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Master Thesis

The Impact of Localization Information on Right Ear Advantage in Dichotic Listening, using a Fused Rhymed Words Test

by

Danielle Hoffmann

Supervised by Dr. Heinz Hättig

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Abstract (English)

The typical finding in dichotic listening with verbal stimuli is right ear advantage (REA). This is interpreted as indicating left-hemispheric specialization for speech. As shown by many authors (Kimura, 1961; Zatorre, 1989; Hund-Georgiadis & al., 2002), consistent left-ear advantage (LEA) points to right-hemispheric speech processing. Kimura explained this observation by postulating that, when two different verbal messages are presented simultaneously to the two ears of the subject, contralateral pathways would inhibit ipsilateral pathways; thus, verbal input to the ear contralateral to the speech-dominant hemisphere would be favoured. To illustrate this relationship, a patient having LEA in the FW12k, a German fused words test, was included in the study. As expected, she showed unilateral right-hemispheric speech processing in the fMRI. The present study's principal aim was to test the effect of introducing localization information into dichotic stimuli on REA. The idea was to enforce ipsilateral pathways' processing, so that REA would be reduced. The localization data used was interaural time difference (ITD) and the dichotic stimuli were fused rhymed words. We created two experiments using two different kinds of fused words. In the first experiment, we used new words ((F+)-words), which were dichotic only at the middle consonant and were easy to localize by the participant. Their inconvenience was that they showed poor ability in creating perceptual asymmetries. The second experiment's words ((nF)-words), were words of the FW12k, and so they were proven to have good intrinsic ability to create ear advantages. They differed in the first syllable, and were more difficult to localize by the participants. All participants first had to show significant REA in the FW12k to be included in the study. Interestingly, compared to the FW12k, REA dropped significantly in the simple dichotic condition in both experiments, only by the change of instruction. In the FW12k, the only

instruction is to choose the word heard, as in the study's experiments, it is also to localize it to the left or the right. This decrease was seen without ITD even having been introduced. When ITD was really present in the stimuli (the ITD-dichotic condition), REA dropped further in the (F+)-words experiment and was re-increased in the (nF)-words experiment. Although difficult to conclude, we based our arguments on the (nF)-words experiment, because we cannot assure the (F+)-words' validity. Based on Hiscock's two stage model (Hiscock & al., 2005), we assume that activation of second-stage processes (by given instruction), is responsible for reduction of REA if the stimuli are not localizable, like in the simple dichotic condition. Although, as soon as they are localizable, by means of ITD, the subject attends to his preferred ear, and re-increases his REA.

Résumé (français)

D'habitude on observe un avantage de l'oreille droite (REA) en écoute dichotique si on utilise des stimuli verbaux. Ceci est interprêté comme indice pour la prédominance de l'hémisphère gauche dans le traitement du langage. Beaucoup d'auteurs (Kimura, 1961; Zatorre, 1989; Hund-Georgiadis et al., 2002) ont également montré, qu'un avantage de l'oreille gauche (LEA) indique plutôt une spécialisation de l'hémisphère droite pour le langage. Kimura a expliqué cette observation en postulant que, en écoute dichotique, les voies controlatérales vont inhiber les voies ipsilatérales. Ainsi, l'input de l'oreille controlatérale à l'hémisphère dominant pour le langage va être prépondérant. Pour illustrer ce lien, on a inclu dans notre étude une patiente qui avait un LEA dans le FW12k, un test d'écoute dichotique allemand. Elle avait des activations unilatérales droites pour le langage en IRMf, comme suggéré par le FW12k. L'objectif principal de cette étude était de voir, si le fait d'introduire de l'information de localisation dans des stimuli dichotiques aurait un effet sur le REA. L'idée était de renforcer ainsi l'activation des voies ipsilatérales pour le traitement des stimuli verbaux, et de diminuer le REA. L'indice de localisation utilisé était un décalage interaural (ITD); les stimuli dichotiques étaient des « fused words ». On a créé deux expériences en utilisant deux sortes de mots différents. Pour la première expérience, on avait créé des nouveaux mots, les (F+)-mots, qui étaient dichotiques que pour la consonne du milieu et étaient facilement localisables. L'inconvénient était qu'ils avaient que de faibles propriétés pour créér des asymetries perceptuelles. Les (nF)-mots de la deuxième expérience, étaient des mots utilisés également dans le FW12k, comme ça on était sûr de leur propriété intrinsèque de créér un REA. Ces mots étaient dichotiques dans leur première syllabe et ils étaient plus difficiles à localiser. Tous les participants passaient d'abord le FW12k et il leur fallait un REA

significatif dans ce test pour être inclu dans l'étude. Comparé au REA dans le FW12k, le REA dans notre expérience était significativement diminué dans la condition d'écoute dichotique simple sans ITD, par la seule différence de consigne. Dans le FW12k, la seule consigne est de choisir le mot entendu, alors que dans notre expérience, les sujets devaient dire en plus s'ils entendaient le mot à droite ou à gauche. Dans la condition avec ITD, REA diminuait d'avantage dans l'expérience-(F+) mais ré-augmentait dans l'expérience-(nF). Même si l'interprêtation de ces résultats est difficile, on a fondé notre argumentation sur l'expérience-(nF), car on ne peut pas être sûr de la validité des (F+)-mots. En se basant sur le « two-stage model » de Hiscock (Hiscock & al., 2005), on pense que l'activation des processus de deuxième niveau (activés par la consigne donnée), est responsable pour la réduction du REA si les stimuli ne sont pas localisables, comme dans la condition de simple écoute dichotique sans ITD. Mais, du moment qu'ils sont localisables, par introduction d'ITD, le sujet a tendance de diriger son attention vers son oreille préférée et de ré-augmenter ainsi son REA.

I-Introduction

Dichotic listening remains a widely used technique to study hemispheric asymmetry for auditory speech processing (Asbjørnsen & Hugdahl, 1995 [2]; Bryden, 1988 [4]; Sætrevik & Hugdahl, 2007 [23]). In the clinical field it is used as a complementary test to determine patients' speech-processing hemisphere before epilepsy-surgery.

After explaining in detail the principle of dichotic listening and most known dichotic listening techniques, I will explain the concept of right ear advantage and the different models trying to explain it.

In order to illustrate the relationship between unilateral speech processing and controlateral ear advantage in an ordinary dichotic listening test, we included one epilepsy patient, who had consistent left ear advantage in the FW12k (German fused rhymed words test; Hättig & Beier, 2000; Hättig, 2004 [9]). As a consequence of this atypical dichotic listening outcome, she got an fMRI exam (functional magnetic resonance imagery). Our first hypothesis was on the outcome of this examination.

To these days, the functional processing and outcome of dichotic listening techniques are not entirely understood; the present study's aim is to provide more information for further understanding of verbal auditory processing in a dichotic listening situation. Our second hypothesis tries to give yet another, slightly different explanation of right ear advantage. The experiment of this study was meant to eliminate some of the artificial character of typical auditory dichotic stimuli, trying to approach a little bit more a natural speech situation. This experimentation should be able to provide more information on verbal auditory processing in healthy subjects.

I-1 Dichotic listening and different dichotic listening techniques

Dichotic listening

The dichotic listening technique consists basically in presenting simultaneously two different auditory stimuli, each to one ear of the subject. This method bears two factors, which make it an artificial situation; first, in a natural hearing situation both ears rarely receive exactly synchronized stimulation without any interaural time difference (ITD) or interaural intensity difference (IID). The second factor is even more artificial; it is the fact that, in a dichotic listening situation, each ear receives different auditory information, which never happens in a natural hearing situation. These peculiarities of dichotic stimuli make it impossible for the brain to localize the source of the dichotic sounds, which it is normally able to do in almost every naturalistic perceptual situation.

The typical outcome of a dichotic verbal auditory presentation is a consistent right ear advantage (REA) in subjects with left-lateralised speech and left ear advantage (LEA) for subjects with right-lateralised speech (Kimura, 1961 [16]; Zatorre, 1989 [29]). Moreover, left lateralised speech is far more common than its opposite in the average population. This is to say that, as most people's speech processing hemisphere is their left hemisphere, in a verbal dichotic listening situation, the most probable outcome is a REA. This means that people report more often, faster and more accurately the verbal stimuli presented to their right ear, rather than the one presented to their left ear.

As mentioned before, the clinical use of dichotic listening tests is to lateralize language processing brain structures in pre-surgical evaluation of epilepsy patients.

Other techniques used to the same purpose are fMRI and the so-called Wada-test, even if the last one is used less often nowadays, because it is an invasive technique and can be quite demanding for the patients and the examiners.

The fMRI is a non-invasive neuroimaging technique, which visualizes the change in cerebral blood-flow related to neural activity in the brain. It bears the advantages that it can also be used for research purposes including healthy subjects and it allows not only to assess receptive but also expressive speech. But because of a few disadvantages, this method is not suitable for all patients, for example, patients having any kinds of metallic devices like pacemakers, or claustrophobic patients. Also, it is very noisy inside the fMRI-device, which can be irritating; and, since one has to lie very still in the fMRI machine for approximately 20 minutes, this method can also be unsuitable with children, especially with children suffering of hyperactivity.

The Wada-test consists in injecting an anaesthetic (usually sodium amobarbital) into one of the internal carotid arteries of the subject to anaesthetize one single hemisphere at a time. Consequently, any language and/or memory function in that hemisphere is shut down, and one is able to assess remaining memory and/or language function of the other, not anaesthetized hemisphere. The invasive nature of the Wada test makes it not suited for all patients, and not at all for use in experimental research. It can be uncomfortable for the subject, and there is a small risk because of the catheter, which is introduced into the artery to administer the sodium amobarbital, especially for subjects suffering of arteriosclerosis or having high cholesterol levels.

That is why a dichotic listening technique can be used as a complementary test in the clinical field, it is non-invasive, not expensive, unproblematic to pass, it can easily be repeated and is proven to be reliable when it yields a clear lateralization to the left hemisphere (Hättig & Beier, 2000; Zatorre, 1989 [29]). The first dichotic listening paradigm was developed in 1945 by Broadbent in a divided attention paradigm for air traffic controllers.

Synchronized digits test

Broadbent presented in his experiment (Broadbent, 1954 [5]) two different, synchronised triplets of digits at each ear of the participants (e.g., "2-5-3" presented to one ear and simultaneously "7-1-4" presented to the other ear), instructing them to repeat as many numbers as possible after each presentation. He noticed that most subjects tended to repeat first the numbers presented to their right ear, and only afterwards reported numbers presented to their left ear.

Furthermore, left-ear performance was less accurate than right-ear performance. This is partially due to the fact that, as the numbers presented to the left ear were generally reported later, the short-term retention span was often exceeded, so that left-ear information was lost meanwhile.

