Autistic Listening

William J. Davies

1. Introduction

Autism is a lifelong neurodevelopmental condition diagnosed by differences in social interaction (e.g., conversation style), social communication (e.g., eye contact) and social imagination (e.g., restricted interests). Incidence rates have risen substantially over the last fifty years, alongside increased availability of diagnosis and changes to diagnostic criteria (Matson and Kozlowski 2011). The current NHS prevalence is 1.1% for the UK. I use the term autism here in the same way as the current diagnostic manuals, to include all autistic spectrum conditions, such as Asperger Syndrome (American Psychiatric Association 2013). Autism may be accompanied by a learning disability, but in the current diagnostic guidelines autism and learning disability are two independent diagnoses. It is notable that, although the basis of autism is neural (autistic brains seem to process information differently), it is diagnosed by observation of behaviour.

The majority of autistic people experience atypical sensory processing, for example a heightened sensitivity to sound or texture (Crane, Goddard, and Pring 2009). These sensory differences were noticed from the earliest identifications of autism (Kanner 1943) although they have only recently been included as a diagnostic feature. Response to sound is probably the most obvious of the sensory differences, so early autism literature often features accounts of children upset by loud sounds in experiments (Hermelin and O'Connor 1970) or covering their ears when they hear a vacuum cleaner or a washing machine (Frith and Baron-Cohen 1987).

The research priorities of autism researchers are not, on the whole, well aligned to those of autistic people (Fletcher-Watson et al. 2018). Hearing differences may be an exception to this. Understanding sensory differences appears in the top ten research topics of the autistic community (Autistica 2015). And there is a large and rapidly growing body of research on hearing in autistic people, especially on auditory processing differences (O'Connor 2012). However, this chapter will argue that this literature provides an incomplete and one-sided picture of autistic auditory experience. This is because almost all of it is conducted by non-autistic researchers looking from the outside, onto an autistic experience they do not share.

2. A model of auditory processing

Before looking at accounts of how autistic people respond to sound, it will be helpful to review a standard model of auditory processing. Figure 1 illustrates an overview of the chain of auditory processing that applies to all humans. Auditory perception is represented as blocks, each performing a function or set of functions and passing output information on to the next block. This functional representation is an abstraction from the biological reality: the blocks do not map exactly onto identifiable anatomical structures. In this section, the function(s) of each block are described as they are thought to occur in an auraltypical person; the many aural divergences described in this book will be reflected in a difference within one or more block in Fig. 1.

<FIGURE 1>

The first stage of auditory processing is hearing. Hearing describes the processing of sound in the ear. The inner ear (the cochlea) is responsible for turning the acoustic signal into neural data that are interpreted by the brain. This first stage is signal detection. The ear also performs low-level processing of the sound to code information such as pitch and loudness into the neural data stream (Fastl and Zwicker 2007). Subsequent stages take place in the brain.

The second stage is labelled listening. Here the incoming signal is parsed into meaningful sound objects. This part of listening is called auditory scene analysis (Bregman 1994). It allows us to take the soundscape around us and separate out the combined sound into separate parts. Often, this is primarily done at the level of sound sources. For example, we are exposed to an indoor soundscape consisting of someone speaking, room reverberation, ventilation noise and traffic noise through the window. Our brain performs auditory scene analysis to integrate the reverb with the speech and separate the ventilation and traffic noise into separate signals. Our attention mechanism selects one of these sounds for further, more detailed processing (Spence and Santangelo 2010).

In this example, we probably selected the speech signal. Speech is a very rich signal containing linguistic information but also many contextual indicators of the person speaking (age, emotional state, education, etc.) The higher processing of these happens in the box labelled ‘Understanding’. If we selected a different sound, perhaps the traffic noise, different processing would be applied to extract information about the context of that sound (such as speeds, distance and so on).

The top of our chain of auditory processing is labelled Responding. This is where conscious processing begins, and we react to the rich sound information in a useful way. If we are listening to speech we are probably now reasoning and perhaps formulating our own verbal response. If we detected a car coming towards us, we are now building motor signals to move out of the way.

