Annual Report 2022

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 an overview of the major activities and the highlights of the research in our Language in Interaction consortium in 2022. The report is also available on our website. Early this year the Scientific Advisory Board evaluated the progress of our research. In their report they concluded that "The consortium brings together an outstanding group of scientists throughout the Netherlands and draws on an impressive array of behavioral, computational, and neural methods. Over the past 10 years, the scientific and societal impact stemming from the LiI consortium has been remarkable… Overall, the science conducted under the LiI consortium has been broadly multi- and interdisciplinary to an extent unique in the world… The board was impressed with the ground-breaking discoveries presented in the Annual Reports and during our meeting." So far, 24 PhD students completed their thesis and were awarded the doctoral degree. More than 410 papers have been published by the consortium until now. These are results to be proud of. The final full year of the consortium is on its way, and will see the completion of five more PhD projects and other research activities. A series of grant applications in the context of Horizon Europe is being prepared, meant to secure the fruits of the Language in Interaction program. This annual report contains a selection of the highlights of 2022, which I hope you will enjoy reading.

Prof. dr. Peter Hagoort

Programme Director

THE MANAGEMENT TEAM

Dr. Esther Steenbeek
Head MT
Coordinator Societal Impact

Carmen Marseille
Programme Manager

Julia Verhoef
Management Assistant

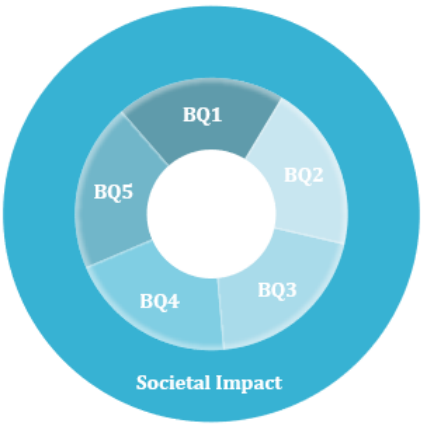
Manon Schmitz
Project controller

Dr. Annemarie van Dooren
Societal Impact Postdoc

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 – Synergy Project.

The five Big Questions are:

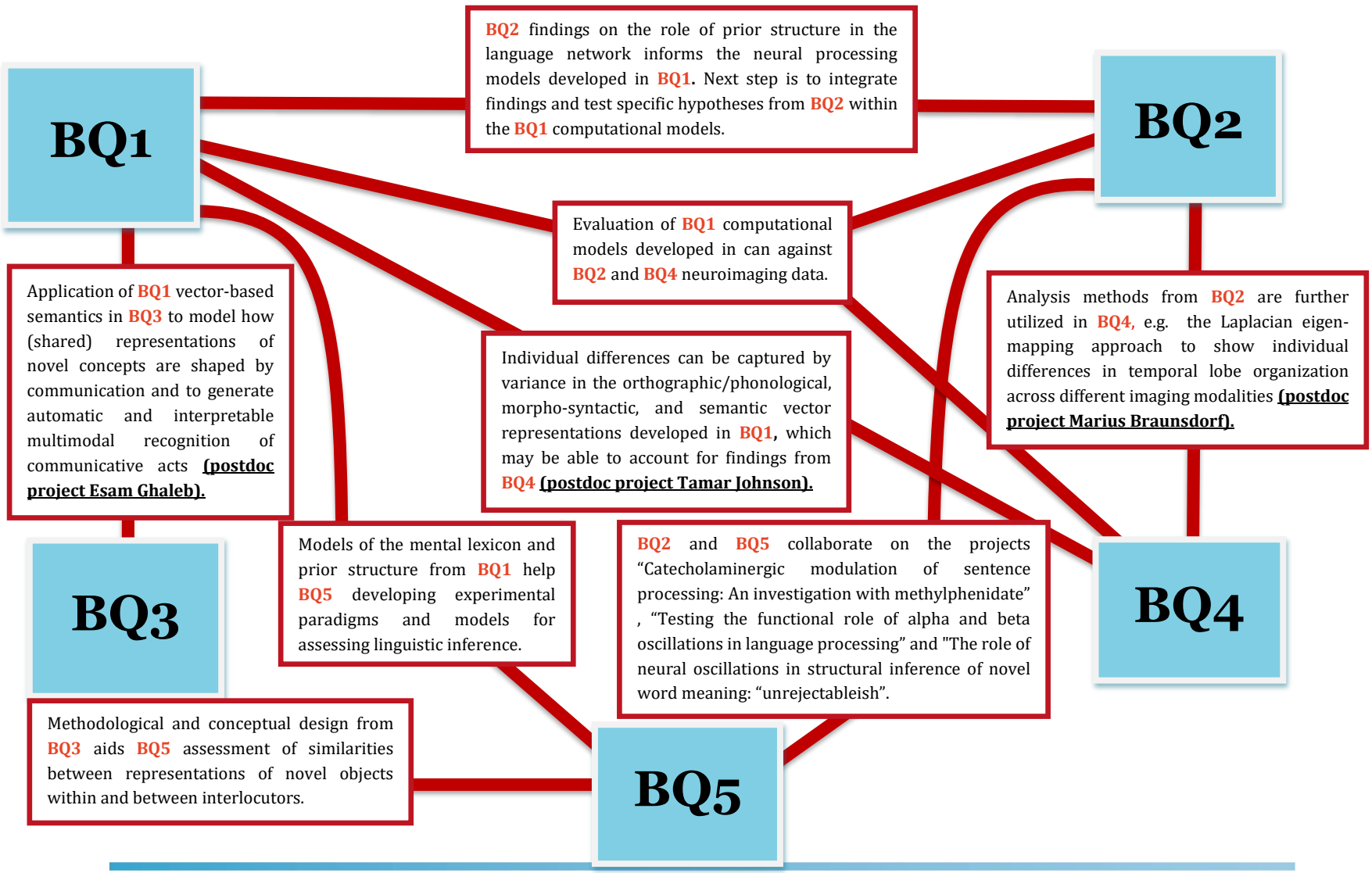
BQ1: The nature of the mental lexicon: How to bridge neurobiology and psycholinguistic theory by computational modelling?
BQ2: What are the characteristics and consequences of internal brain organization for language?
BQ3: Creating a shared cognitive space: How is language grounded in and shaped by communicative 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.

