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What can be learned about brain function from dichotic listening ?*

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A series of studies on the use of dichotic listening as a method to study brain-behavior interactions, including hemispheric asymmetry are reviewed. The dichotic listening method is presented from a historical perspective, followed by an outline of the empirical procedure used in our laboratory. Different methods of validating the dichotic listening procedure against both invasive and non-invasive techniques, including PET blood flow recordings are then presented. The paper is ended with some examples of clinical applications of the dichotic listening technique on brain damaged patients. A major argument in the present paper is that the dichotic listening technique is a method to study the interaction between bottom-up, or stimulus-driven, versus top-down, or instruction-driven laterality. This opens up for a more dynamic and interactive view of brain laterality than the traditional static view that the brain is lateralized only for specific stimuli and stimulus properties.

¿Qué se puede Aprender sobre el Funcionamiento del Cerebro a partir de la Escucha Dicótica?

Se revisan una serie de estudios sobre el uso del estudio de la escucha dicótica como método para estudiar las interacciones entre cerebro y comportamiento, incluyendo la asimetría interhemisférica. Se presenta el método de la escucha dicótica desde una perspectiva histórica seguido por una revisión de los métodos empíricos utilizados en nuestro laboratorio. Posteriormente, se presentan diferentes métodos para validar este procedimiento en contra de las técnicas invasivas y no invasivas. Finalmente, se termina con algunos ejemplos de aplicaciones clínicas de este método en pacientes con daño cerebral. El principal argumento en este documento es que esta técnica es un método para estudiar la interacción entre abajo - arriba, o estímulo - impulso, vs arriba – abajo o instrucción-impulso. Esto lleva a una visión más dinámica e interactiva sobre la lateralización cerebral respecto a la vision estática tradicional de sugiere que

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el cerebro está lateralizado únicamente por estímulos específicos y propiedades de los estímulos.

In the present paper I will give a short overview of the use of dichotic listening (DL) in neuropsychology, and what has been learnt from this method over the last almost 40 years of research and clinical practice, from the pioneering work by Kimura (1960,1961) and Bryden (1963) to modern use of the DL technique in both basic brain science (Tervaniemi et al., 1999; Hugdahl et al., 1999) to clinical practice (Roberts et al., 1990). Recent data both from experimental and clinical studies suggest that the DL method may be a sensitive non-invasive technique to probe not only language lateralization, which is the "classic" application, but also sustained attention (Hugdahl et al., 1986), shift of attention (Asbjørnsen & Bryden, 1998), hemispheric integration and corpus callosum function (Cowell & Hugdahl, in press), evaluation of neurosurgical therapy (Wester et al., 1998), and cognitive dysfunction in psychiatric disorders (Løberg et al., 1999; Bruder, 1995; Wexler, 1986). The basic experimental dichotic listening situation is shown in Figure 1.

It will be argued in the present paper that dichotic listening is a method for the study of bottom-up (stimulus driven) versus top-down (instruction-driven) information processing. A synonym word for bottom-up processing is "automatic" processing, versus "controlled" processing which sometimes is used as a synonym for top-down processing. The basic idea is that certain stimuli are directly processed in specialized areas of the brain without conscious recollection or attentional awareness, while other stimuli, or stimulus-settings require allocation of attentional resources in order to be processed. An example of automatic processing is the right ear advantage (REA) typically found in DL studies to speech stimuli (see Bryden 1988; Hugdahl, 1995 for reviews). The neurological basis for the REA may be the anatomical asymmetry found in the planum temporale area in the superior temporal gyrus (Steinmetz et al., 1989), where the left side is larger than the right side. This may provide a biological foundation for the automatic perception of speech stimuli in the left side of the brain, which in turn causes the right ear advantage. If the subject, however, is required to focus attention either to the right or left ear, the "stimulus-driven" right ear advantage can be either increased or decreased (sometimes shifted to a left ear advantage) depending on which ear the subject is instructed to attend (Asbjørnsen & Hugdahl, 1995). Similarly, Mondor and Bryden (1991) showed that presenting an auditory "cue" in either the left or right ear a few milliseconds before the dichotic stimuli, also affects the ear advantage on a trial-by-trial basis, by having the subject to shift attention between the ears from trial to trial.

