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*Marcia Jenneth Epstein*

Assistant Professor  
University of Calgary  
Canada

## **Dyslexia, distraction and ambient noise**

The role of hearing in reading disabilities and delays

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## Abstract

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*Although hearing is the ‘second sense’ in our species, taking up a smaller proportion of cerebral real estate than vision, such territorial concepts are not accurate maps. Findings from databases in neurology and psychology indicate that accurate auditory processing is crucial to successful acquisition of skills in both reading and writing. Thus, sensory perception may be less easily divided and categorised than we have been led to believe by the traditional model of five discrete senses.*

*Reading, typically regarded as a visual activity, has an auditory foundation. The process of learning to read involves sub-vocalising, sounding out phonemes and words internally in association with the auditory memory, in a reprocessing of the phoneme formation skills practised by the very young child learning to speak. Delays in auditory processing, which are often caused by persistent ambient noise, can inhibit the grouping of written words with similar sounds, as in rhymes and assonance, into recognised patterns. This in turn inhibits recognition of correspondences between letter sequences and word sounds (Bradley & Bryant, 1978). Delayed recognition inhibits fluency in reading, both silently and aloud, and can be a significant cause of dyslexia. While noise occurring in classrooms has been extensively studied for its effects on learning, little is known about the effects of ambient noise in homes: Further study is needed.*

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## Introduction: Do you hear what I see?<sup>1</sup>

*Dyslexia.* To non-specialists, the term summons images of frustrated children and perplexed parents, of adults with substandard reading skills, of heroic struggles to make sense of written texts. It implies a ‘deficiency definition’: something wrong with the visual processing of letter shapes and combinations, word order or perhaps even a deficit in intelligence.<sup>2</sup> Its meaning is in dispute among parents, teachers and even experts: What are the possible causes, explanations and treatments? Is dyslexia a true disability or a variant mode of perception (Paradice, 2001)?

What does not always occur, even in the questions posed by researchers, is consideration of the role of auditory processing. Rather than being a purely visual condition, could dyslexia involve gaps in the connection between seeing written words and hearing patterns in speech? And are such gaps unique to those diagnosed with the condition, or can they occur in children who struggle to read without fitting the criteria for diagnosis?

The questions are relevant because visual and auditory signals are not necessarily distinct. In his extraordinary book *Musophilia*, neurologist Oliver Sacks documented cases of rare abilities to perceive and recall music, along with equally rare disabilities, that can point researchers towards clues about brain functions in

physical hearing, auditory memory and audio-visual perception (Sacks, 2008). His chapter on auditory synaesthesia, 'The Key of Clear Green', provides an introduction to general readers about a form of synaesthesia that associates musical notes with colours:

For most of us, the association of color and music is at the level of metaphor. 'Like' and 'as if' are the hallmarks of such metaphors. But for some people one sensory experience may instantly and automatically provoke another. (Sacks, 2008, p. 165)

Sacks goes on to describe some exemplary patients in whom such abilities are associated with extraordinary talent in music and other arts, and with sensory cross-wiring so intense that – in one example – a composer with acquired blindness could no longer hear music because his brain immediately and involuntarily translated it into silent waves of vivid colour (Sacks, 2008, p. 182).

Synaesthesia is a process associated with unusual variations in brain function. The condition as defined and studied by neurologists can manifest as involuntary associations of letters or numbers with colours, sounds with colours and/or flavours, sounds with localised feelings of pressure or warmth on the body and many other combinations. While true synaesthesia is extremely rare, some interweaving of sensory cues in everyday experience is quite common. Does a picture of a lemon, the word *lemon* or even the colour of one cause you to salivate? If so, you are experiencing an everyday form of sensory integration, a visual-gustatory image composed of experiential memories of the lemon's colour, shape and flavour. This more common form is not a true synaesthesia: It is more accurately labelled cross-modal correspondence (King & Calvert, 2001; Spence, 2011). Some researchers believe it to be the neural basis for the formation of metaphors (Sagiv, 2005).<sup>3</sup>