Collaboration between BQ teams went a step further in 2022, by creating postdocs positions aimed at connecting the dots between the BQ teams. Principal investigators could apply together for postdoc grants, which led to the creation of five new postdoc positions involving multiple BQs. Furthermore, two overarching postdocs and one societal impact postdoc were hired, strengthening the overall synthesis and knowledge application of our research. During the annual Language in Interaction Day Out, our researchers jointly build a conceptual robot that could pass the Turing test for speaking and understanding humans.

OVERVIEW OF MAIN COLLABORATIONS BETWEEN BIG QUESTIONS



2022 IN NUMBERS

The Language in Interaction consortium had a fruitful year in 2022.
We would like to thank all of the academic and support staff who made this possible.

CONSORTIUM STAFF

40	13	41	8
PhD Candidates and Postdocs	Research - Assistants	Professors and PIs	Partner Institutions

CONSORTIUM OUTPUT IN 2022

70	91	11	3
Scientific Publications*	(Online) Talks and Poster Presentations	Awards and Grants	PhD Defenses

* Please refer to our website for the full list of scientific publications of the Language in Interaction consortium.

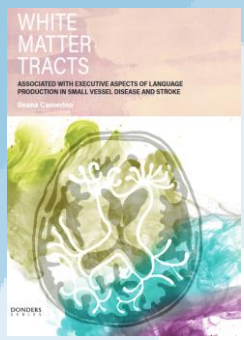
PHD DEFENSES IN 2022

The following 3 PhDs defended their Language in Interaction dissertation in 2022. Congratulations!

Fabian Heim

Leiden University

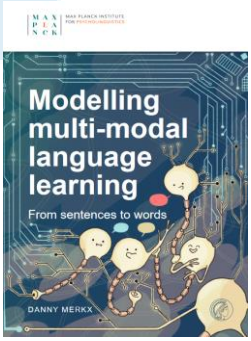
Singing is silver, hearing is gold: impacts of local FoxP1 knockdowns on auditory perception and gene expression in female zebra finches



Ileana Camerino

Radboud University Nijmegen

White matter tracts associated with executive aspects of language production in small vessel disease and stroke



Danny Merkx

Radboud University Nijmegen

Modelling multi-modal language learning: from sentence to words

FINANCES

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

Subproject	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Big Question 1	-	-	-	-	115,516	239,148	332,642	331,892	108,382	240,285	250,562	33,400	1,651,826
Big Question 2	-	-	-	-	6,931	144,816	195,511	280,777	249,810	94,559	216,678	30,515	1,219,597
Big Question 3	-	-	-	-	43,864	256,770	443,771	309,158	224,687	103,791	109,124	47,485	1,538,649
Big Question 4	-	-	-	-	137,649	422,596	710,098	794,825	878,543	782,108	660,426	164,709	4,550,954
Big Question 5	-	-	-	-			16,818	287,385	384,201	478,985	666,318	40,513	1,874,220
Work Packages	50,013	600,730	1,176,631	1,520,791	1,425,461	1,378,271	477,044	172,704	36,045	18,104	-	-	6,855,794
Societal Impact Package	17,862	130,146	156,869	178,723	200,821	195,008	156,203	155,213	76,891	148,392	498,091	199,620	2,113,839
Synergy Project	-	-	-	-	-	-	59,663	252,082	358,502	268,631	335,098	-	1,273,976
Other scientific contracts	89,694	165,513	265,474	487,102	573,517	631,848	562,605	372,037	249,506	407,501	779,369	406,998	4,991,163
Total scientific	**157,569**	**896,389**	**1,598,974**	**2,186,616**	**2,503,759**	**3,268,457**	**2,954,355**	**2,956,073**	**2,566,567**	**2,542,355**	**3,515,665**	**923,239**	**26,070,018**
Management budget	€ 57,617	213,094	175,580	502,993	204,188	215,843	265,116	437,336	209,990	241,806	314,541	185,932	3,024,035
Total	**215,185**	**1,109,483**	**1,774,554**	**2,689,609**	**2,707,947**	**3,484,300**	**3,219,471**	**3,393,409**	**2,776,557**	**2,784,162**	**3,830,206**	**1,109,171**	**29,094,053**