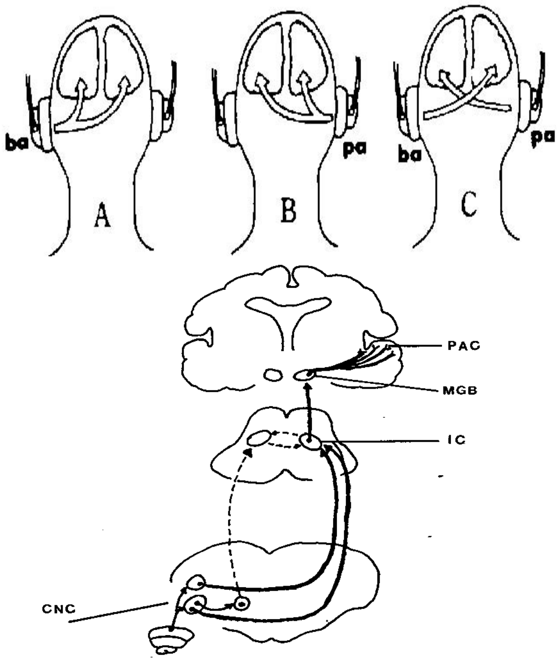

Figure 1. Basic outline of the dichotic listening situation. A = Monaural presentation of syllable ”ba” inthe left ear, with bilateral input to both hemispheres. B = Monaural presentation of the syllable ”pa” in the right ear, with bilateral input to both hemispheres. C = Dichotic presentation of both ”ba” and ”pa”. The preponderance of the contralateral pathways will block the ipsilateral pathways. Thus, the right ear signal will primarily be projected to the left hemisphere, and the left ear signal will primarily be projected to the right hemisphere. CNC = Cochlear Nucelus, IC = Inferior Colliculus, MGB = Medial Geniculate Body, PAC = Primary Auditory Cortex

Applying the model of dichotic listening as an indicator of automatic versus controlled processing, Løberg et al. (1999) showed that schizophrenic patients suffered from both automatic and controlled processing skills, which the authors named "a dual deficits" model for the study of neurocognitive deficits in schizophrenia. This is shown in Figure 2.

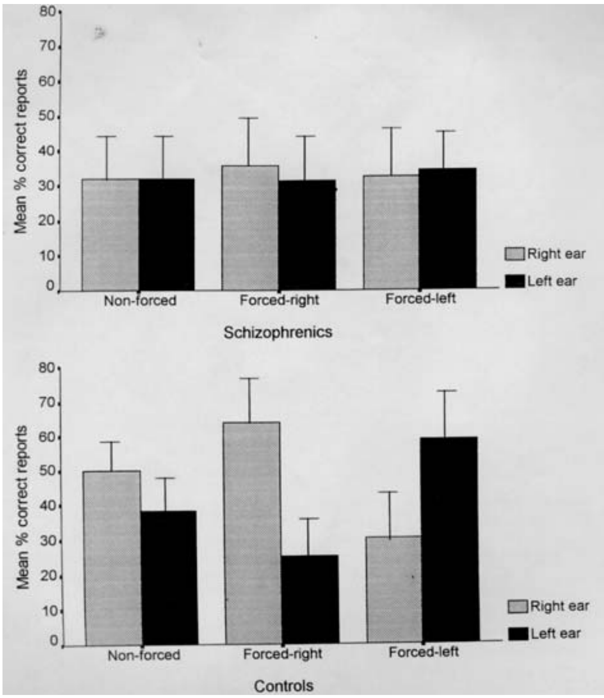

Figure2. Mean percentage correct reports for the left and right ear stimulus during divided (non-forced) and focused (forced-right and forced-left) attention instructions. Note the “flat” response function across attention instructions for the schizophrenic patients (upper graph) compared with the control subjects (lower graph). Data from Løberg et al. 1999

Thus, it will be argued in the present paper that the dichotic listening method taps several other neurocognitive functions than the "classic" laterality function, and that these other functions relate to both attention, arousal, and higher cognitive processes.

It has been argued that the dichotic listening lacks functional validity because it is sometimes hard to find correlations between dichotic listening and other laterality measures (like the visual half-field technique). However, auditory lateralization is probably not related to a single mechanism (cf. Jäncke & Steinmetz, 1993). This means that it should not be a surprise when dichotic listening show low intercorrelations with other laterality tasks, like the visual half-field technique, since these tasks probably index different laterality modules. There is no such thing as *the* laterality function that can be assessed with whatever laterality task or test. Each hemisphere subserves multiple functions that need not correlate with each other. What should correlate, however, are measures of general activation of a hemisphere and tasks that tap specific functions within that hemisphere. This was exemplified in recent data reported by Davidson and Hugdahl (1996). It was found that the magnitude of the right ear advantage (REA) in the dichotic listening task significantly correlated with resting EEG asymmetry. Subjects with larger left than right EEG resting activation also had better recall from the right as compared to the left ear in dichotic listening (see Figure 3).

