Annual Report 2020

Gravitation Consortium
Language in Interaction

LANGUAGE in INTERACTION

NWO
Netherlands Organisation for Scientific Research

The Language in Interaction consortium gratefully acknowledges the support of the Gravitation Programme of the Netherlands Ministry of Education, Culture and Science (OCW) and the Netherlands Organisation for Scientific Research (NWO).

Language in Interaction Consortium

Human language is the most powerful communication system that evolution has produced. It is the basis of culture and social life. It comes in many forms (> 6000 languages today). At the same time, it is deeply rooted in the neurobiology of the human brain. The overarching quest of our programme is to account for, and understand, the balance between universality and variability at all relevant levels of the language system and the interplay with different cognitive systems, such as memory, action, and cognitive control. To achieve this, Language in Interaction brings together researchers from eight different research institutions in the Netherlands to understand this unique capacity in its full glory.

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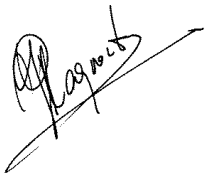
PREFACE

This report contains the highlights of our research in 2020. The report is also available on our website. Due to the COVID-19 pandemic, multiple adaptations were needed to the research plans as originally scheduled. Meetings were held on-line, some of our research was also done on-line. Lab testing could only continue after safety protocols were made or adapted. Despite all these limitations, our research and the intellectual life of the consortium continued as much as possible. In addition, the expertise of the consortium was recruited to optimize communication under conditions of on-line teaching and meetings in the ZOOM-world. We tried to accommodate the consequences of the pandemic for our PhD students and postdocs as much as possible. With the help of the universities and institutes involved in our consortium, we will continue to do so.

Our partnership with NEMO-Kennislink resulted in a new innovative tool for knowledge dissemination, which will be launched in 2021. In addition, we have begun to co-develop new platforms for poster presentations and conference management. As spinoffs, NWA and Horizon Europe proposals are in the phase of preparation, to secure the afterlife of the consortium. I hope you will enjoy reading about the highlights of our Language in Interaction program in 2020.

Prof. dr. Peter Hagoort



Programme Director

THE MANAGEMENT TEAM

Dr. Wendy van Ginkel
Programme Manager

Dr. Esther Steenbeek
Societal Impact Officer

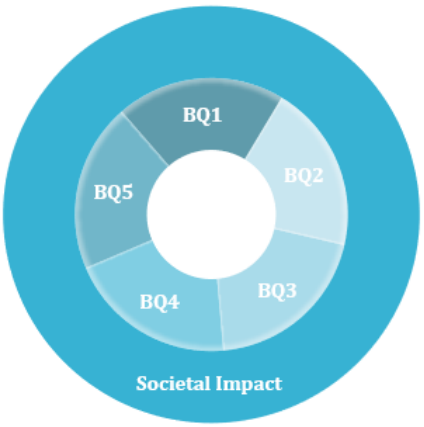
Julia Verhoef
Secretary

Kwan Lee
Project controller

RESEARCH PROGRAMME

THE CONSORTIUM

The Language in Interaction consortium at its core is made up of the five 'Big Questions'. These questions were defined in the second phase of the consortium by integrating the original Work Packages 1 to 5. The Societal Impact work package spans all Big Questions and promotes utilization and societal impact initiatives for all research projects. In 2019, a Synergy Call project was initiated in the LiI Synergy Call.



More information on each Big Question and the Synergy Project can be found on the Language in Interaction website under Research – Big Questions and Research – Projects – Synergy Project.

The five Big Questions are:

BQ1: The nature of the mental lexicon: How to bridge neurobiology and psycholinguistic theory by computational modelling?
BQ2: What are the characteristics and consequences of internal brain organization for language?
BQ3: Creating a shared cognitive space: How is language grounded in and shaped by communicative settings of interacting people?
BQ4: Variability in language processing and in language learning: Why does the ability to learn language change with age? How can we characterise and map individual language skills in relation to the population distribution?
BQ5: The inferential cognitive geometry of language and action planning: Common computations?

COLLABORATIONS BETWEEN THE BIG QUESTIONS

A main motivation behind determining the five big questions was to foster collaboration between researchers in the Language in Interaction consortium. By creating interdisciplinary research teams on topics that intersect, the BQs form the skeleton for the formation of collaborative teams of researchers. Collaborations between the BQ teams have been expanding in 2020, despite the challenging circumstances regarding the COVID-19 pandemic.

2020 IN NUMBERS

The Language in Interaction consortium had a fruitful year in 2020 despite the challenging circumstances. We would like to thank all of the academic and support staff who made this possible.

CONSORTIUM STAFF

31	20	41	8 Partner
PhD Candidates	Postdocs	Professors and PIs	Institutions

CONSORTIUM OUTPUT IN 2020

131	70+	23	11
Scientific Publications*	(Online) Talks and Poster Presentations	Awards and Grants	PhD Defenses

* Please refer to our website for the full list of scientific publications from 2020.

PHD DEFENSES IN 2020

The following 11 PhDs defended their Language in Interaction dissertation in 2020. Congratulations!

Daniel Sharoh

Donders Institute, Radboud University Nijmegen

Advances in layer specific fMRI for the study of language, cognition and directed brain networks

James Trujillo

MPI, Radboud University Nijmegen

Movement speaks for itself: The kinematic and neural dynamics of communicative action and gesture

Jana Thorin

Donders Institute, Radboud University Nijmegen

Can you hear what you cannot say? The interactions of speech perception and production during non-native phoneme learning

Julia Berezutskaya

UMC, University of Utrecht

Data-driven modeling of the neural dynamics underlying language processing

Shruti Ullas

Maastricht University

Lexical and audiovisual bases of perceptual adaptation in speech

Nikki Janssen

Donders Institute, Radboud University Nijmegen

Staying connected as we speak: Behavioral and tractography evidence from health and neurodegenerative disease

Dieuwke Hupkes

ILLC, University of Amsterdam

Hierarchy and interpretability in neural models of language processing

Stephanie Theves

Donders Institute, Radboud University Nijmegen

Mapping conceptual knowledge acquisition in the hippocampal system

Arnold Kochari

ILLC, University of Amsterdam

Perceiving and communicating magnitudes: Behavioral and electrophysiological studies

Joe Rodd

MPI, Radboud University Nijmegen

How speaking fast is like running: Modelling control of speaking rate

Marvin Uhlmann

MPI, Radboud University Nijmegen

Neurobiological models of sentence processing

FINANCES

The following table specifies the budget allocated to the scientific projects in the consortium from start to end of the grant.

Subproject	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Big Question 1	-	-	-	-	115.516	239/148	332.642	331.892	281.469	224.282	42.330	1.567.279
Big Question 2	-	-	-	-	6.931	144.816	195.511	280.777	358.914	121.480	30.000	1.138.428
Big Question 3	-	-	-	-	43.864	256.770	443.771	309.158	286.187	92.849	-	1.432.599
Big Question 4	-	-	-	-	137.649	422.596	710.098	794.825	1.197.827	745.262	70.196	4.078.453
Big Question 5	-	-	-	-	-	-	16.818	287.385	514.349	558.863	323.968	1.701.383
Work Packages	50.013	600.730	1.176.631	1.520.791	1.425.461	1.378.271	477.044	172.704	61.374	-	-	6.863.019
Societal Impact Package	17.862	130.146	156.869	178.723	200.281	195.008	156.203	155.213	146.325	137.281	182.375	1.656.826
Synergy Project	-	-	-	-	-	-	59.663	252.082	312.436	281.123	208.131	1.113.435
Other scientific contracts	89.694	165.513	265.474	487.102	573.517	631.848	562.605	372.037	429.825	220.807	170.512	3.968.934
Total*	**157.569**	**896.389**	**1.598.974**	**2.186.616**	**2.503.759**	**3.268.457**	**2.954.355**	**2.956.073**	**3.588.705**	**2.381.947**	**1.064.613**	**23.520.356**

* The remaining budget is allocated to non-scientific personnel and costs of coordination of meetings (such as consortium meetings, PI meetings, etc.).

BIG QUESTIONS

RESEARCH HIGHLIGHTS

The next sections provide a brief description of the content of each Big Question and updates on the progress and highlights from 2020, including key publications and highlighted awards.

BIG QUESTION 1: THE NATURE OF THE MENTAL LEXICON: HOW TO BRIDGE NEUROBIOLOGY AND PSYCHOLINGUISTIC THEORY BY COMPUTATIONAL MODELLING?

This Big Question addresses how to use computational modelling to link levels of description, from neurons to cognition and behaviour, in understanding the language system. Focus is on the mental lexicon and the aim is to characterize its structure in a way that is precise and meaningful in neurobiological and (psycho)linguistic terms. The overarching goal is to devise causal/explanatory models of the mental lexicon that can explain neural and behavioural data. This will significantly deepen our understanding of the neural, cognitive, and functional properties of the mental lexicon, lexical access, and lexical acquisition.

Progress in 2020

The four BQ1 subprojects proceeded successfully and mostly as planned in the proposal, although progress in two projects was somewhat hampered by their postdocs moving on to faculty positions. Our aim for 2020 was to focus more on integration between the four subprojects. However, because of the challenges and workload in the individual subprojects, it has been difficult to accomplish the integration, in spite of ample ideas and our excellent new coordinating postdoc. In order to strengthen collaborations between subprojects, Marcel van Gerven and Julia Berezutskaya will put together a concrete proposal for applying the Neural Information Flow framework, that was developed in their group, across BQ1.

TEAM MEMBERS

Coordinators and steering group:

Stefan Frank (*coordinator*) Julia Berezutskaya (*coordinating postdoc*)
Marcel van Gerven Hartmut Fitz Jelle Zuidema

PhDs:	Danny Merkx	Alessio Quaresima	Samira Abnar
Other team members:	Karl Magnus Petersson	Peter Hagoort	Jakub Szymanik
	Mirjam Ernestus	Louis ten Bosch	Raquel Fernández
	David Neville	Roel Willems	Umut Güclü
	Luca Ambrogioni	Rens Bod	Lisa Beinborn (*to April 2020*)
Alumni PhDs:	Dieuwke Hupkes	Joe Rodd	Alessandro Lopopolo
	Chara Tsoukala	Marvin Uhlmann	

BIG QUESTION 1: KEY PUBLICATIONS AND AWARD / RESEARCH HIGHLIGHTS

KEY PUBLICATIONS (2020):

1. **Abnar, S.** and **Zuidema, W.** (2020). Quantifying Attention Flow in Transformers. *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics* (pp. 4190–4197). Association for Computational Linguistics. doi: 10.18653/v1/2020.acl-main.385
2. **Beinborn, L.** & Choenni, R. (2020). Semantic drift in multilingual representations. *Computational Linguistics, 46,*
3. **Berezutskaya, J.,** Freudenburg, Z.V., **Ambrogioni, L., Güclü, U., van Gerven, M.A.**, & **Ramsey, N.F.** (2020). Cortical network responses map onto data-driven features that capture visual semantics of movie fragments. *Scientific Reports, 10*(1), 1-21.
4. **Fitz, H.**, **Uhlmann, M.**, van der Broek, D., Duarte, R., **Hagoort, P.**, & **Petersson, K.M.** (2020). Neuronal spike-rate adaptation supports working memory in language processing. *Proceedings of the National Academy of Sciences, 117,* 20881-20889.

AWARD HIGHLIGHTS:

1. **Jelle Zuidema** was awarded a National Research Agenda grant (NWA-ORC), for the project 'InDeep: Interpreting Deep Learning Models for Text and Sound', with 8 co-applicants and 10 partner organizations (companies, not-for-profits). The new project funds 7 PhD positions, 1 postdoc and an extensive public and industrial outreach program (see https://interpretingdl.github.io/projects). It builds in many ways on work carried out as part of Language in Interaction over the last 6 years, including the work by Abnar (BQ1).

BIG QUESTION 1 - HIGHLIGHTS

BQ1 - Highlight 1

Quantifying Attention Flow in Transformers (understanding what's happening inside state-of-the-art models)

Samira Abnar and Jelle Zuidema

Transformers' are the state-of-the-art technology in Natural Language Processing, and also the backbone of models that give the current best predictions of brain activity associated with language processing as measured through ElectroEncephaloGraphy (EEG), Magnetic Resonance Imaging (MRI) or ElectroCorticoGraphy (ECoG). But how do we interpret the internal representations of Transformers? Abnar & Zuidema present two techniques to better analyze and visualize the so-called 'attention network' inside these models.

