# NeDComm Lab

2020 - 2021

by Yury Shtyrov

NeDComm Lab, led by Professor Yury Shtyrov, is an international research group at CFIN which focuses its research on NeuroDynamics of Human Communication (hence the name). Simply put, our research is aimed at understanding the neurobiological foundations of the language function in health and disease. The ability to communicate using language is a uniquely human neurocognitive function whose complexity surpasses all other signalling systems known in the animal kingdom. Language makes us who we are, it enables all our daily activities, including education, work, social life, etc. and thus plays a defining role in our lives and forms a backbone of our society. The loss of linguistic ability, or even a partial damage to it, is therefore not only a tragedy for the affected individuals – it also bears very high costs to the society. In spite of this obvious importance, the brain mechanisms underpinning language remain very poorly understood. Since no suitable animal models are possible for language, it is chiefly studied using non-invasive cross-disciplinary approaches, with methods drawn from neuroscience, psychology, linguistics and other fields. In our group's work, we explore the dynamic processes of storage and access of linguistic representations in the brain using non-invasive human neuroimaging techniques (such as MEG, EEG, MRI), which are combined with psycholinguistic and neuropsychological paradigms in order to address various levels of linguistic information processing in the brain, including speech sound perception, word learning, meaning comprehension, bilingualism, grammar etc.

Although, like all research dependent on close contact with human volunteers, our investigations suffered enormously from the lockdowns imposed during the years of the COVID-19 pandemic, this global disaster did not detail our scientific work. Being largely cut off from the labs, we shifted out activities to online psycholinguistic studies, to improving our analysis techniques and to finalising major projects which had been started before the pandemic.

One such project is a comprehensive investigation of neurolinguistic processes in Parkinson's disease (PD). Although motor symptoms are a hallmark of this disease, patients can also manifest cognitive impairments including deterioration in executive functions as well as language deficits. While the current treatments of PD - dopaminergic medications and deep brain stimulation (DBS) - are associated with remarkable alleviation of the motors deficits, their impact on cognitive functions, particularly language, is still controversial. With generous funding of ~DKK2.6 mln from Danish Independent Research Council (DFF), we ran a set of studies aimed at investigating the automatic stages of language comprehension in PD and understanding how linguistic processing is affected in patients undergoing two different treatments: dopaminergic medication and DBS. To achieve this, we – a team of NeDComm scientists Rasha Hyder, Andreas Højlund, Mads Jensen, Yury Shtyrov, together with our collaborators, including clinicians at Aarhus University Hospital – used magnetoencephalography (MEG) which allows probing rapid neural processes associated with speech perception with high temporal and spatial resolution.