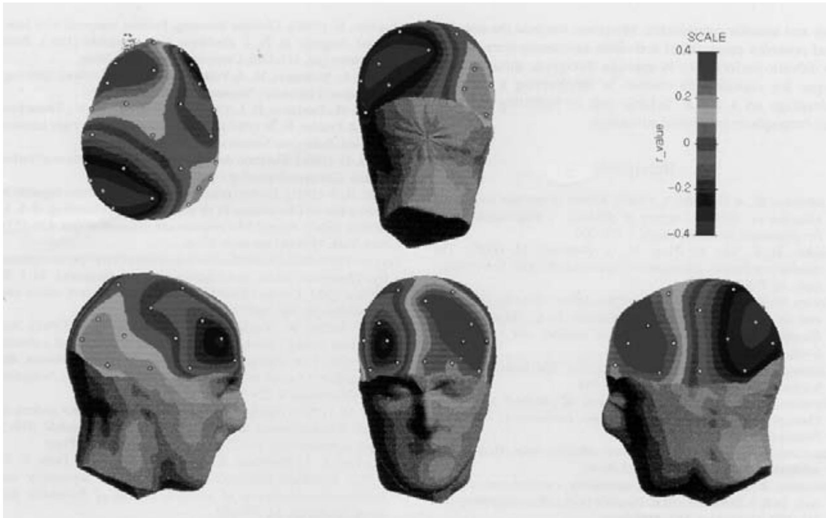

Figure 3. Correlation maps between residualized EEG alpha power and dichotic listening quotient [(Right ear – Left ear) / (Right ear + Left ear) correct reports]. Purple regions indicate that decreased alpha power (= increased activation) is associated with better right ear performance, whereas the orange end of the color spectrum indicates that increased alpha power (= decreased activation) is associated with better right ear performance. data from Davidson and Hugdahl, 1996

This shows that dichotic listening performance may be linked to individual differences in trait-like hemisphere asymmetry.

Brief historic overview

It was Broadbent (1954) who originally developed the dichotic listening technique to simulate the attentional load experienced by air traffic controllers when simultaneously receiving multiple flight information. However, it was Kimura (1961) who developed the present day version of the DL technique for the study of hemisphere function in normal individuals and brain lesioned patients. Finally, Bryden (e.g. Bryden et al., 1983) applied the technique to the study of attention, although these authors argued that attention was a source of error for the study of "true" lateralization, that should be removed from the situation. It was Hugdahl (e.g. Hugdahl & Andersson, 1986) who suggested that the "forced-attention" paradigm in dichotic listening should be used to study the interaction of attention with speech laterality as a paradigm of its own, rather than treating attention as a source for intra-subject error (see Figure 4).

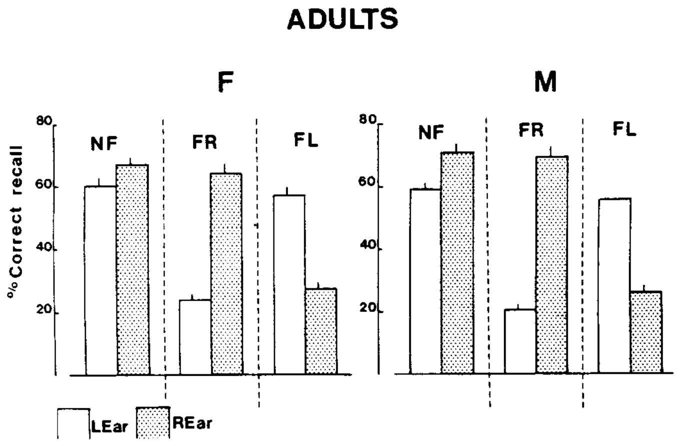

Figure 4. Mean percent correct reports during divided attention (Non-forced, NF)and focused attention (forced-right, FR and forced-left, FL). F = females, M = males. Data from Hugdahl and Andersson,1986

As a tool for probing of brain laterality, dichotic listening has been used in literally thousands of research and clinical reports related to; language processing (Tartter, 1988); emotional arousal (Bryden, 1988), hypnosis and altered states of consciousness (Frumkin, Ripley & Cox, 1978; Crawford et al., 1983), stroke patients (Hugdahl et al., 1990), psychiatric disorders (Nachshon, 1980; Wexler,1986; Bruder, 1995), child disorders, including dyslexia (Bakker & Kappers, 1988; Obrzut & Boliek, 1988; Cohen et al., 1992), congenital hemiplegia (Carlsson et al., 1992).

Auditory laterality: Theoretical models

Dichotic listening literally mean presenting two auditory stimuli simultaneously, and the standard experiment requires that the subject report after each trial which of the two stimuli he/she perceived best. In our laboratory, we typically ask only for one response on each trial, although the subject sometimes may perceive that there are two stimuli being presented on a trial. The most frequent finding is the so called right-ear advantage (REA, see also above), which means better report from the right, as compared to the left, ear under divided attention conditions. Focused attention conditions are discussed separately below. According to Kimura (1967), the REA is a consequence of the anatomy of the auditory projections from the cochlear nucleus in the ear to the primary auditory cortex in the temporal lobe, and of a left hemisphere superiority for the processing of language related materials. The basic REA effect is shown in Figure 5, based on 808 subjects.