CVC nonsense syllables test

Another dichotic listening technique, initially developed by Studdert-Kennedy and Shankweiler (1970 [25]), consists in presenting simultaneously two different consonant-vowel-consonant (CVC) nonsense syllables, which differ either in the beginning, the middle or the end. The subject had to repeat both syllables after each trial. This test eliminates the short-term memory bias, but raises another difficulty: direction of attention. Participants were shown to be able to influence significantly the outcome of a CVC dichotic listening test by directing their attention either to their right or their left ear. When they directed attention to their right ear, they could enforce their right ear advantage, by directing attention to the left ear, they could significantly attenuate their REA and even sometimes change it into a left ear advantage (LEA). Therefore, when using a CVC syllables test, it is essential to work with forced attention paradigms, to control direction of attention. This can be realised by using three different attentional conditions: forced right condition (instructing the subject to focus on his right ear), forced left condition (instructing the subject to focus on his left ear) and divided attention condition (instructing participants to focus on both ears simultaneously (Hugdahl & Hammar, 1997 [12]).

Fused rhymed words test

The fused rhymed words test was first developed by Wexler & Halwes (1983 [28]). It consists in presenting two different, but rhymed words at exactly the same moment one to each ear of the subject. This results generally in the perception of one single fused word by the subject and introduces semantic content into the verbal stimuli. The fused rhymed words test eliminates all possible short-term memory bias, and has been shown to be less influenced by direction of attention, because the subject only perceives one auditory percept (Asbjørnsen & Bryden, 1996). According to the same principles, Hättig (Hättig & Beier, 2000; Hättig, 2004 [9], 2006 [10]) developed two independent dichotic fused words tests (FW10b and FW12k), which can be regarded as parallel tests. The two tests differ mainly in the response condition. While the FW10b offers as response alternatives only written words on the computer screen, the response alternatives of the FW12k have additional visualizations of the respective words (simple prototypic black and white drawings of the denoted objects). The test used in the present study was the FW12k. The lateralisation outcome of the FW12k has been shown to be highly correlated with the FW10b (r = 0.81; Giβke, 2007 [7]), with the FW10b recovering in 91% of the cases the classification by the Wada test

(Hättig, 2004 [9]) and in 97% of the cases the classification by fMRI (Hund-Georgiadis & al., 2002 [14]). Both tests have been tested under forced attention paradigms and showed robust REA under forced right- and forced left attention conditions (Weller, 2005 [27]).

I-2 Right ear advantage (REA) and the most common models to explain it

Structural Model by Kimura

Kimura (1961 [16]) was the first one to use Broadbent's dichotic listening technique with epilepsy-surgery patients, many of whom had also undergone a Wada-test to determine their speech lateralization. She found that with verbal auditory stimuli, most of the subjects that had left-lateralized speech in the Wada procedure, tended to show a right ear advantage (REA) in the dichotic listening situation. Subjects with right-lateralized speech in the Wada test tended to show the opposite effect, they showed a left ear advantage (LEA).

Taking into account the anatomical organization of the auditory pathways - which is like the visual system not only contralateral, but there is a smaller contingent, which is ipsilateral - Kimura explained this observation by postulating that, because the contralateral pathway is anatomically more efficient, information is processed along this contralateral pathway while the ipsilateral one is actively suppressed. In case of left-lateralized speech, the contralateral pathway connecting the left hemisphere with the right ear should be most operative, resulting in the described REA; in case of right-lateralized speech, the opposite (LEA) should be observed (Kimura, 1961 [16]).

Two models have been proposed to complete Kimura's structural hypothesis:

The first, the callosal relay model, postulates that verbal information presented to the right ear gets faster and more accurately to the left hemisphere than the information presented to the left ear. This is because left-ear information is first transferred to the non-dominant hemisphere for speech and has then to cross the corpus callosum, resulting in delayed arrival at the speech dominant hemisphere (Bryden, 1988 [4]; Jäncke, 2002 [15]). Furthermore there would be loss of information, before reaching the speech dominant hemisphere.

The second model, the direct access model, argues that information from the left ear would be processed by the non-dominant hemisphere for language, which is not working as efficiently as the dominant auditory cortex and therefore takes more time to treat the information.

Attentional Hypothesis by Kinsbourne

Another explanation for the observed REA effect is forwarded by Kinsbourne (1970 [17]). He argued that it is not the anatomical predominance of the contralateral pathway over the ipsilateral one that is responsible for the ear advantages observed, but the fact that subjects are expecting verbal stimuli, which primes the speech-dominant hemisphere. This pre-activation leads to re-direction of attention to the opposite hemispace and so to the opposite ear.

Therefore, with subjects who have left-lateralized speech, the fact that they are expecting verbal auditory stimuli, would prime their left hemisphere, which would result in re-direction of attention to their right hemispace and facilitate perception of information on the right ear, resulting in a right ear advantage.

Two-stage explanation by Hiscock

Hiscock distinguishes two stages of auditory processing, differing in speed and character of processing (automatic versus controlled processing) (Hiscock & al., 2005 [11]).

He defines the first stage as being a stimuli-detection stage, which entails rapid processing on an early, pre-attentional "niveau" and is responsible for REA in dichotic signal detection tasks. Asymmetries of detection accuracy arising from this first stage of processing can therefore not be influenced by voluntary shifts of attention, but only by stimulus driven automatic shifts, as for example by lateralized cueing at least 400 or 500 ms before the onset of the dichotic stimuli.

This model does not specify whether this first stage detection asymmetry is due to a stable attentional bias, not controlled by the subject, or rather by structural asymmetry.

The second stage processing is limited in capacity, it is slow, effort demanding and controlled.

This two-stage explanation refers ear asymmetries obtained with traditional dichotic listening tasks to first stage processing, whereas second stage processing explains the impact of forced attention paradigms on these ear asymmetries.

I-3 Posing of the problem and hypotheses

First hypothesis

In order to illustrate the use of the FW12k, and thereby the strong ties between consistent ear advantage measured by the FW12k and contralateral activation for speech processing in fMRI, we also report the case of one epileptic patient who showed left ear advantage in the FW12k, hence, a patient who was classified as having right-hemispheric participation in speech processing by the FW12k. Consequently, our first hypothesis was, that this patient would show bilateral or exclusively right-sided activation for speech in the fMRI.

Second hypothesis

Leading to our second hypothesis, we must first note that Kimura's structural model assumes that the ipsilateral pathways are actively suppressed; but many experiences have shown that there is at least a minimum of information processed by the ipsilateral pathways (for a review and a detailed argumentation, see Geffen and Quinn, 1984 [6]; Bradshaw et al., 1988 [3]). Kinsbourne's attentional model does not address the issue of ipsilateral suppression explicitely, neither does Hiscock's.

As noted above, attentional factors have been proved to play a role in the ear advantage observed in dichotic listening in the CVC syllables test for example (Tweedy & al., 1980 [26]).

Even though those arguments favor the attentional hypothesis, it does not seem to be able to explain why, when using a fused rhymed words test, forced attention paradigms can influence the magnitude of the REA, but can not change it into a LEA when attending the left ear (Asbjørnsen & Bryden, 1996; Hiscock & al., 2005 [11]; Weller, 2005 [27]).

A model like Hiscock's two-stage explanation model, taking into account both attentional and structural factors, seems most appropriate, but he does not differentiate between a stable attentional bias or perceptual asymmetry at the first stage of stimulus processing.

In summary, it is widely acknowledged that in a classic dichotic listening situation, information processed by the ipsilateral pathways is weaker than the one processed by the contralateral ones; this seems to be an equilibrium between inhibition and less activation of ipsilateral pathways. This regulation seems necessary to present to the brain one coherent information, resulting in the known and often reproduced REA.

In a natural situation, auditory stimuli are almost always localizable by means of interaural time difference and interaural intensity difference of the information treated by each ear. However, in a typical dichotic listening situation, there is no information tained in the stimuli that could be used for localisation, so that the ipsilateral pathways, which treat among other factors localisation data, should be less activated, as suggested by Phillips and Gates (1982 [22]).

Our second hypothesis is, that the regulation of inhibition and lack of activation is not absolute and can be disturbed by introducing localisation data into the dichotic stimuli. This localisation information would enforce the activation of the ipsilateral pathways, which would result in a significant diminution of the typically found REA.
Besides the theoretical considerations, there are some clinical observations, that patient's REA was generally reduced, if there was some "localizationable" noise in the room, while the FW12k was administered.
In order to validate our hypothesis, we should observe a less strong REA in the dichotic condition with interaural time difference (ITD-C; experimental condition 2) compared to the one without (DL-C; experimental condition 1

With this experiment, we should be able to investigate the structural component of first stage processing of Hiscock's two-stage explanation of ear asymmetries in dichotic listening.

Two other studies (Morais & Bertelson, 1975 [19]; Spierer, Meuli & Clarke, 2007 [24]) applied paradigms using dichotic stimulation with ITD, but neither of those studies investigated the difference in REA obtained between a classic dichotic listening paradigm and dichotic listening plus ITD.

Morais & Bertelson used a CV-syllables test under two conditions, one free-report condition (Experiment 1) and one forced attention condition (Experiment 2). In their first experiment, REA obtained with ITD failed to reach significance. In their second experiment, they controlled attention by instructing the subject to listen alternatively to the right or the left ear, the result was a significant REA, but this REA was much less important than the one obtained in the classic dichotic situation ($p < 0.025$ and $p < 0.0005$ respectively). Both results would be compatible with our hypothesis.

Spierer, Meuli & Clarke did not compare the asymmetries obtained in their control group between the conventional dichotic listening task and their ITD dichotic task. However, they found a double dissociation of asymmetries obtained in those tasks with neglect patients.

Both of these studies used rather long ITDs (0.7 milliseconds and 1 millisecond respectively). We used an ITD of 0.408 milliseconds, which corresponds to a virtual deviation of a sound source to the left or the right side of 25° respectively, for an inter-ear distance of 15 centimeters, calculated with the cosinus function ((0,15 m * cos (25°)/ 333 m/s = 0,000408 s). Furthermore, to control more variables we used a fused rhymed words technique, which is known to be a lot less influenced by attentional factors than the CV-syllables method.

II- Methods

II-1 Participants

Patients

One epileptic patient was included in the study in order to test our first hypothesis. She was 46 years old and a native German speaker. She suffered of symptomatic focal epilepsy in the left temporal lobe with hippocampus sclerosis since 1995. She showed consistent left ear advantage in the FW12k (λ-value = -2.40).

Healthy subjects

25 healthy subjects participated as volunteers in the study to test our second hypothesis, 10 in the first experiment and 15 in the second. The subjects' mother tongue was either German or Luxemburgish, in the latter case they had learned German just after the age of 6 and could therefore be classified as childhood bilinguals (Hull & Vaid, 2007 [13]). This is important because Hull & Vaid found functional lateralization primarily influenced by age of onset of bilinguism; "bilinguals who acquired both languages by 6 years of age showed bilateral hemispheric involvement for both languages, whereas those who acquired their second language after age 6 showed left hemisphere dominance for both languages."

Participants reported no hearing impairment, and showed a significant right ear advantage in the FW12k (Fused Rhymed Words Test; Hättig, 2004 [9]). Handedness was assessed with the 20-points scale of the Edinburgh Handedness Inventory (EHI) integrated in the FW12k. Consistent right-handedness - no more than 4/20 left-hand-points being acceptable - was necessary to be included in the study. This results in a laterality quotient cut-off at 60/100, which corresponds to the 20th percentile of the right-hander population. Further exclusion criteria were any neurological or psychiatric antecedents.