A Transformer model (in our case GPT2 style, with 24 layers) trained on a large amount of text can predict which word to expect at a masked location in a sentence. In the example, the model strongly predicts "his" at the masked position in the sentence "The author talked to Sara about MASK book" (**Figure 1**, leftmost panel of (a)), presumably because of an expected anaphoric relation with "author" and an unfortunate gender bias. Visualizing raw attention scores (second panel), as was standard in NLP before our paper was published, does not reveal the fact that the model views "author" rather than "Sara" as the likely antecedent.

Our new methods, Attention Rollout (**Figure 1,** third panel) and Attention Flow (**Figure 1,** fourth panel), do this successfully, in this example as well as many others. The paper also discusses limitations, including cases (**Figure 1** (b)) where the two methods disagree.

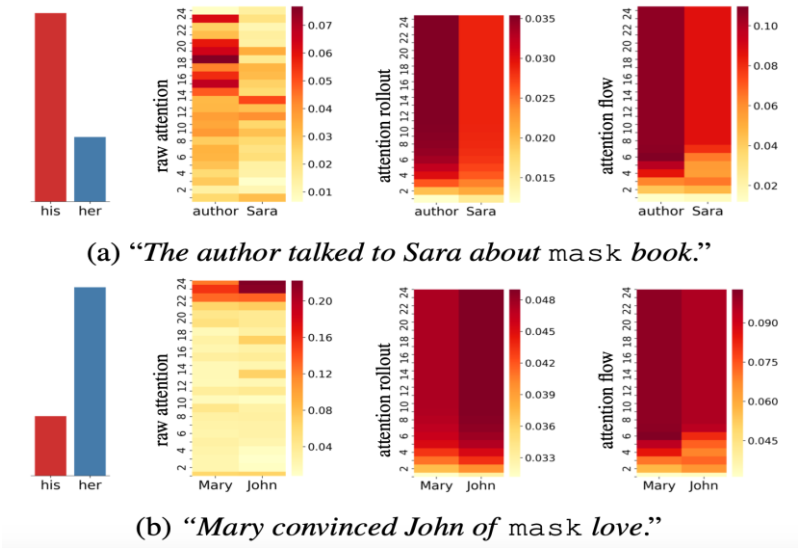


Figure 1. *Predictions made by the Transformer model.*

The paper brings together insights from various branches of computer science, Artificial Intelligence (AI) and cognitive neuroscience, to propose two simple but useful algorithms for interpreting deep learning models in Natural Language Processing (NLP). These models are state-of-the-art for predicting brain imaging data; by making them more interpretable, this work helps getting closer to understanding the neurobiological basis of language processing.

This work builds on much earlier work in Big Question 1, showing the promise of Transformer models (Merkx & Frank; Abnar, Beinborn & Zuidema) and studying ways of interpreting deep learning models (Hupkes & Zuidema).

BQ1 - Highlight 2

Towards naturalistic speech decoding from brain data
Julia Berezutskaya, Nick Ramsey, and Marcel van Gerven

Speech decoding from the brain activity can enable development of brain-computer interfaces (BCI) to restore naturalistic communication in paralyzed patients. In this study we describe a novel approach to speech decoding that relies on a Generative Adversarial Neural Network (GAN) to generate speech based on the neural activity. We used the novel approach to obtain sound reconstructions from the intracranial neural data recorded during a speech listening task and compared them to several simpler speech decoding baselines.

In this project we propose and validate a new speech decoding scheme based on Generative Adversarial Neural Networks (GANs). We used a publicly available dataset of spoken speech to train a GAN. Then, using an intracranial brain dataset we trained a decoder network to predict latent vectors, which were input to the GAN generator. The GAN's generator was used to reconstruct speech spectrograms that were synthesized into speech using an external vocoder. We showed that the GAN-based model (GAN-Z) achieved the best decoding accuracy in terms of recovering high-level sound properties and perceptual quality of sound (see **Table 1** and **Figure 2**). This was in contrast to baseline models (Vanilla and GAN-D) that were trained to decode speech spectrograms directly.

Table 1. *Comparison of three neural decoders with respect to correlation to log-mel frequency values, correct voice activity detection (VAD) and pitch correlation in predictions and target spectrograms. Median and median absolute deviation are reported.*

Model	Mel freq	VAD	Pitch
Vanilla	$.29 \pm .14$	$.62 \pm .11$	$.05 \pm .09$
GAN-D	$.26 \pm .14$	$.61 \pm .11$	$.23 \pm .24$
GAN-Z	$.23 \pm .15$	$.73 \pm .1$	$.21 \pm .27$

These results demonstrate the potential of GAN-based models to advance the BCI field and make continuous speech decoding from the brain in naturalistic noisy environments more plausible.

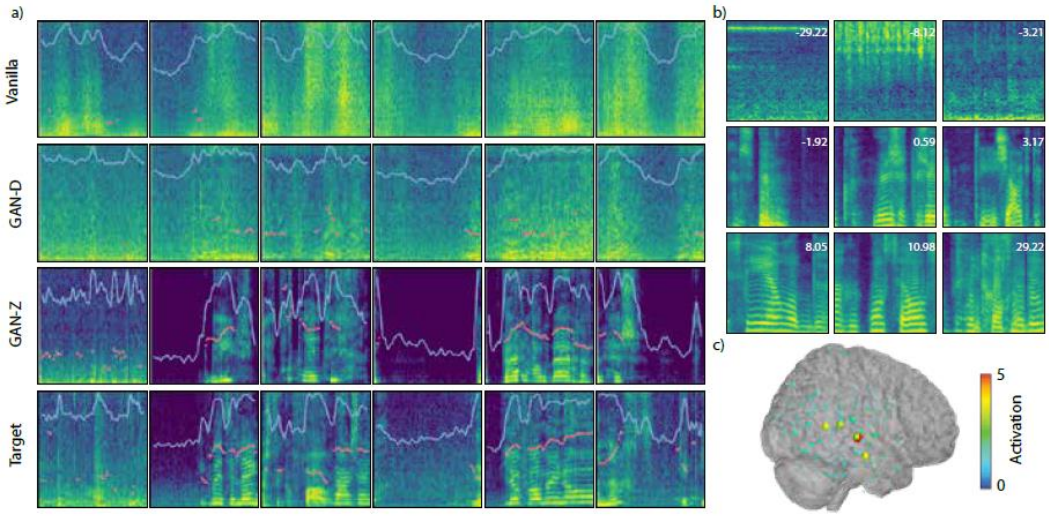


Figure 2. *a) Examples of sound reconstructions. Sound intensity is shown in white and pitch is shown in red. b) "Voice" gradient in the latent space, "voice" score is reported per image on top right. c) Brain activity map associated with high "voice" scores in the spectrogram, averaged over a batch of 128 examples.*

The present study is among the first attempts to leverage advances in automatic sound generation with GANs for reconstructing naturalistic continuous speech from brain recordings. These results demonstrate the potential of GAN-based models to advance the BCI field and make continuous speech decoding from the brain in naturalistic noisy environments more plausible.

BIG QUESTION 2: WHAT ARE THE CHARACTERISTICS AND CONSEQUENCES OF INTERNAL BRAIN ORGANIZATION FOR LANGUAGE?

This Big Question addresses the internal organization of the brain. The human brain provides a neurobiological infrastructure that allows us to acquire and process language, and that co-determines the characteristics of spoken (and sign) and written language. The internal organization of the brain and its cognitive architecture both determine and constrain the space of possibilities for human language. This internal organization can be called the Kantian brain for language. It has resulted in a language-readiness of the human brain that is found nowhere else in the animal kingdom.

Progress in 2020

During 2020, BQ2 completed the final combination of the across sub-project meetings and identified an additional collaborative project. This project investigates how the brain's structural connectome might constrain the rate at which signals may travel between brain regions as measured in MagnetoEncephaloGraphy (MEG) evoked responses. We moved on to define a topic area that the team agreed would be of interest to most of us, namely the role of subcortical brain structures in the timing of language-related processes. This has led to a series of meetings around the topic and the plan is to eventually host a workshop based on these ideas.

TEAM MEMBERS

Coordinators and steering group: Peter Hagoort (*coordinator*) Ashley Lewis (*coordinating postdoc*)

PhDs:	João Ferreira	Ileana Camerino	Guilherme Blazquez Freches
Other team members:	Christian Beckmann	Simon Fisher	Nick Ramsey
	Roy Kessels	Elia Formisano	Clyde Francks
	Floris de Lange	Joanna Sierpowska	Rogier Mars
	Vitória Piai	Ardi Roelofs	Jan Mathijs Schoffelen
	Tineke Snijders	Ivan Toni	Xiangzhen Kong
	Zhigiang Sha	Maggie Wong	
Alumni PhDs:	Daniel Sharoh	Nikki Janssen	

KEY PUBLICATIONS (2020):

1. **Ferreira, J., Roelofs. A.,** & **Piai, V.** (2020). The role of domain-general inhibition in inflectional encoding: Producing the past tense. *Cognition, 200,* 104235.
2. Kong, X. Z., Tzourio-Mazoyer, N., Joliot, M., Fedorenko, E., Liu, J., **Fisher, S. E.,** & **Francks, C.** (2020). Gene expression correlates of the cortical network underlying sentence processing. *Neurobiology of Language, 1*(1), 77-103.
3. **Lewis, A. G.** (2020). Balancing exogenous and endogenous cortical rhythms for speech and language requires a lot of entraining: a commentary on Meyer, Sun & Martin (2020*). Language, Cognition and Neuroscience, 35*(9), 1133-1137.
4. **Freches, G. B.**, Haak, K. V., Bryant, K. L., Schurz, M., **Beckmann, C. F.**, & **Mars, R. B.** (2020). Principles of temporal association cortex organisation as revealed by connectivity gradients. *Brain Structure and Function,* 1-16.
5. **Janssen, N.**, **Roelofs, A.**, **Mangnus, M.**, **Sierpowska, J.**, Kessels, R. P. C., & **Piai, V.** (2020). How the speed of word finding depends on ventral tract integrity in primary progressive aphasia. *NeuroImage: Clinical, 28*, 102450.

BIG QUESTION 2: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. **Christian Beckmann** was awarded a VICI grant from the Netherlands Organization for Scientific Research (NWO).
2. **Vitória Piai** received an Early Career Award from the International Neuropsychological Society.

BIG QUESTION 2 - HIGHLIGHTS

BQ2 - Highlight 1

How the speed of word finding depends on ventral tract integrity in primary progressive aphasia

Nikki Janssen, Ardi Roelofs, Margot Mangnus, Joanna Sierpowska, Roy Kessels, and Vitória Piai

This study explored the extent to which word finding difficulty in Primary Progressive Aphasia (PPA) may be linked to altered integrity of white matter tracts ventral to the sylvian fissure in the human brain. It used picture-word interference (PWI) to emulate contextual noise, and computer simulations based on the WEAVER++ model of word finding to relate the neural results to (disrupted) behaviour. Mixed-effects modelling was performed on naming accuracy and reaction time (RT) data, and fixel-based tractography analyses were conducted to assess the relation between ventral white-matter integrity and naming performance (see **Figure 3**). As expected, naming RTs were longer for individuals with PPA compared to controls and, critically, individuals with PPA showed a larger noise effect. Moreover, the noise effect in control participants did not depend on tract integrity, whereas in individuals with PPA a decreased tract integrity was related to a *reduced* noise effect. Computer simulations supported an explanation of this paradoxical finding in terms of reduced propagation of noise when tract integrity is low.