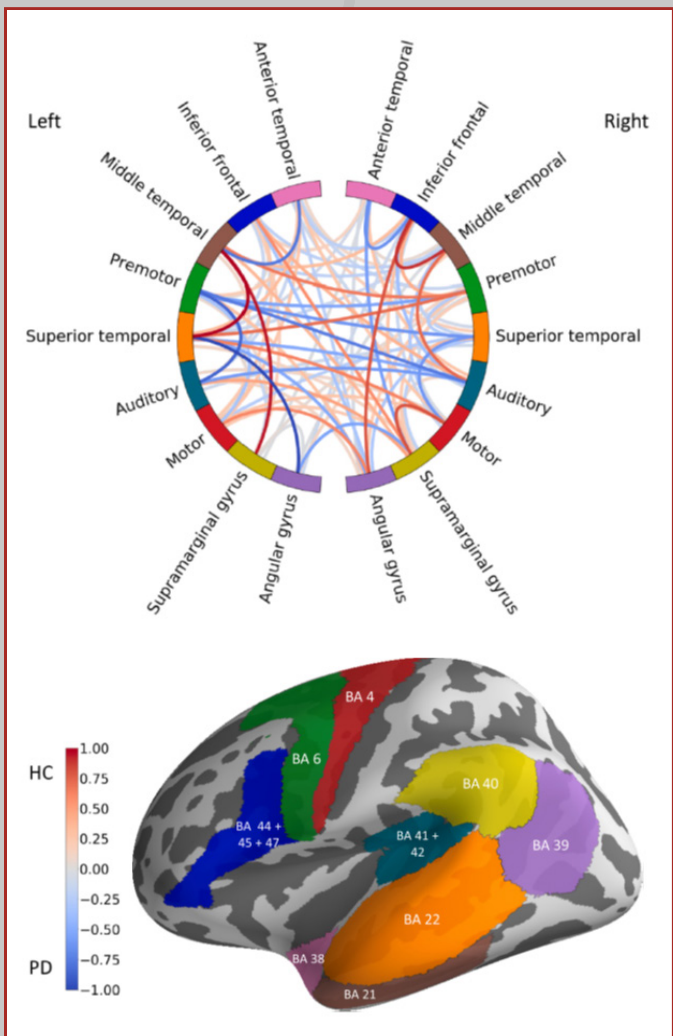



**Figure 1**
Multiple functional connectivity changes during language comprehension in PD patients: machine-learning classification of MEG activity. Regression coefficients values (coded as line's colour intensity) indicate the contribution to the overall class prediction: higher coefficient values in the red connections contribute more to classifying a participant as a healthy control (HC) and higher efficient values in the blue connections contribute more to classifying a participant as a PD patient (PD). Functional connectivity of spoken language processing in early-stage Parkinson's disease: an MEG study. Hyder, R., Jensen, M., Højlund, A., Kimppa, L., Bailey, C.J., Schaldemose, J.L., Kinnerup, M.B., Østergaard, K., Shtyrov, Y. NeuroImage: Clinical, 32, 102718, 2021. https://doi.org/10.1016/j.nicl.2021.102718

First, our findings demonstrated that different key levels of neurolinguistic processes can be addressed in an attention-free manner and without any task-related responses by the patients, and crucially, within a relatively short time. Second, the results revealed that even at an early stage of the disease and despite being medicated, PD patients exhibit different functional connectivity patterns when processing linguistic stimuli, with generally lower levels of correlated area activity as compared with the age-matched control group. These differential connectivity patterns open the possibility of establishing early neurolinguistic markers that may help prodromal detection of alterations early in PD even before the appearance of other cognitive symptoms, potentially leading to efficient and simple diagnostic tools. Furthermore, such neurolinguistic markers may help predict the progression of cognitive decline and perhaps even identify patients who are more prone to develop dementia, which eventually can help delay the functional deterioration of these networks if suitable cognitive training methods can be employed. Finally, our findings suggest that the effects of subthalamic DBS on language processing vary depending on the type of linguistic information.

These results may explain the variability in the existing literature regarding the effects of this treatment on the language functions as well as on the cognitive performance in general. Crucially, they point to the possibility for the DBS to be instrumental for ameliorating not only the motor deficits in PD, but neurolinguistic processes as well. The results constitute the first demonstration of the neural substrates of automatic speech comprehension in PD patients in conjunction with different treatments and provide novel findings for clinical research on PD in particular, as well as on neural language function in health and neurodegeneration in general.

## FACTS

### Group members in 2020-2021:

**Key staff:**

- Yury Shtyrov (PI, Professor)
- Andreas Højlund (Assistant Professor)
- Mads Jensen (Assistant Professor)
- Christopher Bailey (PhD, lab engineer)
- Rasha Hyder (PhD student)
- Oskar Hougaard Jefsen (PhD student)
- Marie Louise Holm Møller (MSc student, RA)