The auditory processing chain is often represented as a one-way system only, from the sound at the ear (bottom) to the conscious response (top). But in fact, there are several pathways from upper layers to lower ones. Two are important to mention here. The first is attention. Attention is often modelled as two competing processes (Shinn-Cunningham 2008). Top-down attention is where we select a sound to listen to. We might choose to pay attention to the speech rather than the ventilation noise (assuming the speaker is interesting enough). But our awareness can be captured by bottom-up attention. This happens when a sound is salient enough. Examples are a sudden bang, or someone speaking our name. Typically-functioning attention is usually modelled as a system in which these competing processes provide a tight focus on one sound only at any one time. When we attend to the speech, we no longer notice the traffic noise.

The second top-down pathway is provided by the brain's predictive model of the world. Sensing the world around us at maximum detail from moment to moment is wasteful of the brain's resources, given that the world does not change very rapidly, most of the time. A more efficient strategy is to build an initial model of our surroundings and then predict the near future. Sensory input can then be mainly used to update the prediction (Clark 2013). In this model, bottom-up attention capture happens when the world deviates from our prediction. This frees up more cognitive resources for planning and reasoning.

3. Autistic auditory processing in the literature

Notable differences between autistic and typical people have been found at all stages of the auditory processing chain in Fig. 1. The view of the autism research literature is almost wholly negative. Researchers have found evidence of several types of difference between autistic and non-autistic peoples' processing of sound. Autistic listening is almost always labelled as impaired, based on the differences found, even when the deficit could be seen as partly or entirely a value judgement. The literature contains evidence on loudness and pitch perception, orientation to sounds, prosody perception, understanding speech in noise, and auditory attention.

3.1 Loudness perception

Loudness and pitch belong in the 'Hearing' block in Fig. 1, being extracted from sound by the inner ear. The aversion to loud sounds found throughout the history of writing on autism is now usually discussed in the literature using the framework of hyperacusis. Hyperacusis is a medical diagnosis that simply means an "unusual tolerance to ordinary environmental sounds" (Baguley 2003). Given the large number of clinical observations and first-person accounts, it is surprising that there have been very few good-quality measurements of hyperacusis in autism. Perhaps the best data are provided by Khalfa et al. (2004). They measured the auditory threshold (the quietest sound that can be detected) and the loudness discomfort level (at which sound is perceived as very uncomfortable) in both autistic and typical teenagers. The autistic participants had the same threshold, but a significantly lower loudness discomfort level. The relationship between objective sound intensity and perceived loudness was also different between the two groups. More research is needed, but this different loudness-intensity function seems to be the basis for the reported hyperacusis.

3.2 Pitch perception

The literature is clear that some autistic people are better at judging (relative) pitch changes (Bonnel et al. 2003) and are more likely to have absolute ("perfect") pitch judgement. It has been estimated that 5% of autistic people exhibit absolute pitch vs 0.05% of the general population (Rimland and Fein 1988). Reading this literature as an autistic researcher, it is striking that the authors who report these results often frame them in a negative light. Suggestions include that superior pitch perception might lead autistics to focus on irrelevant stimuli, that it could be responsible for poorer performance at speech decoding or associated with worse social integration generally. Mottron et al. (1999) are one of the few groups to make the obvious observation that superior pitch perception in a child might indicate a future in music.

3.3 Speech in noise

Listening to speech in background noise is a key task for most people. Humans with unimpaired hearing typically perform this task very well, with enough intelligibility for conversation achieved when the speech is only a few decibels above the background noise level. Because speech and many background noises are dynamic signals, changing all the time, good performance in a speech-in-noise task depends on being able to extract information from brief glimpses of the speech when it emerges above the background. Several results suggest that autistic people perform more poorly on this task (for example, Alcántara et al. 2004) perhaps due to less complete separation of the speech and noise objects in the Listening stage of Fig. 1.

3.4. Speech prosody

Prosody refers to the elements of speech additional to the “words”, such as changes in intonation, stress, rhythm, etc. These convey a variety of social cues including turn-taking and emotion. Some researchers have reported that autistic people perform more poorly at perceiving affective prosody – detecting the emotional state of the speaker. This is usually interpreted using the theory that autistic people have impaired theory of mind (Baron-Cohen 2000). A more sophisticated experiment was performed by Chevallier et al. (2011). They gave participants a demanding cognitive task to perform in addition to evaluating the emotional state of the speaker. Results showed that autistic participants performed more poorly than typical participants on the affective prosody task, but only when the additional cognitive load was high. These results are inconsistent with a pervasive deficit in theory of mind. Instead, the results are consistent with a situation in which an autistic listener must do additional cognitive work to consciously process non-verbal cues embedded in the speech of a non-autistic speaker, as predicted by the double empathy theory of Milton (2012). A recent experiment by Crompton et al. (2020) investigated this directly and found that autistic-with-autistic and non-autistic-with-non-autistic speech communication was equally effective, while autistic-with-non-autistic communication was significantly less effective.