II-2 Stimulus materials

First Experiment: F+ words

The words used in this first experiment were 14 monaural words (7 pairs of rhymed words) that were paired either with their rhyming pendant or with themselves to create the different experimental conditions. To create the different words, we took blocks of three rhymed words, which were digitised natural speech; the members of each block only differed in their middle consonant (e.g. le[g]er, le[b]er, le[d]er). One of these words was used as the so-called “frame word” (“le[g]er” in this case), of which we silenced the middle consonant and replaced it by the middle consonant of one of the two other words (“[g]” replaced by “[b]” or “[d]” for this example). With this editing procedure, using the program Cool Edit Pro 2.1, we got two rhymed words that were exactly identical in the beginning and the end (i.e. in the frame) and differed only in their middle consonant (le[d]er and le[b]er). Stimulus amplitude was normalized to 50%; words were administrated to the subject with a resolution of 16 bits and at a frequency of 44100 samples/second. Furthermore, the two rhymed words had exactly the same length, and consonant onset times were on the exact same sample for each word pair, so that the combination of the two resulted in a dichotic pair that fused into a single auditory percept for the dichotic listening control situation.

Second Experiment: nF words

The words used in the second experiment were 14 monaural words (7 pairs of rhymed words) of the FW12k. They were paired either with their rhyming pendant or with themselves to create the different experimental conditions. To see the details of creation of these rhymed words pairs, see Hättig (20049). Briefly, to create the different words, they also took blocks of three rhymed words, which were digitised natural speech; the members of each block only differed in the first syllable (e.g. [T]opf [K]opf [Z]opf). All three words were cut at the level of the vowel (Tϕpf, Kϕpf, Zϕpf). Of the additional third word, ("Zϕpf" in this case) they kept the ending (ɔpf) and replaced the beginning with the first syllable of one of the other two words, ("[Zc]" replaced by "[Tc]" or "[Kc]" for this example). With this procedure they obtained two rhymed words that were exactly identical in the end and differed only in their first syllable ([Tc] ɔpf and [Kc] ɔpf). The two first syllables were adjusted in length, so that the two rhymed words had exactly the same length. By combination of the two resulted a dichotic pair that fused into a single auditory image.

To introduce location data into both the first and the second experiment stimuli, we created interaural time difference by delaying one of the two channels by 18 samples, which equals 0,408 milliseconds. This duration corresponds to the interaural time difference observed when auditory stimuli are emanating either from 25° to the left of the midline of head and body aligned, or from 25° to the right of the subject (azimuth -25° or 25°). The word pairs were combined in different ways to generate 2 control and 2 experimental conditions. Stimuli were presented to the subjects using Sontec Stereo Dynamic Headphones CD-850. Subjects were told to keep their head immobilized looking on the computer screen placed in front of them. The different experimental conditions were programmed and administrated using the program Presentation 11.0..

Experimental conditions, control conditions and procedure were exactly identical in both experiments, the only difference were the words used. To differentiate between the two experiments throughout the whole document, conditions and subjects of the first experiment with the words having an identical frame, are noted with a “(F+)” for words with the same frame (e.g. Leber/Leder); participants and conditions of the second experiment with the FW12k words with a “(nF)” for words with no such frame (e.g. Braut/Kraut).

Dichotic Listening Condition (Experimental Condition 1; DL-C):

This condition consists in a standard dichotic presentation; dichotic words are presented to the subject with no interaural time difference, hence no localisation of the fused auditory image is possible, as in any dichotic listening test. Stimuli onset times were controlled and matched exactly.

Dichotic Lateralization Condition (Experimental Condition 2; ITD-C):

We placed two different rhymed words on each auditory channel and delayed one of them 0,408 milliseconds in time. The subjects still perceived one fused word and could now lateralize this auditory percept by comparing ITD of the identical part of the words. Word pairs and lateralization to the right or the left were completely randomised.

Lateralization Control Condition (LCC):

We placed the same word on the left and the right auditory channel and delayed one of them 0,408 milliseconds in time, so that the word seemed to originate either from the right or from the left of the subject; depending on what channel was delayed. This condition was needed in order to make sure that subjects could correctly localise the stimuli presented, using the interaural time difference as the sole localisation information.

Word Recognition Control Condition (WRCC):

In this control situation we placed again the same word on the left and the right channel, but this time there was no interaural time difference between the two, so that no localisation of the auditory percept was possible. This control situation was used in order to make sure that subjects could correctly identify the artificially produced words.

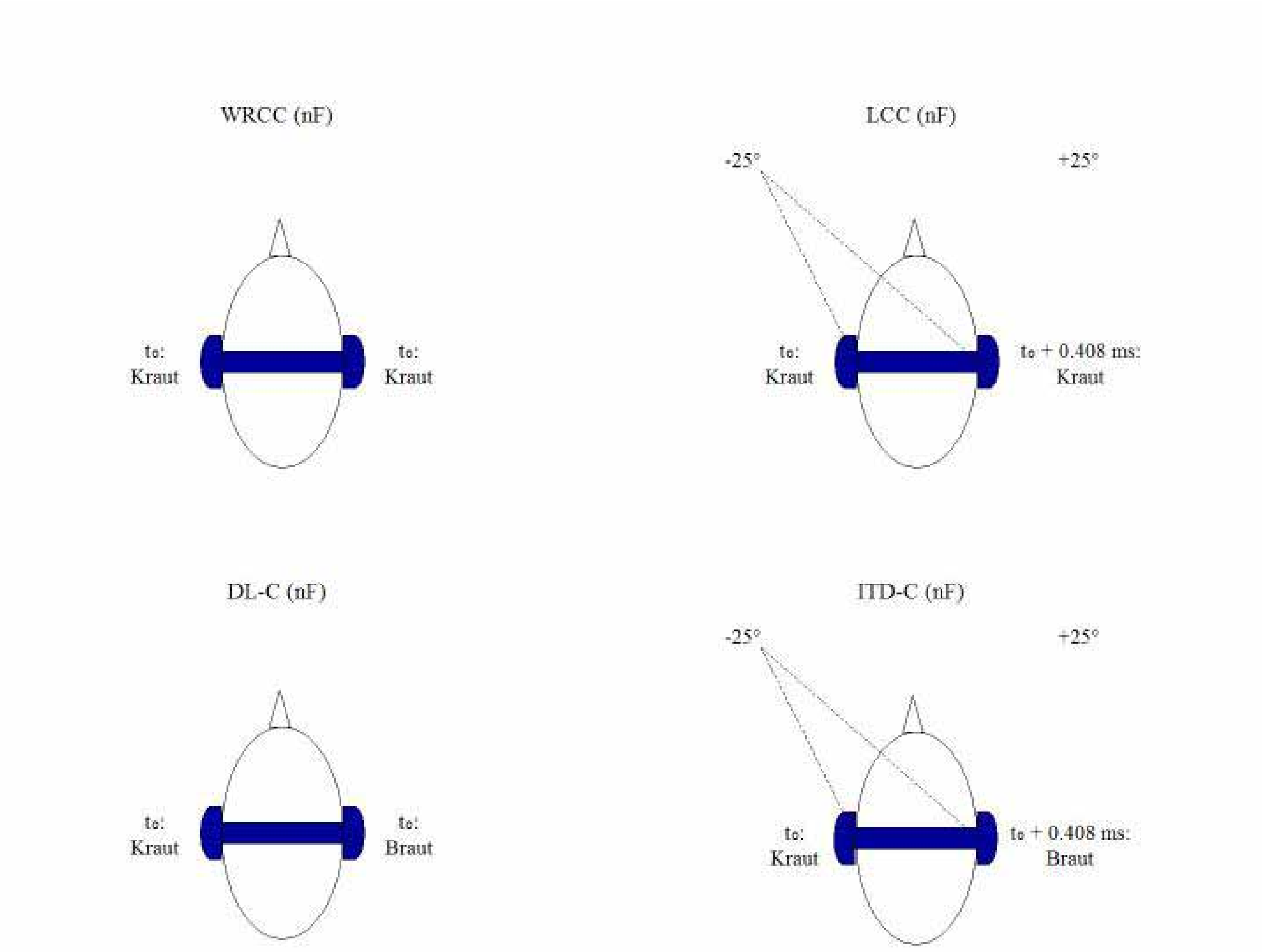

Fig. 1: Example of the control and experimental conditions.

Subjects had to answer two questions after each presentation,

1) What word was heard, by choosing between the two rhymed words being presented visually in two different response fields on the screen one above the other, the position of the response fields was controlled throughout the presentations;
2) Where the heard word emanated from, by choosing between “li”, or “re”, “li” meaning it came from the left and “re” that it came from the right. The two possibilities were presented on a horizontal line, with “li” being on the left and

"re" on the right side. These parameters were not changed during the experiment.

Answers were given by clicking with a standard laptop touchpad (left button, manipulated with the right hand).

II-3 Procedure

First hypothesis

After having passed the FW12k, the patient passed an fMRI examination. In the fMRI she did a rhyme-decision paradigm, a synonym-decision paradigm and a semantic sentence decision paradigm.

Second hypothesis

To determine their right ear advantage (REA), all 25 subjects first passed the FW12k, during which 12 fused rhymed word pairs are presented to the subject and their λ-index was calculated. In order to be able to participate at the study, subjects had to attain a λ-index of at least 0.39 (Giβke, 2007 [7]).

At the beginning of the FW12k, which took approximately 15 minutes, subjects were familiarized with the words used in the test; they were presented visually to them on the computer screen. The participants had to read them and confirm for each one that they knew what they meant, if they did not, the experimenter explained the meaning of the words to them. In the FW12k, answers are given by clicking on a picture of the heard word. The first part of the FW12k is a short control condition during which words are presented unilaterally to one ear at a time, to be sure that speech comprehension is intact at both ears.

After passing the FW12k, the first 10 subjects passed the first experiment; the last 15 passed the second experiment. Those who passed the first experiment passed an additional trial in which they were familiarised with the (F+)-stimuli and during which those new stimuli were presented unilaterally to the subjects to be sure they were recognized on both ears.

The experiments themselves consisted of 3 blocks and as noted above, they were exactly identical apart from the stimuli used. The first part contained stimuli of both control conditions (LCC and WRCC). The final two blocks consisted of the presentation of stimuli of the experimental conditions (DL-C and ITD-C). Each block took approximately 10 minutes. Stimuli of the three parts were presented to the subjects in a random sequence; each block contained 112 stimuli presentations. This corresponds to 112 trials for each experimental condition and 56 for each control.

Each experimental combination of words, channels, and time delay was presented 4 times. Subjects needed approximately 45 minutes to complete the FW12k and the second experiment; those who passed the first experiment took approximately 50 minutes due to the additional familiarisation trial. Experiment duration varied a little bit among the subjects as they could control the interstimuli difference in the experiment. The subsequent word was not presented until the subjects clicked on the "next word" tab to allow the participants to introduce small pauses if they felt the need to do so. Between blocks we gave the possibility to take a few minutes break if the subjects wanted to, but they all continued and passed the whole experiment at once.

