn, 2007). In *vision*, Bertone *et al*. found individuals with ASC are more accurate at detecting the orientation of first-order gratings (simple, luminance-defined) but less accurate at identifying second-order gratings (complex, texture-defined) (Bertone *et al*., 2003). In the *auditory* modality, superior pitch processing has been found in ASC (Mottron *et al*., 1999; Bonnel *et al*., 2003; Heaton *et al*., 2008). In a case study, Mottron *et al*. reported exceptional absolute judgement and production of pitch (Mottron *et al*., 1999). Bonnel *et al*. found superior pitch discrimination and processing abilities in individuals with high-functioning autism (Bonnel *et al*., 2003). O'Riordan and Passetti (2006) also reported superior auditory discrimination ability in children with ASC, and Jaevinen-Parsley *et al*. (2002) showed superior perceptual processing of speech in children with autism.

In the *tactile* modality, Blakemore *et al*. (2006) showed hypersensitivity to vibrotactile stimulation. In addition, the ASC group rated supra-threshold tactile stimulation as significantly more tickly and intense than did the control group. Tommerdahl *et al*. (2007) reported that participants with ASC outperformed controls in tactile acuity after short adaptation to a vibrotactile stimulus period of 0.5 s. (Note that this hypersensitivity is not always observed. On a tactile discrimination task, O'Riordan and Passetti (2006) found no differences in children with autism compared to controls.) Cascio *et al*. (2008) investigated tactile sensation and reported increased sensitivity to vibrations and thermal pain in ASC, while detection to light touch and warmth/cold were similar in both groups.

Only two previous studies have been reported investigating olfaction in ASC, and unlike the research into the other senses which consistently find hypersensitivity, both of these studies reported *deficits* in identifying odours despite intact odour detection (Bennetto and Kuschner, 2007; Suzuki *et al*., 2003). Looking more closely at the two previous studies into olfaction in ASC, both required participants to explicitly identify the odour from a choice of responses, a methodology likely to involve both executive function and memory. For example, the study by Bennetto and Kuschner (2007) required participants to decide which of four possible responses an odour matched. A simpler task might provide a purer test of low-level olfactory discrimination in ASC.

An experiment from our lab examined vision in ASC in terms of basic sensory detection thresholds (acuity – Ashwin *et al*., 2009; cf. Bach and Dakin, 2009). Ongoing studies from our lab are also testing sensory detection thresholds in other modalities (touch, audition and olfaction). Full details of these experiments are reported elsewhere (Ashwin *et al*., 2008; Ashwin *et al*., submitted; Tavassoli *et al*., submitted). Results from these and other experiments demonstrated greater sensory perception in ASC across multiple modalities. In the context of the earlier discussion of hyper-systemizing and excellent attention to detail, we surmise that these sensory differences in functioning may be affecting information processing at an early stage (both in terms of sensation/cognition, and in terms of development) in ways that could both cause distress but also predispose to unusual talent. These results of hypersensitivity confirm previous findings, and mirror anecdotal reports of individuals with ASC (Grandin, 2000). For example, Temple Grandin writes that 'overly sensitive skin can be a big problem . . . Shampooing actually hurt my skin . . . To be lightly touched appeared to make my nervous system whimper, as if the nerve ends were curling up'. In terms of increased sensitivity to certain types of auditory stimuli (high frequencies), there are anecdotal reports that individuals with autism tend to avoid certain sounds. Grandin states 'I can shut out my hearing and withdraw from most noise, but certain frequencies cannot be shut out . . . High pitched, shrill noises are the worst'. Mottron *et al*. (1999) reported the case of a woman with autism who was hypersensitive to frequencies from 1 to 5 kHz at 13 years of age, and to 4 kHz at 18 years.

Enhanced sensitivity may be specific to certain stimuli in all modalities. In vision, Bertone *et al*. (2003) pointed out the importance of specific stimuli in investigating visual differences in ASC. In the case of touch, Blakemore *et al*. (2006) reported hypersensitivity for higher frequency (200 Hz) vibrotactile stimulation, but not for lower (30 Hz). Pinpointing the precise stimuli in which enhanced sensitivity occur in ASC will be important for future research. To our knowledge, the highest frequency that has been used to investigate hearing in ASC is 8 kHz (Bonnel *et al*., 2003). Our ongoing study investigates very high frequencies, up to 18 kHz (Tavassoli *et al*., submitted). The reported hypersensitivity through frequencies above 16 kHz is especially important since some environmental sounds operate at or above this range of frequencies. Grandin reported, 'Some of the sounds that are most disturbing to autistic children are the high-pitched, shrill noises made by electrical drills, blenders, saws and vacuum cleaners'.

Hypersensitivity could result from a processing difference at various sensory levels including the density or sensitivity of sensory receptors, inhibitory and exhibitory neurotransmitter imbalance or speed of neural processing. Belmonte *et al*. (2004) suggested *local range neural overconnectivity* in posterior, sensory parts of the cerebral cortex is responsible for the sensory 'magnification' in people with ASC. Whilst our lab and others have tested sensory profiles in ASC using fMRI (Gomot *et al*., 2006, 2008; Belmonte *et al*., 2010), the combination of imaging and genetic approaches to study sensory perception in fMRI may lead toward a more complete picture. We conclude that the search for the association between autism and talent should start with the sensory hypersensitivity, which gives rise to the excellent attention to detail, and which is a prerequisite for hyper-systemizing.

Finally, excellent attention to detail may exist in ASC because of evolutionary forces positively selecting brains for *strong systemizing*, a highly adaptive human ability (Baron-Cohen, 2008). Without systemizing, *Homo sapiens* would not have developed new stone tools in the Stone Age, or ornaments, metal tools weapons through smelting and the use of forges in the Iron Age. Nor would humans have developed mathematics in Greece in the sixth century BC or in China in 300 BC and India in 100 AD. Nor would we have seen the supreme achievements of suspension bridges or machines in the Industrial Revolution or computers in the Digital Revolution. There is little question that humans have dominated the planet because of their remarkable ability to transform their environment through invention, and at the heart of such fabrication of new tools is systemizing – understanding how things work. The 'paradoxical brain' is thus a phrase that neatly sums up how an ability that has been extraordinarily useful across human evolution can – when taken to extremes – also be associated with disability.

Future challenges and questions

This view outlined in this chapter nevertheless raises new questions and challenges. Why should systemizing in classic autism focus on more concrete repetitive actions whilst systemizing in Asperger Syndrome might focus on more abstract repeating patterns (such as mathematics)? Can IQ alone explain these different manifestations of strong systemizing? And why should strong systemizing give rise to social disability? Is it simply because the social world is hard if not impossible to systemize? Or is it because innate social modules are also impaired? How can the strong systemizing in ASC, and evidence of enhanced memory (Hillier *et al.*, 2007), be harnessed to facilitate education and intervention, to reduce disability? Teaching social skills via computers and in other systematic formats may be one such approach, but there is clearly an opportunity for much more in this area. Finally, what are the neural mechanisms underlying enhanced functioning in conditions such as those described in this chapter – for example, is altered connectivity between brain structures the key (Boso *et al.*, 2010), or can neuronal hypertrophy or anomalous forms of cell migration/cell structure be part of the explanation (cf. Conacher, 1990; Lee *et al.*, 2006; Casanova *et al.*, 2007; Huang, 2009)?

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