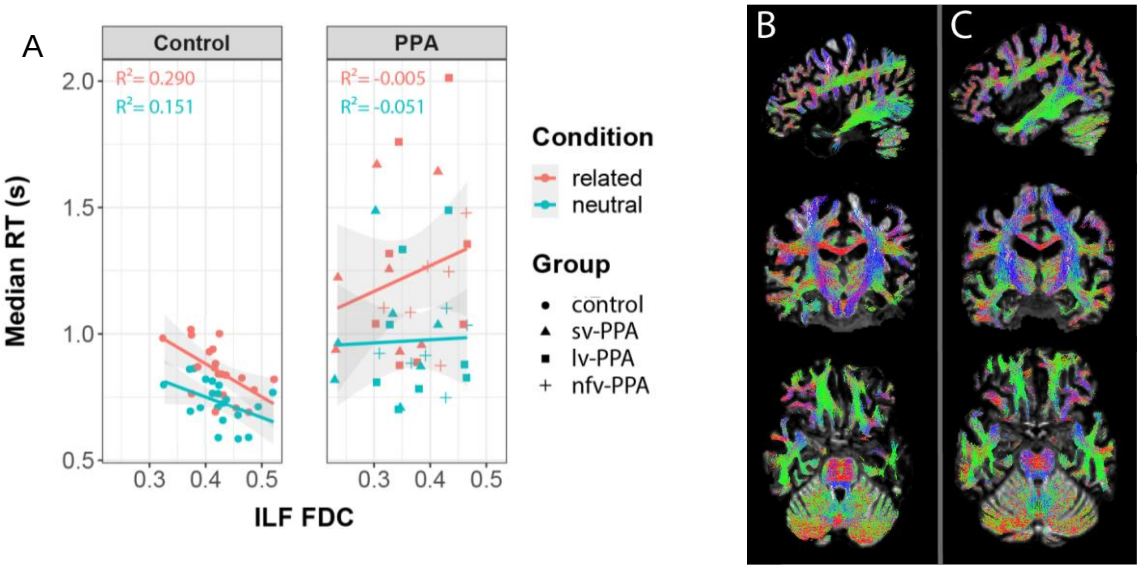


Figure 3. *(A) Fibre density and cross-section (FDC) and reaction time per group per condition for the inferior longitudinal fasciculus (ILF). Each dot corresponds to a participant. Lines depict the best-fitting linear regression line to the data and shaded areas indicate 95% CI. RT = response time. (B) Whole-brain tractogram of a PPA patient. (C) Whole-brain tractogram of a cognitively unimpaired control participant.*

By using multimodal analyses, this study indicates the significance of the ventral pathway for naming, and the importance of RT measurement in the clinical assessment of PPA. It also used

computational modelling to probe, and strengthen some of the counterintuitive relationships observed between white matter integrity and naming latency in PPA individuals. A key insight is that when it comes to the quality of information transmission in the brain, the motto 'more is better' is too simplistic to adequately account for the relationship between anatomical connectivity and behavioural performance. This project would not have been possible without a combination of clinical expertise, and expertise in neuroimaging, white matter neuroanatomy, speech production, and computational modelling. The LiI consortium offers unique opportunities for such wide-ranging collaborations.

BQ2 - Highlight 2

Gene expression correlates of the cortical network underlying sentence processing

Xiang-Zhen Kong, Simon E. Fisher, and Clyde Francks

A key question in modern neuroscience is which genes regulate brain circuits that underlie cognitive functions. To shed light on the molecular architecture underpinning language circuits, in this project we aim to combine functional brain imaging data from living individuals with gene transcription profiles from post mortem tissue samples from specific brain regions (**Figure 4**).

In our first study of this project (Kong et al. 2020), we revealed reliable gene expression-functional network correlations using three different definition strategies for the sentence processing network, and identified a consensus set of genes related to connectivity within this network. The genes involved showed enrichment for neural development and actin-related functions, as well as association signals with autism, which can involve disrupted language functioning. Our findings help elucidate the molecular basis of the brain's infrastructure for language, as distinct from functional networks important for other aspects of cognition.

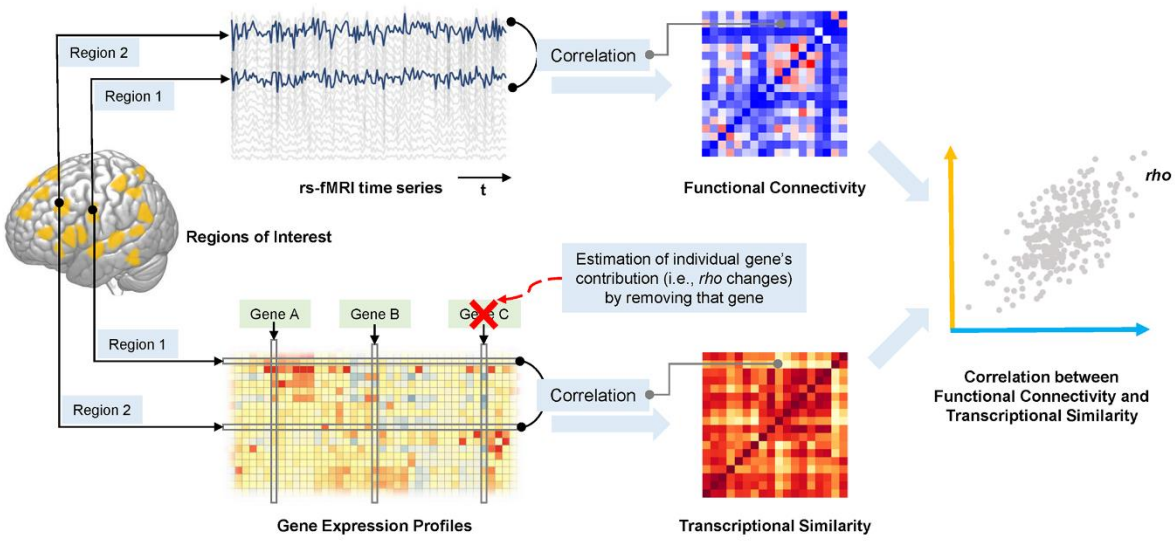


Figure 4. *Schematic of the pipeline for computing the correlation between resting-state functional connectivity and transcriptomic similarity, within a network of regions first defined according to task fMRI data.*

This project involves the synergy of cognitive neuroscience, brain imaging and genomic data. To our knowledge, we reported the first evidence for a link between gene transcription profiles and language networks. This has contributed to a multi-level understanding of the brain's infrastructure for language. Due to its interdisciplinary nature, this project requires complementary expertise from cognitive neuroscience, neuroimaging, bioinformatics, genomics, post mortem anatomy and histology. Collaboration and team science are therefore 'baked in' to the study concept and execution.

BIG QUESTION 3: CREATING A SHARED COGNITIVE SPACE

How is language grounded in and shaped by communicative settings of interacting people?

This Big Question considers the influence of two different dimensions over multiple communicative resources (speech and gestures) and linguistic structures (from phonology to pragmatics), namely: the temporal structure of communicative interactions and the functional dynamics of real-life communicative interactions. Language is a key socio-cognitive human function predominantly used in interaction. Yet, linguistics and cognitive neuroscience have largely focused on individuals' coding-decoding signals according to their structural dependencies. Understanding the communicative use of language requires shifting the focus of investigation to the mechanisms used by interlocutors to share a conceptual space.

Progress in 2020

There is deep collaboration between all BQ3 subprojects. The qualitative results that follow from our simulation studies will be related to the empirical findings from the other subprojects and vice versa, the empirical observations from the other subprojects will inspire the qualitative hypotheses to be tested. The computational simulations allow us to test for qualitative differences in interactive behaviour by manipulating the cognitive capacities of the agents—something that is difficult to do with human test subjects—while simultaneously leading to explicit theories of computational mechanisms. Those theories are then used to guide the quantification and analyses of the dialogue observations.

TEAM MEMBERS

Coordinators and steering group: Ivan Toni (*coordinator*) Mark Blokpoel (*coordinating postdoc*)

PhDs:	Lotte Eijk	Marlou Rasenberg	
Other team members:	Sara Bögels	Mark Dingemanse	Christian Doeller
	Mirjam Ernestus	Judith Holler	Stephen Levinson
	Branka Milivojevic	Asli Özyurek	Iris van Rooij
	Herbert Schriefers	Rui Liu	Laura van de Braak
	Wim Pouw	Flavia Arnese	Marieke Woensdregt
Alumni PhDs:	Linda Drijvers	James Trujillo	

KEY PUBLICATIONS (2020):

1. **Rasenberg, M.**, **Özyurek, A.**, & **Dingemanse, M.** (2020). Alignment in Multimodal Interaction: An Integrative Framework. *Cognitive Science, 44*(11):e12911.
2. **Stolk, A., Bašnáková, J.**, & **Toni, I.** (2020). *Joint epistemic engineering: The neglected process of context construction in human communication.* In: Routledge Handbook of Neurosemiotics (Editors: Ibanez A., Saravia, SS.)
3. **van Rooij, I.**, & **Blokpoel, M.** (2020). Formalizing verbal theories: A tutorial by dialogue. *Social Psychology, 51,* 285-2984.
4. Van Arkel, J., **Woensdregt, M., Dingemanse, M.**, & **Blokpoel, M.** (2020, October). A simple repair mechanism can alleviate computational demands of pragmatic reasoning: simulations and complexity analysis. *In the 24th (Virtual) Conference on Computational Natural Language Learning (CoNLL 2020)* (pp. 177-194). The Association for Computational Linguistics.
5. **Dingemanse, M.** (2020). Resource-rationality beyond individual minds: the case of interactive language use. *Behavioral and Brain Sciences, 43*, 23–24.

BIG QUESTION 3: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. **Iris van Rooij** (1) won the 2020/2021 Distinguished Lorentz Fellowship & Prize, and (2) acquired a Donders Centre for Cognition PhD Grant (co-supervised with Johan Kwisthout) (2020) 'How to grow an internal model: A toolbox for the computational modeler.'
2. **Mark Dingemanse** (1) was awarded the Heineken Young Scientist Award om Humanities by the Royal Netherlands Academy of Sciences, (2) was awarded the Radboud Science Award together with Tessa van Leeuwen for their long-running collaboration on language, perception, and synesthesia, (3) was elected to the inaugural cohort of the Radboud Young Academy, and (4) received a Hong Kong University General Research Fund grant in collaboration with co-PI Youngah for a 2-year postdoc on word learning and iconicity.
3. **Wim Pouw** was awarded a NWO VENI grant entitled 'Social Resonance: How biomechanical constraints solve multimodal challenges in human communication'.

BIG QUESTION 3 - HIGHLIGHTS

BQ 3 - Highlight 1

Computational challenges in explaining communication

Laura van de Braak, Mark Dingemanse, Ivan Toni, Iris van Rooij, and Mark Blokpoel

When people are unsure of the intended meaning of a word, they often ask for clarification. One way of doing so—often assumed in models of communication—is to point at a potential target: "Do you mean [points at the rabbit]?" However, what if the target is unavailable? Then the only recourse is language itself, which seems equivalent to pulling oneself up from a swamp by one's hair. We created two computational models of communication, one able to point (**Figure 5**, orange) and one not (**Figure 5**, blue). The latter incorporates additional sophisticated inference to resolve the meaning of non-pointing signals.

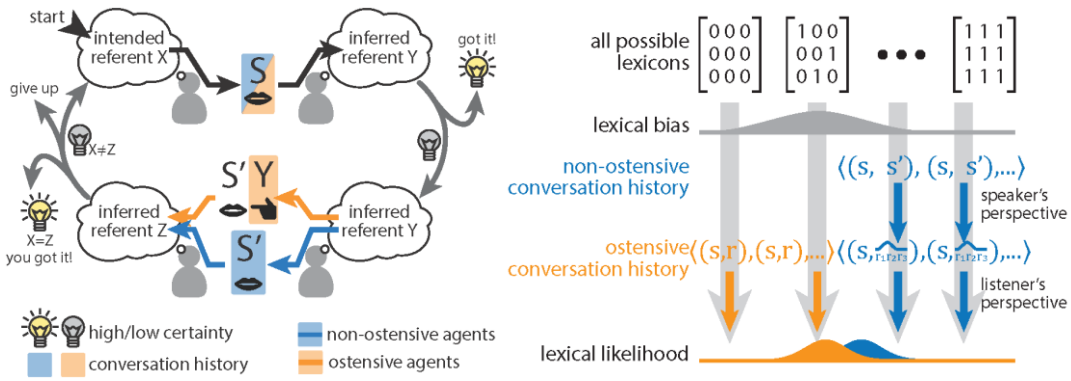


Figure 5. *Left: Structure for ostensive (orange) and non-ostensive (blue) dialogue for one intended referent X. Black, orange and blue arrows denote input-output of information. Gray arrows denote agents' decisions for continuing or ending the dialogue. Agents remember all turns and take this into account for future inferences. The key difference is that ostensive agents base future inferences on the ostensively declared referent Y (orange rectangle) whereas the non-ostensive agents base future inferences on a verbal signal S' (blue rectangle). The initiator infers referent Z from S' to determine whether they think that the responder understands them. Right: The inference mechanisms driving both models. Agents compute a probability distribution over all possible lexicons given their lexical bias and the dialogue history to attempt to infer a common lexicon. Non-ostensive agents (blue) require additional inference to infer the meaning of clarification requests s', whereas ostensive agents (orange) get unambiguous feedback r.*

The simulation results confirm that ostensive agents can achieve factual understanding, and they underscore the difficulty of computationally explaining non-ostensive communication. Without referentially clear signals, non-ostensive agents have no way of knowing when their inferences are factually correct and understand each other only at chance level (see also **Figure 6)**. The challenge is clear: Without direct feedback, what computational infrastructure allows communicators to attain sufficient meta-understanding about their state of factual understanding? Given that the model presented here is not lacking in inferential capacity, it seems that more reasoning of the same kind is not the right answer. Computational theories of communication need to be expanded with a different kind of reasoning, one that explains how people can use context, background knowledge and other semiotic resources to attain sufficient meta-understanding.