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 2022, 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.

The BQ1 endeavour is inherently interdisciplinary in that it applies computational research methods to explain neural, behavioural, and linguistic empirical phenomena. One of its main innovative aspects is bringing together neurobiology, psycholinguistics, and linguistic theory (roughly corresponding to different levels of description of the language system) using a single mathematical formalism; a feat that requires extensive interdisciplinary team collaboration.

Progress in 2022

BQ1 entered its final phase in 2022, with two PhD students submitting their dissertations, and the contract of the coordinating postdoc ending. The BQ focussed on increasing internal collaboration and interdisciplinary work. To this end, three new research assistant positions were created. The first RA assisted the team in simulating iEEG data using a neurobiologically realistic neuron model. Two other RAs will assist in developing a reference corpus of syntactically interesting phenomena in Dutch, annotate these with human judgements and behavioural/neurophysiological measures, and evaluate a range of large neural language models on their ability to learn the phenomena.

TEAM MEMBERS

Coordinators and steering group:			
Stefan Frank (*coordinator*)	Julia Berezutskaya (*coordinating postdoc*)		
Marcel van Gerven	Hartmut Fitz	Jelle Zuidema	
PhDs:	Samira Abnar	Marianne de Heer Kloots	Alessio Quaresima
Other team members:	Rens Bod	Mirjam Ernestus	Raquel Fernández
	Peter Hagoort	Karl Magnus Petersson	Jakub Szymanik
	Petros Vlachos		
Collaborators:	David Neville	Roel Willems	
PhD graduates 2022:	Danny Merkx		

BIG QUESTION 1: KEY PUBLICATIONS AND AWARD / RESEARCH HIGHLIGHTS

KEY PUBLICATIONS (2022):

1. **Merkx, D.,** Scholten, S., **Frank, S.L., Ernestus, M.,** & Scharenborg, O. (in press). Modelling word learning and recognition using visually grounded speech. Cognitive Computation.
2. **Quaresima, A., Fitz, H.,** Duarte, R., van den Broek, D., **Hagoort, P., and Petersson, K.M.** (2022). The Tripod neuron: A minimal structural reduction of the dendritic tree. Journal of Physiology, 58
3. Yang, J., Van den Bosch, A., **& Frank, S.L.** (2022). Unsupervised text segmentation predicts eye fixations during reading. Frontiers in Artificial Intelligence, 5, 731615

AWARD HIGHLIGHTS:

1. **Stefan Frank** was awarded a NWO-SSH Open Competition Grant (project title "The statistics of language as a novel window into the multilingual mind")
2. **Raquel Fernández** was appointed Professor of Computational Linguistics and Dialogue Systems, University of Amsterdam
2. **Danny Merkx** won the best student paper award at the Cognitive Modeling and Computational Linguistics workshop.
3. **Julia Berezutskaya** was awarded a NWO-XS Open Competition Grant (project title "REANIMATE: bRain triggered Electrical stimulAtioN for Inducing Muscle Activation in individuals with sEvere facial paralysis")

BQ1 - Highlight 1

Visually grounding word embeddings to better capture human semantic knowledge
Danny Merkx, Stefan Frank and Mirjam Ernestus

Distributional semantic models capture word-level meaning that is useful in many natural language processing tasks and have even been shown to capture cognitive aspects of word meaning. The majority of these models are purely text based, even though the human sensory experience is much richer. In this paper we create visually grounded word embeddings by combining English text and images and compare them to popular text-based methods, to see if visual information allows our model to better capture cognitive aspects of word meaning. Our