3.5. Perceptual capacity

The perceptual capacity of a person is a measure of their ability to process sensory information. It can be measured by loading a person with several simultaneous stimuli while asking them to perform a task (such as detect one target stimulus within the mixture). Remington and Fairnie (2017) found that autistic adults could cope with a higher load (in terms of number of distractor sounds) while remaining accurate. This is one of very few results in the literature which explicitly conclude that autistic auditory processing can be superior. One might hypothesise that this superiority might be the result of some autistic adults having many years' training at performing the additional cognitive tasks involved in consciously processing the social cues embedded in the speech of non-autistic interlocutors.

3.6 Auditory attention

There is a large body of autism research that identifies differences in what autistic people attend to and how fast they attend to it. Most of this is in the visual domain, however, and there remain significant gaps in the auditory literature. Visual results show better performance at processing local detail with either worse or equivalent performance on the global whole, depending on the study (Mottron et al. 2006). Auditory results are more mixed, and differences seem smaller. One significant group of auditory attention studies measure automatic orientation towards sound. Here the researcher emits a sound in the presence of a child and then measures the extent or speed with which the child turns towards the sound. Sometimes the stimulus is speech, sometimes a click or tone. A typical result is provided by Dawson et al. (2004) who report that autistic toddlers are significantly less likely to interrupt their play and turn towards a "social stimulus" such as snapping fingers or humming. An alternative explanation – that the autistic toddler has a better focus on her rewarding play task – is not discussed by the researchers.

Van de Cruys et al. (2014) have proposed that differences in autistic attention (and other perceptual features) could be accounted for by a brain that ignores fewer of its own top-down prediction errors. This could potentially explain why small, local changes are more noticeable to autistic people and perhaps also why responses to large-scale change arrive more slowly.

4. Anecdotal reports

If mainstream autism research tends to see autistic differences (and even superiorities) as deficits, how do autistic people see themselves? A simple way to access autistic views is to look online. There have been several generations of autistic discussion forums, autistic blogs and, more recently, autistic use of social media. A convenience sample of this material was surveyed for accounts of auditory processing experiences by autistic people. Sources providing significant data were the web forums Wrong Planet, Reddit and AutismForums, individual blogs (especially those linked from the large Actually Autistic Blogs List) and Twitter. All the material examined was written by people presenting as autistic themselves. The material was subjected to thematic analysis (Braun and Clarke 2006) from the standpoint of an autistic researcher with a good knowledge of auditory perception concepts. I was particularly interested in accounts of autistic listening experience from the inside out, in contrast to most of the published literature (Davies 2019).

Three main themes emerged: hyperacusis and being overwhelmed by sound, difficulty processing a target sound (especially speech) in the presence of noise, and rich processing of soundscapes. The first two themes have been studied in the autism research literature, as summarised above. The third has not and so will be the focus here. The theme of rich processing of soundscapes emerged as a way of describing the active, sometimes playful way in which autistic people spoke of using the sound environment around them. Several times, I was struck by similarities with the kind of analytical listening that trained musicians employ, especially conductors or bandleaders, or by the acquired familiarity a mechanic might use to diagnose a fault. The soundscape theme has three sub-themes, as illustrated in Figure 2.

<FIGURE 2>

4.1 Using structure

In several accounts autistic people reported being aware of a structure in the soundscape and sometimes not just perceiving the structure but using it, either as a way to extract meaning or as a form of play. This may be discussed in terms of how individual sounds relate to each other or more abstracted patterns are noticed and valued:

"the possibility of engaging with layers of relatively gentle sound, thinking about different elements of it & identifying sounds seems to satisfy my brain in the same way as a flow state."

One way of engaging with structure is to perform a decomposition, to use top-down attention to break the soundscape into smaller parts. Some people enjoy this kind of analysis with music:

“I also escape into layers of music. I have a good musical memory and can replay songs in my head as if I were dropping a needle on a record. I can zero in on the different melodies, rhythms, timbre. I can bring the bass section forward and back.