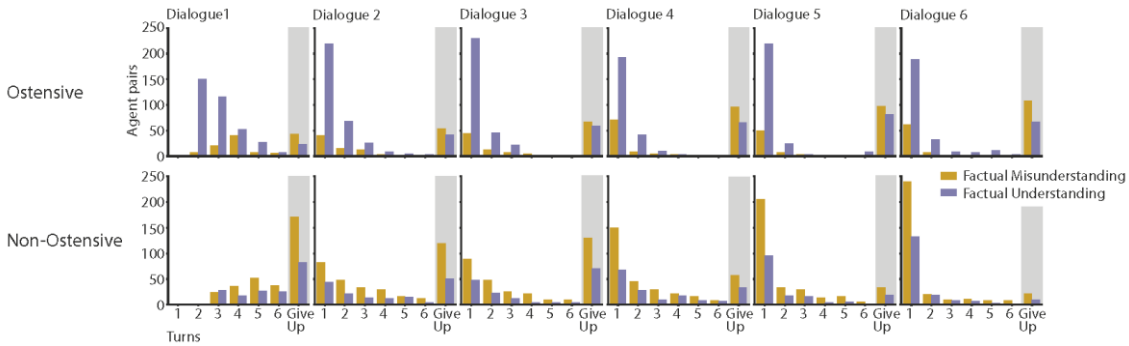


Figure 6. *Structure of dialogue progression for ostensive (above) and non-ostensive agents (below). Conversation progresses from left to right. Each graph shows for the i^{th} dialogue the distribution of agent pairs over the repair sequence length. The rightmost bars in each graph shows how many agent pairs gave up in that dialogue and the colors indicate factual understanding.*

This framework guides the integration of intuitive theories from the subprojects in BQ3 in a unified, formal theoretical framework, which is instrumental to BQ3's interdisciplinary goal. The project and its team members have proven to be highly successful in translating difficult computational notions to non-expert collaborators. Through focus sessions, it has been the foundation of BQ3 internal collaboration, giving the team members a common language to speak.

BIG QUESTION 4: VARIABILITY IN LANGUAGE PROCESSING AND IN LANGUAGE LEARNING

This Big Question aims at characterizing variation in language processing and learning skills and at relating variation at the behavioural level to variation in the underlying neurobiology and genetics of individuals. The BQ has two strands: Strand A focuses on language processing skills in young adults, and Strand B on language learning skills in children and adults.

Progress in 2020

Strand A has developed a comprehensive battery of tests targeting 1) linguistic knowledge, 2) general cognitive skills, and 3) language processing skills (word comprehension and production, sentence comprehension and production). Seven-hundred individuals between 18 and 30 years of age will complete the battery. Due to limitations in testing capacity connected to the Covid-19 pandemic, the originally planned number of 1000 participants had to be adjusted to 700.

Strand B investigates variability in individuals' learning ability, focusing on why second-language (L2) acquisition typically becomes harder in adulthood. Strand B focuses on two aspects of foreign language learning: grammar and vocabulary acquisition.

TEAM MEMBERS

Coordinators and steering group: Antje Meyer (*coordinator 4A*), James McQueen (*coordinator 4B)* Florian Hintz (*coordinating postdoc 4A*), Willeke Menks (*coordinating postdoc 4B*)

PhDs:	Lisette Jager	Merel Burgering	Christina Isakoglou
	Lot Snijders Blok		
Other team members:	Christian Beckmann	Jan Buitelaar	Anne Cutler
	Jelle de Boer	Kristin Lemhöfer	Guillén Fernandez
	Simon Fisher	Clyde Francks	Barbara Franke
	Peter Hagoort	Esther Janse	Gabriele Janzen
	Suzanne Jongman	Bob Kapteijns	Roy Kessels
	Roy Kessels	Robert van Dongen	Beate St Pourcain
	Julia Udden	Jean Vroomen	Marjolijn Dijkhuis
	Clara Ekerdt	Vera van 't Hoff	Evan Kidd
	Xin Liu	Andre Marquand	Olha Shkaravska
	Atsuko Takashima	Carlo Rooth	

KEY PUBLICATIONS (2020):

1. Donnelly, S., & **Kidd, E.** (2020). Individual differences in lexical processing efficiency and vocabulary in toddlers: A longitudinal investigation. *Journal of Experimental Child Psychology, 192*: 104781.
2. **Hintz, F.**, **Dijkhuis, M.**, **van't Hoff, V.**, **McQueen, J. M.**, & **Meyer, A. S.** (2020). A behavioural dataset for studying individual differences in language skills. *Scientific data, 7*(1), 1-18.2.
3. Kia, S. M., Huijsdens, H., Dinga, R., Wolfers, T., Mennes, M., Andreassen, O. A., ... & **Marquand, A. F.** (2020, October). Hierarchical Bayesian Regression for Multi-Site Normative Modeling of Neuroimaging Data. In *International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 699-709). Springer, Cham.
4. **Takashima, A.,** Konopka, A., **Meyer, A.**, **Hagoort, P.**, & Weber, K. (2020). Speaking in the brain: The interaction between words and syntax in sentence production. *Journal of cognitive neuroscience, 32*(8), 1466-1483.

BIG QUESTION 4: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. **Anne Cutler** (1) was awarded a Silver Medal in Speech Communication from the Acoustic Society of America, and (2) was elected Corresponding Fellow by The British Academy.
2. **Evan Kidd** was part of a documentary that won an international Emmy award.
3. **Andre Marquand** received an ERC consolidator grant and (2) was part of a team of authors who received a 'best paper' award for the paper 'Hierarchical Bayesian Regression for Multi-Site Normative Modeling of Neuroimaging Data' at the International Conference on Medical Image Computing and Computer-Assisted Intervention.

BIG QUESTION 4 - HIGHLIGHTS

BQ4 - Highlight 1

An open-access data source for exploring individual differences in language skills and general cognitive abilities.

Florian Hintz, Marjolijn Dijkhuis, Vera van 't Hoff, James McQueen, and Antje Meyer

Although most people learn to speak their mother tongue fluently, native speakers differ in their ability to use language. Adult language users not only differ in the number of words they know, they also differ in how quickly they produce and understand words and sentences. How do individuals differ across language tasks? Are individual differences in language ability related to general cognitive abilities?

Addressing such questions requires testing large numbers of individuals on a large number of language and cognitive tests (as opposed to focussing on a specific aspect or domain, e.g. vocabulary knowledge). Since individual-differences studies are often expensive and labour-intensive, few labs can conduct them. BQ4's Individual Differences in Language Skills (IDLaS) test battery was designed to facilitate individual-differences research. We recently assessed the quality of the test battery (including tests measuring linguistic knowledge, general cognitive skills, and linguistic processing abilities, see **Figure 7**) in a group of 112 individuals in a large-scale pilot study. Next, to test-retest reliability and measures of data distribution, we assessed the feasibility of asking participants to complete four hours of behavioural tests. The majority of the tests proved to be reliable and suitable for the *IndividuLa* main study, which is currently ongoing.

Figure 7. *Summary of the Language in Interaction test battery.*

We made the entire dataset from our large-scale pilot study available, including raw as well as pre-processed data, as an open-access data resource (here). Our goal is to encourage interested researchers to perform exploratory or targeted analyses on the relationships between language and/or more general cognitive abilities by providing the data for free.

We hope that this unprecedented resource will be of interest for many researchers and potentially inspire new research programs. Making this resource available will contribute to disseminating the work carried out in BQ4.

BQ4 - Highlight 2

A new adaptive test for assessing receptive vocabulary

Florian Hintz, Marc Brysbaert (Ghent University), James McQueen, and Antje Meyer

This work was concerned with developing a new receptive vocabulary test for Dutch and, at later stages, for other languages. Using Dutch prevalence norms for more than 54.000 words from an earlier study that specify to which extent a word is known by the public, we devised an adaptive test that measures how many words an individual knows (see **Figure 8** for a screenshot of the website created for this project).

Many of the existing tests measuring receptive vocabulary size involve other skills not connected to vocabulary, such as picture processing (in case of picture-word verification tasks) or sentence processing (in the case definition tasks). Moreover, irrespective of their performance on the test, participants often have to respond to all items, which can lead to the test being too easy or too difficult for some participants. Here, we developed a test that (1) minimizes the involvement of non-relevant skills as much as possible by presenting participants with a written word asking them a simple yes/no question (i.e., 'Do you know that word?') and (2) adapts to the performance level of the participant by means of a staircase procedure. The test is included in the BQ4 test battery and part of the main study. The development of a Hungarian version is underway. The development of English and German versions is planned for the future.

Stairs4Words overcomes some of the limitations of extant vocabulary tests; it is easy and quick to do. The test may be used for research, but also clinical and educational purposes. To develop the test, we collaborated with Marc Brysbaert from Ghent University, who had previously collected the prevalence norms. His expertise and his familiarity with the prevalence norms were vital for the project.

Figure 8. *Screenshot of the Stairs4Words website.*

BIG QUESTION 5: THE INFERENTIAL GEOMETRY OF LANGUAGE AND ACTION PLANNING: COMMON COMPUTATIONS?

The efficiency and flexibility with which humans generate meaning during language comprehension (or production) is remarkable. How does our brain do it? To move beyond the many extant attempts to address this big quest, BQ5 will treat linguistic inference as an instance of an advanced generative planning solution to the multi-step, sequential choice problems that we also face in other cognitive domains (e.g. chess, foraging and spatial navigation). Thus BQ5 anticipates to make unique progress in unravelling the mechanisms of fast, flexible and generative linguistic inference by leveraging recent major advances in our understanding of the representations and computations necessary for sequential model-based action planning. This approach will also lead us to revise current dual-system dogma's in non-linguistic domains, that have commonly over-focused on the contrast between a cognitive (flexible, but slow) and a habitual (fast, but inflexible) system: The current quest will encourage the integration of so-called 'cognitive habits' and their associated cognitive map-related neural mechanisms into theoretical models of both linguistic and non-linguistic inference.

Progress in 2020

In 2020, three new postdocs and one PhD student joined BQ5, completing the BQ5 team. The team organized various BQ5-wide meetings on the joint overarching goals. In addition, BQ5 have set up a Team Code (incl. an Authorship Guideline) to increase the efficiency, efficacy and transparency of BQ5 team work. BQ5 has also initiated a journal club to discuss relevant literature on (linguistic) inference, cognitive map-based decision making and generative planning etc.

TEAM MEMBERS

Coordinators and steering group:

Roshan Cools (*coordinator*) Andrea Martin (*coordinator*)
Xiaochen Zheng (*coordinating postdoc*)

PhDs: Elena Mainetto

Other team members:

Branka Milivojevic	Rene Terporten	Roel Willems
Bob van Tiel	Hanneke den Ouden	Saskia Haegens
Iris van Rooij	Mark Blokpoel	Mona Garvert
Monique Flecken	Ashley Lewis	Stefan Frank
Naomi de Haas	Peter Hagoort	Yingying Tan
Ivan Toni	Ioanna Zioga	

KEY PUBLICATIONS (2020):

1. Baas, M., Boot, N., van Gaal, S., De Dreu, C. K., & **Cools, R.** (2020). Methylphenidate does not affect convergent and divergent creative processes in healthy adults. *Neuroimage, 205*, 116279.
2. Kwisthout, J. & **van Rooij, I.** (2020). Computational resource demands of a predictive Bayesian brain. *Computational Brain & Behaviour, 3*, 174–188.
3. Martin, A. E. (2020). A compositional neural architecture for language. *Journal of Cognitive Neuroscience, 32*(8), 1407-1427.
4. **Willems, R. M.**, Nastase, S. & **Milivojevic, B.** (2020). Narratives for Neuroscience. *Trends Neuroscience. 43*(5), 271-273.
5. Westbrook, A., van den Bosch, R., Määttä, J. I., Hofmans, L., Papadopetraki, D., **Cools, R***., & Frank, M. J.* (2020). Dopamine promotes cognitive effort by biasing the benefits versus costs of cognitive work. *Science, 367*(6484), 1362-1366.

