Linguistics and the Brain: Theoretical, Experimental, and Clinical Insights

Inaugural Lecture Roel Jonkers; 20-10-2023

Members of the Board of Directors, esteemed guests,

In the next half hour, I have the privilege of taking you through the versatile discipline of neurolinguistics, as we have shaped it in Groningen and as we aim to continue shaping it. Naturally, I'll begin with the question of what neurolinguistics is. While I have some idea myself, nowadays, as scientists, we can use a relatively new source for unbiased advice, namely ChatGPT. So, I asked ChatGPT in Dutch what Neurolinguistics is, and they came up with the following description:

'Neurolinguistics is an interdisciplinary field that studies the relationship between language and the human brain. It focuses on understanding the neural basis of language processing, language production, language disorders, and language acquisition. Neurolinguistics combines knowledge and methods from linguistics, neuroscience, and psychology to gain insight into how language is represented and processed in the brain. It investigates the structural and functional organization of language areas in the brain, as well as the processes involved in understanding and producing language. Through various techniques such as functional imaging (e.g., functional MRI), electroencephalography (EEG), and studies of patients with language disorders such as aphasia, neurolinguistics seeks to understand the neural mechanisms underlying language processing. This knowledge can aid in understanding normal language processes and identifying the causes and treatments of language disorders. Neurolinguistics also has broader implications for other areas, such as language development in children, understanding bilingualism, the relationship between language and cognition, and even the development of language-based interfaces for communication with computer systems.' (Source: ChatGTP)

I won't read this description in its entirety, but I'll highlight a few things. It's good to see that the first content word after neurolinguistics in this description is 'interdisciplinary.' We bring together knowledge from linguistics, psychology, and neuroscience, with language as our starting point. In our case, we're talking about speaking, understanding, reading, and writing language, at both the word and sentence levels. Our knowledge of language focuses on three aspects of linguistics: we study the individual sounds of language through phonology, words through semantics, and sentence structure through syntax. What we want to know is how these components of linguistics are represented in our brains and how the processes of sound, word, and sentence production work in the brain.

To learn more about these processes, we have two methods at our disposal. We can use techniques, as mentioned in ChatGPT's description, such as EEG or TMS, and if you're wondering, perhaps ask ChatGPT what this means: I will later provide you with some examples of our research, in which I'll further explain these methods. Another important source of information is language pathology. Children and adults with language and speech disorders due to brain injury, such as aphasia or tumors, or adults with diseases like Parkinson's or dementia, children with language development disorders or dyslexia: their language and speech usage provide insight into how our brains work.

We approach this primarily from a scientific perspective. Theory formation about language and speech processing processes cannot be done without the input of neurolinguistics. But of

course, there's a second important goal. Based on the knowledge we gain, we can improve the diagnosis and treatment of language and speech disorders.

Today, based on our research on the phonological, semantic, and syntactic processing of language, as well as on the disorders that can occur in this processing, I want to show what we have added and hope to add to the knowledge about our brains and the respective disorders.

We start with a bit of neuroanatomy. Because when we talk about language and the brain, what are we referring to? First, we need to distinguish four brain regions, the so-called lobes, focusing on the left hemisphere because language is largely localized there in most people.

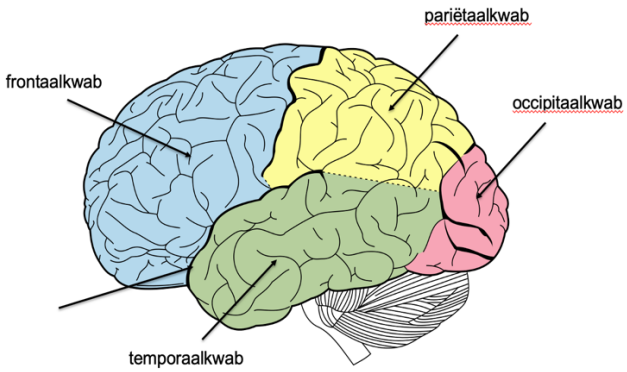

Figure 1: Overview of the four brain lobes

These are the frontal lobe, the temporal lobe, the parietal lobe, and the occipital lobe. The classic language model assumed three key components for language processing. In the frontal lobe lies Broca's area, and it was generally assumed that this area plays a significant role in sentence structure. In the temporal lobe lies Wernicke's area, also referred to as a mental lexicon, and it is important for word retrieval. Between Broca's area and Wernicke's area lies a fiber tract that connects the two areas, the arcuate fasciculus, and that fiber tract plays a crucial role in vocalization. Here we see our three levels of linguistics reflected in three separate areas in our brain.