Although hearing is considered the 'second sense' in our species, taking up a smaller proportion of cerebral real estate than vision, such territorial concepts are not fully accurate maps. Sensory perception may be less easily divided and categorised than we have been led to believe, with the boundaries of each sensory mode somewhat permeable because of neurological connections (Shimojo & Shams, 2001; Seitz et al., 2007; Spence, 2007). Rather than five distinct senses, we experience a spectrum of sensory cues to which our brains and nervous systems may respond with mixed signals as well as specific ones. The integration of smell with taste is easily recognised in the everyday experiences of food preparation and eating. The integration of hearing with vision is subtler, but it happens routinely. When speaking on a phone we can deduce some characteristics of the person on the other end of the conversation, whether or not we have ever actually seen them, because tones of voice give indications of gender, age, size, cultural and linguistic origin, emotional state and sometimes even personality. Listening to music, we may form images and see colours, shapes and/or waves of light with closed eyes. A chord or phrase can

have tones of honey or butter or jalapeño, evoking both colour and taste. Hearing melds also with tactile and haptic sensations: Music and speech can produce shivers and heat. High-pitched sounds, commonly perceived to be located high in space, are associated with ‘small bright objects’ (Spence, 2011). Compelled to move by heard rhythms, we nod, tap, sway, dance.

The integration of sensory perceptions into an overlapping spectrum is not even limited to physical experience. We constantly summon sensory memories<sup>4</sup> and use them in the service of the imagination, constructing or reconstructing scenes and conversations, journeys, emotions, events, meals. Memory feeds imagination as familiar experiences are moved into the service of new contexts to provide the basis for creativity, humour and even science fiction movies that echo with the calls of alien monsters. We are able to remember sounds as well as visual images, tactile and kinaesthetic sensations, odours and flavours.<sup>5</sup> Is the voice of a former friend still familiar in your memory after many years’ absence? Can you recall the sounds of a street you lived on as a child, as well as the way it looked?

## Hearing with the body

Consider the process of hearing itself. Molecules of air are set in motion by an instigating action, producing a wave that moves outwards from its source. Reaching you, the wave is funnelled by your *pinnae* – the visible outer ears – into your ear canals. There they vibrate the *tympanum* (ear drum) and are transmitted to the middle ear, where tiny bones and muscles modify and move the vibration into the spiral *cochlea* of the fluid-filled inner ear. As specialised cells in the *cochlea* detect specific frequencies, sounds are translated into signals perceived by the auditory nerves and transmitted to the brain for interpretation. All of this happens instantly, as the brain detects the location and gauges the nature and urgency of the sound while integrating the information arriving at each ear, but the reception of sound waves is not limited to the ears. It is literally tactile as well as auditory. The vibrating sound wave strikes skin and then bone and the watery substance of individual cells with approximately equal force, although only the ear has evolved to amplify the wave and transmit it to the brain. The tactility of sound contributes to its auditory qualities, since the physical process of hearing is initiated by an act of percussion – compressed waves of air striking the eardrum – and sustained by vibration within the middle and inner ears. Tactility also plays a role in the learning of language through speech and writing as the muscles of mouth, tongue, hands and fingers become accustomed to meaningful patterns.

## Seeing with the ears

The brain connects sound directly to vision as well as motion. Audio-visual connections are easily demonstrated by the skill of lip reading, or even more universally by the layers of information added to speech by facial expression, posture and gesture. Sounds stimulate parts of the visual cortex in certain circumstances (Molholm et al., 2002; Romei et al., 2007; Vidal et al., 2008), most strongly in the blind, but also to some extent in sighted individuals (Cate et al., 2009). The interrelation of these sensory modes is not surprising, although its manifestations can be unexpected.<sup>6</sup> Auditory signals can even activate peripheral vision: Sounds that are perceived as significant signal the areas of the brain that process vision to *prepare* to see the source of the sound as you turn your head to find it, even when it is initially outside the range of vision (Cate et al., 2009). This neural connection had obvious survival value when the source of the sound was a predator lying in wait, but a predator that could stay reasonably quiet, at least against a soundscape of constant and loud biophonic calls, would benefit from another phenomenon discovered in the same experiment: Sounds that do not attract attention do not activate peripheral vision. Evolution favours the wary, but protects against sensory overload. If every sound in the environment required us to have a look at its source, not much else would get accomplished. Human nervous systems are finely tuned to balance attention to the environment with mental focus. When sonic conditions are familiar, loudness is low or moderate, and onset is not startling, attention is not drawn to the sound. When loud sounds predominate or multiple sound sources are competing for attention, challenges to concentration occur. They affect listening skills and the development of literacy.