BIG QUESTION 5: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. **Roel Willems** (1) was awarded a Radboud Excellence Initiative visiting scholar grant, (2) was awarded an ERC ITN Grant ELIT: Empirical Study of Literature Innovative Training Network, and (3) received a festival award at the DRONGO language festival.
2. **Iris van Rooij** (1) was awarded the 2020/2021 Distinguished Lorentz Fellowship & Prize at the Netherlands Institute for Advanced Study in the Humanities and Social Sciences (NIAS), and (2) was awarded a Donders Centre for Cognition PhD Grant (co-supervised with Johan Kwisthout) entitled 'How to grow an internal model: A toolbox for the computational modeler'.
3. **Andrea Martin** was awarded a Max Planck Independent Research Group entitled 'Language and Computation in Neural Systems'.

BIG QUESTION 5 - HIGHLIGHTS

BQ 5 - Highlight 1

Isolating representations of word meaning

Elena Mainetto, Xiaochen Zheng, Hanneke den Ouden, Mona Garvert, Naomi de Haas, Andrea E. Martin, and Roshan Cools (in collaboration with Stefan Frank and Danny Merkx from BQ1)

In this pilot experiment, we test the hypothesis that humans represent word meaning in a manner that is dependent on sentence context and independent of word form. We conducted a pilot study (n=32) and will follow it up with a large sample replication (n = 118). Subjects learned to associate symbols with homonyms' meanings that can be derived from a meaning-constraining sentence. Next, subjects were tested in a set of tasks, including a repetition priming task where they performed orientation discrimination judgments on a sequence of the trained symbols.

Linear mixed effect modeling of RTs revealed a trend in the expected direction of the key meaning repetition factor (estimate= -2.032, std=1.052, p=0.0552) (see **Figure 9**). Thus reaction times are faster when the same meaning of a homonym word is consecutively elicited by a symbol, compared with when different meanings of the same homonym word are consecutively elicited. We will replicate this effect with a powered study.

This study is performed by an interdisciplinary team comprising three areas of specialization: language, relational mapping and model-based planning. The team aims at advancing research on whether generative meaning inference relies on computations analogous to those implied in generative action planning known to operate on map-like representations that are composed of behaviourally relevant distances. The current project is challenging due to language differences and common conceptual misalignment between neurolinguists and decision/memory neuroscientists.

Through active, resilient and well-coordinated team science, we achieved an integrative novel design, unique ideas and preliminary advance in understanding that were not otherwise possible.

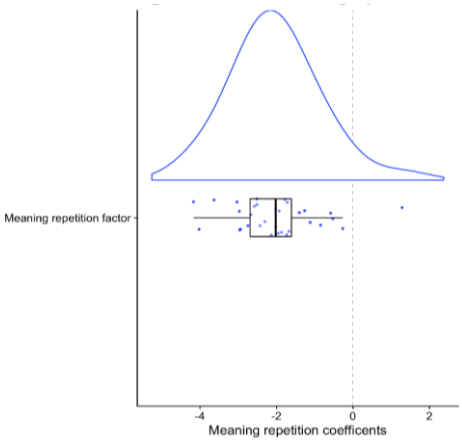


Figure 9. *Linear mixed effect model coefficients of the meaning repetition factor for each subject. A coefficient with value of 0 indicates no effect; a negative meaning coefficient indicates faster RT for subsequent symbols with the same meaning compared to different meanings.*

SYNERGY PROJECT

COMMUNICATION IN CONTEXT

A major challenge of understanding the human language faculty is to account for the extreme flexibility with which humans employ their words and gestures in everyday communicative interactions. We seem to be endowed with a remarkable ability to rapidly find relevant context for understanding and using intrinsically ambiguous communicative behaviors. The Synergy project aims to understand what counts as context and how that context determines the meaning of an utterance.

Across several interrelated projects, we will test the notion that a large portion of the context is contingent on joint knowledge implied by the ongoing interaction between interlocutors, i.e. a flexible and mutually coordinated 'shared conceptual space'. First, neural mechanisms will be identified critically supporting shared conceptual spaces by having people interact in novel communicative settings minimizing the need for the use of pre-existing shared representations. This is achieved through dual-fMRI and dual-EEG studies in individuals with Autism Spectrum Disorder (ASD) examining the possibility that the poor communication and interaction abilities characteristic of ASD are caused by difficulties in using the conceptual space defined by the ongoing interaction.

Second, neural mechanisms will be identified constraining the meaning of utterances during controlled dialogs. This is achieved through combined eye-tracking and fMRI/EEG studies in ASD individuals quantitatively varying the strength of conflicting semantic constraints on the communicative meaning of verbal and gestural utterances. Overall, using specially designed experimental protocols, the studies aim to provide a new theoretical and empirical foundation for understanding human communication, as well as a new window into understanding and treating disorders of human communication in neurological and neurodevelopmental disorders.

Progress in 2020

A website was launched for the Synergy Project at https://www.mutualunderstanding.nl/. The project entered its second year, with data collection underway for the two fMRI studies central to the main goal of the project: 'Communication in Context: Social interaction in Autism Spectrum Disorder' and 'Communication in Context: Language use in Autism Spectrum Disorder'. The two studies efficiently share data acquisition from a relatively large cohort of neurotypical and neurodivergent participants, including 52 autistic, 52 social anxiety, and 52 neurotypical control individuals (N = 156). Data analysis of the various parts of these projects is underway. The Synergy Project has also applied for and obtained CMO approval of the two EEG studies that will build on the fMRI study findings.

TEAM MEMBERS

Coordinators:	Arjen Stolk (*coordinator*)	Jana Bašnáková (*coordinator*)
PhDs:	Margot Mangnus	
Other team members:	Saskia Koch	

KEY PUBLICATIONS (2020):

1. Stolk, A., **Bašnáková, J.**, & **Toni, I.** (2020). Joint epistemic engineering: The neglected process of context construction in human communication. *PsyArXiv* (https://psyarxiv.com/rwfe6/)

SOCIETAL IMPACT

Our consortium aims at implementing research outcomes directly in society. As staying in the lead in science imposes high demands on researchers, all general dissemination and PR activities both within the consortium and to outside world are organised by the LiI-office. In addition, one work package is specifically dedicated to societal impact within our organizational structure. The focus of this work package is on charting and developing ways for LiI research outcomes to be applicable and relevant in the outside world. It shapes the LiI infrastructure for societal impact by ensuring that the means and personnel are available to support researchers in their efforts.

These range from ideas, theories, inventions and innovations towards actual use and benefit to society. Key innovation is the active encouragement of LiI researchers to transform ideas into commercial and/or societal products. The Societal Impact WP coaches and assists them in identifying and designing applications (of any kind), in finding partners, and finding their way in the world of patent and grant application. Where necessary, external infrastructure will be recruited consisting of tools, personnel, organization and expertise. Members of the Societal Impact WP participate in research projects in the domain of language research that can be applied in clinical, educational or technological settings.

TEAM MEMBERS

Coordinators:	Peter Hagoort (*work package leader*)
Team members:	Esther Steenbeek (*societal impact officer*)
Alumni PhDs:	Alessandro Lopopolo

1. APPLYING CONSORTIUM KNOWLEDGE TO ONLINE COMMUNICATION

Research results of the consortium were sought to be made applicable to larger societal challenges. First, as the current societal effects of the coronavirus pandemic have substantial consequences for communication among citizens, the Language in Interaction consortium was uniquely equipped to be involved in developing ideas for measures and advice on how communication during this time can be improved. The WP started projects that can contribute to society and societal dynamics. Communication has moved to a large extent to digital environments, such as online video meetings like Skype, ZOOM, etc. How can communication in these environments be improved such that linguistic exchange is optimal? Consortium members originating from the five Big Questions were involved in interactive sessions with users to discuss the challenges they face. Questions were posed by two educational institutes: Radboud In'To Languages and the Radboud Teaching and Learning Centre. One challenge specific to educational context is how to stimulate the involvement of students in interacting with both the teacher and other students (mutual involvement) in an online setting. Advice was formulated in an advisory letter (found here) and focuses among others on how to improve bringing your message across using multimodal signals, that is, integrating visual with auditory information such as hand gestures. The advice was also captured in an infographic (see **Figure 10**).

To streamline conversations in group meetings, it was advised to make consistent use of specific visual cues that facilitate taking turns. And, to improve interaction, it was advised to integrate more and shorter moments of explicit interaction. Suggestions are summarized in the infographic below. Researchers of the Language in Interaction consortium are also involved in a new project from our consortium partner NEMO Kennislink, as part of an SIDN grant awarded to them for a project exploring the challenges that we face in communicating online and how online platforms can be made more user friendly to accommodate for these challenges. Language in Interaction researchers will be part of in-depth interviews and discussions to provide detailed suggestions on how to improve interaction in online platforms.

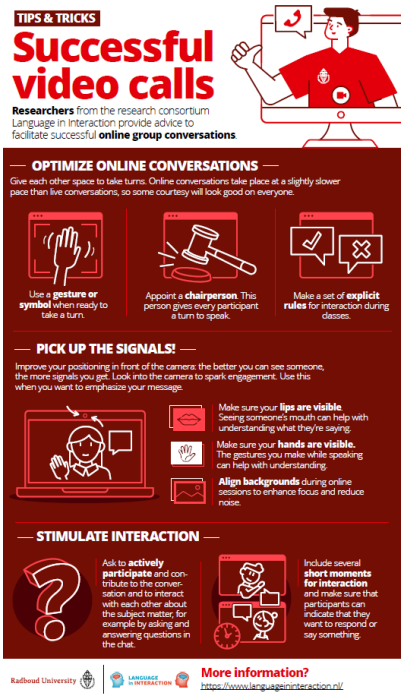


Figure 10. *Screenshot of the advisory infographic (download here in English and Dutch)*

2. PARTNERING WITH LOGOCLICKS ON SIMPTELL APHASIA APP

In 2020, the Societal Impact WP conducted a pilot to make existing apps of Language in Interaction more sustainable for the future and to embed researchers' knowledge in long-term partnerships with external, non-academic parties. One of these apps is the therapy app SimpTell. It is specially developed for people with permanent Broca's aphasia. This is a form of aphasia caused by acquired brain injury in which the expression of spoken and written language is disturbed. For more than 30,000 people with aphasia in the Netherlands, to be able to 'just say something' is not self-evident. In order to bring this innovative app to the market and make it available for people with aphasia, Radboud University was looking for a social partner. The university found this partner in Logoclicks Development, the company which developed Afasietherapie.nl and Afasietherapie.be. Based on scientific research, consortium members succeeded in developing a solution for daily practice. The collaboration with Logoclicks now offers the opportunity to give SimpTell a social application and to make it more readily available to people with aphasia.

The collaboration between Logoclicks and consortium members aims to combine SimpTell and Afasietherapie.nl into one smart eHealth solution. It is an important outlet of research to work together on therapy tools for this group of people for whom communication is no longer obvious.

TENURE TRACKS

There are three tenure tracks within the LiI consortium:

1. Tenure Track 1: **Stefan Frank**
2. Tenure Track 2: **Jelle Zuidema**
3. Tenure Track 3: **Vitória Piai**

The following section details the progress for these tenure tracks in 2020.

TENURE TRACK 1: STEFAN FRANK

Computational Psycholinguistics of Sentence Processing
Centre for Language Studies, RU

PhD candidate: Chara Tsoukala (PhD defense date: April 21st, 2021)

As details of the cognitive processes and representations underlying language use continue to be uncovered, and ever increasing amounts of behavioural and (neuro)physiological data are collected, it becomes more and more difficult to capture the immense complexity of human language processing in theories that are specified only verbally. In contrast to verbal description, implemented computational models that simulate aspects of processing are able to generate fine-grained, quantitative predictions and can thereby expose how, exactly, observed properties of language comprehension and production may emerge.

The general aim of this tenure track was the development and application of computational models of human sentence processing, bridging between linguistic and cognitive theory, psychological experimentation, and neuroimaging data; particularly in the context of multilingualism. The basic assumption behind this work is that the mind is for a large part a statistical system: It extracts (linguistic) patterns from observations and applies abstractions over these patterns when processing novel input. Any model of such a system embodies particular assumptions about the relevant processes and representations. The cognitively most plausible assumptions can then be identified by comparing how well different models' predictions fit human processing data.