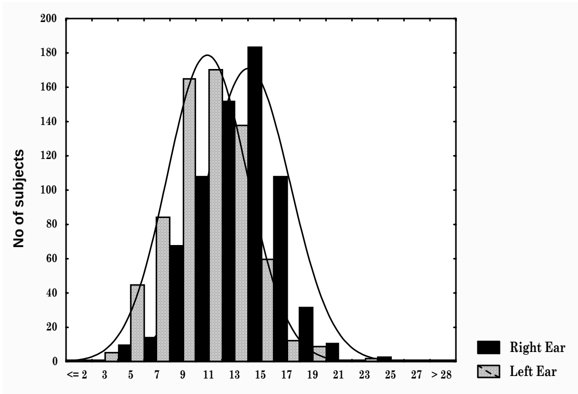

Figure 5. Distribution of subjects (y-axis) against the spectrum of correct reports (x-axis; min = 0, max = 30), split for right and left ear reports. Note the bell-shape for both the left and right ear scores, and the apparent shift to the right for the Right Ear curve, indicating the REA effect. Curves based on N = 808 normal subjects

The auditory system may conveniently be divided into five separate relay stations (Brodal, 1981; Nerad, 1992). An auditory stimulus activates neurons in the cochlear nucleus at the level of the vestibulocochlear nerve. Among the subdivisions of the cochlear nucleus, the ventral acoustic stria enters the second level, the superior olivary complex. From here, both inhibitory and excitatory impulses are projected within the lateral lemniscus to the dorsal and ventral nucleus of the lateral lemniscus, which make up the third-level relay station. Up to the level of the nuclei of the lateral lemniscus, the auditory system projects bilaterally, to both sides. However, from the nuclei of the lateral lemniscus, projections are mainly contralateral, projecting to the fourth relay station, the inferior colliculus in the tectum. The contralateral fibers then innervates the medial geniculate body in the pulvinar thalamus, which is the fifth relay station, sending its axons to neurons in the auditory cortex in the posterior superior temporal gyrus (Price, et al., 1992; Brugge & Reale, 1985). Thus, although auditory signals from one ear reach both auditory cortices in the temporal lobes, the contralateral projections are stronger and more preponderant. Furthermore, although the input to the inferior colliculus is both ipsi- and contralateral, the projections *from* the inferior colliculus are greater from the contralateral ear. This will, in the end, favor representation of the contralateral ear in the auditory cortex (cf. Brodal, 1981).

The "classic" model (e.g. Kimura, 1967; Sparks & Geschwind, 1968; Sidtis, 1988) suggesteds that the REA is caused by several interacting factors. The auditory input to the contralateral hemisphere is more strongly represented in the brain. Second, the left hemisphere (for right-handers) is specialized for language processing. Third, auditory information that is sent along the ipsilateral pathways is suppressed, or blocked, by the contralateral information. Fourth, information that reaches the ipsilateral right hemisphere has to be transferred cross the corpus callosum to the left hemisphere language processing areas.

Taking all of these steps together, the REA will thus reflect a left hemisphere language dominant hemisphere. The classic model was supported by the papers of Sparks and Geschwind, (1968), and by Milner et al., (1968). These authors reported a complete, or near-complete extinction in the left ear channel in commissurotomized patients after dichotic presentations. The argument was that in order to report from the left ear, the signal had to travel from the right auditory cortex, via the corpus callosum, to the language dominant left region. Damage to the pathway anywhere along this route should consequently yield extinction of the left ear input. A similar argument was made that lesions in the left auditory region would produce a left ear extinction effect. By the same token, a left ear advantage (LEA) would typically indicate a right hemisphere processing dominance and a no ear advantage (NEA) would indicate a bilateral, or mixed, processing dominance. Unpublished data from our laboratory have shown that individuals with crossed laterality, i.e. crossed hand and eye preference, fail to demonstrate a significant REA in dichotic listening compared to individuals with non-crossed eye-hand laterality.

Practical considerations: Test administration

In the present review, the stimuli were paired presentations of the six stop-consonants /b,d,g,p,t,k/ together with the vowel /a/ to form consonant-vowel (CV) syllable pairs of the type /ba - ga/, /ta - ka/ etc. The syllables were paired with each other for all possible combinations, thus yielding 36 dichotic pairs, including the homonymic pairs. The homonymic pairs were included as "test-trials", and were not included in the statistical analyses. Each CV-pair was recorded three times on the tape, with three different randomizations of the 36 basic pairs. Thus, the total number of trials on the tape was 108. The 108 trials were divided into 3 x 36 trial-blocks, one trial-block for each instructional condition, non-forced attention (NF), forced-right (FR), forced-left (FL), see below for details. In some studies only the NF condition was used. For each condition, the analysis was based on 30 trials. Each subject was given a standardized set of instructions prior to the test. The instructions were of the format:

"You should listen to the six different sounds which are given on this page. (show the six syllables on a page of paper.) After each presentation, you should repeat whichever sound you hear. Say the sound loud and clear directly after it has been presented. Sometimes it will seem as if you hear two different sounds at the same time. Don't worry about this, but say the sound you seemed to hear best or most clearly. Don't spend time thinking, but just repeat the sound as soon as it has been presented." In some instances, e.g. when testing patients with expressive language difficulties, the experimenter asked the patient to point to a sheet of paper where the syllables were written in capital letters (e.g. Hugdahl, Wester & Asbjørnsen, 1990).

The syllables were read by a male voice with constant intonation and intensity. Mean duration was approximately 350 ms., and the intertrial interval was about 4 sec. The syllables were read through a microphone and digitized for computer editing on a PC. After digitization, each CV-pair was displayed on the screen and synchronized for simultaneous onset and offset between the right and left channels. The synchronization was performed on the PC computer with a specially developed software running as an application under MS-Windows.