Due to modern techniques, but also clinical examples, this highly simplified representation of language ability in our brain has undergone significant changes in, say, the last 20 years. The model we now speak of provides a much more complex representation of language, taking into account not only the cortical areas, or the cerebral cortex, but also paying attention to the important role of the deeper subcortical areas and even more importantly, perhaps, the connections between the different areas, also referred to as language pathways, even to the role of white matter in our brain in language processing. The accompanying image illustrates an example of this.

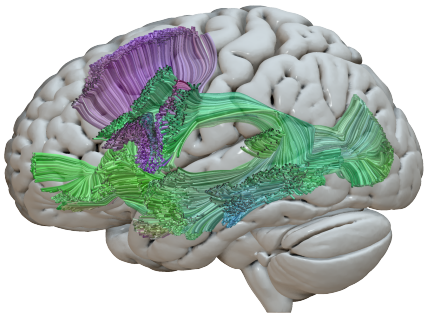

Figure 2: Overview of language pathways

Based on research into the language processing of non-language-impaired and language-impaired subjects, we have gained this knowledge and thus know more about our brain. But given the significant changes in recent years, we are fairly certain that we also know less than we thought, but that is all the more reason to continue with the research, of which I will give you various examples, always starting from the disciplines of phonology, semantics, and syntax.

Syntax

Let's start with syntax. One of the aspects through which we as neurolinguists can demonstrate our added value in neurobiological research is our linguistic knowledge of the verb. Neurologists and neuropsychologists often did not progress beyond the processing of nouns in their studies, but verbs specifically require much more complex processing, given their meanings but also their role in sentence construction. To learn more about these verbs, PhD student Effy Ntemou conducted research using Transcranial Magnetic Stimulation, abbreviated TMS.

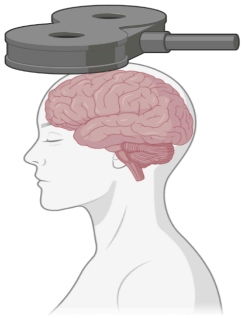

Figure 3: Simplified representation of TMS operation

TMS is a non-invasive method in which short magnetic pulses are generated in a coil, causing certain brain areas to be inhibited or activated. Based on the location where this occurs, it can be deduced which knowledge is processed in specific areas of the brain. Specifically, Effy

investigated how the transitivity of the verb is cortically represented. Transitivity refers to intransitive verbs, which are verbs that only have a subject and no direct object, such as 'skating' or 'bending,' as opposed to transitive verbs like 'grind' and 'kiss,' which require a direct object. In my own doctoral research, I had already shown that individuals with aphasia, a communication disorder caused by a language impairment after acquired brain injury, exhibited differences in the problems they had with transitive or intransitive verbs. Effy has now been able to demonstrate the locations in non-language-impaired subjects of the processing of these verbs. She used images that she had subjects name, depicting transitive and intransitive verbs, and then she used TMS to deactivate various areas. Effy applied TMS in the frontal, parietal, and temporal areas, both in the left and right hemispheres, and it was precisely in the left temporal area where she found significantly more errors with transitive than with intransitive verbs, indicating that this area is important in processing what we call the argument structure, i.e., the fact that some verbs require a direct object and others do not.