**Students and interns:**

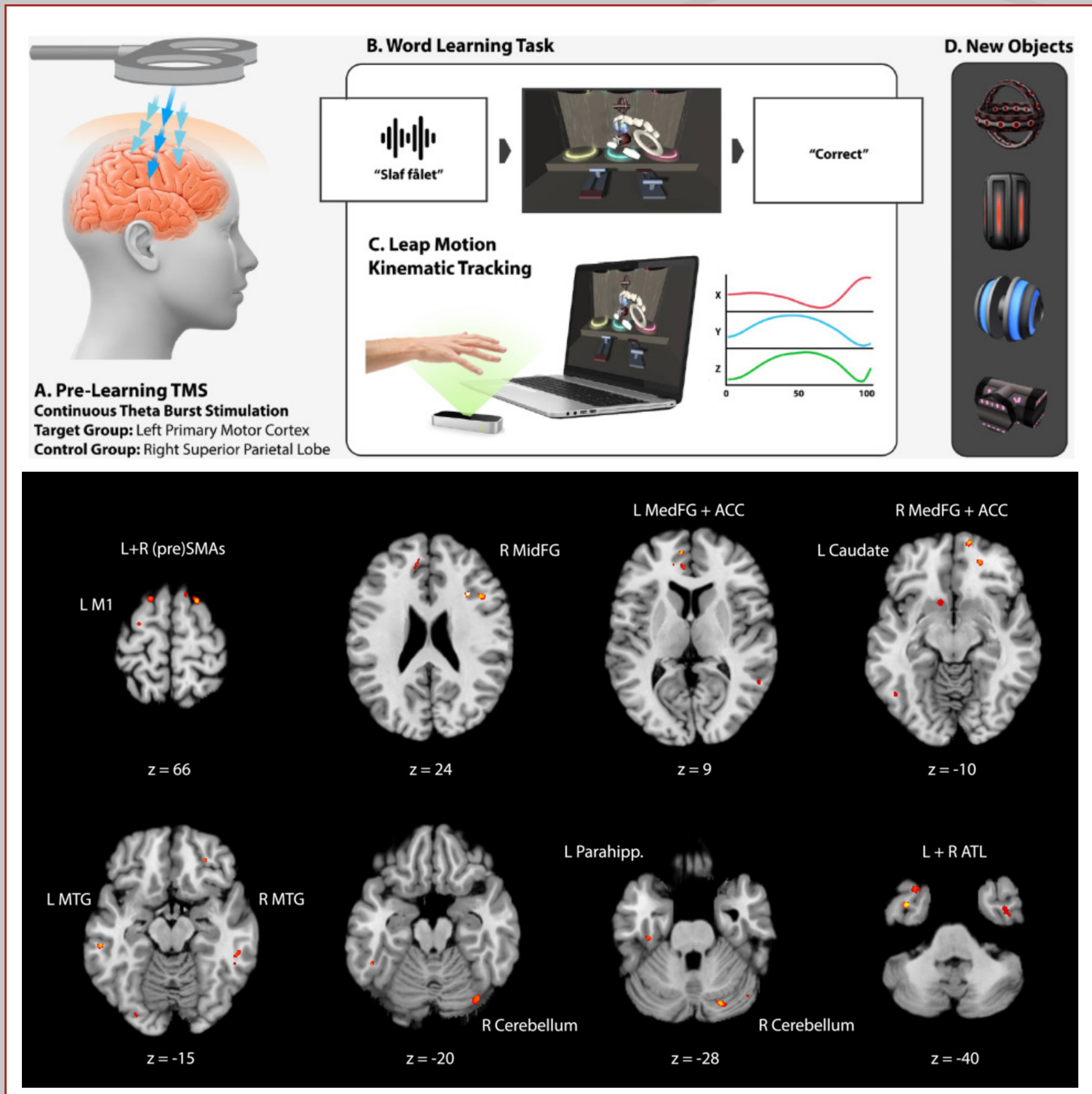
- Solvej Wilbrandt Kjær (BA, Aarhus)
- Jon Lapresa-Serrano (MA, Aarhus)
- Afroditi Ntourountzi (MA, Aarhus)
- Ida Styrbæk Møller (MA, Aarhus)
- Milena Osterloh (BA, Freie Universität Berlin)
- Alberto Furgoni (PhD student, BCBL, San Sebastian)

### International collaborators:

- University of Helsinki, Finland
- Lund University, Sweden
- Northumbria University Newcastle, England
- Freie Universität Berlin
- Cambridge University, England
- University of California San Francisco, USA
- Glasgow University, Scotland
- Ecole Normal Superior, Paris
- HSE University, Moscow
- University of Salamanca, Spain
- Goldsmiths, University of London
- University of Messina, Italy
- and many others

### Supported by grants from:

- Danish Independent Research Council
- European Commission
- Danish Parkinson's Disease Association
- Health Research Foundation of Central Denmark Region
- Lundbeck Foundation
- and others



