# Auditory Laterality: Dichotic Listening and fMRI Studies

Norwegian leading discoveries in neurology and neurolscience are presented in a series of short articles in ACNR, initiated by the journal. All the selected discoveries have links to ongoing research projects in leading groups. They span from clinical to more basic topics. The discoveries are all relevant for clinicians evaluating and treating patients with brain and nervous system disease. Neuroscience with a clinical focus has been a priority for Norwegian research. Further expansion is planned in cooperation between the universities, the university hospitals, the Research Council of Norway, and the Norwegian Brain Council. Although the discoveries in this series are presented as Norwegian, they all appear in an international context. They represent small pieces fitting into the bigger puzzle, but contribute in elucidating mechanisms for brain and neuromuscular function, thus laying foundations for improved treatment of human disease.

***Kenneth Hugdahl***
is professor of Biological Psychology at the University of Bergen and holds an adjunct professorship at the Division of Psychiatry, Haukeland University Hospital. He has published more than 250 articles, and edited five books, among them the MIT Press series on brain asymmetry and laterality. He has received many awards and scholarships for his research, among them Honorary Doctorate at the University of Turku, Finland, and an ERC Advanced Grant Award. His main research interests are in cognitive neuroscience and psychiatric disorders, in particular fMRI and dichotic listening studies of auditory hallucinations in schizophrenia.

***Correspondence to:***
Kenneth Hugdahl,
Department of Biological and medical Psychology,
Jonas Lies vei 91,
N-5009 Bergen, Norway.
Email: Hugdahl@psybp.uib.no

## Auditory laterality and hemispheric asymmetry

The differing perceptual and cognitive functions of the two cerebral hemispheres is one of the great discoveries and mysteries of the human brain (see Hugdahl & Westerhausen, 2009 for a recent review of the field). Ever since the groundbreaking work by the Nobel Laureate Roger Sperry (see Sperry 1974), mapping the different functions of the cerebral hemispheres has been a major research area. Most research on hemispheric asymmetry was however focused on the visual system, although the principles governing the workings of the hemispheres should be supra-modal. In 1984 (Hugdahl & Andersson, 1984) our group began research on auditory laterality, using a simple technique called dichotic listening (DL) which had been introduced to neuropsychology in 1961 by Doreen Kimura. We used a variant of the technique with dichotic presentations of simple speech sounds consisting of pairs of consonant-vowel (CV) syllables (see Figure 1) that was first used by Studdert-Kennedy and Shankweiler (1970). The DL technique means that two different auditory stimuli are presented at the same time, one in each ear, and without informing the subject or patient that there are two different sounds. The task of the subject is simply to report which sound she/he perceives on each trial, typically repeating the sequence for a 100 such trials. The result is normally a 'right-ear-advantage' (REA) with better performance for the right ear stimulus, also when controlling for inter-aural differences in hearing acuity, caused by left temporal lobe processing advantage for speech sounds. This simple technique has several advantages when studying perceptual and cognitive processes particularly in psychiatric and neurological patients, not the least its simple structure which means that patients with severe disorders and diseases can be compared on the same parameters across processes. Over the years our group has used the DL technique to study deficits in hemispheric asymmetry for speech sound processing in numerous psychiatric and neurological disorders, and the CV-syllables variant we developed in the 1980s is today in use in clinics and laboratories worldwide.

## Localising the neuronal basis of the REA

In 1999 we published the first brain imaging study, using PET $^{15}$0 with dichotic presentations of CV-syllables stimuli, which showed increased activations in the left superior temporal gyrus (Hugdahl et al., 1999), thus validating the REA performance effects with brain activation measures. The PET results have later been replicated with fMRI (van deen Nort et al., 2008), thus showing the robustness of the neuronal mechanisms generating the REA.

## The forced-attention paradigm: How cognition modulates asymmetry of perception

During the 1970s and 1980s there were several studies investigating how cerebral asymmetry may be modulated through influences from higher cognitive processes, e.g. attention (see e.g. Kinsbourne, 1970). In 1986 we reported that the REA could be modulated and even shifted to a left ear advantage in healthy adult individuals when they were instructed to pay attention to the right or left ear stimulus (Hugdahl & Andersson, 1986; see also Bryden et al., 1983), which we labelled "the forced-attention" paradigm. This was a surprising finding since most theories of hemisphere asymmetry at that time considered laterality differences to be the result of the nature of the stimulus. Moreover, there was a general consensus that the 'instruction-effect' was simply the result of differential focusing of attention. This view was however challenged in later studies in our laboratory, particularly in neurological and psychiatric patients with cortical or subcortical damage and/or corresponding cognitive dysfunction (see Wester et al. 2001; Løberg et al., 2006 for examples). We observed that a common denominator across many clinical groups was that the patients could not perform the 'forced-left' condition, when instructed to pay attention to the left ear stimulus of the dichotic pair (see Westerhausen & Hugdahl, 2010 for a recent overview). We realised that the situation with attention focused on the left ear stimulus was a cognitive conflict situation, tapping executive (frontal lobe) functions, while the situation with attention focused on the right ear was a non-conflict situation, tapping attention (parietal lobe) functions. We were later able to verify these assumptions by using fMRI to measure regional changes in neuronal activation in these areas (Thomsen et al., 2004; Westerhausen et al., 2010 using fMRI, see also O'Leary et al., 1996 using PET). See Figure 2 which shows fMRI brain activation data in the prefrontal cortex, particularly in the anterior cingulate. This activation pattern is uniquely associated with instructing the subjects to pay attention to and report the left ear syllable from the dichotic stimulus pair, and not