After computer-editing, the CV-pairs were *originally* taken from the computer (over the D/A board) and recorded on a Revox B-77 stereo reel-to-reel tape-recorder. The reel-to-reel tape was then copied onto a chrome dioxide cassette and played to the subject from a SONY Walkman WM DDII stereo minicassette player. The output from the minicassette player was calibrated between channels, and the mean output intensity was 75 dB SPL when measured with a Bruel and Kjaer 2204 sound-level meter equipped with a Bruel and Kjaer 4521 "artificial ear". The CV-syllables were presented to the subject with the help of miniature "plug-in"-type earphones.

In more *recent studies*, we bypass the tape-recorder and cassette stages for stimulus presentation, and either present the digitized stimuli directly from the PC (using the MEL software environment and a standard SoundBlaster soundboard), or record the stimuli on a CD, which is played from a standard CD-player.

In most of the studies, the subjects were tested for differences between the ears in hearing acuity. Hearing thresholds were determined for each ear for the frequencies 500, 1000, 2000, 3000 and 5000 Hz. Subjects with larger threshold differences than 5 dB between the ears on any of the frequencies tested were excluded from the study. The 500 to 5000 Hz range was chosen because most of the spectral energy in the CV-syllables are in this range.

Forcing attention to either the left or right ear stimulus

The typical procedure in our laboratory is that data are collected with a common procedure, involving three different attentional instructions; labelled non-forced; forced-right, and forced-left, respectively.

In the non-forced condition (NF), which always was presented first for reasons of not confusing the subject, the subject was told that he/she would hear repeated presentations of the six CV-syllables (ba, da, ga, pa, ta, ka), and that he/she should report which one he/she heard from the six possible after each trial. The subjects were furthermore told that "on some occasions there seems to be two sounds coming simultaneously". They should not bother about this, and just report the one they heard first, or best. Subjects were instructed not to think about the syllables but give the answer that spontaneously came into their mind after each presentation. They were usually showed a cardboard sheet with all six syllables written before the experiment started. In our laboratory, we have shifted to the use of only single-correct trials that are scored, or alternatively, the subject is instructed always only to report *one* item on each trial irrespective of whether they perceived one or both items (see Bryden, 1988 for a discussion of single- versus double-answers).

When subjects are left free to report the items as in the NF situation, they may choose the order in which they report. They may also differentially attend to the right and left ear input (see Bryden et al., 1983; Hugdahl & Andersson, 1986). It may even be the case that right-handed subjects find it easier to focus attention on items from the right, rather than from the left, ear. Thus, in order to control for strategy effects, subjects were requested to "only listen to, and report from the right ear" on the following 1/3 of the trials. Using a focused-attention condition makes it possible to simultaneously study structural and dynamic laterality effects within the same paradigm. The NF condition basically taps a structural laterality component, while the FR and FL conditions taps the modification of structural laterality by dynamic cognitive factors, like attention and arousal. This will be discussed more in detail in later sections of the paper. In the "forced-attention" situations, subjects were required to report only the *right* ear input in one third of the trials, to attend to and report only the *left* ear input in another third of the trials (see Bryden et al., 1983; Hugdahl & Andersson, 1986). The presentation order of the FR and FL conditions was counterbalanced across subjects.

A crucial question when both evaluating the classic structural model and when validating dichotic listening data is to what extent it can be shown that a) dichotic listening correlates with other measures of brain laterality, and b) it correlates with brain lesion data, that is, the extent to which dichotic listening performance can predict the side of lesion in brain damaged patients. Both of these questions will be addressed.

Wada-validation

The standard validation procedure for dichotic listening has been the Wada-procedure (Wada & Rasmussen, 1960) in epileptic patients undergoing surgery. The Wada test means that probe with a barbituare (Sodium Amytal) is placed into either the left or right femoral artery, and led up to the branching of the internal carotid artery with the middle and anterior cerebral arteries where the barbiturate is injected. This sedates the hemisphere for about 5-10 minutes, and the experimenter can then test for the presence of language (as well as other cognitive functions) in the sedated hemisphere. The procedure is replicated on the other hemisphere after a short resting period.

In a recent study from our laboratory (Hugdahl et al., 1997) we compared dichotic listening performance in 13 subjects who had undergone Wada testing, knowing in advance which side of the brain speech was located to. The study had two purposes: a) to validate the CV-syllables dichotic listening method with the invasive amobarbital «Wada» technique in children/adolescents; b) to compare pre-and post surgery dichotic listening performance, specifically with regard to the degree to which a particular pre-operation ear advantage was maintained, or was changed post-operatively.