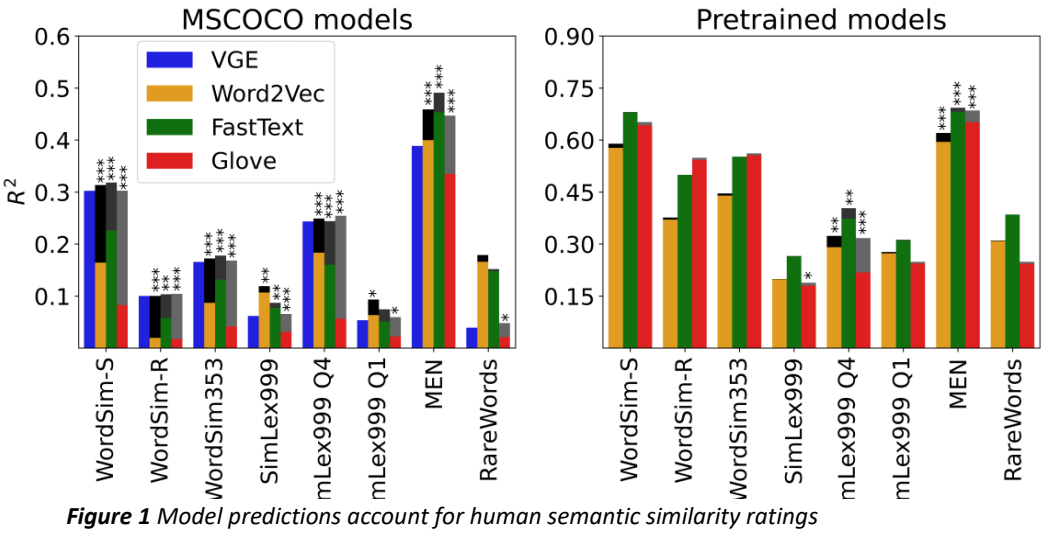


Figure 1 *Model predictions account for human semantic similarity ratings*

analysis shows that visually grounded embedding similarities are more predictive of the human reaction times in a large semantic priming experiment than the purely text-based embeddings.

The visually grounded embeddings also correlate well with human word similarity ratings. Importantly, in both experiments we show that the grounded embeddings account for a unique portion of explained variance, even when we include text-based embeddings trained on huge corpora. This shows that visual grounding allows our model to capture information that cannot be extracted using text as the only source of information.

The coloured bars indicate the proportion of explained variance (R2) on eight data(sub)sets by four word-embedding models: our Visual Grounded Embeddings (VGE) and three well known text-based models. The grey-scale bars on top of the R2 of the text-based models indicate the semi-partial R2 and their significance (* $p < .05$, ** $p < .01$, *** $p < .001$) of the VGEs after controlling for the variance explained by that text-based model. Left panel: models trained on the MSCOCO dataset of image-caption pairs. Right panel: models trained on very large text-only datasets.

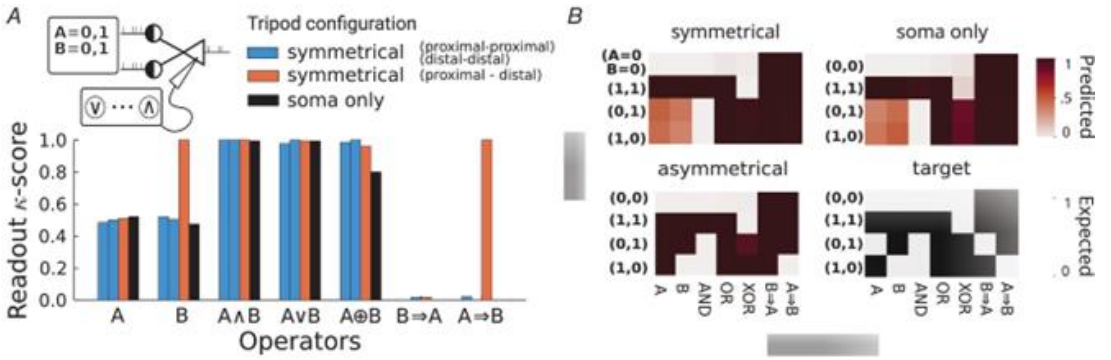
BQ1 - Highlight 2

The Tripod neuron: a minimal structural reduction of the dendritic tree

Alessio Quaresima, Hartmut Fitz, Renato Duarte, Dick van den Broek, Peter Hagoort, Karl Magnus Petersson

Neuron models with explicit dendritic dynamics have shed light on mechanisms for coincidence detection, pathway selection and temporal filtering. However, it is still unclear which morphological and physiological features are required to capture these phenomena. In this work, we introduce the Tripod neuron model and propose a minimal structural reduction of the dendritic tree that is able to reproduce these computations. The Tripod is a three-compartment model consisting of two segregated passive dendrites and a somatic compartment modelled as an adaptive, exponential integrate-and-fire neuron. It incorporates dendritic geometry, membrane physiology and receptor dynamics as measured in human pyramidal cells.