Tab. 1: Procedure description

Experiment		Control conditions	Experimental conditions
(F+) words N=10	→ FW12k	WRCC (F+) LCC (F+)	DL-C (F+) ITD-C (F+)
(nF) words N=15	→ FW12k	WRCC (nF) WRCC (nF)	DL-C (nF) ITD-C (nF)

III- Results

III-1 First Hypothesis:

As mentioned before, the patient had a λ-index of (–2.40), which corresponds to a consistent LEA. The fMRI images show the sum of the activated brain structures in all three language paradigms. The activations observed in Broca's and Wernicke's area pointed to an exclusively right-lateralized language processing by this patient.

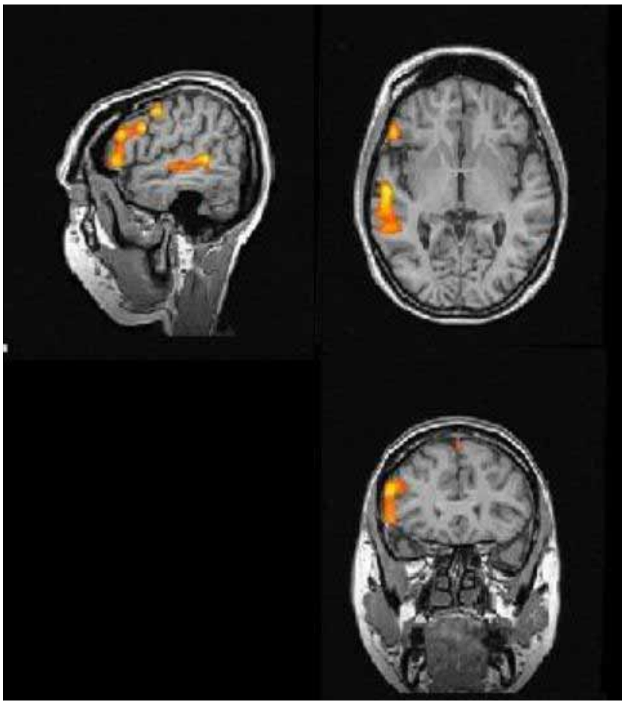

Fig. 2: Sagittal, axial and coronal slides, visualizing the sum of activations in the three language paradigms. On sagittal and axial slides one sees Broca's and Wernicke's areas activated, whereas the coronal slide is a relatively frontal one, so here is visualized the activation of Broca's area.

III-2 Second Hypothesis:

To be able to compare the data of the FW12k and the data of the two experiments of this study, we recalculated the λ-values obtained in the FW12k. In our study we determined λ-values using so-called single ear points (sEP), meaning we noted down one right ear point each time the subject chose the word administrated to his right ear and one left ear point each time he chose the one presented to his left ear. We then computed λ using the formula: λ=ln(sREP/sLEP) where sREP stands for single right ear point and sLEP for single left ear point. The λ determined by the FW12k uses double ear points (dEP). A double ear point is only noted if the subject chooses under both possible stimuli arrangements within a same word pair (i.e. [Braut presented to the left, Kraut to the right ear]; and [Kraut presented to the left, Braut to the right ear]) the word administrated to one given ear. In this case, his answers depend on the ear of entry. If he always hears the same word out of a pair of dichotic words, he rather stays loyal to a word than the ear of entry; this observation is called stimulus dominance. The double point procedure is used to eliminate stimulus dominance in the λ calculated, the formula used is λ=ln(dREP/dLEP). In the present study, we did not take into account stimulus dominance, therefore, λ-values of the FW12k were recalculated by transforming dEP into sEP, so they would be comparable to the λ-values obtained in our experimental conditions. Right Ear Advantage (REA) results in positive λ-values, whereas Left Ear Advantage (LEA) results in negative λ-values. Ear advantage to either side is even more important as λ-value is high, a high negative λ reflects important LEA, and a high positive λ reflects important REA.

First Experiment (F+ words):

<u>*Control conditions:*</u>

The ten subjects who participated in the first experiment attained a high mean word identification score in both control conditions “word recognition control condition” (WRCC (F+)) and “lateralisation control condition” (LCC (F+)) (96,07% and 93.21% respectively). Their localisation judgements in the LCC (F+) were also close to 100% correct (95,36%).

<u>*Experimental conditions:*</u>

In the “dichotic lateralization condition” (ITD-C (F+)) lateralisation performance dropped to 83, 84% but remained largely above chance ($\mu \pm 2\sigma = 60\%$).

For mean λ-scores of the FW12k and the experimental conditions of the first experiment, see Table 2.

Tab. 2: Mean λ-values and standard deviation of each condition of the first experiment.

Conditions (F+)						
FW12k		**DL-C (F+)**		**ITD-C (F+)**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	
0.64	(0.42)	0.08	(0.62)	0.03	(0.56)	10

We performed a Friedman’s analysis of variance (Friedman’s ANOVA) on these data; this revealed a significant main effect for condition (ANOVA Chi^2 (N=10, FG=2) =6.2; $p<0.04505$). This main effect was followed up with Wilcoxon’s Test for dependent samples, which yielded a significant difference of mean values between the

FW12k and the DL-C (F+) (N=10, T=8, Z=1.987624, p=0.046854) and the FW12k and ITD-C (F+) (N=10, T=3, Z=2.497271, p=0.012516), but the difference between DL-C (F+) and ITD-C (F+) failed to reach significance (N=10, T=22, Z=0.560612, p=0.575063).

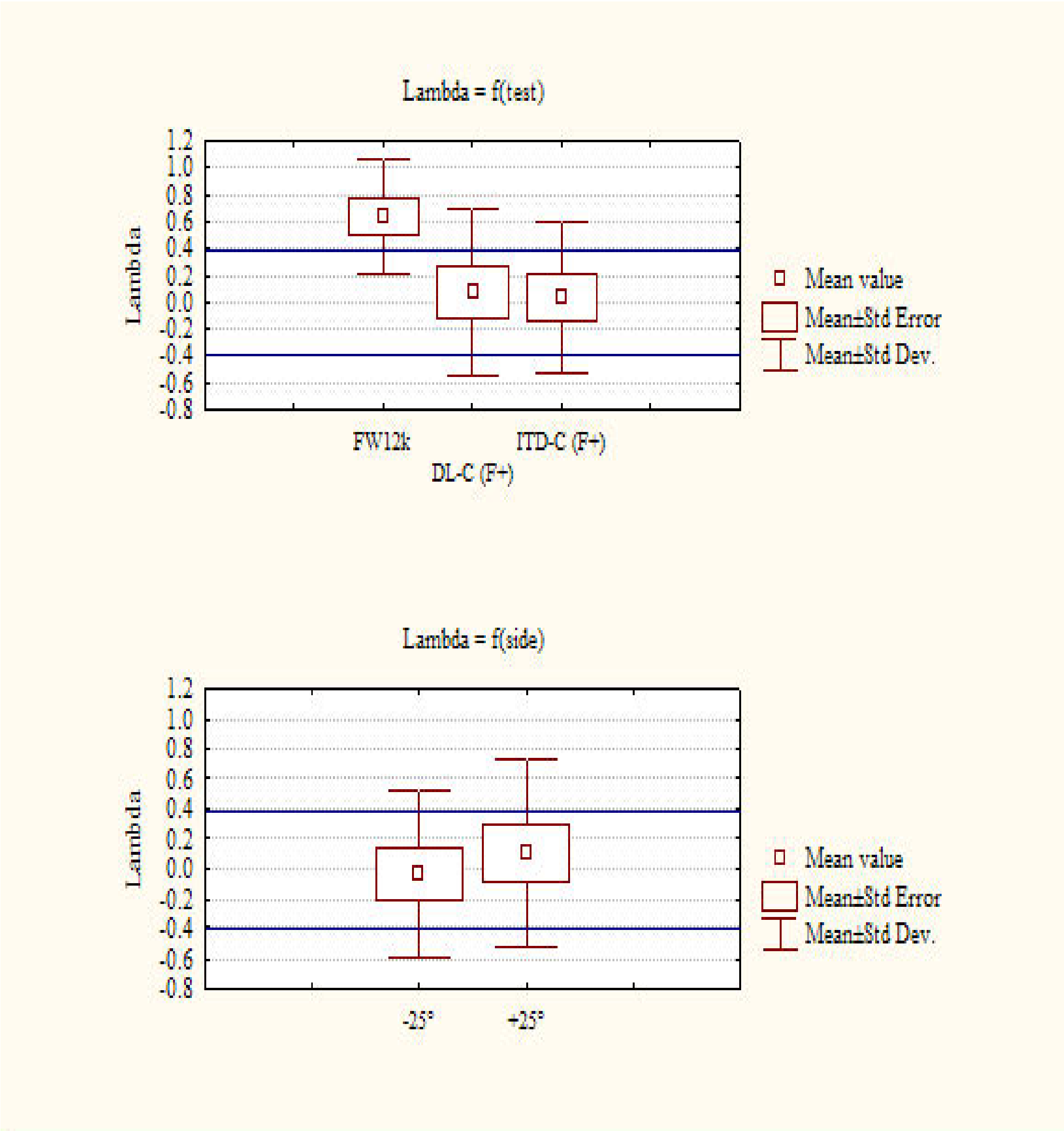

Fig. 3: λ-values in the different tests and from both sides in the ITD-C (F+) condition. The blue lines at λ= –0.39 and at λ= 0.39 delimitate bilateral classified λ-values.

We also compared λ-values obtained when the word arrived 0.408 milliseconds earlier on the left ear (-25°condition) with when it arrived 0.408 milliseconds earlier on the right ear (+25° condition), using Wilcoxon's Test for dependent samples. The different λ-values measured in the two ITD-situations failed to reach significance (N=10, T=14, Z=1.376047, p=0.168808).

Second Experiment (nF words):

Control conditions:

Participant's mean performance was close to 100% correct in word identification in the non-dichotic control tasks WRCC (nF) and LCC (nF) (99,29% and 100% respectively). In the LCC (nF) condition they also attained a high mean percentage of correct lateralisation judgments (97,86%).

Experimental conditions:

Mean lateralisation performance dropped significantly (Wilcoxon's Test for dependent samples, Z=3,41; p=0,000655) in the ITD-C (nF) condition compared to the LCC (nF) condition, but remained significantly above chance (62,26%; $\mu \pm 2\sigma$ = 60%). So, localisation performance in the ITD-C (nF) condition was much worse than in the ITD-C (F+).

To see mean λ-values and standard deviations of the three situations see Table 3.

Tab. 3: Mean λ-values and standard deviation in each condition of experiment 2.