Others describe doing this decomposition with everyday soundscapes:

“If I'm alone in the house, I sometimes "unpick" everything I can hear, to relax. So, that's the fridge, that's the road outside, that's bird song, that's the electricity in the walls, that's the lamp" etc. The world is noisy, but easier when I've noticed how/why noisy.”

This kind of exercise can be pleasurable for its own sake, or it might be used as a relaxation technique. It is notable that some respondents explicitly made connections between musical and non-musical sounds:

“When in natural surroundings. Woods, beach etc. I can separate and rejoin sounds into individual music type notes then back into symphonies.”

The phrase ‘zooming in’ is quite often used when autistic people discuss listening. It suggests using top-down attention to traverse the structure of a soundscape by focussing on more and more detailed levels:

“When I listen to music I can "zoom in" on different parts of it. I can find the structure of different parts and split it up.”

“I do that too ! I guess it's one of our superpower. For me it's a positive trait. For all the artist friends I met, it's a positive trait to have someone that can somehow "really" listen and understand their creations.”

In a previous paper, I described using my own experience of using my attention to zoom in on an outdoor soundscape to examine it at smaller and smaller scales, down to attributes of the initial attack of a car exhaust impulse, for example (Davies, 2015). When I presented this at a conference (before my autism diagnosis), my fellow acousticians met me with polite bemusement. I was also surprised that in my experiments, my (presumed) neurotypical participants did not seem to do this either, tending instead to group lots of sounds in a complex soundscape into ‘background’ (Woodcock et al., 2017). For autistic people, there is almost always something to be noticed in the background.

4.2 Pleasure

In many accounts, autistic people expressed pleasure from listening in several ways. Sometimes this was taking pleasure in the exercise of an ability or power, perhaps one they knew to be unusual. At other times, it is pleasure to be gained from revealing hidden small sounds, or from experiences that come gradually, after time is invested. This autistic person gains pleasure in methodically examining a rich soundscape in detail. There’s a hint here that there’s a lot going on in what could be lumped together in ‘background’ sound:

“Tiny nature sounds. When I tune in there is so much going on, even in a 'quiet' place. One of my favourite sound experiences was hearing people whispering together in a foreign language in a hushed library (probably for more ASMR-like reasons). Calming, deepening, 'flow' for sure”

Single sound objects can also reward detailed, patient examination:

“My mum had a ceiling extractor fan in the bathroom. I swear I could listen to that thing for hours. The complexity of different oscillations beating against each other, and the patterns/non-patterns that would create, was beautiful to get lost in”

While repetitive behaviour is heavily stigmatised in most of the literature (and also often in society) it is interesting to read autistic people’s accounts of repeated listening to a song or sound. Sometimes this seems to be a form of play in itself:

“I fixate on songs and would replay one over and over again (even in my head) & would constantly 'dissect' it by tuning out certain parts (ie. 1 replay I'd only listen to the guitar & drown out other parts).”

Many accounts mention the idea of detailed listening engendering a flow state. Flow is a term coined by Csikszentmihalyi to describe “the experience of complete absorption in the present moment” (Nakamura and Csikszentmihalyi 2009). It is widely viewed as highly positive and many texts advise readers on how to attain it when performing tasks. Autistic people are sometimes puzzled that flow seems to be regarded as somewhat elusive and difficult to experience, since the common autistic experience of complete engagement with an interest fits the definition of flow well (McDonnell and Milton 2014). Thus, it is not hard to find accounts of autistic detailed listening that seem to describe a flow state:

“When I work on my musical projects, I tend to hear the whole score in my head and piece every instrument loop detail where they fit. It relaxes me and makes me extremely aware of what I’m doing to the point that I lose track of time.”

4.3. Detail is always there

Several autistic people note that they seem to be continually aware of a high level of detail in the soundscape around them, suggesting the atypical attention mechanism reported in the literature. If the background always has something going on, it can be hard to ignore. For some this lead to overwhelm. For others, the continual detail is sometimes annoying, while perhaps also useful:

“I’m in a choir. I am not diagnosed as autistic but have been diagnosed with hyperacusis is, and have my suspicions. I focus on each singer’s voice. I can tell you who can’t hit the high G, who keeps breathing in the middle of a phrase, etc. It is bothersome but I can’t stop.”

“I can pick out individual bird song and locate the bird. However in a restaurant or cafe I can’t filter the background, I can hear everyone’s conversations which can be interesting or very annoying.”

