Abstract

This keynote presentation reviewed the process of auditory assembly of the perceived environment and how this assemblage is potentially benefitted by having two (stereo) sensory inputs. The presentation outlined some of the concepts regarding the evolutionary advantage of adaptation and focussed on the improved survival afforded those organisms who can most rapidly and correctly identify potentially harmful, or helpful stimuli in their surroundings. The advantage of having two ears, the binaural benefit, was described and evaluated in this context. The basic auditory scientific experiments conducted in our laboratory were reviewed, demonstrating improved auditory performance results from having two auditory inputs even if the “normal” levels of binaural benefit are not accrued. The role of the cortex and higher level processing was discussed with the suggestion being made that, even with a degraded primary sensory input in organisms with impaired hearing, extraction of information of benefit to survival can and is retrieved better with binaural hearing.

The white peppered moth resides in Northern England. This moth’s dominant phenotype changed from whitish gray to a solid black and then back again in conjunction with a concomitant change in building colour during first the industrial revolution and then second after the post WWII clean-up. The moth’s remarkable ability to extract and assemble sensory data about its surround and then respond to it, no doubt saved several of its kind from predation. The ability to change is a key factor in determining an organism’s ability to survive and that the ability to adapt puts an organism at an advantage.

The ability of an organism to adapt is a direct result of sensing the changes in the environment which signal either safety or danger and assembling these sensory clues correctly through a process known as feature extraction. It is of interest that humans have developed very good abilities to make decisions based on sensory data that they receive and, in fact, human decision making skills are superior to other animals in which more primary sensory superiority (vision, olfaction) has been more significantly developed. Consider how difficult it is to catch a fish or snatch a toy from a dog. These animals have sensory abilities and motor functions that are an equal match for our cleverness in trying to outwit them. As clinicians and scientists focused on the auditory system we are interested in determining what processing occurs in children with potentially degraded sensory inputs that occur in varying degrees of deafness. The question is to look at children with degraded primary sensory input (i.e., deafness) and ask if there is a significant advantage in extracting features from their environment using two ears as opposed to just one. In other words, is there a truly a binaural benefit?

One of the key factors that determine the accuracy with which we assemble sensory information, aside from its quality, is the quantity of the information we receive. The input of two simultaneous streams of information, as would occur with two eyes or two ears, offers information processing systems additive data beyond that contained in the two primary inputs. This “stereoscopic” information, plus our sensory experiences, allows us to process our environments with high fidelity and surprising accuracy. There is comparison relationship between two inputs and advanced processing that establishes a multi-dimensional model based on the sensory input. Whereas the visual system relies heavily on spatial information, the auditory system more heavily relies on timing information. These comparisons in the auditory system are performed primarily at the level of the brainstem.
In our laboratory we have shown that the auditory system develops abnormally in children in whom there is prolonged unilateral sensory deprivation and that furthermore this reorganization does not normalize even with eventual restoration of bilateral input (Gordon, et al., 2008, 2011, 2012; Gordon, Wong and Papsin, 2010, 2013; Gordon, Jiwani and Papsin, 2013). What has been less clear is what effect the central reorganization of the auditory system might have on perceptual capacity of the organism and even more importantly the effect on sensory reassembly.

Our research group, as well as others, have demonstrated that the benefits of bilateral cochlear implantation have only slight benefits on speech perception abilities of children (Gordon and Papsin, 2009; Van Deun, van Wieringen and Wouters, 2010); Chadha, et al., (2011). Additionally, there are some indications that asymmetric inputs from auditory input, as would be the case with cochlear implants placed with a long inter-implant delay, might further diminish the speech and language outcomes (Jewell, Papsin and Gordon, 2012).

Sensory perception, and more importantly, reassembly of the auditory world relates to perception in the three dimensional environment. Here the critical skill required is locating the source of the incoming data. When successfully done, this allows the rest of the sensoria (i.e. vision) to focus and enrich the incoming information by providing corroborating or conflicting information to help the reassembly and decision making process. It is here that the bilateral input, even with the degraded primary input as provided by cochlear implants, shows the greatest benefit. In both spatial unmasking and lateralization experimental paradigms, our group has shown greatest improvements in bilateral conditions and especially in children with simultaneous or near-simultaneous hearing habilitation (Gordon and Papsin, 2009; Chadha, et al., 2011; Gordon, Wong and Papsin, 2013; This corresponds closely to the degree (specifically the lack) of central auditory system reorganization. What is fascinating is that the simultaneous or near-simultaneous cochlear implant recipients use inter-aural timing cues to make nearly correct responses in the lateralization condition – even though by definition the primary sensory data is devoid of temporal information (Gordon et al., in preparation).

An interesting finding occurs in these studies and also in a number of other studies related to this work. That is, children with bilateral implants hear in ways we didn’t think they could. This may be akin to moths changing colours to survive. The information about the three dimensional world may be so critical that one wonders if our processing system, the system that humans preferentially developed over olfaction for example, has determined a novel way to solve the reassembly puzzle with degraded but importantly, bilateral input. Another interesting finding is that correct responses take longer for children using cochlear implants to make than would be the case in children with normal hearing. Reaction time is a surrogate measure of cognitive effort and therefore suggests that the correct answer is taking more effort to establish in children with bilateral cochlear implants. Putting it all together we have a sensory reassembly story that seems to make the moth’s pale by comparison.

The human information processor needs information to orient, communicate and evaluate its environment. Despite the fact that the preferred sensory information is not available (i.e. lack of timing cues with cochlear implants) humans with bilateral cochlear implants might have found a novel way to extract the sensory information they need to negotiate their multi-dimensional environment. It just may take them longer to do it since they are relying on cortical processes to replace the factory-installed processors in the brainstem that rely on temporal information. This hypothesis is highly speculative, to be sure, but there is other sensory experimental data that suggests such processing does occur (Czarnecki, et al., 2012).

Children need to extract as much information from their environments as they can; for those children with hearing loss this extraction process is tiring and involves considerable cognitive effort. Children have far less experience on which to understand tense, grammar and the way the world around them actually works. The rapidity of the diagnosis and habilitation and the quality of the input, whether it be a result of bilateral input or better hearing aid fitting, are the subjects central to this conference. They are amongst the many other topics of this conference devoted to improving the quality of the sensory input and improving the ability of the child to extract important information from their environment and reassemble it correctly. A main purpose of this presentation is to point out that the superiority of human information processing may make it possible to use heretofore unusable data to satisfy its need for information. That is an exciting prospect and should inspire us all to apply the knowledge presented at this conference to best provide the highest fidelity and reliable auditory data to the children with hearing loss in our care. Then, like moths, these children will seek the light on their own.
References


Acknowledgement: For the Symposium proceedings publication, I have elected to write in prose style and refer to the published literature for more detailed study of the work and concepts presented. The goal of this address was to inform and inspire rather than solely transmit data which is published in full form elsewhere. I have included my two academic partners in our cochlear implant program as coauthors of this paper. They have shared in the experimentation and data analysis that informs this work and hours of discussion among us have generated much of the material I presented in the keynote address.