Conditions (nF)						
FW12k		**DL-C (nF)**		**ITD-C (nF)**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	
0.55	(0.25)	0.3	(0.35)	0.42	(0.42)	15

A Friedman's analysis of variance (Friedman's ANOVA) was performed on these data and revealed a significant main effect for condition (ANOVA Chi² (N=15, FG=2) =9.254237; p<0.00978). This main effect was followed up with Wilcoxon's Test for dependent samples which revealed a significant difference of mean values between the FW12k and the DL-C (nF) (N=15, T=8, Z=2.953402, p=0.003143) and the DL-C (nF) and ITD-C (nF) (N=15, T=17, Z=2.228565, p=0.025844).

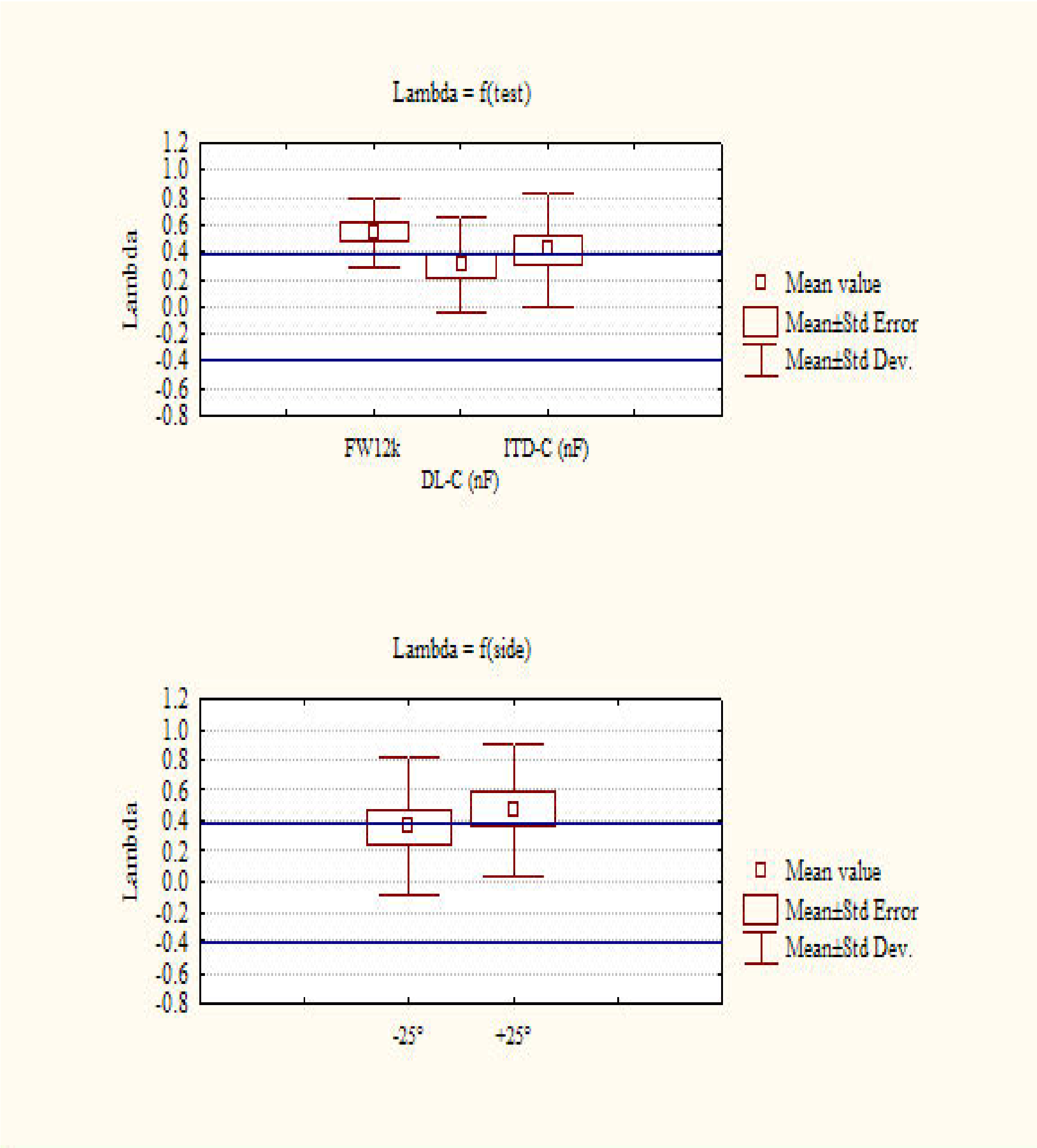

Fig. 4: λ-values in the different tests and from both sides in the ITD-C (nF) condition. The blue lines at λ= –0.39 and at λ= 0.39 delimitate bilateral classified λ-values.

Comparison of λ-values obtained between the –25° and the +25° condition, using Wilcoxon's Test for dependent samples, failed to reach significance (N=15, T=22, Z=1.642313, p=0.100526).

To make sure that the experimental conditions of the second experiment measured the same effect than the FW12k we ran Spearman's correlation analysis for these data, which revealed significant correlation between all of the three conditions, see Table 4.

Tab. 4: Spearman's correlation analysis for correlation between the three conditions

	FW12k	**DL-C (nF)**	**ITD-C (nF)**
FW12k	1	0.676658	0.603048
DL-C (nF)	0.676658	1	0.960274
ITD-C (nF)	0.603048	0.960274	1

IV- Discussion

In the present paper, we wanted to evaluate what happens to ear advantage if interaural time difference is introduced into fused dichotic words stimuli. We used two sets of words because both types of words had different properties: the first experiment's words were new words that were not tested before on their ability to produce a REA in a normal dichotic listening situation. Their advantage however was, that their dichotic part was in the middle and not in the beginning, which we assumed to be interesting for our ITD-C condition. The second experiment's words were words used in the FW12k and are known to produce REA in an average dichotic listening situation. But in the ITD-C (nF) condition, these words, which differed in their initial consonant, made lateralization judgements really difficult, as expected.

IV-1 First Hypothesis:

The results confirmed our first hypothesis; the epileptic patient who had left ear advantage in the FW12k showed right-hemispheric activation for speech processing in the fMRI and is therefore classified as having right-lateralized speech.

IV-2 Second Hypothesis:

First Experiment

Participants of the first Experiment had their REA obtained in the FW12k significantly decreased in both experimental conditions. It was further decreased in the ITD-C (F+) compared to the DL-C (F+), but this last difference did not reach significance. These results would be compatible with our second hypothesis, but are difficult to be interpreted in that way, as we saw in the DL-C (F+) condition that those words do not produce as important asymmetries as expected and as necessary for a dichotic listening technique.

Furthermore, we noted that side of sound source did not influence REA significantly, meaning that λ-values did not differ significantly whether the word on the right or the left ear was delayed.

Nevertheless, we showed that an ITD of 0.408 milliseconds is sufficient to allow good localisation judgments from the subjects, and as this difference approaches the most a natural hearing situation, we would suggest that this difference should be used for future studies, to eliminate additional bias.

Second Experiment

In the second experiment, to eliminate any bias of words' ability to create ear asymmetries in an average dichotic listening situation, we used 7 of the 12 word pairs used in the FW12k. Like this, we knew that they work well for this kind of dichotic experiment.

Even so, we saw a significant decrease of λ-values in our DL-C (nF) condition compared to the λ-values obtained in the FW12k, as in the first experiment, but to a lesser extent.

What was different this time, was that λ-values in the DL (nF) condition and in the ITD (nF) condition differed significantly, but it was in the opposite sense to our hypothesis and to the results of the first experiment.

Moreover, we noted that localisation performance had dropped significantly, it remained above chance, but compared to the LCC (nF) condition and localisation performance in the ITD-C (F+) of the first experiment it had decreased considerably.

Once again, side of sound source determined by interaural time difference did not influence REA significantly.

IV-3 General Discussion:

The first hypothesis' investigation was meant to illustrate the use of dichotic listening techniques in the clinical field, and the strong ties between ear advantages in a dichotic listening technique as the FW12k and contralateral speech processing. This relationship has been further illustrated and tested in other studies (Zatorre, 1989 [29]; Hättig, 2004 [9]; Hund-Georgiadis & al., 2002 [14]). Zatorre, in his study, found a high correlation between the Wexler & Halwes fused rhymed words test and the Wada test; Hättig found a 91% correspondance between the FW10b (which is highly correlated with the FW12k) and the Wada test. Finally, Hund-Georgiadis and al. found a 97.5% correspondance between ear advantage obtained in the FW10b and contralateral activation for speech in the fMRI.

These results indicate that the fused rhymed words test is a reliable technique in the clinical field, if one pays attention to small lateralization gradients (small λ-values) and lesion effects. Known lesion effects are inhibition of stimuli presented at the contralesional (right) ear in patients with left-hemispheric mesio-temporal lesions (Hättig, 2004 [9]). Of course, with the development of imagery techniques, the use of fMRI to determine speech-processing lateralization will gradually increase, but dichotic listening remains an interesting and valid screening technique, and should not be forgotten in cases of patients having metallic devices or claustrophobic patients.

In the experimental field, dichotic listening continues to be an interesting tool to investigate speech processing. Additionally to the advantages noted above, when compared to the fMRI technique, dichotic listening is a cheap and rapid evaluation of speech processing side; also, it yields reliable results, especially with young healthy subjects.

Concerning our second hypothesis, it is very difficult to conclude with the results obtained in this study.

First of all, our second hypothesis could not be confirmed in the present study.

In the first experiment, the results tend in the same direction as our hypothesis, but they are more than delicate to interpret in this sense, as they do not even produce a right ear advantage in the dichotic condition without interaural time difference. In four out of ten subjects, they even changed their right ear advantage of the FW12k into a left ear advantage in the DL-C (F+). Besides, correlation analysis only showed weak correlation between the FW12k and both experimental conditions. This lets one to argue, that the experimental conditions of our first experiment do not necessarily measure the same processes than the FW12k, meaning that they do not necessarily measure asymmetric auditory processing.

In the second experiment, λ-values from the DL-C (nF) condition differed again significantly with those obtained in the FW12k. This time, this observation could not be due to the words used. They were able to generate reliable right ear advantage in the FW12k, passed 5 minutes before, and there was nothing changed about them. Besides, correlation between the FW12k and both experimental conditions was high and reached significance.

There is one important comment to make though; in the second experiment, localisation performance in the ITD-C (nF) condition dropped drastically compared to the LCC (nF) localisation control condition and the ITD-C (F+) condition of the first experiment. Additionally, participants reported that they had the impression that the words were localized in the centre of their head and that they had trouble giving a localisation judgement at all.

The significant drop in λ-values between the FW12k and the dichotic listening condition (DL-C) in both experiments must be explained by the instructions given to the subjects; it was the only difference between them. In the FW12k, participants were simply told to listen and to click on the word heard after each trial. In the DL-C conditions, subjects were also told to listen, and to click on the word heard after each trial, but additionally to this, they were told that the word heard would come either from the left or the right of their head. This instruction reduced λ-values significantly and finds support in the finding of another study (Weller, 2005 [27]). In that study, the investigators used the same fused rhymed words technique as in the present one and they tested the effect of forced attention paradigms on right ear advantage. They found that right ear advantage dropped in the forced left and in the forced right condition compared to the non-forced condition, even though right ear advantage remained significant in all three conditions.