## Reading by hearing

Among the early predictors of educational success for children – including social class, parental culture and income, and nutrition – the most directly significant are listening and literacy. Listening to spoken information and instruction is central to education in any culture, whether it involves the socialisation and literacy skills of children or the introduction of older students and workers to new skills. Reading is the key to employment and economic success in literate and technological cultures, as well as a portal to social proficiency and the navigation of complex issues in a modern democratic society. It might even be said that both functional democracy and post-industrial economy depend on a literate population.

The causes of substandard literacy and learning skills are many: malnutrition, poverty, inadequate instruction, stress, abuse, cultural pressures and stereotypes, disabilities. There is also a far less obvious cause to add to the list: the distraction and

confusion induced by noisy conditions in the home or school. Neuroscientists are now aware that auditory memory, the ability to store and recall sounds, is a crucial component in the process of developing vocabulary and reading skills (Ceponiene et al., 1999; Glass, Sachse, & von Suchodoletz, 2008). The development of auditory memory is enhanced by auditory activities: speaking to and with the child, reading aloud, singing and training in music (Trainor, Shahin, & Roberts, 2003; Shahin, Roberts, & Trainor, 2004). This is because language is, at least initially, a largely auditory activity. Its progress depends upon several levels of interaction that involve the auditory system (hearing and listening), vocal apparatus (formation of speech sounds with the larynx, lips, tongue, teeth and palate), respiratory system (regulation of air flow in the diaphragm and lungs to control the speed and loudness of speech) and parts of the brain that govern the comprehension of speech as well as its rhythms and inflections.

A pre-verbal child can produce an enormous range of abstract speech-like vocal sounds – babbling, crooning and squealing – that are gradually edited, through listening to surrounding adults, down to the vocabulary of a native language. Language learning in its earliest stage is in part a matter of listening for which sounds elicit responses from adult caregivers and therefore carry meaning. Speech encompasses a feedback loop: We listen as we speak, gradually learning as children to make subtle adjustments in phrasing, pacing, tone and loudness in order to optimise meaning and response from others. We also learn to imitate familiar speakers, picking up the accents of parents unless they are modified by the surrounding community or the school. The speech of children with congenital deafness is hesitant because such feedback is lacking, and diligent practice through speech therapy is necessary to compensate for the lack of internal auditory reinforcement.

Thus, reading – commonly regarded as a visual activity – has an auditory foundation. The process of learning to read involves sub-vocalising, sounding out phonemes and words internally in association with the auditory memory, in a reprocessing of the phoneme formation skills practised by the very young child learning to speak. Delays in auditory processing can inhibit the grouping of written words with similar sounds, as in rhymes and assonance – and steady rhythms – into recognised patterns: There is a reason why early reading primers contain phrases like ‘the cat with the hat sat on the mat’. Such delays in turn inhibit recognition of correspondences between letter sequences and word sounds (Cohen, Glass, & Singer, 1973; Bradley & Bryant, 1978). Delayed recognition erodes fluency in reading both silently and aloud, and can be a major cause of deficient reading skills.

## Dyslexia as auditory deficiency?

Auditory processing is now recognised as having a significant role in dyslexia, which is technically defined as a neurological condition that affects ability to read and write because the connection between written letters and the phonemes they represent does not develop effectively. Reading disabilities are now known to be associated with deficits in phonology (Veuillet et al., 2007) and with the processing of rapid acoustic stimuli in the left prefrontal cortex of the brain (Gaab et al., 2007). This knowledge, obtained through both conventional testing and functional Magnetic Resonance Imagery (fMRI) scans of the brain, is leading to treatments that involve practising the coordination of visual and auditory perceptions (Veuillet et al., 2007; Törmänen & Takala, 2009) to strengthen the neural connections between hearing and reading.