All subjects had symptomatic epilepsy with partial seizures. The Wada-test results revealed that 10 subjects had left hemisphere language, with 3 subjects having right hemisphere language. All 3 right hemisphere language subjects showed a left ear advantage (LEA) on the dichotic listening test, both pre- and post-operatively, with 8 and 7 of the 10 left hemisphere dominant subjects showing a right ear advantage (REA), pre- and post-operatively, respectively. However according to discriminant analysis, knowledge of dichotic listening performance led to correct classification according to the WADA-test results in 92.31% of all subjects. Thus, a quantitative classification procedure like discriminant analysis may be more sensitive when predicting hemisphere speech dominance from dichotic listening data than a qualitative procedure based on the ear advantage dichotomy, which typically has been used in the most other Wada-validation studies. See Figure 6.

PET-validation

The Wada procedure has two disadvantages when comparing dichotic listening performance to performance on the Wada test. First it is an invasive technique, which means that only patients can be tested. There are no Wada tests being performed on intact individuals. This leads to the second disadvantage, the experimenter is dealing with a damaged brain which is compared with intact brains in healthy individuals.

The advent of the new hemodynamic imaging techniques of PET and fMRI (Frackowiak et al., 1997) have however changed this, and it is now possible to show localized changes in blood flow to a specific cognitive stimulus without using an invasive technique. The PET-technique was used by Hugdahl et al. (1999) where 15-O PET was used to monitor regional changes in blood flow to the left and right superior temporal gyrus and the planum temporale area in 12 healthy individuals. Blood flow change was monitored to both CV-syllables and short excerpts of musical instruments having the same duration and intensity as the CV-syllables. The subjects were required to press a button placed on their chest whenever they detected a pre-determined target-sound". Thus, the paradigm was slightly changed from the standard behavioral DL paradigm because of the restrictions caused by the PET technique (controlling for overt verbal responses for example).

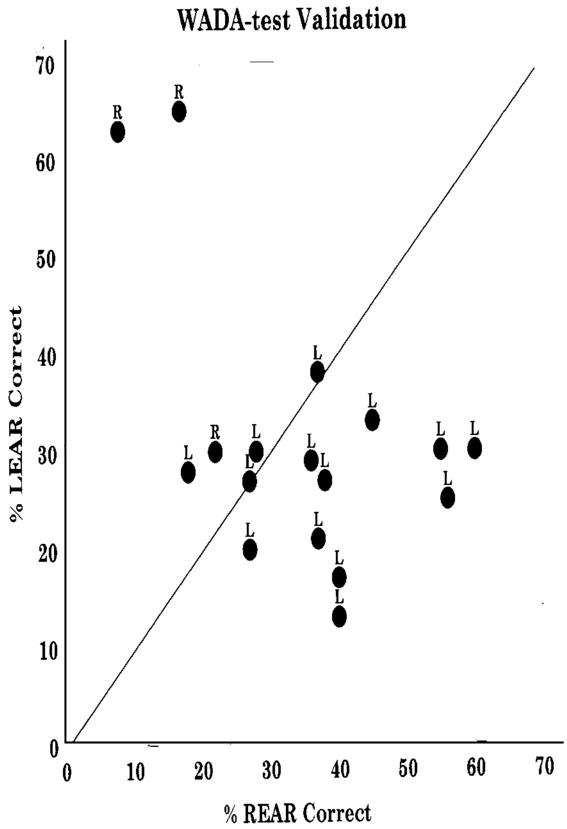

Figure 6. Scattergrams of the dichotic listening test results, outlining individual data. each dot represents an individual case. L = subjects with left hemisphere language dominance as determined from the WADA-test. R = Subjects with right hemisphere language dominance as determined from the WADA- test. X-axis = % correct reports from the right ear, Y-axis = % correct reports from the left ear. The diagonal line = 45 degree “symmetry-line”. Data from Hugdahl et al. 1997.

The primary aim of the PET study was to record regional changes in the distribution of cerebral blood flow (CBF) with the ^{15}O-PET technique to dichotically presented consonant-vowel (CV) and musical instrument stimuli, in order to test the basic assumption of differential hemispheric involvement when stimuli presented to one ear dominate over stimuli presented in the other ear. All stimuli were 350 ms in duration with a 1000 ms interstimulus interval, and were presented in blocks of either CV-syllables or musical instruments pairs. Twelve normal healthy subjects had to press a button whenever they detected a CV-syllable or a musical instrument target in a stream of CV- and musical instrument distractor stimuli. The targets appeared equally often in the right and left ear channel. The CV-syllables and musical instruments targets activated bilateral areas in the superior temporal gyri, mainly in the planum temporale area. However, there were significant interactions with regard to asymmetry of the magnitude of peak activation in the significant activation clusters. The CV-syllables resulted in greater neural activation in the *left* hemisphere while the musical instruments, resulted in greater neural activation in the *right* hemisphere. The changes in neural activation were closely mimicked by the performance data which showed a right ear superiority in response accuracy for the CV-syllables, and a left ear superiority for the musical instruments. In addition to the temporal lobe activations, there were activation tendencies in the left inferior frontal lobe, right dorsolateral prefrontal cortex, left occipital lobe, and cerebellum. The PET data are seen in Figure 7.