5. Discussion

It is clear from the literature that many autistic people process sound differently to non-autistic people, in several respects. Differences are seen at all levels of auditory processing, from low-level attributes like pitch and loudness, to higher-level features such as extracting information from speech. Almost all of the autism literature frames these differences as deficits. It is hard not to think that the overwhelmingly negative account in the literature is at least partly due to researchers starting out with a view that autistic people are inferior and looking for evidence to support this. This impedes progress in autism research for four reasons. The first is simply that it prevents straightforward recognition of autistic superiority where it exists. Better pitch perception should probably not be viewed as a deficit. Secondly, deficit framing distorts a balanced evaluation of existing results. For example, a recent meta-analysis of the literature on affective speech prosody perception in autistic people found the differences between autistic and typical listeners was "likely due to the tendency of the existing research to overly focus on deficits in autism" (Zhang et al. 2021). Thirdly, where there are problems that really affect autistic people, as in hyperacusis, deficit research usually stops at identifying the flawed humans or perhaps goes on to suggests a remedy at the level of the individual. Adopting a more equal standpoint can change conclusions significantly. For example, a difference in the function connecting sound intensity to loudness could be seen as a neutral difference. The distress of hyperacusis then comes from environments which are not adapted to someone with a steeper intensity-loudness function. Perhaps hyperacusis will eventually be a problem of disabled accessibility. Finally, the deficit researcher does not set out to look for positive aspects of autistic experience and so misses the potentially novel, such as the rich processing of soundscapes described above.

Some of the accounts of autistic soundscape listening can be related to findings in the auditory perception literature. The awareness of detail might be explained by differences in auditory attention, and perhaps ultimately by differences in the brain's predictions about the environment. The spontaneous soundscape decomposition and zooming across scale seem novel, however, and potentially in contrast with poorer performance at separating speech from noise. This deserves further qualitative and quantitative investigation. Hyperacusis in autistic people needs a more comprehensive study and perhaps warrants the attention of acoustic engineers to help design more accessible everyday acoustic environments. Finally, the pleasure of autistic listening, especially when achieving a flow state, should be more widely known and celebrated.

References

Alcántara, José I., Emma J.L. Weisblatt, Brian C.J. Moore, and Patrick F. Bolton (2004) 'Speech-in-noise perception in high-functioning individuals with autism or Asperger's syndrome.' *Journal of Child Psychology and Psychiatry* 45(6), pp. 1107-1114.

American Psychiatric Association (2013) 'Diagnostic and statistical manual of mental disorders' (DSM-5®). *American Psychiatric Pub*.

Autistica (2015) *Your Questions: Shaping Future Autism Research*. Available at https://www.autistica.org.uk/downloads/files/Autism-Top-10-Your-Priorities-for-Autism-Research.pdf (accessed 9 April 2021).

Baguley, David M. (2003) 'Hyperacusis'. *Journal of the Royal Society of Medicine* 96(12), pp. 582-585.

Baron-Cohen, Simon (2000) 'Theory of mind and autism: A review'. *International review of research in mental retardation* 23, pp. 169-184.

Bonnel, Anna, Laurent Mottron, Isabelle Peretz, Manon Trudel, Erick Gallun, and Anne-Marie Bonnel (2003). 'Enhanced pitch sensitivity in individuals with autism: a signal detection analysis', *Journal of Cognitive Neuroscience* 15(2), pp (226-235.

Braun, Virginia, and Victoria Clarke (2006) 'Using thematic analysis in psychology', Qualitative Research in Psychology 3(2), pp. 77-101.

Bregman, Albert S (1994) *Auditory scene analysis: The perceptual organization of sound*. Cambridge, MA: MIT Press.

Chevallier, Coralie, Ira Noveck, Francesca Happé, and Deirdre Wilson (2011) 'What's in a voice? Prosody as a test case for the Theory of Mind account of autism', *Neuropsychologia* 49(3), pp. 507-517.

Clark, Andy (2013) 'Whatever next? Predictive brains, situated agents, and the future of cognitive science', *Behavioral and Brain Sciences* 36(3), pp. 181-204.

Crane, Laura, Lorna Goddard, and Linda Pring (2009) 'Sensory processing in adults with autism spectrum disorders', *Autism* 13(3) pp. 215-228.

Crompton, Catherine J, Danielle Ropar, Claire VM Evans-Williams, Emma G Flynn, and Sue Fletcher-Watson (2020) 'Autistic peer-to-peer information transfer is highly effective.' *Autism* 24(7) pp. 1704-1712.