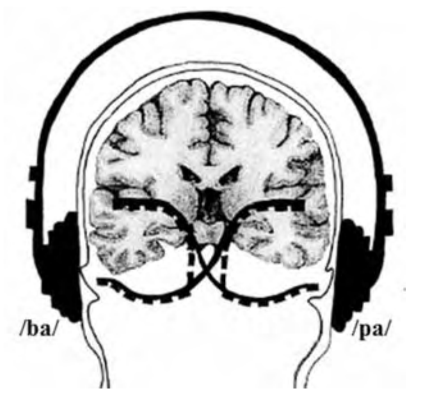


Figure 1: Illustration of outline of the standard consonant-vowel syllables DL paradigm. The right ear advantage is thought to be caused by the more preponderant contralateral auditory pathways and the specialization for processing of speech sounds in the left peri-Sylvian region.

observed when instructing the subjects to pay attention to and report the right ear syllable. This was a remarkable observation when we first observed it since the only difference between the two conditions is the instruction to move attention to either the right or left ear stimulus, and it should not matter which side in auditory space the subject was attending to.

Based on the early observations in our laboratory, the current view is that the 'forced-attention' DL- paradigm actually taps three different cognitive processes; perceptual, attentive, and executive functions. An important aspect of this discovery is that three complex cognitive phenomena can be studied within the same experimental paradigm, with minimal experimental manipulations between the three conditions, maximising experimental control of extraneous confounding variables. In fact, the only procedural difference between the 'forced-left' and 'forced-right' instructions is a single word in the instruction ('right' versus 'left'), otherwise all parameters stay constant across conditions.

**The intensity-modulated paradigm: Quantifying degrees of cognitive dysfunction**

In 2008 our group used a simple physical manipulation of the syllable stimuli to increase or decrease the bottom-up load when studying the effects of attention instructions on perceptual asymmetries (see Westerhausen et al., 2010; see also Berlin, 1977). By gradually changing the relative intensity of the right or left ear stimulus in incremental steps of 3dB we were able to show for the first time that subjects tolerated much less of an intensity increase in the right ear when instructed to pay attention to the left ear stimulus, than the other way around, thus showing a parametric way of manipulating cognitive effort needed to exert cognitive control. A more recent fMRI study (Westerhausen et al, 2010) has in addition shown that there is a corresponding parametric modulation of neuronal activation in prefrontal and anterior cingulate areas corresponding to the gradual change in performance. With this development of the technique we foresee a new way of testing various psychiatric and neurological patients for degrees of neuropsychological dysfunctions across diagnostic categories, something that has not been possible before. Parametrically quantifying degrees of cognitive dysfunction in patient groups with different diagnoses could reveal subtle commonalities in cognitive deficits in aetiologically unrelated diagnostic categories, in particular in psychiatric patients, could have consequences for diagnosis and treatment.

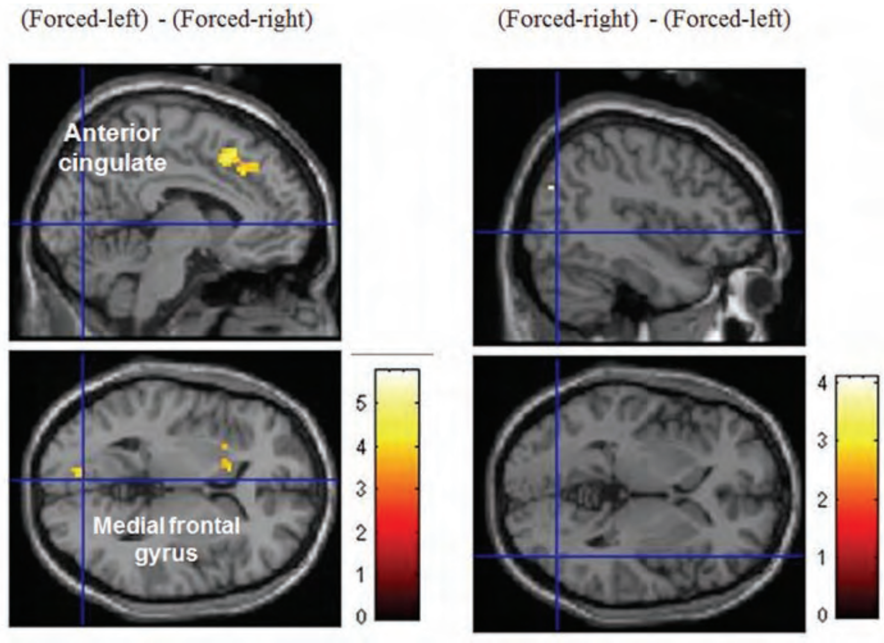


Figure 2: Functional MRI (fMRI) data showing significant activation in prefrontal and anterior cingulate cortex when contrasting images acquired during the "forced-left" condition with images acquired during the "forced-right" condition, not seen in the reversed comparison. (modified after Thomsen et al., 2004)