Semantics

Moving on to semantics. A study that addresses both grammatical aspects and semantic aspects of verbs is the research of Dr. Vânia Correia de Aguiar and her group. She has secured a prestigious NWO VIDI grant and collaborates with three PhD students, Cheyenne Svaldi, Kim Vos, and Aliene Reinders, on studies into the processing and learning of verbs by children with developmental language disorders, children with posterior fossa tumors, and children with typical language development. In the group of children with developmental language disorders, there is clearly a delayed language development that can occur in all areas of language, while there are no identifiable causes for these language disorders, such as brain injury or cognitive impairment. However, these disorders may have a neurological basis. There is currently a study underway in which MRI scans are being made of these children and children without developmental language disorders to investigate whether there may indeed be differences in brain structures.

Posterior fossa tumors are the most common brain tumors in children, and the initial research by Vânia's group shows that these children experience clear language problems after surgery aimed at removing the tumor as much as possible. The research will examine children with posterior fossa tumors 2 to 3 weeks after surgery to assess their ability to process and learn verbs, taking into account the transitivity of verbs, which I mentioned earlier, and we see an example from the test developed for this purpose here.

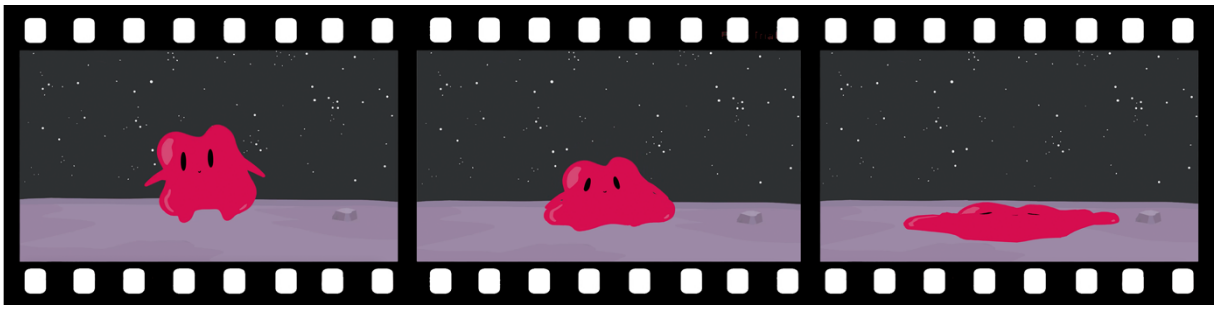

Figure 4: Example verb learning task item melt

Some of the children with posterior fossa tumors undergo radiation therapy in addition to surgical removal of the tumor. It is expected that these children will experience even greater problems because certain areas of the brain will be damaged. The research will therefore also

focus on getting an image of these areas, in order to develop adapted protocols for the areas to be specifically irradiated, thereby preserving as much language as possible.

Phonology

If we make the transition to phonology, I would like to demonstrate how we have used electroencephalography, or EEG, to map differences in brain activation patterns between groups when pronouncing words. In EEG, electrodes are placed on the scalp of a test subject, recording brain waves, or electrical activity. Unlike MRI, which allows us to create images of specific locations in the brain, we cannot do that with EEG. However, we can effectively represent the time course of processes. The idea is that participants perform various tests, and certain items lead to more activity, which is reflected in the EEG signal. This way, processes of word retrieval, grammatical, and phonological processing can be tracked.

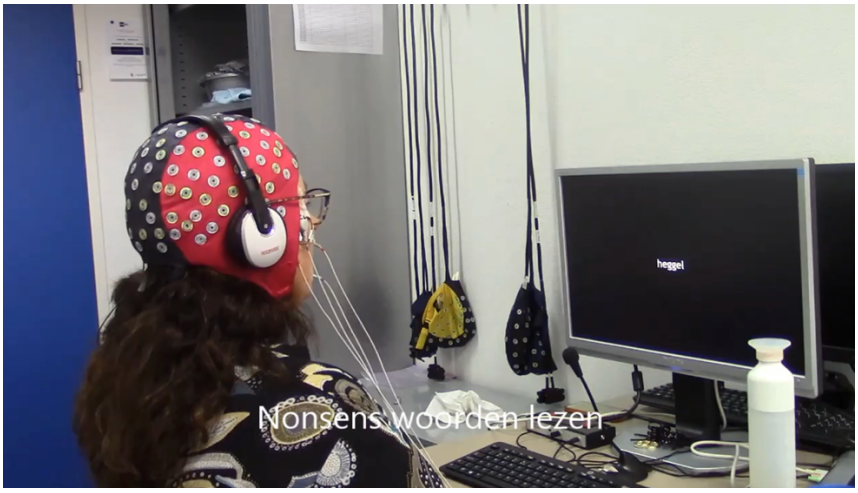

Figure 5: Example EEG research

Within our research group, Dr. Srdjan Popov leads various studies using EEG, and we are fortunate that our EEG equipment is up-to-date, partly due to contributions from sector funds. When we focus on word pronunciation, three processes are important:

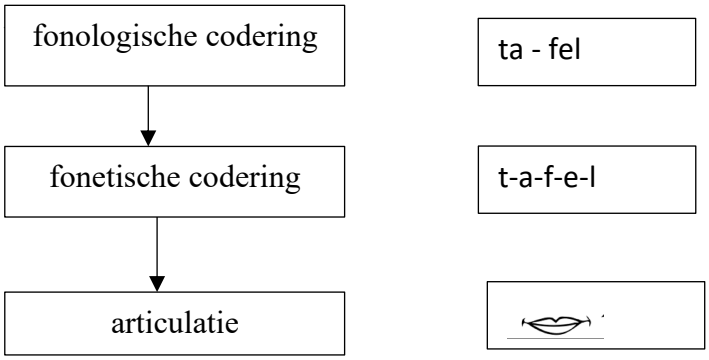

Figure 6: Simplified representation of the word pronunciation process

To pronounce a word like "table," we first need to break it down into syllables, a process referred to as phonological encoding. Then we identify the different sounds (phonetic encoding), and finally, we program our articulatory organs such as the mouth, lips, and tongue to produce those sounds, referred to as articulation. Former PhD candidate Jakolien den Hollander attempted to distinguish between two syndromes where problems occur at these levels, namely aphasia and apraxia of speech.

Apraxia of speech is a disorder resulting from brain damage in the programming of articulatory organs. With aphasia, we know there can be specific problems with articulation. We refer to this as phonological disorders. It has actually never been successful to distinguish between these two syndromes, as apraxia of speech rarely occurs alone and almost always accompanies aphasia. Therefore, Jakolien, Roelien Bastiaanse, and I attempted to investigate whether there might be differences in EEG patterns between these two groups. I would like to note here that the original idea came from Peter Mariën, our Flemish colleague who unfortunately passed away too early.

In comparing the data of people with aphasia and people with apraxia of speech, we discovered differences in EEG patterns during word repetition between the two groups at the second level, the level of phonetic encoding, as depicted here.

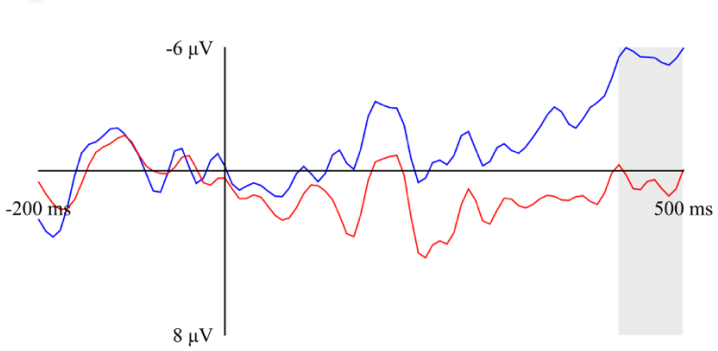

Figure 7: Deviating EEG patterns during phonetic encoding (blue is aphasia; red is apraxia of speech)

During the time frame in which this process occurs, about 430-500 milliseconds after the word to be repeated was presented, there was a clear difference in the signal between people with a phonological disorder (in blue) and those with apraxia of speech (in red). In this way, EEG contributes to the diagnosis of apraxia of speech. I will show later how such a good diagnosis is again meaningful for its treatment.