Davies, William J (2019) 'Autistic Listening.' *Aural Diversity Conference*, Leicester, UK, 30 Nov - 1 Dec. Available at http://usir.salford.ac.uk/id/eprint/56380/ (accessed 9 April 2021).

Dawson, Geraldine, Karen Toth, Robert Abbott, Julie Osterling, Jeff Munson, Annette Estes, and Jane Liaw (2004) 'Early social attention impairments in autism: social orienting, joint attention, and attention to distress', *Developmental Psychology* 40(2), p. 271.

Fastl, H., and E. Zwicker (2007) *Psychoacoustics: Facts and Models*, T. S. Huang, T. Kohonen and M. R. Schroeder (eds). Berlin: Springer.

Fletcher-Watson, Sue, Jon Adams, Kabie Brook, Tony Charman, Laura Crane, James Cusack, Susan Leekam, Damian Milton, Jeremy R Parr, and Elizabeth Pellicano (2018) 'Making the future together: Shaping autism research through meaningful participation', *Autism* 23(4) pp. 943-953.

Frith, U, and S Baron-Cohen. 1987. 'Perception in Autistic Children.' In Handbook of Autism and Pervasive Development Disorders, edited by D. J. Cohen and A. M. Donnelan, 85-102. Wiley.

Hermelin, Beate, and Neil O'Connor. 1970. Psychological experiments with autistic children. Oxford: Pergamon.

Kanner, Leo. 1943. 'Autistic disturbances of affective contact.' Nervous child 2 (3) pp. 217-250.

Khalfa, Stéphanie, Nicole Bruneau, Bernadette Rogé, Nicolas Georgieff, Evelyne Veuillet, Jean-Louis Adrien, Catherine Barthélémy, and Lionel Collet (2004. 'Increased perception of loudness in autism.' Hearing research 198 (1-2) pp. 87-92.

Matson, Johnny L, and Alison M Kozlowski (2011) 'The increasing prevalence of autism spectrum disorders', *Research in Autism Spectrum Disorders* 5(1), pp. 418-425.

McDonnell, Andy, and Damian Milton (2014) 'Going with the flow: reconsidering 'repetitive behaviour'through the concept of 'flow states',' in *Good Autism Practice: Autism, Happiness and Wellbeing*, G Jones and E Hurle (eds), pp. 58-63. Edgbaston: British Institute of Learning Disabilities.

Milton, Damian EM (2012) 'On the ontological status of autism: the 'double empathy problem',' *Disability & Society* 27(6) pp. 883-887.

Mottron, Laurent, Michelle Dawson, Isabelle Soulieres, Benedicte Hubert, and Jake Burack (2006) 'Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception', *Journal of Autism and Developmental Disorders* 36(1), pp. 27-43.

Mottron, Laurent, Isabelle Peretz, Sylvie Belleville, and N Rouleau (1999_ 'Absolute pitch in autism: A case study', *Neurocase* 5(6) pp. 485-501.

Nakamura, Jeanne, and Mihaly Csikszentmihalyi (2009) 'Flow theory and research', *Handbook of Positive Psychology*, pp. 195-206.

O'Connor, K (2012) ‘Auditory processing in autism spectrum disorder: a review’, *Neuroscience & Biobehavioral Reviews* 36(2), pp. 836-854.

Remington, Anna, and Jake Fairnie (2017) ‘A sound advantage: Increased auditory capacity in autism’, *Cognition* 166, pp. 459-465.