Dyslexic children have particular difficulty understanding speech in background noise, especially when the background itself consists of speech, as is often the case. Ability to recognise the communicating voice and distinguish it from others is impaired, creating a 'critical deficit in noise-exclusion' (Chandrasekaran et al., 2009). Since excluding irrelevant sound is crucial to receiving accurate spoken communication, these children can be disadvantaged in social situations as well as in school, but they are not unique in this respect: Learning in noisy conditions can also disadvantage children without a diagnosed disorder. When the process of learning takes place in the presence of significant levels of noise, important signals are missed and distraction overcomes focus. Distraction leads to confusion, and crucial neuronal connections can be delayed or poorly developed.<sup>7</sup> This is true of very young children learning to speak, older ones learning to read and anyone learning a second or subsequent language (Kohnert et al., 2005).

## The soundscapes of school

What can be done to provide dyslexic children with an easier route to success? Understanding the influence of auditory environments – or soundscapes – on learning is an important piece of the puzzle.

Whether situated in a formal classroom, a kitchen or a tent, learning involves verbal interaction as well as reading. When the student cannot hear or pay attention to instructions or dialogue, much of the content in both verbal and mathematical instruction is lost (Pimperton & Nation, 2010). Intrusive noise from outside the place of learning can be a cause, but noise inherent in classrooms – including the mechanical sounds of ventilation systems as well as the noise made by mechanical toys and active children – can also be a major problem. Noise lures students' attention away from the often repetitive tasks that constitute early stages of learning.

Its most direct detriment, however, may result from masking, in which one acoustic signal effectively hides or scrambles another, as when the roar of a ventilation fan causes students at the back of the classroom to miss what the teacher is saying about preparing for the math quiz. Even indoor noise of low or moderate intensity can ‘evoke substantial impairments in performance’ (Klatte, Bergström, & Lachmann, 2013) if it is not relevant to a learning task, because simultaneous competing sources produce distraction. Task-irrelevant speech has similar effects (Hughes & Jones, 2001).

Research has been conducted since the 1970s on classroom noise. Much of it has been driven by fear of lost productivity due to distraction, but there is also a larger issue to consider: neurological reactions to noise, and how they affect cognitive development in children and ability to concentrate in adults. The issue is especially crucial for children in the early stages of education because the neural circuitry of their brains is still developing and their attention can be easily fragmented. Since critical attitudes to learning are also in formative stages, any interference with success can set up expectations that inhibit confidence. Children are not usually able to diagnose the causes of their fear or frustration, and parents may be at a loss to do so. A complaint like ‘I can’t understand the teacher’ – when student and teacher are fluent in the same language – might lead parents to schedule a hearing test and a meeting with the teacher, but asking about the acoustics of the classroom is unlikely to occur to them as a potential source for a solution to their child’s problem.

Just as classroom acoustics influence what is learned, the soundscape that surrounds a place of learning can predispose students to success or failure. Schools in densely populated urban districts with heavy traffic and those located near airports are especially vulnerable to problems with noise levels that can interfere with auditory perception, aggravate stress and disrupt learning environments (Matsui et al., 2004; Clark et al., 2005; Stansfeld et al., 2005). A large Pan-European study conducted in the early 2000s under the auspices of the World Health Organization included 89 schools located near airports in England, the Netherlands and Spain. Researchers tracked the test scores of 2,844 children aged nine to 10 years. Statistics were adjusted for such variables as language spoken at home and education level of parents, as well as diagnosed dyslexia and hearing impairment (Clark et al., 2005). After all adjustments, a correlation remained between aircraft noise and delays in learning, whether the noise was experienced at school or at home. The authors concluded that the chronic environmental stress caused by aircraft noise could impair cognitive development in children, especially with regard to reading comprehension.

An animal study published in 2003 suggests that considerable attention should be given to further research in this area. Infant rats raised in noisy conditions showed developmental delays in the neural connections and responses of the primary audi-

tory cortex in the brain; mature development of the cortex did not occur even in adulthood. Because development of sensory perception follows a common pattern in all mammals, the study's authors concluded that noise was also implicated as 'a risk factor for abnormal child development' (Chang & Merzenich, 2003). The title of their article leaves no ambiguity about the seriousness of the implication: 'Environmental noise retards auditory cortical development'.