Another group of individuals with speech disorders that we have been researching in various ways in recent years, both in terms of speech production and perception, are people with Parkinson's disease. Aspects of speech within linguistics are studied from the perspective of phonetics, a sister discipline of phonology. Through doctoral research by Vass Verkhodanova, Jidde Jaccobi, and Teja Rebernik, in collaboration with Martijn Wieling, Ben Maassen, Wander Lowie, Matt Coler, and Michael Proctor, we are trying to discover aspects of speech that could play an important role in the early diagnosis of Parkinson's disease and thus in faster treatment. People with Parkinson's disease often suffer from so-called hypokinetic dysarthria. This leads to monotone speech, disturbed voice quality, and inaccurate

pronunciation. Vass Verkohadanova had a group of speech therapists familiar with hypokinetic dysarthria and a group of untrained Dutch, German, and Slavic-speaking participants listen to 30 fragments of people with speech problems and Parkinson's disease, and 30 people who did not have speech problems. Participants were asked to indicate whether the speech sounded healthy or unhealthy. Surprisingly, untrained Dutch and German evaluators were better at this than the speech therapists. Vass indicated that this means specific features are being observed, which, especially in non-native speakers, are independent of the content of the spoken language. But what is also important about this outcome is that an untrained layperson is able to recognize abnormal speech.

The pronunciation of people with Parkinson's disease can now be much better mapped out because we have the unique opportunity within the Speech Lab Groningen of Martijn Wieling to study the dynamics of speech using electromagnetic articulography. With this technique, sensors are glued to the tongue, lips, and jaw, after which the position of these sensors and thus the articulators can be studied during speech. In this way, for example, we can register how the tongue and jaw collaborate in saying a /t/ and whether there are differences in speech movements between people with and without Parkinson's disease.

Figure 8: Example of electromagnetic articulography

This technique is also combined in the Speech Lab with ultrasound, which is better able to study the contours of the tongue. By combining these techniques, it is possible to investigate both the production of vowels and consonants. This way, the entire speech process can be visualized.

Jidde Jacobi has shown, using EMA among other methods, that tremor, the uncontrolled shaking often seen in Parkinson's disease, also occurs regularly in the muscles of the tongue; something that was previously seen as a symptom that occurred very sporadically. Currently, Teja Rebernik is researching the role of internal auditory feedback in people with Parkinson's disease.

Spontaneous speech

Research in which phonology, semantics, and syntax come together is research into spontaneous speech. This is the language that is closest to the test subject's normal spoken language. It is elicited using a number of conversation questions, allowing us to examine pronunciation, word choice, and sentence structure. We are currently conducting research in this area, among others, into language problems in dementia. We probably all know

Alzheimer's dementia, and within the course of that dementia, people always experience language problems, but we see this even more clearly in people who develop dementia, where language problems are the first sign. We refer to this as primary progressive aphasia, or PPA. Non-fluent primary progressive aphasia and semantic dementia are two forms of PPA. Because language problems are the first sign here, it is important to search for markers that can lead to an early diagnosis of PPA and its variants, and if this can be done through features of spontaneous speech, it could be a simple and fast way.

Now spontaneous language is very important for the neurolinguist, and it is also something where the neurolinguist is particularly needed for analysis because such an analysis requires a lot of linguistic knowledge. However, analyses are very time-consuming, and there are always some differences between evaluators, who can also make mistakes. Therefore, lecturer and PhD candidate Roelant Ossewaarde is currently working on using machine learning to automatically analyze spontaneous language conversations of both non-language-impaired individuals and people with Primary Progressive Aphasia (PPA). Simply put, software can annotate the sentences spoken (identifying nouns, verbs, conjugations, pauses), and machine learning generates a hypothesis based on part of the data, which is then tested against the rest. These types of analyses can be done quickly, and Roelant has, for example, investigated the role of pauses in the fragments. There are actually two types of pauses we use in this regard: short pauses to find a word or longer pauses to end a sentence. Both groups of participants with PPA showed deviations from the control group. People with non-fluent aphasia showed many more shorter pauses, while people with semantic dementia showed fewer shorter pauses than the control subjects, but more longer pauses, which were, however, shorter than those of the control subjects. This means that the latter group speaks in a rapid staccato speech.