Thus, statistical models of language are developed, implemented, and trained on linguistic data; and their quantitative predictions of behavioural and/or neural responses serve to evaluate to the models' value as cognitive theories. In addition, we ran human language comprehension experiments to test specific (model) predictions of language use as rooted in the application of language statistics. The development of computationally explicit models contributes to the overarching quest of LiI because it is instrumental in bridging between functional, algorithmic, and implementational (neural) levels of explanation; and thereby coming to a comprehensive understanding of observed language phenomena. More specifically, implemented statistical models of language processing form testable theories of how properties of the cognitive system interact with properties of the language, which speaks to the question of boundary conditions of language and language use. In addition, as the majority of the world's population is multilingual, accounting for the full variability in human language use requires moving beyond the single-

language case, as we do when developing multilingual models and by running experiments that investigate cross-linguistic differences in mono- and bilingual contexts.

Progress in 2020

Stefan Frank continued four collaborative projects in his tenure track with researchers from a.o. the Radboud University, University of Birmingham, and University College London. Two new projects were initiated with researchers from the Radboud University, the National French Institute for Mathematics and Computer Science in Bordeaux, France, and the University of Potsdam. There were ongoing collaborations with BQ1 and the tenure track PhD project produced output in the form of scientific publications (published and under review). The PhD's defense takes place in April 2021 and also marks the end of this tenure track.

KEY PUBLICATIONS (2020):

Roete, I., **Frank, S. L.**, Fikkert, P., & Casillas, M. (2020). Modeling the Influence of Language Input Statistics on Children's Speech Production. *Cognitive Science, 44*(12), e12924.

TENURE TRACK 1: STEFAN FRANK - HIGHLIGHT

Cross-linguistic structural priming in recurrent neural networks

Stefan Frank and Yung Han Khoe

Neural network models of language have displayed a remarkable ability to capture aspects of syntactic processing. The question remains to what extent they learn abstract syntactic properties. Recent work on structural priming (a.k.a. syntactic persistence/adaptation) in Recurrent Neural Networks (RNNs) suggests that they indeed (implicitly) represent sentence structure. We extend these results to the bilingual domain. It is well known that bilingual people show syntactic priming between their two languages, suggesting that the mental representation of structure is language independent. We demonstrate that the same is true in RNN models of sentence production and "comprehension" (i.e., next-word prediction) when trained on two languages simultaneously.

Figure 11 shows this result for a next-word prediction RNN trained on approximately 18 million sentences from Dutch and English text corpora. It is then tested on 120 Dutch and 120 English garden-path sentences such as "The thief shot the jeweler and the cop risked his life". The local structural ambiguity is resolved on the critical verb risked. Human reading-time experiments have shown that risked is read more slowly than in the unambiguous sentence "The thief shot the jeweler, and the cop risked his life", which has a comma after and, preventing the reading that "the jeweler and the cop" forms an object NP. The RNN's word surprisal estimates for the critical verbs are higher in the ambiguous than unambiguous sentences, that is, the model simulates the garden-path effect. More importantly, when it is primed by first training it on a single ambiguous sentence, the garden-path effect is smaller than when it is primed with an unambiguous sentence. This also happens (albeit to a lesser extent) when the prime sentence is in the other language. Hence, cross-linguistic priming occurs in the RNNs, demonstrating that it has learned a language-independent representation of syntactic structure.

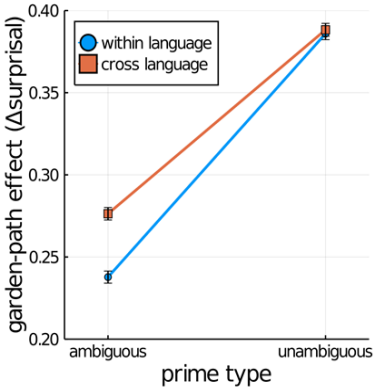


Figure 11. *Size of the garden-path effect (surprisal in ambiguous minus unambiguous structures) as a function of prime type (ambiguous or unambiguous structure) and language combination (within- or cross-language priming). Error bars denote 95% confidence intervals.*

TENURE TRACK 2: JELLE ZUIDEMA

Hierarchical structure in natural language: bridging computational linguistics, neurobiology and formal semantics

Institute for Logic, Language, and Computation, UvA

PhD candidate: Dieuwke Hupkes (PhD defense date: June 17th, 2020)

A unique feature of human language – and the key property that arguably sets it apart in nature – is its hierarchical compositionality: all languages allow meaningful atomic units (e.g. words) to be combined into larger units, and these larger units to be further combined to form meaningful sentences. The work performed within this tenure track investigates **(1)** how corpus data and computational models can be used to study the nature of this combinatory system, **(2)** how such a system may be implemented in a neural architecture, **(3)** how the system may be learned by children and machines, and ultimately, **(4)** how such a system emerged in evolution.

Progress in 2020

Continuing on the work done in 2015-2019 which already studied subgoals 1-3 in detail, further progress has been made on subgoal (3). Hupkes et al. published a major paper in a top AI journal (JAIR) on compositionality. The paper has attracted much attention on social media, and led to invitations to present this work at IJCAI 2020 and at various academic institutions. Progress on (4) was presented in a paper by Van der Wal et al. (2020), with Hupkes as lead author. This paper studies properties of languages that emerge in an evolutionary simulation. An important new development was the focus on the Transformer architecture, reflected in the work with Abnar and Ahmed and providing a novel perspective on questions 1, 2 and 3. This architecture has since 2018 quickly replaced almost all other models in natural language processing. In 2019, Abnar et al. had already shown that the Transformer based BERT model provides a good scaffold to predict fMRI measures of brain activity in language processing. In 2020, Ahmed obtained parallel results on predicting EEG measures of brain activity (see highlight). Furthermore, Abnar developed techniques to analyze the inner working of the Transformer model (Abnar & Zuidema, 2020), and made an extensive study of the relation between Transformers and LSTMs (Abnar, Dehghani & Zuidema, 2020). In June 2020, Hupkes successfully defended her PhD thesis.

KEY PUBLICATIONS (2020):

1. **Hupkes, D.,** Dankers, V., Mul, M., & Bruni, E. (2020). Compositionality decomposed: how do neural networks generalise?. *Journal of Artificial Intelligence Research, 67*, 757-795.
2. **Abnar, S**., & **Zuidema, W.** (2020). Quantifying attention flow in transformers. arXiv preprint arXiv:2005.00928.
3. van der Wal, O., de Boer, S., Bruni, E., & **Hupkes, D.** (2020). The Grammar of Emergent Languages. arXiv preprint arXiv:2010.02069.
4. Dekker, P., & **Zuidema, W.** (2020). Word prediction in computational historical linguistics. *Journal of Language Modelling, 8*(2), 295-336.
5. Cornelissen, B., **Zuidema, W.**, & Burgoyne, J. A. (2020). Mode Classification and Natural Units in Plainchant. *In Proceedings of the 21th International Conference on Music Information Retrieval* (ISMIR 2020). Montréal, Canada.

AWARDS:

Jelle Zuidema (1) was awarded a Natioanl Research Agenda grant (NWA-ORC) for the project 'Opening the Black Box of Deep Learning for Lanugage, Speech and Music', and (2) received a best paper award at ISMIR'20 with Bas Cornelissen and Ashley Burgoyne.

TENURE TRACK 2: JELLE ZUIDEMA - HIGHLIGHT

Modelling EEG responses to narrative speech

Rasyan Ahmed, Jelle Zuidema, and Tom Lentz

We identify neural correlates of both the onset of semantic processing in the brain, and of the modulation of that processing by how surprising newly received words are. To the best of our knowledge, we present the first evidence of patterns similar to both the well-known N400 component and N400 effect, known from controlled Event-Related-Potential (ERP) experiments, using naturalistic data and computationally implemented models of predictability.

When listening to a spoken narrative, listeners build up representations of the story and its characters and events, and integrate the information conveyed by each new incoming words with the representation of the preceding context. Decades of research have revealed signatures of this process in the brain activity that can be measured from outside the skull, and has shown that the compatibility of the new information with existing representations and expectations affects these signatures. Most of this work uses carefully controlled experimental settings and manually selected levels of compatibility; best known results from this tradition are the so-called N400 component (reflecting semantic processing) and the N400 effect (reflecting, roughly, the modulation of the component by how surprising the incoming word is). We analysed a data set made available by Broderick et al. (2018). It contains EEG data collected in a naturalistic setting (where naive participants listen to an audiobook). We propose a computationally implemented measure of compatibility based on predictability by a Transformer language model, a state-of-the-art technique from the field of Natural Language Processing. Crucially, compared to earlier work we replace both the baselines and the compatibility measure. We show that a 'static' model (that assigns equal probability to every word) performs equally well as Broderick's model and only models the 'N400 component' (see **Figure 12**); moreover, we find that the Bert models give much more accurate predictions and also capture the N400 effect. We use techniques from modern Natural Language Processing to build predictive models of the cognitive neuroscience of language, improving over prior work in this area and contributing to one of the overall quests of LiI: to link models of language processing to the neurobiology of language.

We have profited from interactions with members of BQ1, in particular Stefan Frank, and from LiI more generally, in particular Peter Hagoort, in identifying the weaknesses of earlier work and developing our own improvements.

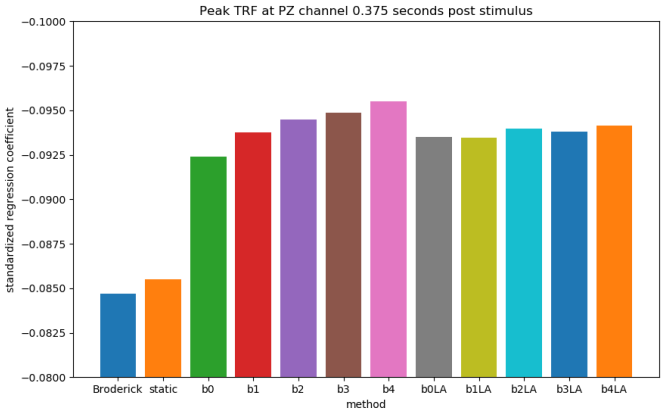


Figure 12. *Regression coefficients for peak TRF at PZ channel 0.375 seconds post-stimulus, data from Broderick et. al. (2018) containing EEG data collected in a naturalistic setting (listening to an audiobook). The figure shows results from different analysis models.*

TENURE TRACK 3: VITÓRIA PIAI

Hierarchical structure in natural Neuropsychology of Language and Language Disorders

Donders Centre for Cognition and Donders Centre for Neuroscience, RU and RUMC

Postdoctoral Research Associate: Joanna Sierpowska
PhD candidate: Ileana Camerino

This tenure track focuses on performing pre-clinically and clinically oriented research on language. This position bridges the gap between clinical and non-clinical research on language in Nijmegen, nationally and internationally, and promotes interactions between RU and RUMC. It aims at establishing a research programme on language function and dysfunction. This approach takes the strength of both basic and applied fields to widen the theoretical understanding of brain and language relationships and to improve the care for clinical populations that suffer from speech, language, and communication deficits.

Progress in 2020

Previously established collaborations with different groups from RUMC (Neurosurgery, Neurology, Audiology, and Otorhinolaryngology) and other medical centres were continued, with scientific publications and conference presentations resulting from them over the course of 2020.

Speech-language therapists or neuropsychologists helping with recruitment of patients for our studies are welcomed to attend one experimental session and learn about what we do. They report that they learn substantially from these opportunities. In some cases, observations during these experimental sessions have led to modifications by the therapist in the treatment plan of their patients, leading to improvement in therapy outcome. In our project with cochlear implant (CI) users, our findings were insightful for clinicians in that they indicated that the poor school and work outcomes of young implanted CI users are not due to poor low-level auditory functioning.

Findings from the project on head-neck cancer have direct implications for clinicians working with head-neck cancer patients. Our findings indicate that some patients in this population may need a more detailed examination of their cognitive and speech functioning before they start being treated. These results have received media attention due to their importance for health professionals.

KEY PUBLICATIONS (2020):

1. Roos, N. M., & **Piai, V.** (2020). Across-session consistency of context-driven language processing: A magnetoencephalography study. *European Journal of Neuroscience, 52*(5), 3457-3469.
2. **Piai, V.**, De Witte, E., Sierpowska, J., Zheng, X., Hinkley, L. B., Mizuiri, D., ... & Nagarajan, S. S. (2020). Language neuroplasticity in brain tumor patients revealed by magnetoencephalography. *Journal of cognitive neuroscience, 32*(8), 1497-1507.
3. **Piai, V.**, Klaus, J., & Rossetto, E. (2020). The lexical nature of alpha-beta oscillations in context-driven word production. *Journal of Neurolinguistics, 55*, 100905.