We characterize the response of the Tripod to glutamatergic and GABAergic inputs and identify parameters that support supra-linear integration, coincidence-detection and pathway-specific gating through shunting inhibition. Following NMDA spikes, the Tripod neuron generates plateau potentials whose duration depends on the dendritic length and the strength of synaptic input. When fitted with distal compartments, the Tripod encodes previous activity into a dendritic depolarized state. This dendritic memory allows the neuron to perform temporal binding, and we show that it solves transition and sequence detection tasks on which a single-compartment model fails. Thus, the Tripod can account for dendritic computations previously explained only with



more detailed neuron models or neural networks. Due to its simplicity, the Tripod neuron can be used efficiently in simulations of larger cortical circuits.

Figure 2. *Asymmetric dendrites enhance separability of logical operations.*

A, Cohen's kappa-score accuracy of linear readout classifiers on logical operators for symmetric, asymmetric and soma-only models. The dendritic configurations are proximal–proximal and distal–distal (blue), proximal–distal (orange) and soma-only (black). B, Shade of red indicates the average predicted truth-value for each input condition (y-axis), operator (x-axis) and dendritic configuration (top and left panels). Black and white table (bottom-right) indicates the expected truth-values. For example the AND operator for symmetric dendrites shows dark red (true) for condition A = 1, B = 1, and white for all the remaining conditions, corresponding to the target truth-values.

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

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. The big question is to characterize the Kantian brain for language.

Progress in 2022

During 2022 the BQ2 team meetings continued, and were mainly focused on discussions around potential perspective papers that may be written based on the combined knowledge within the BQ2. Three broad topic areas were identified that fall under the following headings: 'The role of subcortical brain structures in the timing of language-related processes'; 'The current state of neural oscillations research in language processing'; 'Which levels of description of human neural architecture are most relevant to which levels of description of language processing?'. A new postdoc was hired to bridge between the BQ2 and BQ4, applying connectopics methods developed in the context of the BQ2 to individual differences data from the BQ4.

TEAM MEMBERS:

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

PhDs:	João Ferreira	Guilherme Blazquez Freches	
Other team members:	Christian Beckmann	Marius Braunsdorf	Simon Fisher
	Elia Formisano	Clyde Francks	Roy Kessels
	Floris de Lange	Lukas Lütje	Rogier Mars
	Vitória Piai	Nick Ramsey	Ardi Roelofs
	Jan-Mathijs Schoffelen	Sourena Soheili-Nezhad	Ivan Toni
Collaborators	Umut Güçlü	Daniel Sharoh	Maggie Wong
PhD graduates 2022:	Ileana Camerino		

KEY PUBLICATIONS (2022):

1. **Camerino, I., Ferreira, J.,** Vonk, J. M., **Kessels, R**. P., de Leeuw, F. E., **Roelofs, A.,** David Copland, & **Piai, V.** (2022). Systematic Review and Meta-Analyses of Word Production Abilities in Dysfunction of the Basal Ganglia: Stroke, Small Vessel Disease, Parkinson's Disease, and Huntington's Disease. Neuropsychology Review, 1-26.

2. **Sierpowska, J**., Bryant, K. L., **Janssen, N**., **Blazquez Freches,** G., Römkens, M., **Mangnus, M., Mars, R., & Piai, V.** (2022). Comparing human and chimpanzee temporal lobe neuroanatomy reveals modifications to human language hubs beyond the frontotemporal arcuate fasciculus. Proceedings of the National Academy of Sciences, 119(28), e2118295119.

3. Cao, Y., Oostenveld, R., Alday, P. M., & **Piai, V**. (2022). Are alpha and beta oscillations spatially dissociated over the cortex in context-driven spoken-word production?. Psychophysiology, 59(6), e13999

4. Eising, E., Mirza-Schreiber, N., De Zeeuw, E. L., Wang, C. A., Truong, D. T., ..., St Pourcain, B., **Francks, C.**, & **Fisher, S. E.** (2022). Genome-wide analyses of individual differences in quantitatively assessed reading- and language-related skills in up to 34,000 people. Proceedings of the National Academy of Sciences of the United States of America, 119(35): e2202764119.

5. Heilbron, M., Armeni, K., **Schoffelen, J., Hagoort, P., & de Lange, F. P.** (2022). A hierarchy of linguistic predictions during natural language comprehension. Proceedings of the National Academy of Sciences of the United States of America, 119(32): e2201968119.

AWARD HIGHLIGHTS

1. **Clyde Francks** was appointed Professor of Brain Imaging Genomics, Radboud University Medical Center

BIG QUESTION 2 - HIGHLIGHTS

BQ2 - Highlight 1

Low frequency neural oscillations for feedback signalling during sentence comprehension

Ashley Lewis, Floris de Lange, and Peter Hagoort

The purpose of this project is to develop linguistic paradigms in which the relative contributions of feedforward and feedback information streams can be manipulated in order to study the associated neural architecture. This magnetoencephalography (MEG) study used Dutch sentences that provided either strong contextual constraint towards a particular target word (TW), or were less constraining and allowed multiple TWs as a potential sentence completion. In half of the experimental blocks the TW in the sentence was visually degraded (this was made explicit to participants at the beginning of each block), thus encouraging readers to rely more on feedback information provided by the sentence context to fill in the missing feedforward information.