This effect (decrease of REA after instruction change) could be due to an additional bilateral cortical activation provoked by the change in instruction, but this explanation seems sparsely sufficient to explain a reduction in right ear advantage of that amplitude as observed in the present study.

Sætrevik and Hugdahl (2007 [23]) reported in their study the existence of top-down interaction of attention with perception. In Hiscock's two-stage model, this top-down interaction corresponds to the second-stage of stimulus processing. Briefly, all these results indicate that there are attentional processes, which are able to influence perception. Even if they are not sufficient to change a right ear advantage into a left ear advantage in a fused rhymed words test (using appropriate words), instruction to localize the presented stimuli in this study seemed to be able to lift top-down inhibition of ipsilateral pathways. This decline in inhibition does not seem total since it was not sufficient to extinguish right ear advantage in this experiment, it was only able to reduce it.

The observed change from right ear advantage into left ear advantage in the first experiment of the present study should be seen with the outmost caution, because we do not know if these words would be able to produce ear advantages even without instruction manipulation.

Concerning the interaural time delayed dichotic stimuli in the ITD-C of both experiments, we would like to stress, that ear advantages were not significantly influenced by potential facilitation or inhibition of first perceived stimuli, or by side of presentation. Neither in the first, nor in the second experiment, did right ear advantages differ significantly with side of presentation. We therefore have to suggest that asymmetries observed rather depend on ear of entry than on perceived sidedness of the auditory stimuli. These findings are exactly opposite to those of Morais & Bertelson (1975 [19]), but as noted above, the dichotic technique used in their study is more likely to be importantly influenced by additional attentional mechanisms. Our results go in the same direction as those of Murray & McLaren (1990 [20]), when they examined the effect of head-turn on right ear advantage using a fused rhymed words test.

Regarding our second hypothesis; the further decrease of right ear advantage in the ITD-C (F+) condition compared to the DL-C (F+) condition of the first experiment would tend into the same direction as our hypothesis; but as said before, it seems questionable to interpret these data because we do not know if they would fulfil the basic criteria of creating perceptual asymmetries in a dichotic listening test without instruction to report the sound source.

On the subject of our second experiment, we saw an increase in right ear advantage in the ITD-C (nF) condition as compared to the DL-C (nF) condition; this of course invalidates our hypothesis.

One possible explanation for this observation can be found in several author's work. Sætrevik & Hugdahl and Hiscock & al. interpreted REA, in a dichotic listening test with given instructions, as the result of the interaction of two processes.

Sætrevik and Hugdahl distinguish between the "stimulus-driven" automatic processing, which produces right ear advantage in dichotic listening, and "instruction-driven" controlled processing, which allows healthy subjects to influence, and in some dichotic techniques, to overcome right ear advantage (Sætrevik & Hugdahl, 2007 [23]).

Hiscock's two-stage model postulates that the first stage of processing is an automatic, pre-attentional stage, and is responsible for ear advantages observed in dichotic listening, without given instruction to attend to one ear in particular. The second stage is participant regulated, effortful and depends on decision rules from the participant.

Moreover, Hiscock puts forward, "If the stimuli can be localised accurately, signals from the attended ear will be reported selectively. If the stimuli can not be localised at all, the increased reporting of signals from the attended ear will be matched by an increase in intrusions from the unattended ear."

In our study, the stimuli in the DL-C (nF) condition could not be localised at all, even though subjects had the instruction to localise them; this could be the explanation for the decrease in REA compared to the FW12k where no instruction was given, and second stage processes should not be as operative. In the ITD-C (nF) condition, although stimuli localisation was very difficult, participant's performance remained significantly above the chance level. Because of the given instruction, second-stage processes were active and subjects attended automatically to one ear, which would logically be the right one, as they are most likely to have left-lateralized speech processing. This would explain re-augmentation of REA in the ITD-C (nF) compared to the DL-C (nF). This REA was not as strong as REA in the FW12k, because second-stage processes were active, which was not necessarily the case in the FW12k, and activation of second-stage processes has been shown to reduce REA, even if the instruction was to attend to the right ear (Weller, 2005 [27]).

It is widely accepted that attentional top-down processes as well as perceptual bottom-up processes influence auditory processing asymmetries in dichotic listening. With the results of this study one could hypothesize, that the reason why, in dichotic listening, information processed by the ipsilateral pathways is weaker than information processed by the contralateral pathways, is rather because of top-down inhibition than because of a lack of bottom-up activation. With a change in instruction to localise stimuli, inhibition on ipsilateral pathways, which are thought to treat among other, localisation information, is lifted partially. Nevertheless, as soon as localisation information is actually present, attention seems to be shifted to the preferred ear, and ipsilateral pathway processed information no longer taken into account. The second-stage processes seem to overcome first-stage processes.

All these interpretations of present data can only be suggestions, as there is rather important bias in our study. There are two very important things that should be looked at, to be able to interpret these results. First, one should find rhymed words that differ in their middle part and would therefore be easy to localize, even if they were presented dichotically. Localisation performance dropped extensively in the ITD-C (nF) condition compared to both the LCC (nF) condition and the ITD-C (F+) condition. This difficulty in localisation of the (nF) words should be due to the fact that in this experiment, the dichotic part of the stimuli was not the middle part as in the (F+) stimuli, but it was right at the beginning, which is also the most important part of the word to extract spatial cues from. Subjects reported to answer mostly by guessing, and even though their performance still remained above chance, this factor could have influenced considerably the results. Furthermore they must be tested beforehand, without specific instructions, for their intrinsic ability to create ear asymmetries. With these words this study could be reproduced and those results should make our findings clearer.

Second, one factor should be examined in detail: instruction given to the subject. There should be at least one additional experimental condition, a condition with interaural time delay and no change of instruction compared to the typical fused rhymed words test. In that case second-stage processes should be not, or less activated, and would not necessarily overcome first-stage processes.

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And not to be forgotten: I of course thank all the participants for their patience and cooperation.

VI- Appendix

VI-1 FW12k

Questionary

Date of the test: ______________________________

Name: ______________________________

Birth Date: ______________________________

Sex: ☐ Male ☐ Female

Mothertongue: ______________________________

If the mothertongue is not German, age of learning German: __________

____

Laterality: ______________________________

Any known hearing deficits: ______________________________

____

Any known psychiatric or neurological antecedents: __________

____

EHI integrated in the FW12k = EHI of Oldfield (1971), modified:

Clear lateralization = 2 points, if the subjects uses both hands to do the given activity, one point is attributed to each side.

	Left ! Right
1. Writing	x x ! x x
2. Drawing	x x ! x x
3. Throwing (e.g. a ball)	x x ! x x
4. Holding scissors	x x ! x x
5. Holding a toothbrush	x x ! x x
6. Holding a knife (without a fork)	x x ! x x
7. Holding a spoon	x x ! x x
8. Hand used to distribute cards	x x ! x x
9. Lit a match	x x ! x x
10. Opening a cigarette box	x x ! x x
	(ΣL ! ΣR)

Left LQ < 0

%ile:	10	20	30	40	50	60	70	80	90	100
LQ:	-28	-42	-54	-66	-76	-83	-87	-90	-92	-100

Right LQ > 0

%ile:	10	20	30	40	50	60	70	80	90	100
LQ:	+48	+60	+68	+74	+80	+84	+88	+92	+95	+100

$$LQ = \frac{\Sigma R - \Sigma L}{\Sigma R + \Sigma L} * 100$$

Unilateral Part of the FW12k:

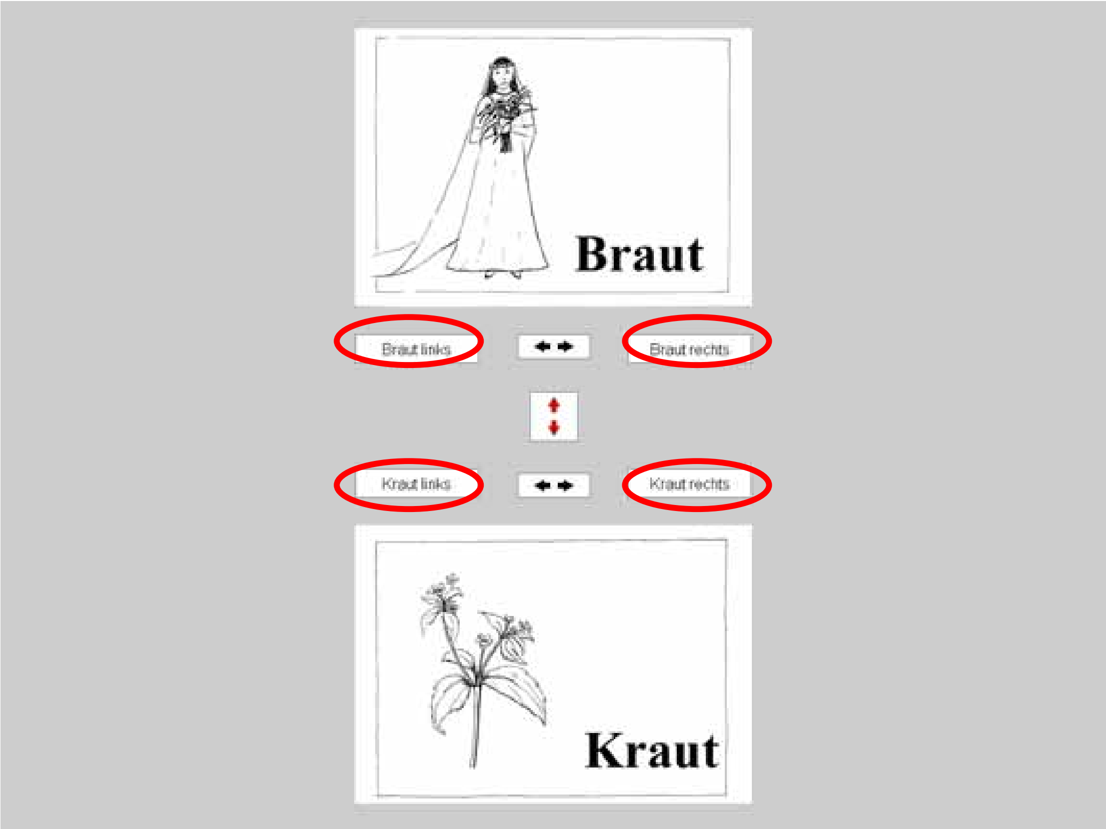


Fig. 5: Example of the unilateral part of the FW12k.

Instruction in this unilateral part:

You are going to hear a word on one ear, and you have to answer in clicking on one of the four small response fields, depending on the word heard and the ear on which you heard it. If you hear “Braut” on your left ear you click on the “Braut links” tab, if you hear “Kraut” on your right ear, you select the “Kraut rechts” tab.