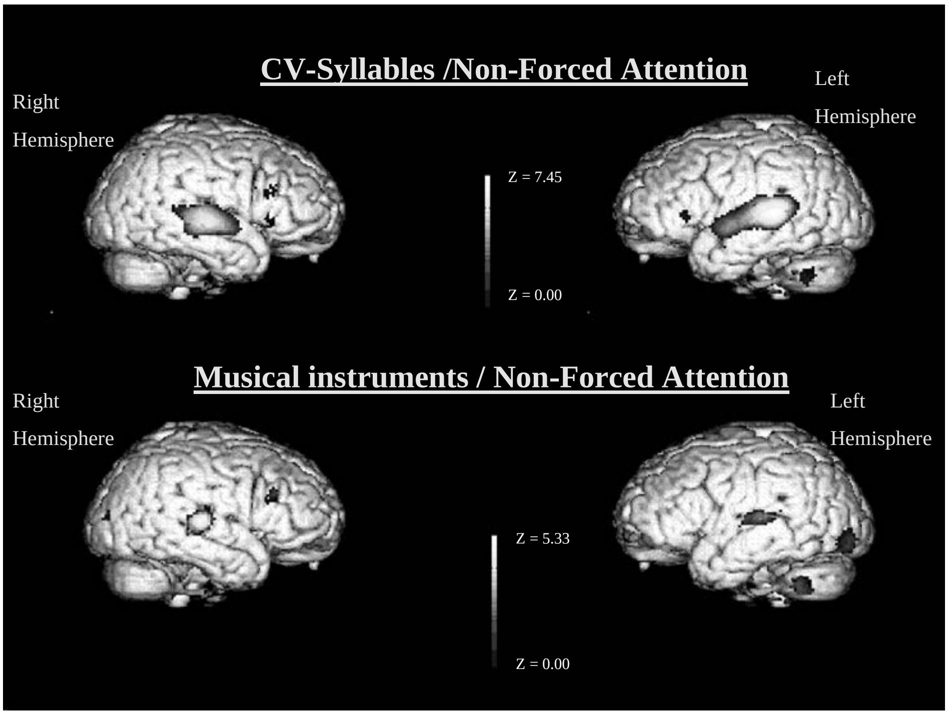

Figure 7. Changes in regional cerebral blood flow (rCBF) measured with ^{15}O – PET as a function of verbal or musical stimulus presentations in the dichotic listening situation. Data from Hugdahl et al., 1999.

Lesion-data

Hugdahl et al. (1999, submitted) compared left and right damaged lobe patients on the standard CV-syllables dichotic listening test addressing the issue of using the dichotic listening procedure to evaluate the relative effects on speech perception in left versus right hemisphere damaged patients.

The patients were tested with dichotic presentations of consonant-vowel syllables, which allows for specific probing of the left and right hemisphere function. The task was to report which syllable they heard. In one condition they received no specific instruction about focusing of attention (non-forced), in another condition they were instructed to focus attention on the right ear stimulus (forced-right), and in still another condition they were instructed to focus attention on the left ear stimulus (forced-left). The right lesioned patients had a right ear advantage under all conditions, while the left lesioned patients showed no advantage for either ear except a right ear advantage during the attend left condition. During the forced-right attention condition, once again the right lesioned group showed a significant right ear advantage. A similar effect was also seen in the left lesioned group, but it was statistically weaker. During the forced-left attention condition, neither group could modify their reports through shifting of attention to the left ear, and showed an unexpected right ear advantage also in this condition, where healthy individuals show a left ear advantage. It is suggested that the left frontal lobe patients showed evidence of a "dual-deficit", involving impairment of both stimulus processing and attentional modulation, while the right frontal patients only showed evidence of impairment of attentional modulation. Thus, the distinction between automatic versus controlled processing could be applied to the functional integrity of these patients. The results are shown in Figure 8.