Visual degradedness was achieved through low-pass spatial filtering, somewhat akin to noise-vocoding with speech stimuli. Based on previous literature we hypothesized that alpha oscillations (8-12 Hz) prior to the onset of the TW would provide an index of feedback signalling in the MEG when participants try to anticipate which TW will appear in the input. Beamforming was used to obtain time-resolved estimates of activity at 15684 points on a cortical sheet constructed from each participant's individual anatomical MRI, and pointwise connectivity in the alpha band was computed using imaginary coherence. Dimensionality of these estimates was reduced to 374 cortical parcels based on a modified version of the Conte69 atlas, and cluster-based permutation statistics were used to compare connectivity estimates between conditions of interest.

Figure 3 shows the most relevant result, with increased connectivity ($p = 0.008$) between left frontal and left temporal cortical regions (i.e., perisylvian regions often implicated in sentence comprehension) in blocks where the TW was visually degraded, prior to the onset of the TW. This increased alpha connectivity when readers anticipate a need to use feedforward information to predict a visually degraded TW is consistent with our hypothesis that feedforward signalling in the brain's language network is carried out via low frequency neural oscillations. Follow-up analyses will probe the direction of information transfer in these perisylvian language networks using Granger causality.

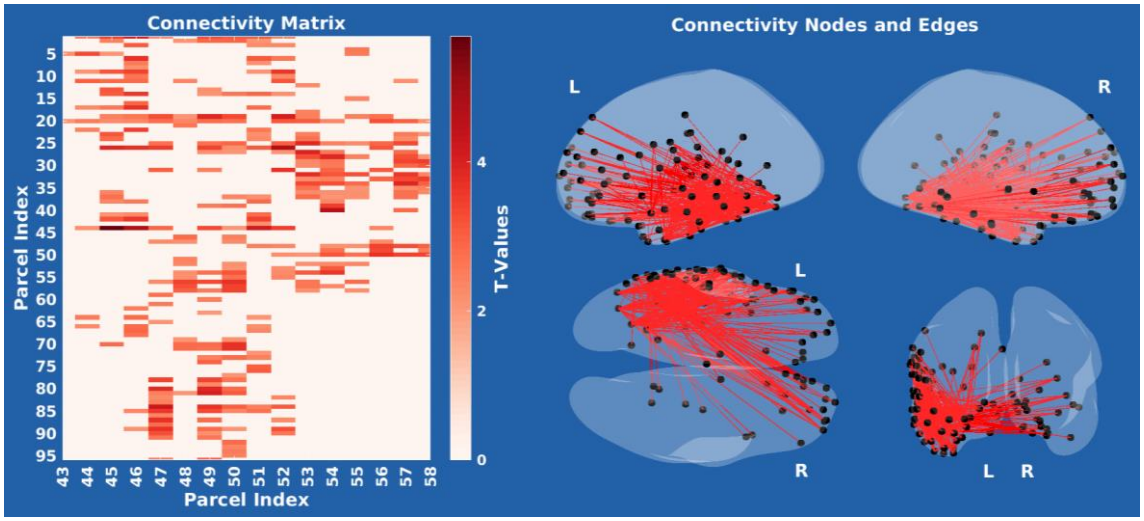


Figure 3. Pre-TW alpha connectivity for visually degraded vs non-degraded contrast. *Left: connectivity matrix with T-values indicating cortical parcels exhibiting increased alpha band connectivity in visually degraded experimental blocks, masked by the cluster-based permutation statistics output. Right: Connectivity values projected onto inflated cortical surface for connections surviving multiple comparisons correction. Black dots indicate nodes, and red lines edges, with the thickness of the line proportional to connectivity strength. Left (L) and right (R) hemispheres marked.*

This project directly addresses a core question of the BQ2: the role of low and high frequency neural oscillations in feedback and feedforward signalling in the brain to support language processing. In doing so, it brings together experts from psycholinguistics/cognitive neuroscience of language, prediction and attention, and cutting-edge methods for the analysis of neural oscillations.

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 dimensions over multiple communicative resources (speech, 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 2022

Deep collaboration between BQ3 active members continues to be at the root of this initiative. In 2022, the team has shared with the community the empirical data collected in BQ3, making it attractive and accessible to different sub-fields (e.g. phonologists, conversation analysts, cognitive neuroscientists, computational linguists). This example of team-science and open-science has resulted in a publication illustrating the features of the shared dataset, and this initiative has already attracted numerous request for accessing those data. Collaboration with BQ1 has set in motion a new project providing in-depth quantitative investigations of the face-to-face multimodal interactions recorded in BQ3. The latter step, besides generating novel insights in its own right, opens the way to relate variations in communicative behaviour to variations in neural representations of the dialogue referents. We have also started new analyses of the behavioural and neuroimaging data focused on explaining sources of inter-individual differences.