Roelant also conducts similar comparisons with grammatical and lexical analyses, where we see deviations, particularly in the quantity of nouns, verbs, and pronouns, as well as differences in word choice. In all three sub-studies, the groups with PPA can be distinguished reasonably well, but not optimally. Our idea is that only when we combine the three linguistic analyses can we arrive at a good diagnosis.

We are also participating in a large national study led by Professor Yolande Pijnenburg of Amsterdam UMC, which investigates various aspects of so-called presenile dementia. We are partially responsible for the language component there. Presenile means that dementia begins before the age of 65, and you can imagine that a diagnosis is even more difficult in such cases. If someone aged 55 begins to have language problems, they are more likely to be thought of as having a burnout rather than dementia. With the method now being developed, we hope to provide an important contribution to a good and rapid diagnosis, which ultimately could include the development of an app or software that can at least provide an indication based on a recorded conversation that the individual should consider contacting a neurologist.

Use of neurolinguistic knowledge for the treatment of individuals with speech and language disorders

The dementia app mentioned earlier is still futuristic, if it can come in such a form, but it nicely bridges with the research I now want to discuss further with you, namely the use of our neurolinguistic knowledge for better diagnosis and treatment of people with language and speech disorders. The knowledge gained from the research I discussed earlier is of course used to improve diagnosis, but very concretely, we also conduct research on the development of diagnostic tools and treatment materials. Regarding the development of apps, within our

group, it is primarily Dr. Dörte de Kok who is leading this effort. She played a key role in the development of the Token Test app.

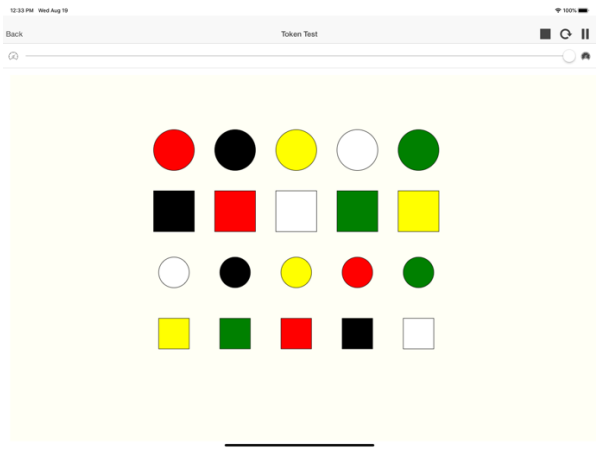

Figure 9: Example of the Token Test app

The Token Test is a test that was developed a long time ago, originally designed to test grammatical comprehension, but ultimately, it was found not to measure that. However, it turned out to be excellent at diagnosing aphasia. It appears that all individuals who may have aphasia score poorly on this Token Test, making it a very important diagnostic test. This test has been available as an app for some time now, making it easy to administer, but it has an additional advantage. It is also easy to provide translations into many other languages.

Our chair group has been providing the European master's program in Clinical Linguistics for almost 25 years, a joint program, which means we award a joint degree with our partners in Joensuu and Ghent. Thanks in part to funding from the Erasmus Mundus program of the EU for about 20 years, we can attract students from all over the world to this program. With the help of these students, among others, the app has already been translated into 42 languages, with the most recent addition being Greenlandic.

Another app developed within our group is the ACTIE app. It is based on a therapy program that Roelien Bastiaanse and I developed with the help of two students at the end of the last century for practicing verb production and sentence construction, and this program is now available in the form of an app. PhD candidate Pauline Cuperus has just published a study on the effectiveness of this app.

The focus of the ACTIE app is mainly on the treatment of grammatical problems. Another, external PhD candidate, Judith Feiken, is researching the development and application of a web platform together with some colleagues from the business sector under the name Stapp Solutions. Within this platform, diagnostic tests and treatment options are offered for individuals with apraxia of speech and people with aphasia at the sound and word level. Judith will also conduct an effectiveness study of the treatment of language and speech problems in these groups.