## Hearing the home

Does ambient noise inside the home have effects on children comparable to classroom noise? The impact of expressway traffic noise on apartment tower interiors in New York City was briefly studied in an early phase of ambient noise research during the 1970s and found to have a detrimental effect on the reading ability of resident children in the second through fifth grades who lived on the tower's lower floors (Cohen, Glass, & Singer, 1973), but subsequent conclusive studies are rare because of methodological differences in the research (Evans & Lepore, 1993). Even less is known about the effects of using television, electronic games and broadcast media as ambient noise in the home, probably because measuring such effects would require permission from large numbers of parents to place recording equipment within their homes – an unlikely prospect. Laboratory-based studies on pre-school children provide some clues, however. One American study observed children of approximately two years of age watching a TV tuned to an adult programme, so that it would not capture their full attention, while playing with toys for one hour: The TV was kept on for half the hour to serve as 'background television'. The authors cite prior studies demonstrating that 'television exposure for children aged 30 months and younger is associated with poorer cognitive and language development', and state that TV used as an unattended audio-visual background results in noise that 'may have a general disruptive effect that has been observed on children in noisy environments' (Schmidt et al., 2008). Two-year-olds are not ready to read, so additional studies focussing specifically on children acquiring reading skills are needed, especially for those diagnosed with dyslexia. Consideration is also due to the question of layered soundscapes in the home, combining television, computer games, appliances, toys and/or conversations with tasks requiring concentration. How are listening skills and learning being affected? Can reduction of ambient noise reduce distraction and aid the acquisition of reading skills in children with disabilities? Is complete quiet beneficial for them? Clear answers to those questions are not yet available. Children, like adults, vary in their tolerance for noise and distraction, but tolerance is not the same as lack of effect. Because reading depends on audio-visual cross-modal correspondences, and hearing happens even in the absence of conscious listening, the effects of ambient noise on auditory process-

ing and cognitive development require further investigation as well as consistent methodologies that will enable the comparison of studies. In the meantime, assistive listening devices in the form of classroom FM systems are showing promise for the treatment of dyslexia. By reducing the variability of subcortical responses to sound, they reduce variability in processing, enabling children to relate phonemes to letters more accurately (Hornickel et al., 2012). Their success provides additional evidence for the importance of auditory perception in audio-visual processing: As the researchers state, ‘active engagement with sound, specifically the meaningful speech of a teacher, and increased participation in an academic curriculum can reduce auditory processing variability in children with dyslexia’.

## Conclusion

Reading is essential to active participation in modern societies, safety at work, access to new information and a wide range of aesthetic and intellectual pleasures. New readers, whether child or adult, may struggle with the intricate process of learning its requisite skills. Those diagnosed with dyslexia – or showing some of its spectrum of characteristics – encounter significant barriers that can diminish their confidence and enthusiasm for learning. They deserve all the support we can give them, including wider recognition of the auditory and audio-visual components of the process.

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## Notes

- 1 Brief parts of this article are excerpted from sections of my forthcoming book, *Living with Noise: A Listener's Guide*.
- 2 In fact, the condition can be present in highly intelligent people.
- 3 Neurologists and psychologists differ somewhat in their labelling of synesthetic conditions; because research is in its early stages, terminology is not necessarily consistent. The term pseudosynesthesia is used by some investigators; it may also be used to describe 'learned synesthesia', which is practised rather than involuntary.
- 4 E.g., think – right now – of red.
- 5 To experience and stimulate the gustatory imagination, read recipes and look at pictures of food. Like the auditory imaginations of musicians, many of whom can hear music internally without physically listening to it, the gustatory imaginations of chefs and expert cooks are more thoroughly developed than those of the general population.
- 6 E.g., tinnitus, the sensation of ringing or buzzing in the ears, can even be modified by eye position in rare cases (Lockwood et al., 2001).
- 7 Although it is a recognised and significant factor, the insufficiency of defective auditory processing as a sole cause of reading problems is easily shown by the reading proficiency of hearing-impaired individuals. Children with profound deafness learn by means of 'increased reliance on the articulatory component of speech when the auditory component is absent' (MacSweeney, 2008).