TEAM MEMBERS

Coordinators and steering group: Ivan Toni (*coordinator*)

PhDs:	Lotte Eijk	Marlou Rasenberg	
Other team members:	Sara Bögels	Mark Dingemanse	Christian Döller
	Mirjam Ernestus	Raquel Fernandez	Esam Ghaleb
	Judith Holler	Stephen Levinson	Tianyi Li
	Asli Özyürek	Wim Pouw	Iris van Rooij
	Herbert Schriefers	Jan-Mathijs Schoffelen	
Collaborators	Mark Blokpoel	Laura van de Braak	

KEY PUBLICATIONS (2022):

1. **Eijk, L., Rasenberg, M., Arnese, F., Blokpoel, M., Dingemanse, M., Doeller, C. F., Ernestus, M., Holler, J., Milivojevic, B., Özyürek, A., Pouw, W., van Rooij, I., Schriefers, H., Toni, I., Trujillo, J.P., & Bögels, S.** (2022). The CABB dataset: A multimodal corpus of communicative interactions for behavioural and neural analyses. NeuroImage, 264, 119734.
2. **Dingemanse, M.**, Liesenfeld, A., **Rasenberg, M.,** Albert, S., Ameka, F. K., Birhane, A., ... & Wiltschko, M. (2023). Beyond Single-Mindedness: A Figure-Ground Reversal for the Cognitive Sciences. Cognitive science, 47(1), e13230.
3. **Rasenberg, M., Pouw, W., Özyürek, A.,** & **Dingemanse, M.** (2022). The multimodal nature of communicative efficiency in social interaction. Scientific Reports, 12(1), 19111.

4. **Liu, R., Bögels, S.,** Bird, G., Medendorp, W. P., & **Toni, I.** (2022). Hierarchical Integration of Communicative and Spatial Perspective-Taking Demands in Sensorimotor Control of Referential Pointing. Cognitive Science, 46(1), e13084.
5. **Holler, J.** (2022). Visual bodily signals as core devices for coordinating minds in interaction. Philosophical Transactions of the Royal Society B, 377(1859), 20210094.

BIG QUESTION 3: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS

1. **Asli Özyürek** was appointed Director of Multimodal Language Department of Max Planck Institute for Psycholinguistics.

BIG QUESTION 3 –HIGHLIGHTS

BQ3 - Highlight 1

The multimodal nature of communicative efficiency in social interaction

Marlou Rasenberg, Wim Pouw, Asli Özyürek, Mark Dingemanse

This project proposes a synthesis of work on joint action and language use, using primary data, novel methods and theoretical insights from the CABB project to study communicative efficiency in social interaction. Combining kinematic measures and annotations derived from speech, it investigates how people divide the joint work of arriving at mutual understanding.

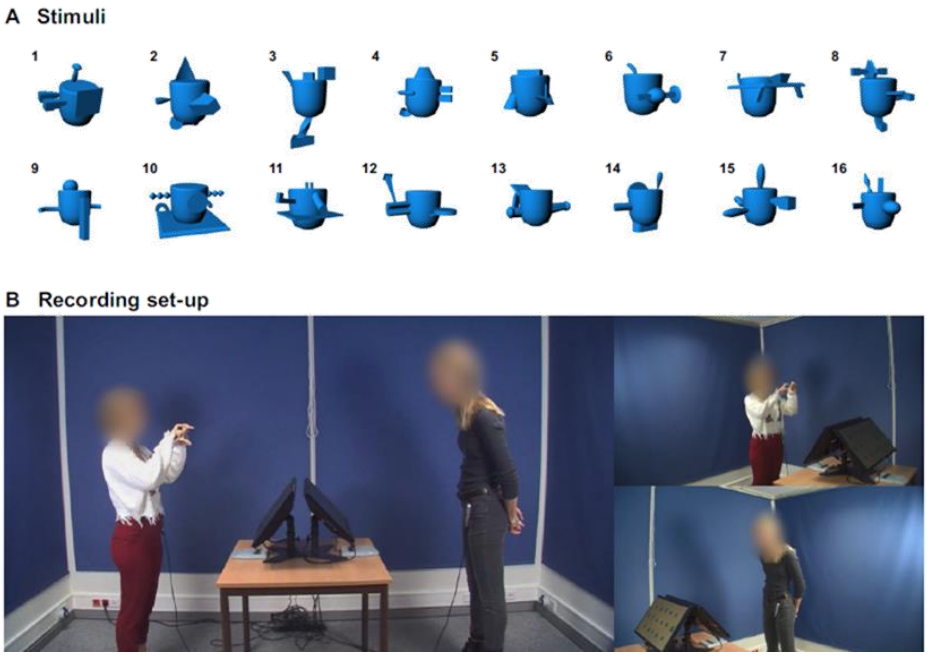


Figure 4. *A) "Fribbles" used as stimuli; B) Experimental set-up.*

We have investigated whether and how people minimize their joint speech and gesture efforts in face-to-face interactions, using linguistic and kinematic analyses. We zoom in on other-initiated repair—a conversational microcosm where people coordinate their utterances to solve problems with perceiving or understanding. We find that efforts in the spoken and gestural modalities are wielded in parallel across repair turns of different types, and that people repair conversational problems in the most cost-efficient way possible, minimizing the joint multimodal effort for the