Dichotic Part of the FW12k:

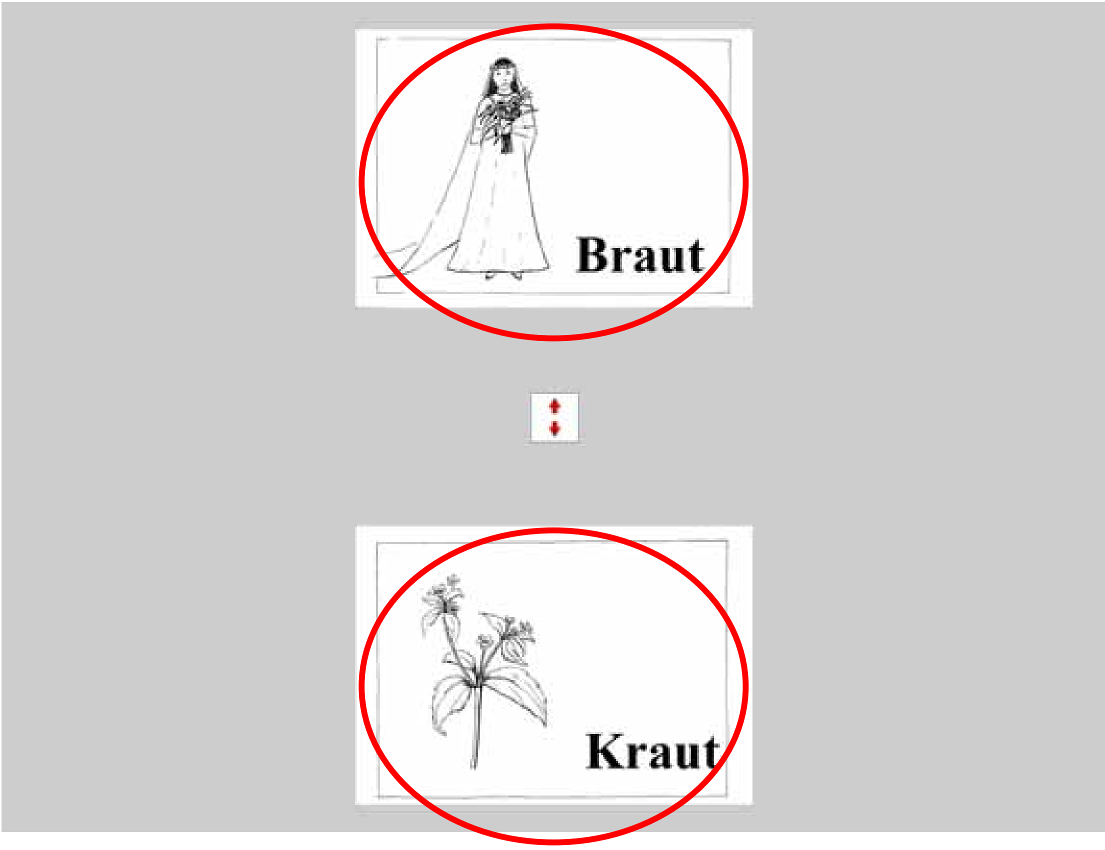


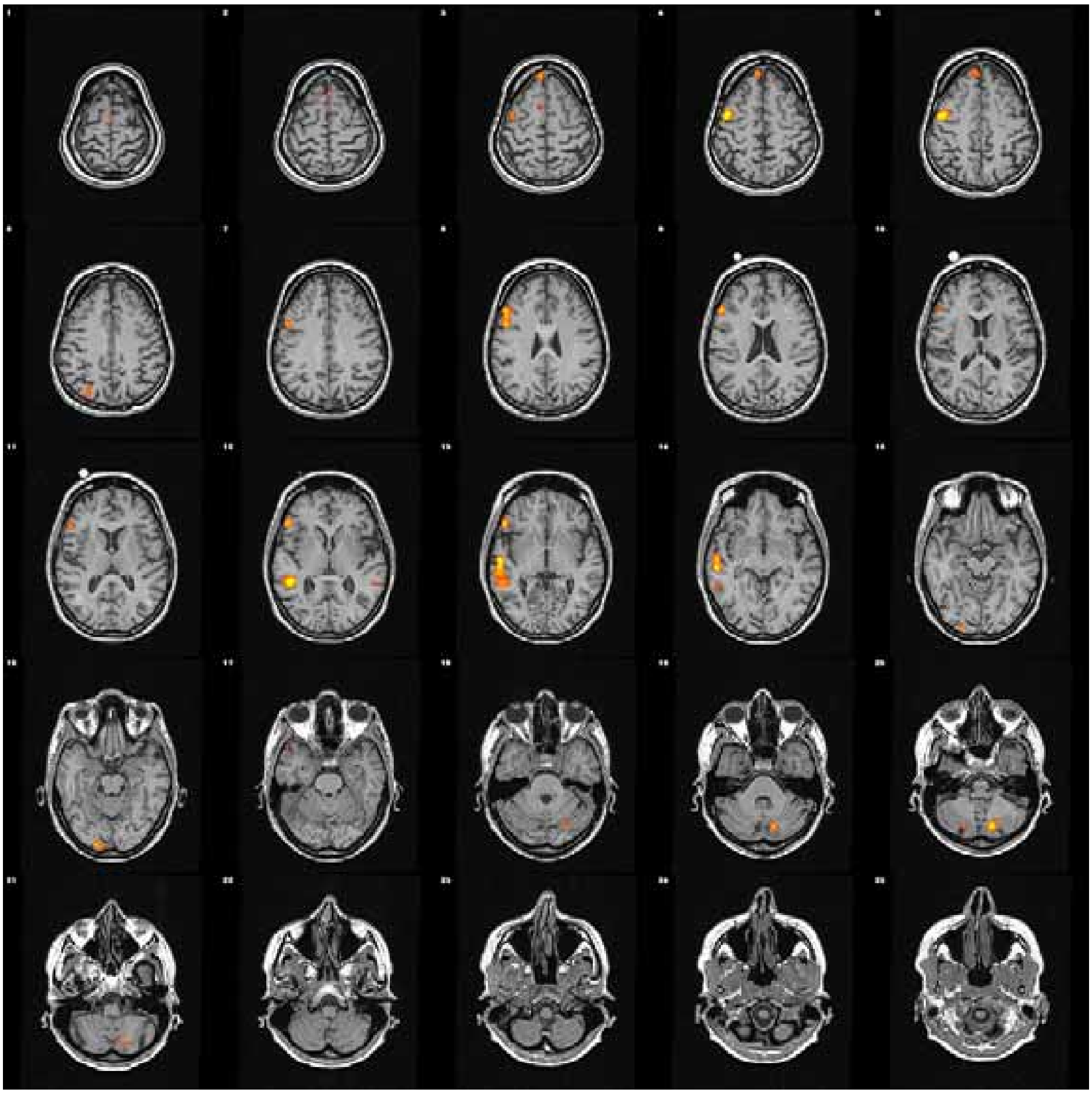
Fig. 6: Example of the screen in the dichotic part of the FW12k.

Instruction of the dichotic part:

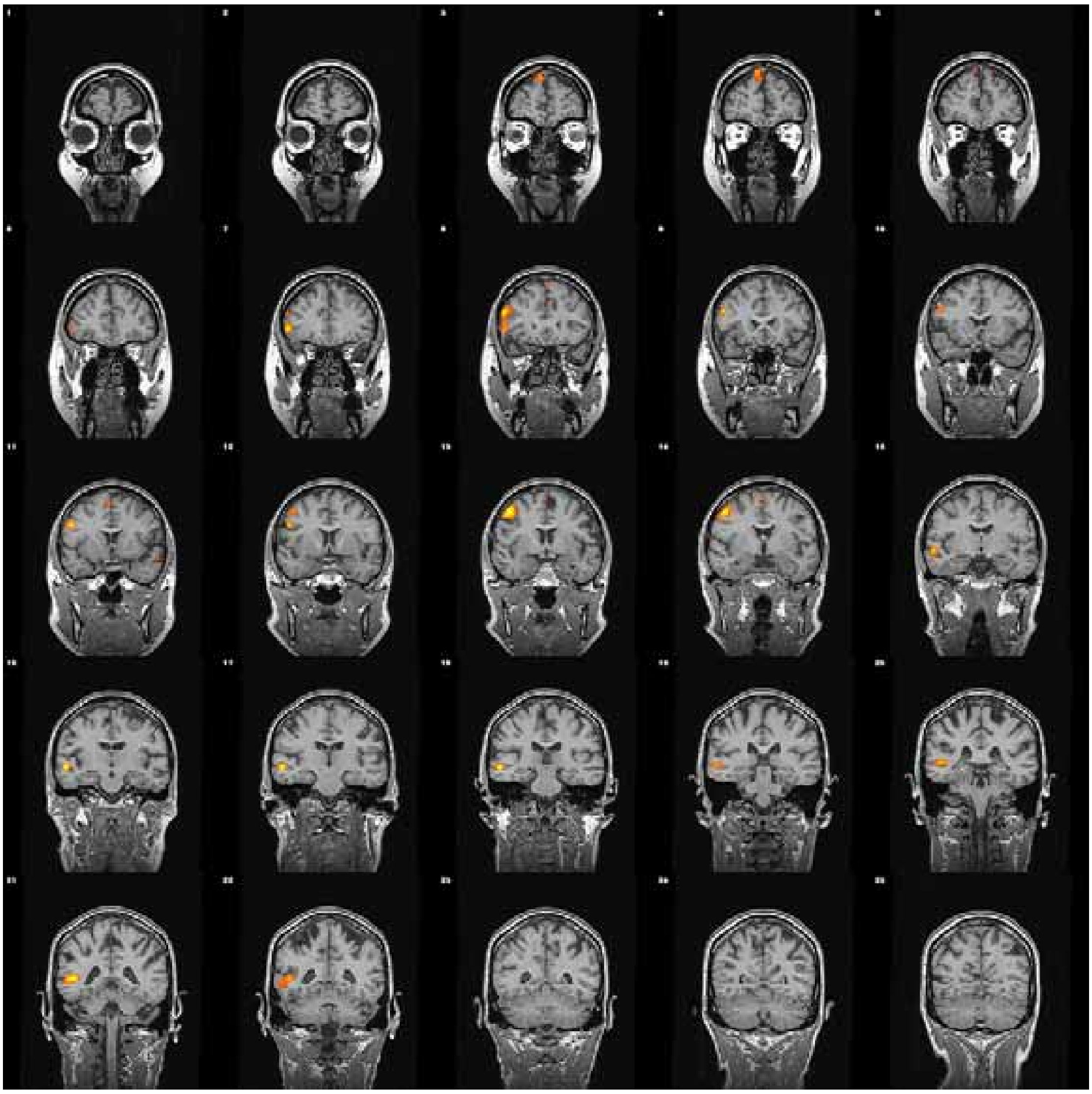
Now you are going to hear the words on both ears. We modified them electronically, that is why they can seem less sharp than those before. Only choose the word you heard by clicking on the picture of the corresponding word.