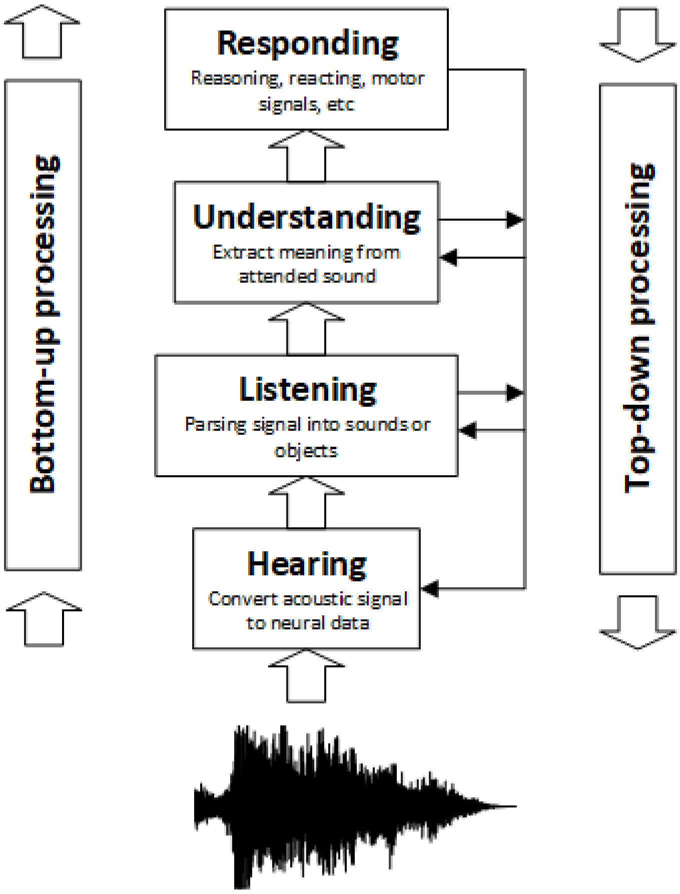
Rimland, B, and D Fein (1988) ‘Special talents of autistic savants’ in *The exceptional brain: Neuropsychology of talent and special abilities,* Loraine K Obler and Deborah Fein (eds.), pp. 472–492. New York, NY: Guilford Press.

Shinn-Cunningham, B. G (2008) ‘Object-based auditory and visual attention’, *Trends in Cognitive Sciences* 12, pp. 182-186.

Spence, Charles, and Valerio Santangelo (2010) ‘Auditory attention’ in *Oxford Handbook of Auditory Science: Hearing*, C. J. Plack (ed.), pp. 249-270. Oxford: OUP.

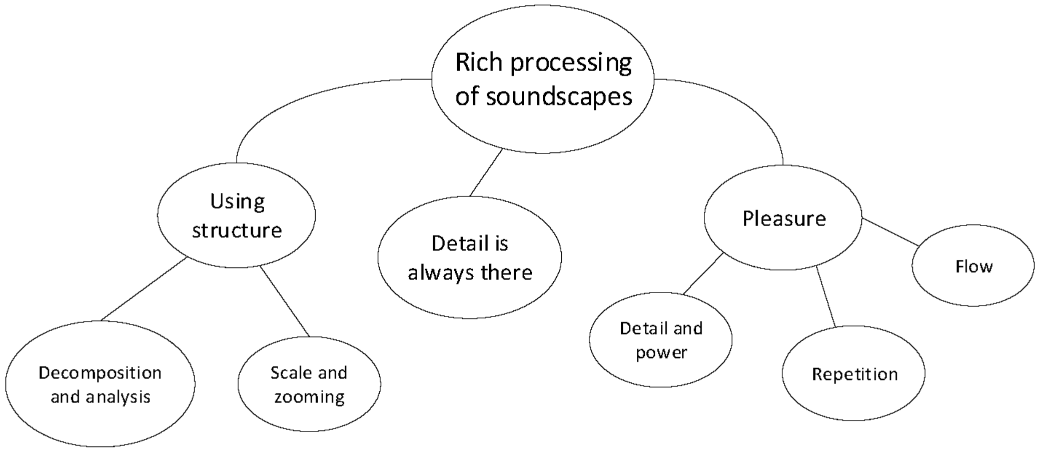
Van de Cruys, Sander, Kris Evers, Ruth Van der Hallen, Lien Van Eylen, Bart Boets, Lee de-Wit, and Johan Wagemans (2014) ‘Precise minds in uncertain worlds: predictive coding in autism’, *Psychological Review* 121(4), pp. 649-675.

Zhang, Minyue, Suyun Xu, Yu Chen, Yi Lin, Hongwei Ding, and Yang Zhang (2021) ‘Recognition of affective prosody in autism spectrum conditions: A systematic review and meta-analysis’, *Autism*: 1362361321995725.



Bottom-up processing
Responding
Reasoning, reacting, motor signals, etc
Understanding
Extract meaning from attended sound
Listening
Parsing signal into sounds or objects
Hearing
Convert acoustic signal to neural data
Top-down processing

<Figure 1>


Rich processing of soundscapes
Using structure
Detail is always there
Pleasure
Decomposition and analysis
Scale and zooming
Detail and power
Repetition
Flow

<Figure 2>