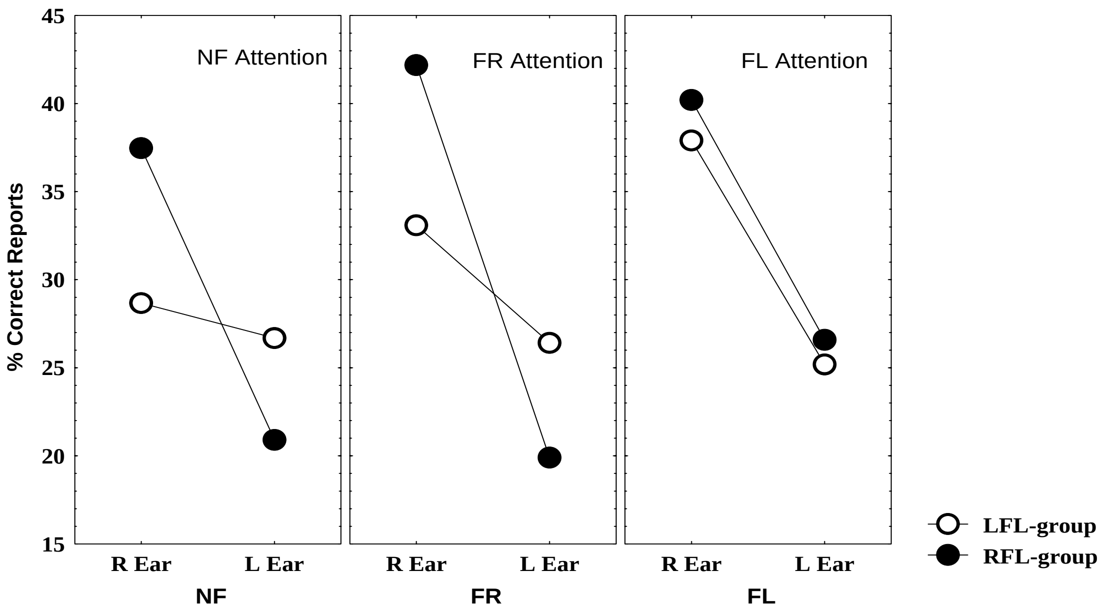

Figure 8. Mean percent correct reports from the right and left ears during divided attention (NF) and focused attention (FR and FL),split for patients with left (LFL-group) and right (RFL-group) frontal lobe lesions. data from Hugdahl, Bodner, Weiss, & Benke (submitted).

Pre- and post-surgery performance

In another study on brain damaged patients we compared dichotic listening performance in patients with arachnoid cysts before and after surgical renmoval of the cyst. Arachnoid cysts are more frequently located in the left side of the brain, typically situated in the interior of the Sylvian fissure, where the middle (arachnoid) fossa duplicates (probably prenatally) which gradually grows into a fluid filled "ballon". The cyst exerts pressure on both the temporal and frontal lobe tissue, and may cause serious epileptic like discharges and migraine like attacks.

In a series of studies in collaboration with the Neurosurgery Department at the University Hospital in Bergen we have used dichotic listening as a mean to evaluate postoperative normalization of cognitive function, both automatic (speech lateralization) and controlled (attention) processing. In addition to the traditional CV-syllables test, we have also used a dichotic memory test where whole words are presented dichotically with the task for the patient to remember the words for later recall tests. For illustrations of these studies, see for example Wester et al., (1998) and Figure 9.

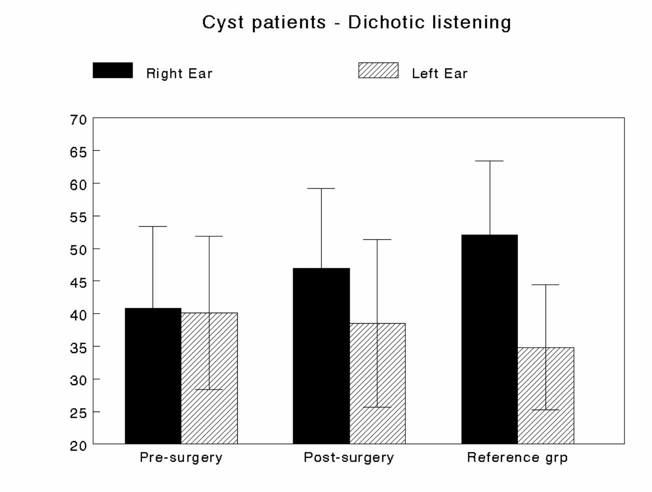

Figure 9. Mean percentage correct reports from the right and left ear in patients with arachnoidal cysts in the left temporal lobe. The patients are compared before and after surgery, and with a healthy reference group

In one study, six adults were treated successfully for arachnoid cysts in the left temporal fossa. Before surgery, the normal Right Ear Advantage (REA) was absent in the memory test. The patients also performed poorly in a forced attention task consisting of dichotic presentations of consonant-vowel syllables. Surgical treatment of the cysts with internal shunting procedures led to clinical improvement. Improvement was also associated with a rapid normalisation on the dichotic tests, with a postoperative REA and enhanced overall memory performance. The response patterns in the forced attention dichotic listening tests also improved. These ameliorations appeared shortly after the operation, in some cases within hours. The results indicate that arachnoid cysts in the left temporal fossa may impair cognitive functions, and that neuropsychological tests may be necessal-y to reveal these impairments. A dramatic improvement was recorded shortly after surgery, even after many years of functional impairment. It is concluded that test batteries for cognitive functions should be developed and included routinely in the pre-operative assessment of patients with middle fossa aracllnoid cysts. This may broaden the indications for operative treatment of these cysts.

Summary and conclusions

In the present paper I have reviewed a series of studies in our laboratory concerned with the sue of dichotic listening as a method for the study of both speech laterality and higher order attentional processes. The dichotic listening method is reviewed in a brief historical perspective, followed by an outline of the empirical procedure used in our laboratory. Different methods of validating the dichotic listening procedure against both invasive and non-invasive techniques, including PET blood flow recordings are then presented. The paper is ended with some examples of clinical applications of the dichotic listening technique on brain damaged pateints. A major argument in the present paper is the dichotic listening technique is a method to study the interaction between bottom-up, or stimulus-driven, versus top-down, or instruction-driven laterality, which opens up a more dynamic and interactive view of brain laterality than the traditional static view that the brain is lateralized only for specific stimuli and stimulus properties.

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