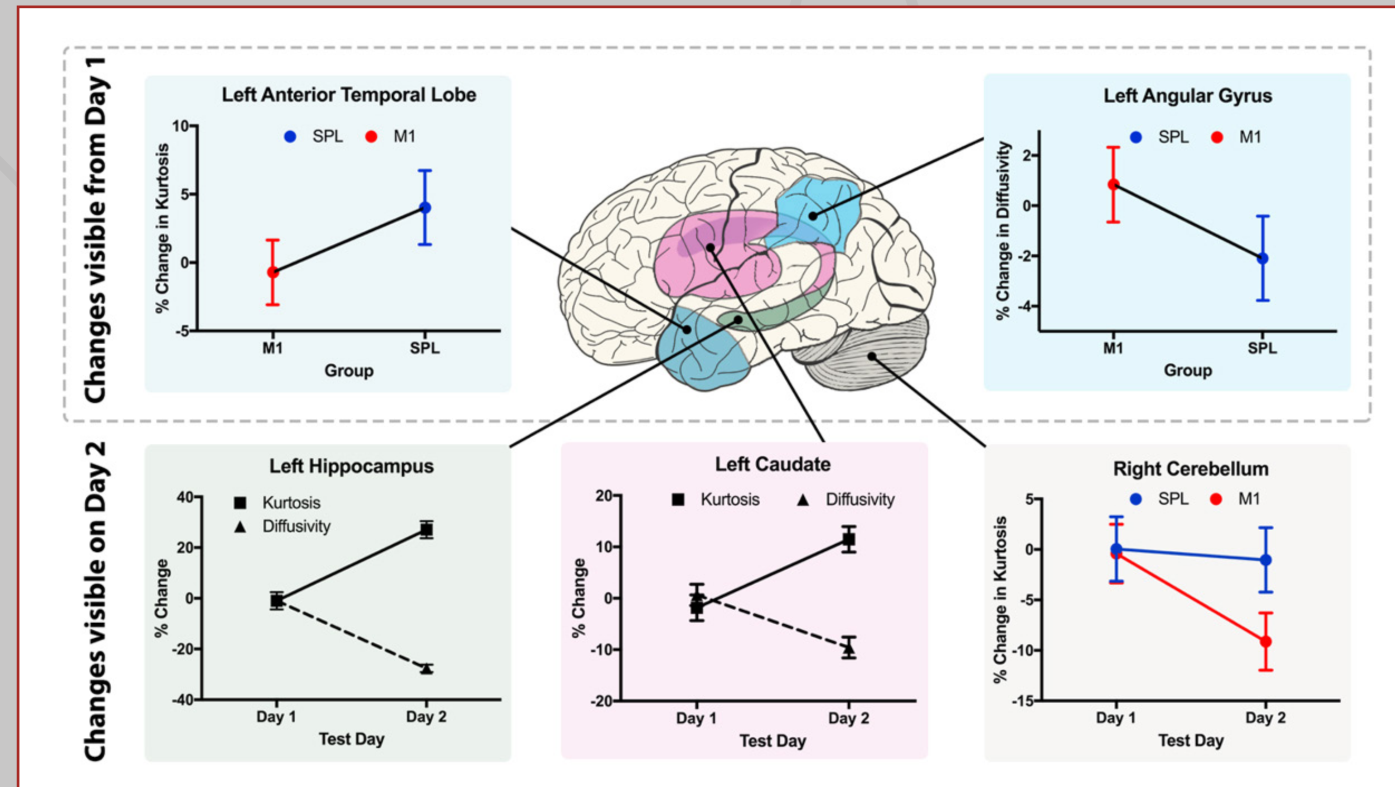




**Figure 2 - page 50 and 51**

Numerous microstructural chances in the brain commencing immediately after a 40 min learning session.

(upper left) Task design: Participants underwent (A) 40 seconds of cTBS over primary motor cortex or a control site, prior to (B) learning new verbs and nouns in a 3D computer game, whilst (C) their learning performance and movement kinematics were tracked. (D) Illustration of the novel 3D objects. All participants received DKI brain scans directly before and after the language task, as well as after 24 hours. Machine-classification analysis indicated (lower left) multiple learning-induced microstructural modifications. Key semantic areas and other brain structures showed both immediate and longer-term structural changes as a result of learning (above).

Vukovic N, Hansen B, Lund TE, Jespersen S, Shtyrov Y (2021) Rapid microstructural plasticity in the cortical semantic network following a short language learning session. PLoS Biology 19(6): e3001290. https://doi.org/10.1371/journal. pbio.3001290

An equally – or perhaps even more important – breakthrough was made in studying the microstructural mechanisms the brain uses for rapidly learning new words. Human skill to quickly and efficiently learn new words, building up huge lexicons of many thousands of words throughout our lifespans, remains a mystery to science. Conventional knowledge maintains that language learning—especially in adulthood—is slow and laborious. Furthermore, its structural basis in the brain remains unclear. Even though behavioural manifestations of learning are evident near-instantly (e.g., we can start using new words immediately), previous neuroimaging work has largely studied slow neural changes associated with months or years of practice.

To overcome this gap, a massive NeDComm project carried out in collaboration with CFIN colleagues at Neurophysics and other groups investigated rapid neuroanatomical plasticity accompanying new lexicon acquisition using a virtual-reality learning environment and a combination of neuroimaging techniques. The results show that it is possible to measure and to externally modulate (using transcranial magnetic stimulation, TMS) cortical microanatomic reorganisation within mere minutes of new word learning. Learning-induced microstructural changes, as measured by diffusion kurtosis imaging (DKI, a novel method for measuring brain microstructure) and assessed using machine learning-based analysis, were evident in a distributed network of brain areas including prefrontal, temporal, and parietal neocortical sites immediately after only a 40-minute learning session. These changes likely reflect integrative lexico-semantic processing and formation of new memory circuits in the brain immediately during the learning tasks. These findings suggest a structural basis for the rapid neocortical word encoding mechanism and reveal the causally interactive relationship of multiple brain regions in supporting learning and word acquisition.