VI-2 First hypothesis

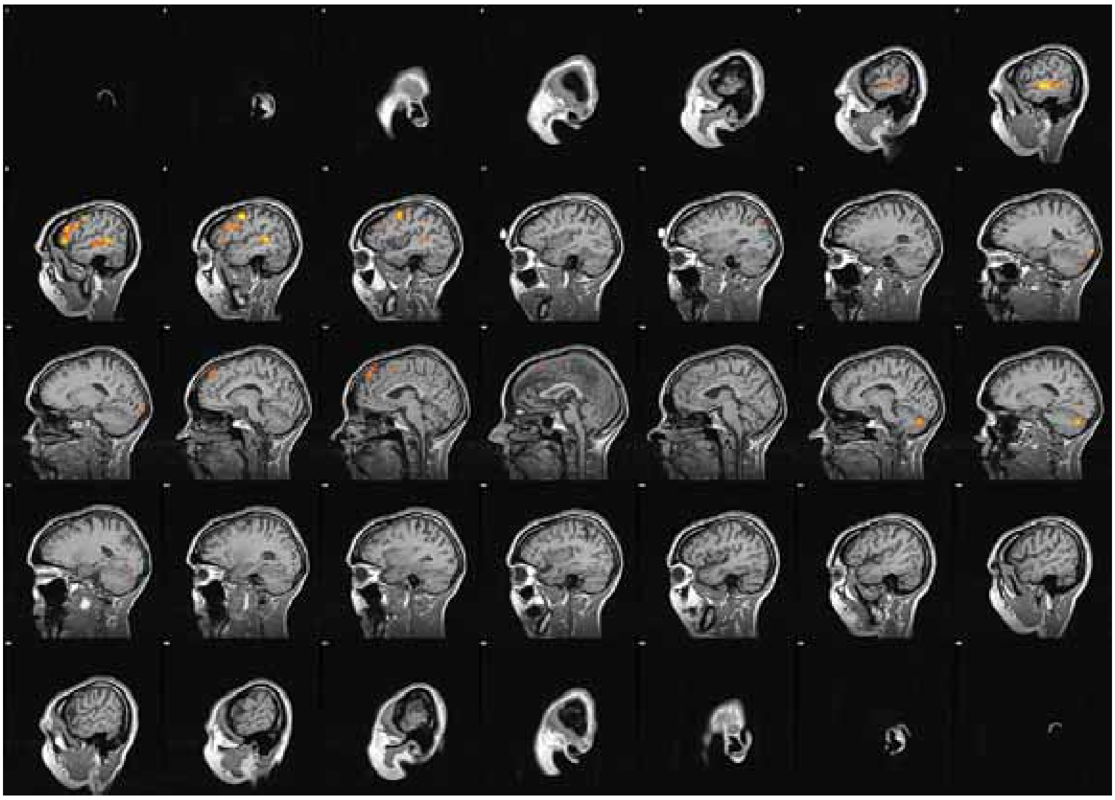
Axial slides



Coronal slides



Sagittal slides



VI-3 Second hypothesis

First Experiment ((F+) words):

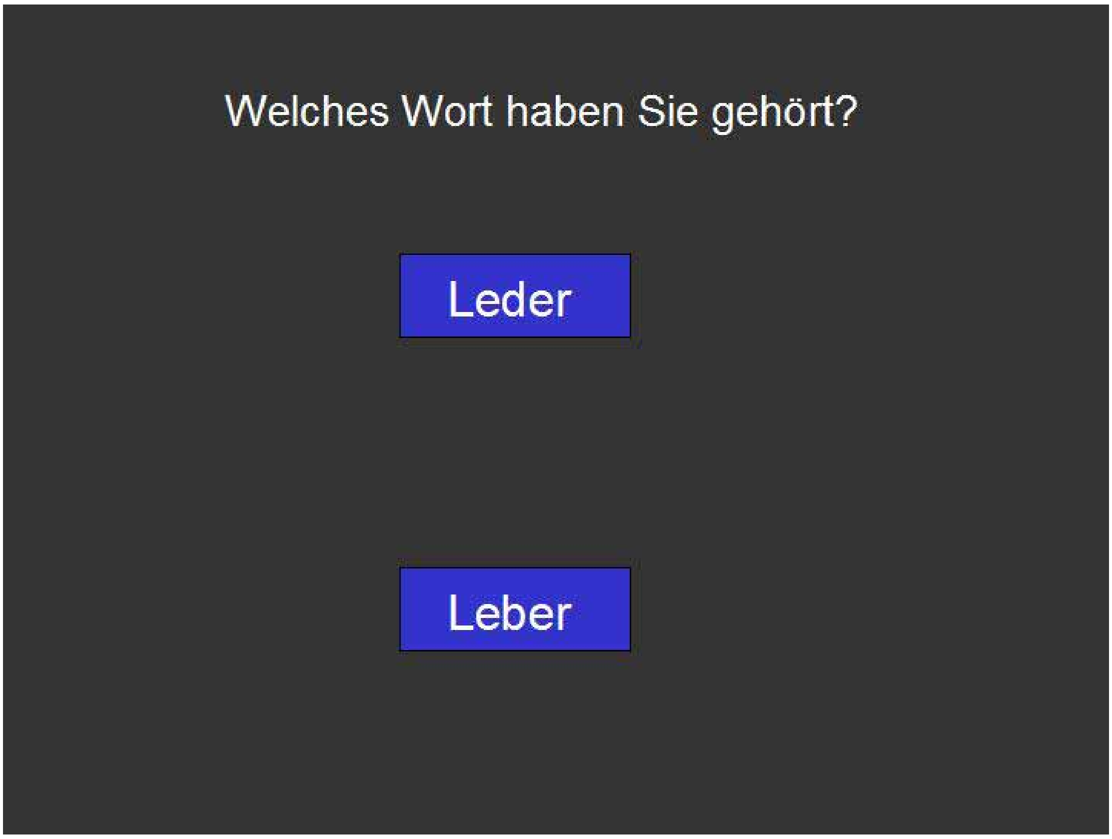


Fig. 7: Example of the computer screen in the first Experiment. (What word did you hear?)

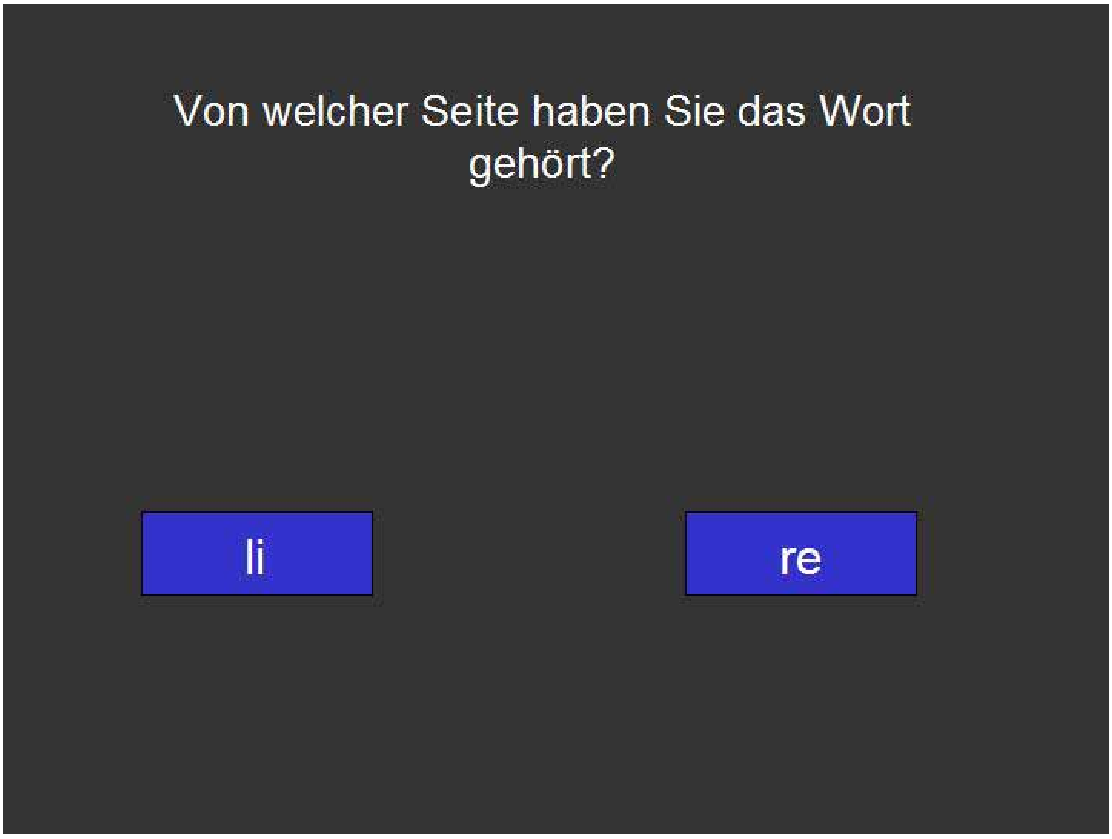


Fig. 8: Example of the computer screen of the first Experiment for the second question. (Where did the word come from?)

(F+) words:

Reden	**Regen**	**Nagel**	**Nadel**	**Leder**
Leber	**Siegen**	**Sieden**	**Lieder**	**Lieber**
Leben	**Legen**	**Lagen**	**Laden**	

Tab. 5: Words used in Experiment 1.

Participant's details:

Age		**EHI-LQ**		**Mothertongue**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**German**	**Lux.**	
24.4	**(3.37)**	**94**	**(9.66)**	**4**	**6**	**10**

Tab. 6: Demographic description of Experiment 1 participants.

Word recognition and lateralization hit rates in percent:

W-WRCC(F+)		**W-LCC(F+)**		**L-LCC(F+)**		**L-ITD-C(F+)**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	
96.06	**(5.45)**	**93.19**	**(7.93)**	**95.34**	**(4.14)**	**83.84**	**(8.3)**	**10**

Tab. 7: Hit rates in word recognition and lateralization performance in percent. "W" stands for "word recognition hit rates" and "L" stands for "lateralization hit rates".

VI-4 Experiment 2.

The computer screen looked the same in the second Experiment than in the first, apart from the words.

(nF) Words:

Braut	**Kraut**	**Brücke**	**Krücke**	**Dorn**
Korn	**Kohl**	**Pol**	**Gabel**	**Kabel**
Bau	**Tau**	**Gold**	**Colt**	

Tab. 8: Words used in Experiment 2.

Participant's details:

Age		**EHI-LQ**		**Mothertongue**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**German**	**Lux.**	
29.8	**(8.79)**	**93.3**	**(8.16)**	**5**	**10**	**15**

Tab. 9: Demographic description of Experiment 2 participants

Word recognition and lateralization hit rates in percent:

W-WRCC(nF)		**W-LCC(nF)**		**L-LCC(nF)**		**L-ITD-C(nF)**		**N**
Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**	
99.3	**(1.9)**	**100**	**(0)**	**97.8**	**(3.7)**	**62.2**	**(9.1)**	**15**

Tab. 10: Hit rates in word recognition and lateralization performance in percent. "W" stands for "word recognition hit rates" and "L" stands for "lateralization hit rates".