Therapy at the sound level is also being applied by external PhD candidate Mirjam van Tellingen. She is involved in the application of music therapy for children with a speech disorder. A previous study by former PhD candidate Joost Hurkmans showed that music therapy was effective for adults with apraxia of speech, and the same therapy is now being

applied to children. The initial pilots show progress in speech in children treated with this therapy.

However, it's not just apps that are being developed within our research group. In the treatment of patients with so-called low-grade glioma tumors, efforts are made to remove these tumors. Among other things, when these tumors are found in or around language areas, this has long been done via awake surgeries. During such surgery, a language test is administered, during which the surgeon temporarily activates and deactivates areas. If errors are made on the language test when the area is inactive, the surgeon knows that this area is important for language and will try to preserve that area as much as possible. Dr. Adrià Rofes has been involved in various studies in this area within our research group.

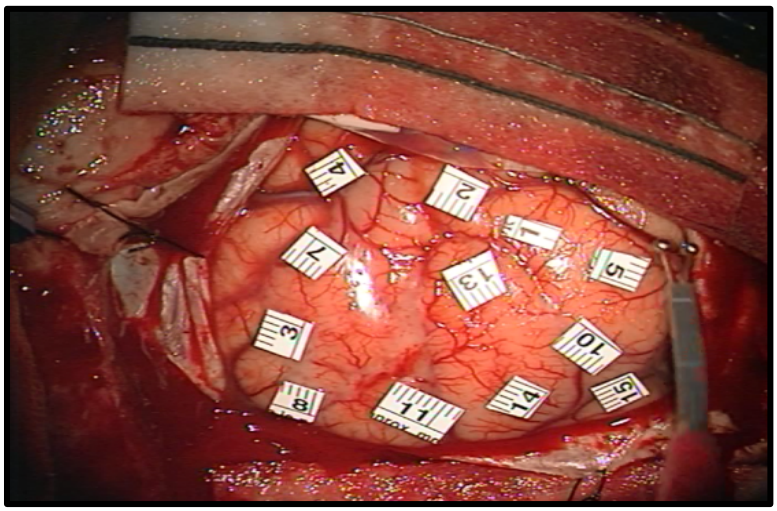

Figure 10: recording of awake surgery (numbers depict areas that will be checked)

We saw, as I mentioned earlier, that also in these surgeries, the initial focus was mainly on eliciting a noun, which didn't always result in the desired outcome because patients were left with significant language impairments. It was also found that it was important to include verbs and sentence construction in the tests. It is now clear that these tests yield better results, and it is gratifying to see that the tests are also becoming standard practice in countries such as France, Germany, Italy, and the United Kingdom for awake surgery operations. Recently, two PhD candidates have been appointed within Adrià's group who are funded based on his collaboration with Europe's largest university hospital, Charité in Berlin, and with another important center in this field, Lariboisière in Paris. Both organizations financially contribute to the payment of these PhD candidates through double degree sandwich projects of our faculty. Lena Rybka is researching the relationships between language and memory problems in people with brain tumors and the likelihood of returning to work, while Logan Gaudet is researching the ability to diagnose mild language disorders via semantic associations.

Developments that benefit society have been incorporated into the Groningen Expertise Center for Language and Communication. It is headed by Dr. Dörte de Kok, and naturally, app development is included there, as well as the Dyslexia Center. Within neurolinguistics in Groningen, we provide education in the field of dyslexia and conduct research into this reading and spelling disorder. The dyslexia center was set up to administer tests and conduct research on students with dyslexia. Together with Barry de Groot, working at the department of Orthopedagogy, and Dr. Liset Rouweler, a former PhD candidate of ours, many students

are tested for dyslexia annually. Subsidies have been made available by the University of Groningen under the Quality Agreements framework for this purpose. Dyslexia is the most common disability among students in higher education, with about 5% of all students suffering from dyslexia. For our university, this amounts to more than 1500 students. Some of these students also have dyscalculia. Failure to properly recognize these disorders will mean that these students do not receive the proper help and support they need, which can lead to study delays, higher dropout rates, and, consequently, psychosocial problems.

The results of the dyslexia tests are also used for further scientific research. Additionally, PhD candidates regularly conduct research on dyslexia. At present, this applies to Alessia Rossetto, who is studying the role of semantic interpretability in reading non-existent words by individuals with and without dyslexia.