**Conclusions**

In this brief overview of research in our laboratory on auditory laterality and top-down modulation of a bottom-up perceptual asymmetry effect, I have shown how our laboratory over the years has revealed how an assumed pure behavioural effect has distinct neuronal correlates localised to the upper posterior parts of the peri-Sylvian region, using both PET and fMRI measures. I have furthermore shown how influences from higher cognitive processes, such as attention and executive functions, modulate lower level processes, such as perception, and that this also have neuronal correlates in prefrontal and parietal lobe areas. Finally, I have shown how this research has revealed a common profile of cognitive dysfunction (with unique neuronal correlates) across diagnostic categories for psychiatric and neurological dysfunctions. ◆

REFERENCES

Berlin CI. (1977). *Hemispheric asymmetry in auditory tasks.* In S Harnad & RW Doty & L Goldstein, J Jaynes, G Krauthamer (Eds.), *Lateralization in the nervous system.* New York: Academic Press (303-324).

Bryden MP, Munhall K, & Allard F. *Attentional biases and the right-ear effect in dichotic listening.* Brain and Language, 1983;18:236-48.

Hugdahl K, & Andersson B. *A dichotic listening study of differences in cerebral organization in dextral and sinistral subjects.* Cortex, 1984;20:l35-l4l.

Hugdahl K, & Andersson L. *The "forced-attention paradigm" in dichotic listening to CV-syllables: A comparison between adults and children.* Cortex, 1986;22:417-32.

Hugdahl K, Brønnick K, Kyllingsbæk S, Law I, Gade A, & Paulson OB. *Brain activation during dichotic presentations of consonant-vowel and musical instruments stimuli: A 15O-PET study.* Neuropsychologia, 1999;37:431-40.

Hugdahl K, & Westerhausen R. *What is left is right: How speech asymmetry shaped the brain.* European Psychologist, 2009;14:78-89.

Kimura D. *Cerebral dominance and the perception of verbal stimuli.* Canadian Journal of Psychology, 1961;15:166-71.

Kinsbourne M. *The cerebral basis of lateral asymmetries in attention.* Acta Psychologica, 1970;33:193-201

Løberg E-M, Jørgensen HA, Green MF, Rund BR, Lund A, Diseth Å, Øie M, Hugdahl K. *Positive symptoms and duration of illness predict functional laterality and attention modulation in schizophrenia.* Acta Psychiatrica Scandinavica, 2006;113:322-31.

O'Leary D, Andreasen NC, Hurtig RR, Kesler ML, Rogers M, Arndt S, Cizadlo T, Watkins GL, Boles Ponto LL, Kirchner PT, Hichwa RD. (1996). *Auditory attentional defecits in patients with schizophrenia.* Archives of General Psychiatry, 1996;53:633-41.

Sperry RW. (1974). *Lateral specialization in the surgically separated hemispheres, The Neuroscience: Third Study Program*. Cambridge: MIT Press.

Studdert-Kennedy M, Shankweiler D. *Hemispheric specialization for speech perception.* Journal of the Acoustical Socitey of America, 1970;48:579-94.

Thomsen T, Specht K, Rimol LM, Hammar Å, Nyttingnes J, Ersland L, Hugdahl K. *Brain localization of attentional control in different age groups by combining functional and structural MRI.* Neuroimage, 2004;22:912-9.

Van den Noort M, Specht K, Rimol LM, Ersland L, Hugdahl K. *A new verbal reports fMRI dichotic listening paradigm for studies of hemispheric asymmetry.* Neuroimage, 2008;40:902-11

Wester K, Irvine DRF, Hugdahl K. *Auditory laterality and attentional deficits after thalamic haemorrhage.* Journal of Neurology, 2001;248:676-83.

Westerhausen R, Hugdahl K. (2010). *Cognitive control of auditory laterality.* In K. Hugdahl & R. Westerhausen (Eds.). *The two halves of the brain - Information processing in the cerebral hemispheres.* Cambridge, MA: MIT Press (469-99).

Westerhausen R, Moosmann M, Alho K, Belsby SO, Hämäläinen H, Medvedev S, Specht K, Hugdahl K. *Identification of attention and cognitive control networks in a parametric auditory fMRI study.* Neuropsychologia, 2010;48:2075-81.