AWARDS:

Vitória Piai (1) received an Early Career Award from the Interantional Neuropsychological Society, and (2) received an inter-faculty collaborative grant from the Radboud University Nijmegen for the project 'Adaptive Language Intiative' with James McQueen (BQ4) and Asli Özyürek (BQ3).

LINGUISTICS POSTDOC:

NATALIA LEVSHINA

Natalia Levshina joined the Language in Interaction consortium in October of 2019 and is the consortium's go-to expert on (corpus) linguistics. She is employed by the consortium as a coordinating postdoc. Natalia is the contact for any questions on corpus methods. Additionally, she has her own line of research that is largely embedded within Big Question 3.

RESEARCH AIMS

Natalia's research within the Language in Interaction consortium largely focuses on the question of how the mechanisms of human interaction shape linguistic structure and use. She investigates language universals and diversity that can be explained by main pragmatic principles and rational behaviour of language users.

Her main hypothesis is that predictability (surprisal) of grammatical and lexical meanings has an effect on language structure and use. She examines this notion on specific linguistic phenomena: argument marking, word order, semantic tightness of syntactic roles and lexical semantics

Progress in 2020

Natalia Levshina has initiated several parallel projects since the start of her appointment with the consortium:

1. 'Differential argument marking from an interdisciplinary perspective'
2. 'Lexical pragmatics and rational behavior'
3. 'Communicative efficiency and language evolution: Correlational and causal analysis of different types of cues in expression of core grammatical roles'
4. 'Communicative efficiency in language structure and use'

These projects largely involve corpus data, innovative online experiments and typological data.

Preliminary results from the projects conducted by the linguistics postdoc suggest that human rationality, which is assumed by classical theories of language communication, has a limited effect on language structure and use. Furthermore, results suggest that research needs to use real interaction data in experiments in order to model the emergence of efficient language patterns.

KEY PUBLICATIONS (2020):

1. **Levshina, N.** (2020). Database of Annotated Core Arguments: English, Lao and Russian (Version 1.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.4065523
2. **Levshina, N.** (2020). Efficient trade-offs as explanations in functional linguistics: some problems and an alternative proposal. *Revista da ABRALIN 19*(3): 50-78.
3. **Levshina, N.** (2020). How tight is your language? A semantic typology based on Mutual Information. *In Proceedings of the 19th Workshop on Treebanks and Linguistic Theories* (pp. 70-78).
4. **Levshina, N.** (2020). Conditional inference trees and random forests. *In Practical Handbook of Corpus Linguistics*. Springer.

OVERVIEW OF PHD PROJECTS

PHDS WHO DEFENDED THEIR DISSERTATION IN 2020

1. Hierarchy and interpretability in neural models of language processing

PhD Candidate: Dieuwke Hupkes (*PI: Jelle Zuidema)*

Dieuwke defended her dissertation in June 2020. Congratulations!

DISSERTATION:

Hupkes, D. (2020). Hierarchy and interpretability in neural models of language processing. (Doctoral dissertation, Amsterdam Institute for Logic, Language and Computation).

KEY PUBLICATION:

Hupkes, D., Dankers, V., Mul, M., & Bruni, E. (2020). Compositionality decomposed: how do neural networks generalise?. *Journal of Artificial Intelligence Research, 67*, 757-795.

2. Language regions in Interaction: An investigation of directional connectivity in the human language system using laminar fMRI

PhD Candidate: Daniel Sharoh (*PIs: David Norris and Peter Hagoort)*

Daniel defended his dissertation in January 2020. Congratulations!

DISSERTATION:

Sharoh, D. L. (2020). Advances in layer specific fMRI for the study of language, cognition and directed brain networks (Doctoral dissertation, Radboud University Nijmegen)

KEY PUBLICATION:

Sharoh, D., Van Mourik, T., Bains, L. J., Segaert, K., Weber, K., Hagoort, P., & Norris, D. G. (2019). Laminar specific fMRI reveals directed interactions in distributed networks during language processing. *Proceedings of the National Academy of Sciences, 116*(42), 21185-21190.

3. Feedback loops in learning to perceive and produce non-native speech

PhD Candidate: Jana Thorin (*PIs: James McQueen and Peter Desain)*

Jana defended her dissertation in February 2020. Congratulations!

DISSERTATION:

Thorin, J. (2020). Can you hear what you cannot say? The interactions of speech perception and production during non-native phoneme learning (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Thorin, J., Sadakata, M., Desain, P., and McQueen, J. M. (2018). "Perception and production in interaction during non-native speech category learning," The *Journal of the Acoustical Society of America, 144*, 92–103.

4. Data driven investigation of intrinsic dynamic brain states underlying language processing

PhD Candidate: Julia Berezutskaya (*PIs: Nick Ramsey and Peter Desain)*

Julia defended her dissertation in April 2020. Congratulations!

DISSERTATION:

Berezutskaya, J. (2020). Data-driven modeling of the neural dynamics underlying language processing (Doctoral dissertation, Utrecht University).

KEY PUBLICATION:

Berezutskaya, J., Baratin, C., Freudenburg, Z. V., & **Ramsey, N. F.** (2020). High - density intracranial recordings reveal a distinct site in anterior dorsal precentral cortex that tracks perceived speech. *Human brain mapping, 41*(16), 4587-4609.

5. Driving forces behind perceptual adaptation in speech
PhD Candidate: Shruti Ullas (*PIs: Elia Formisano and Anne Cutler)*

Shruti defended her dissertation in June 2020. Congratulations!

DISSERTATION:

Ullas, S. (2020). Lexical and audiovisual bases of perceptual adaptation in speech. (Doctoral dissertation, University of Maastricht)

KEY PUBLICATION:

Ullas, S., Formisano, E., Eisner, F., & Cutler, A. (2020). Interleaved lexical and audiovisual information can retune phoneme boundaries. *Attention, Perception, & Psychophysics*, 1-9.

6. Modeling and mapping generalization and knowledge acquisition in the hippocampal-prefrontal-thalamic circuit
PhD Candidate: Stephanie Teves (*PIs: Christian Döller and Guillén Fernández)*

Stephanie defended her dissertation in June 2020. Congratulations!

DISSERTATION:

Theves, S. (2020). Mapping conceptual knowledge acquisition in the hippocampal system (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Theves, S., Fernández, G., & Doeller, C. F. (2020). The hippocampus maps concept space, not feature space. *Journal of Neuroscience, 40*(38), 7318-7325.

7. Neural processing of action, gesture and language in healthy and autistic individuals
PhD Candidate: James Trujillo (*PIs: Asli Özyürek and Harold Bekkering)*

James defended his dissertation in February 2020. Congratulations!

DISSERTATION:

Trujillo, J. P. (2020). Movement speaks for itself: The kinematic and neural dynamics of communicative action and gesture (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Trujillo, J. P., Simanova, I., **Özyürek, A., & Bekkering, H.** (2020). Seeing the unexpected: How brains read communicative intent through kinematics. *Cerebral Cortex, 30*(3), 1056-1067.

8. Neurobiologically realistic computational models of language processing
PhD Candidate: Marvin Uhlmann (*PIs: Karl-Magnus Petersson and Peter Hagoort)*

Marvin defended his dissertation in September 2020. Congratulations!

DISSERTATION:

Uhlmann, M. (2020). Neurobiological models of sentence processing (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Fitz, H., **Uhlmann, M.**, Van den Broek, D., Duarte, R., **Hagoort, P.**, & **Petersson, K. M.** (2020). Neuronal spike-rate adaptation supports working memory in language processing. *Proceedings of the National Academy of Sciences, 117*(34), 20881-20889.

9. Contributions of dorsal and ventral neural pathways to speaking in health and disease
PhD Candidate: Nikki Janssen (*PIs: Roy Kessels and Ardi Roelofs)*

Nikki defended her dissertation in December 2020. Congratulations!

DISSERTATION:

Janssen, N. (2020). Staying connected as we speak: Behavioral and tractography evidence from health and neurodegenerative disease. (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Janssen, N., **Roelofs, A.**, **Mangnus, M.**, **Sierpowska, J.**, **Kessels, R. P.**, & **Piai, V.**

(2020). How the speed of word finding depends on ventral tract integrity in primary progressive aphasia. *NeuroImage: Clinical, 28*, 102450.

10. How to slow down and speed up: the regulation of speech rate
PhD Candidate: Joe Rodd (*PIs: Antje Meyer and Mirjam Ernestus)*

Joe defended his dissertation in September 2020. Congratulations!

DISSERTATION:

Rodd, J. (2020). How speaking fast is like running: Modelling control of speaking rate (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Rodd, J., Decuyper, C., **Bosker, H. R.**, & Ten Bosch, L. (2021). A tool for efficient and accurate segmentation of speech data: announcing POnSS. *Behavior Research Methods, 53*(2), 744-756.

11. Processing vague expressions: The interplay between semantics, pragmatics and cognition
PhD Candidate: Arnold Kochari (*PIs: Robert van Rooij and Herbert Schriefers)*

Arnold defended his dissertation in September 2020. Congratulations!

DISSERTATION:

Kochari, A. (2020). Perceiving and communicating magnitudes: Behavioral and electrophysiological studies. (Amsterdam Institute for Logic, Language and Computation).

KEY PUBLICATION:

Kochari, A. (2020). Processing symbolic magnitude information conveyed by number words and by scalar adjectives.

ONGOING PHD PROJECTS IN 2020

12. Encoding and decoding the neural signatures of natural language comprehension
PhD Candidate: Alessandro Lopopolo (*PIs: Antal Van den Bosch and Karl-Magnus Petersson)*

DEFENSE DATE: January 12, 2021

KEY PUBLICATION:

Lopopolo, A., **van den Bosch, A.**, **Petersson, K. M.**, & **Willems, R. M.** (2021). Distinguishing syntactic operations in the brain: *Dependency and phrase-structure parsing. Neurobiology of Language, 2*(1), 152-175.

13. Sharpening sensory predictions by linguistic primes
PhD Candidate: Lara Todorova (*PIs: Harold Bekkering and Peter Hagoort)*

DEFENSE DATE: February 9, 2021

KEY PUBLICATION:

Todorova, L., Neville, D., & Piai, V. (2019). Lexical-semantic and executive deficits revealed by computational modelling: a drift diffusion model perspective.

14. Bilingual sentence production and code-switching: Neural network simulations
PhD Candidate: Chara Tsoukala (*PI: Stefan Frank)*

DEFENSE DATE: April 21, 2021

KEY PUBLICATION:

Tsoukala, C., Broersma, M., **van den Bosch, A.**, & **Frank, S. L.** (2021). Simulating code-switching using a neural network model of bilingual sentence production. *Computational Brain & Behavior, 4*(1), 87-100.

15. Connectivity-based fingerprinting of memory and language network dynamics
PhD Candidate: Izabela Przezdzik (*PIs: Christian Beckmann and Guillén Fernández)*

DEFENSE DATE: June 24, 2021

KEY PUBLICATION:

Przeździk, I., Faber, M., Fernandez, G., Beckmann, C. F., & Haak, K. V. (2019). The functional organisation of the hippocampus along its long axis is gradual and predicts recollection. *Cortex, 119*, 324-335.

16. Neurogenomics of vocal learning: decoding the functions of FoxPs in vocal perception and production learning
PhD Candidate: Fabian Heim (*PIs: Carel Ten Cate and Simon Fisher)*

KEY PUBLICATION:

Heim, F., Fisher, S. E., ten Cate, C., Scharff, C., & Riebel, K. (2016). Birds and brains-what songbirds tell us about language. *In the FENS Hertie Winterschool on Neurobiology of Language and Communication*.

17. Neuropsychology of language and language disorders
PhD Candidate: Ileana Camerino (*PIs: Vitória Piai, Roy Kessels, and Erik de Leeuw)*

KEY PUBLICATION:

Camerino, I., Sierpowska, J., Reid, A., Meyer, N. H., Tuladhar, A. M., **Kessels, R. P.**, … **& Piai, V.** (2021). White matter hyperintensities at critical crossroads for executive function and verbal abilities in small vessel disease. *Human Brain Mapping, 42*(4), 993-1002.