Alessia, like a large part of the other previously mentioned PhD students, is an Idealab PhD candidate.

As with our joint EMCL master's program, where we train international students in clinical linguistics and award a joint degree with our two partners, we also do this at the doctoral level within the Graduate School Idealab, which is led in Groningen by Dr. Srdjan Popov. This is a collaboration between Macquarie University in Sydney, the University of Potsdam in Germany, Newcastle University in England, and us, and here too, we train for a joint Ph.D. degree. PhD students do at least part of their training and research at two of the partners. We are very pleased that the faculty has recently indicated that we can continue this collaboration for another five years.

Three of these Idealab students have remained unnamed. Sara Shogi Javan is conducting EEG and behavioral research on the processing of ambiguity in prepositional constructions. Jonathan Gerona is researching grammatical problems in people with aphasia in Tagalog, the main language of the Philippines, and Solveig Castelli is soon completing her doctoral research on the influence of predictability of word combinations on the ability to find words in our mental dictionary.

Ladies and gentlemen, I began my story by highlighting the importance of the interdisciplinary nature of our discipline. You have seen that this collaboration involves colleagues from the humanities and the social and medical sciences, both locally, nationally, and internationally. But this collaboration goes further, both in our research and in our education. I have already mentioned our joint master's program in Clinical Linguistics, where our faculty is the lead and where, with the support of Dr. Adrià Rofes and Alice Pomstra, we collaborate not only with our regular partners but also with many partners within and outside Europe in clinical fields, as well as with companies in the field of app development or the development of equipment for language research, which offer internships to our students. We are already in the process of applying for new European funding for the cohort 2025-2031.

In education, we have been working well with our colleagues from the Speech Therapy program at Hanze University of Applied Sciences for 33 years, and for about 20 years, we have been offering students of the Bachelor of Linguistics the opportunity to transfer to a Bachelor of Speech Therapy, allowing them to do part of this study in our BA program, and vice versa, we offer graduates of Speech Therapy the opportunity to follow our Master of Neurolinguistics through an abbreviated program. The fact that this was a unique collaboration at that time was highlighted by the fact that, at the start, the education supplement of The New York Times paid attention to it. By now, we also engage in co-teaching through Dr. Margot Bochane, Lecturer at the Speech Therapy program, who has been giving lectures in our program for several years. Collaboration with Hanze University of Applied Sciences and with the Alfacollege is also seen when it comes to the development of apps. App design for clinical applications has become part of the EMCL program, and guest lecturers from the mentioned institutions are involved in it.

We also collaborate with the working field. We have many contacts with special education institutions, organizations like Kentalis and Auris, and rehabilitation centers. They offer internships to our students, but we involve them, and they involve us in scientific research, and I am pleased to see that we have come to projects with many centers that have led to publications or even doctoral trajectories. However, clinicians also participate in our education, as guest lecturers, or, as in the case of Nynke van den Bergh, a clinical linguist at Kentalis, as the instructor of a complete course.

Last but certainly not least, I would like to mention Afasienet in the context of collaboration.

The foundation of which I have been chairman for the last five years and in which we try to bring together all people who are in one way or another involved with aphasia. Of course, these are the individuals with aphasia, but also the practitioners, referrers, and researchers. In that form of individuals with aphasia, I would like to highlight all the people who participate in our research in one way or another. Without them, no research takes place, but they are also often the people we do it for. Theory is important and helps us think about how our brain works, especially regarding all aspects of language and speech that occur within it, but ultimately, we want to use that knowledge to try to improve the lives of adults and children suffering from these speech and language disorders with the development of diagnostic and treatment materials.

At the end of this inaugural lecture, I am fortunate to have the opportunity to briefly express my gratitude. Given these constraints, I will not focus on all the people I have encountered within and outside the university over the past 36 years with whom I have had the pleasure of collaborating. Of course, I am grateful for that collaboration, but here, I will only express gratitude to the four most important women in my life. Sabine, Sterre, Luna, and Zonne. Nothing compares to you!

I have spoken.