18. Perception of multidimensional sounds in humans and birds: Are speech categories special?
PhD Candidate: Merel Burgering (*PIs: Jean Vroomen and Carel Ten Cate)*

KEY PUBLICATION:

Burgering, M. A., van Laarhoven, T., Baart, M., & **Vroomen, J.** (2020). Fluidity in the perception of auditory speech: Cross-modal recalibration of voice gender and vowel identity by a talking face. *Quarterly Journal of Experimental Psychology, 73*(6), 957-967.

19. The Game of Language: Complex Communication and Mental States
PhD Candidate: Iris van de Pol (*PIs: Ivan Toni and Johan Van Benthem)*

KEY PUBLICATION:

van de Pol, I., Steinert-Threlkeld, S., & Szymanik, J. (2019). Complexity and learnability in the explanation of semantic universals of quantifiers. *Proceedings of the 41st Annual Meeting of the Cognitive Science Society, 2019*.

20. Genomics of speech and language disorders: The next generation
PhD Candidate: Lot Snijders-Blok (*PIs: Hans Brunner and Simon Fisher)*

KEY PUBLICATION:

Blok, L. S., Kleefstra, T., Venselaar, H., Maas, S., Kroes, H. Y., Lachmeijer, A. M., … & Study, T. D. (2019). De novo variants disturbing the transactivation capacity of POU3F3 cause a characteristic neurodevelopmental disorder. *The American Journal of Human Genetics, 105*(2), 403-412.

21. Do brain potentials reflect individuals' potential to learn a second language? Individual differences in language interaction during L2 acquisition
PhD Candidate: Lisette Jager (*PIs: Nils Schiller and James McQueen)*

KEY PUBLICATION:

McQueen, J. M., Krutwig, J., **Jager, L.**, Desain, P., Witteman, J., & Schiller, N. O. (2018). Learning foreign-language sounds in adulthood: Listening, speaking, and individual differences. *The Journal of the Acoustical Society of America, 144*(3), 1716-1716.

22. Alignment in dialogue at the phonological, syntactic and semantic levels
PhD Candidate: Samira Abnar (*PIs: Jelle Zuidema, Marcel van Gerven, and Raquel Fernández)*

KEY PUBLICATION:

Abnar, S., Dehghani, M., & **Zuidema, W.** (2020). Transferring inductive biases through knowledge distillation. *arXiv preprint arXiv:2006.00555*.

23. Alignment in dialogue at the phonological, syntactic and semantic levels
PhD Candidate: Lotte Eijk (*PIs: Mirjam Ernestus and Herbert Schriefers)*

KEY PUBLICATION:

Eijk, L., Fletcher, A., McAuliffe, M., & Janse, E. (2020). The Effects of Word Frequency and Word Probability on Speech Rhythm in Dysarthria. *Journal of Speech, Language, and Hearing Research, 63*(9), 2833-2845.

24. Modelling psychological and perceptual aspects of the mental lexicon
PhD Candidate: Danny Merkx (*PIs: Stefan Frank, Mirjam Ernestus, and Raquel Fernández)*

KEY PUBLICATION:

Merkx, D., & **Frank, S. L.** (2019). Learning semantic sentence representations from visually grounded language without lexical knowledge. *Natural Language Engineering, 25*(4), 451-466.

25. Anatomical and connectopic adaptations to language: A comparative approach
PhD Candidate: Guilherme Blazquez-Freches (*PIs:Christian Beckmann and Rogier Mars)*

KEY PUBLICATION:

Freches, G. B., Haak, K. V., Bryant, K. L., Schurz, M., **Beckmann, C. F.**, & Mars, R. B. (2020). Principles of temporal association cortex organisation as revealed by connectivity gradients. *Brain Structure and Function*, 1-16.

26. The role of subcortical structures in language
PhD Candidate: João Ferreira (*PIs:Ardi Roelofs and Vitória Piai)*

KEY PUBLICATION:

Ferreira, J., **Roelofs, A.**, & **Piai, V.** (2020). The role of domain-general inhibition in inflectional encoding: Producing the past tense. *Cognition, 200*, 104235.

27. Multimodal and pragmatic alignment in dialogue
PhD Candidate: Marlou Rasenberg (*PIs: Asli Özyürek and Mark Dingemanse)*

KEY PUBLICATION:

Rasenberg, M., Özyürek, A., & **Dingemanse, M.** (2020). Alignment in multimodal interaction: An integrative framework. *Cognitive Science, 44*(11), e12911.

28. Longitudinal normative modelling
PhD Candidate: Christina Isakoglou (*PIs: Christian Beckmann and Jan Buitelaar)*

KEY PUBLICATION:

Hintz, F., Voeten, C. C., **Isakoglou, C.**, **McQueen, J. M.**, & **Meyer, A. S.** (2021, March). Individual differences in language ability: Quantifying the relationships between linguistic experience, general cognitive skills and linguistic processing skills. *In the 34th Annual CUNY Conference on Human Sentence Processing (CUNY 2021).*

29. Learning and adaptation in neurobiological models of language processing
PhD Candidate: Alessio Quaresima (*PIs: Karl-Magnus Petersson, Jelle Zuidema, and Peter Hagoort)*

KEY PUBLICATION:

Quaresima, A., Van den Broek, D., **Fitz, H.**, Duarte, R., & **Petersson, K. M.** (2020). A minimal reduction of dendritic structure and its functional implication for sequence processing in biological neurons. *In the Twelfth Annual (Virtual) Meeting of the Society for the Neurobiology of Language (SNL 2020).*

30. Communication in context: Language use in Autism Spectrum Disorder

PhD Candidate: Margot Mangnus (*PIs: Jana Bašnáková and Arjen Stolk*)

KEY PUBLICATION:

Janssen, N., **Roelofs, A.**, **Mangnus, M.**, **Sierpowska, J.**, **Kessels, R. P.**, & **Piai, V.** (2020). How the speed of word finding depends on ventral tract integrity in primary progressive aphasia. *NeuroImage: Clinical, 28*, 102450.

31. Neurochemical mechanisms of inference for reward maximization and meaning generation

PhD Candidate: Elena Mainetto (*PIs: Hanneke den Ouden and Roshan Cools)*

Elena Mainetto's PhD project started in 2020 with Big Question 5.

PHDS WHO DEFENDED THEIR DISSERTATION BEFORE 2020

32. From Kawapanan to Shawi, topics in language variation and change

PhD Candidate: Luis Miguel Rojas Berscia (*PIs: Stephen Levinson and Pieter Muysken)*

Luis won the 2019 AVT/Anéla Dissertation Prize for his dissertation.

DISSERTATION:

Rojas-Berscia, L. M. (2019). From Kawapanan to Shawi: Topics in language variation and change (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Rojas-Berscia, L. M. (2019). Nominalization in Shawi (Chayahuita). *Nominalization in the languages of the Americas*, 491-514.

33. On the oscillatory dynamics underlying speech-gesture integration in clear and adverse listening conditions

PhD Candidate: Linda Drijvers (*PIs: Asli Özyürek and Ole Jenssen)*

Linda obtained her doctorate with a cum laude distinction.

DISSERTATION:

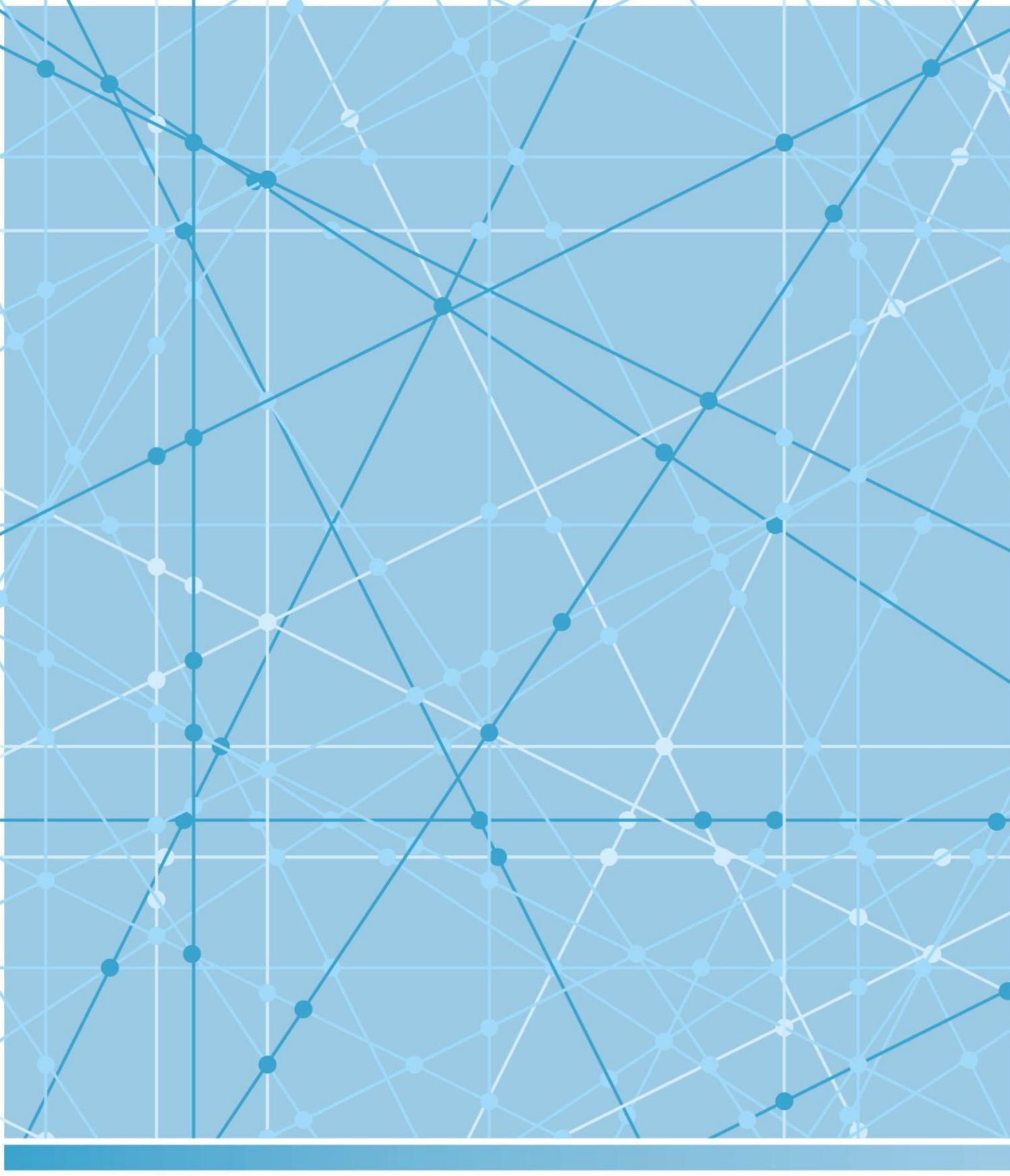
Drijvers, L. (2019). On the oscillatory dynamics underlying speech-gesture integration in clear and adverse listening conditions (Doctoral dissertation, Radboud University Nijmegen).

KEY PUBLICATION:

Drijvers, L., Ozyurek, A., & Jensen, O. (2018). Hearing and seeing meaning in noise: Alpha, beta and gamma oscillations predict gestural enhancement of degraded speech comprehension. *Human Brain Mapping*, 39(5), 2075-2087.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ASD	Autism Spectrum Disorder
BCI	Brain Computer Interface
BQ(s)	Big Question(s)
CI	Cochlear Implant
CLS	Centre for Language Studies
CMO	Commissie Mensgebonden Onderzoek
DCC	Donders Centre for Cognition
DCCN	Donders Centre for Cognitive Neuroimaging
ECoG	ElectroCorticoGraphy
EEG	ElectroEncephaloGraphy
ERP	Event Related Potential
fMRI	functional Magnetic Resonance Imaging
GAN(s)	Generative Adversarial Neural Network(s)
IDLaS	Individual Differences in Language Skills (test battery)
ILLC	Institute for Logic, Language, and Computation
L2	Second Language
LiI	Language in Interaction
LSTM	Long Short-Term memory
MEG	MagnetoEncephaloGraphy
MPI	Max Planck Institute for Psycholinguistics
MRI	Magnetic Resonance Imaging
NLP	Natural Language Processing
PI	Principal Investigator
PPA	Primary Progressive Aphasia
PWI	Picture-word Interference
RNN(s)	Recurrent Neural Network(s)
RT(s)	Reaction Time(s)
RU	Radboud University
RUMC	Radboud University Medical Center
VAC	Voice Activity Detection
WP	Work Package



LANGUAGE
in INTERACTION

NWO
Netherlands Organisation for Scientific Research