dyad as a whole. These results are in line with the principle of least collaborative effort in speech and with the reduction of joint costs in non-linguistic joint actions. The results extend our understanding of those co-efficiency principles by revealing that they pertain to multimodal utterance design.

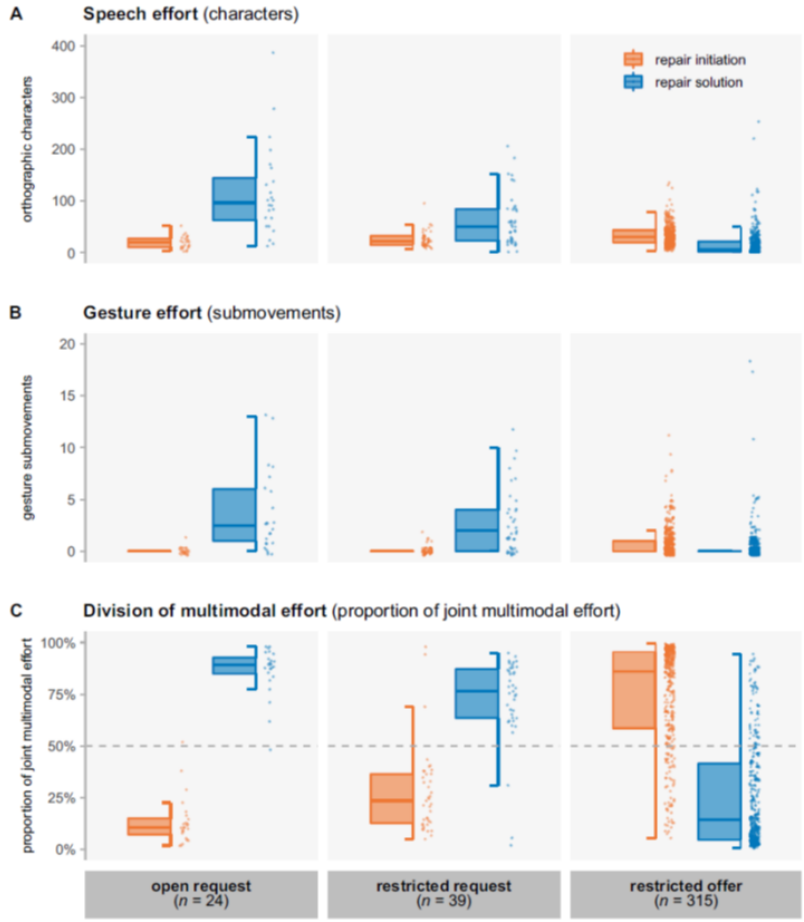


Figure 5 *Boxplots showing the effort invested in the repair initiation (orange) and repair solution (blue), for repair formats of increasing specificity (open request < restricted request < restricted offer). The boxes represent the interquartile range; the middle line the median; the whiskers the minimum and maximum scores (outliers excluded). Every dot represents a repair initiation or solution. Absolute speech effort (A) and absolute gesture effort (B) both go up in repair initiations and down in repair solutions as repair formats become more specific. Proportional multimodal effort (C) shifts from repair initiation to repair solution as we move towards more specific repair formats. The dashed line represents equal division of effort across participants.*

The findings indicate that speech and gesture efforts rise and fall together across repair types and sequential positions. This corroborates the view that speech and gesture are integral parts of a single multimodal communicative system, providing a novel and quantitative interdisciplinary perspective on studies of language use and nonlinguistic joint action. This project is a direct result of BQ3's multidisciplinary approach, integrating different aspects of human communication in a comprehensive multimodal dataset relevant for a wide range of disciplines.

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 2022

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). Approximately 700 individuals between 18 and 30 years of age have completed the battery and provided saliva samples. Analyses are currently underway. Work in the neurobiological sub-project of Strand A is still ongoing. Data collection will be finished in the summer of 2022.

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, in two sub-projects. In each of these sub-projects, data are collected from a behavioural test battery on second language acquisition and cognitive measures and from functional MRI experiments (on grammar and word-learning, respectively), and structural and resting state MRI measures are also taken.

TEAM MEMBERS

Coordinators and steering group: Antje Meyer (*coordinator BQ4A*), James McQueen (*coordinator BQ4B)* Florian Hintz (*coordinating postdoc*)

PhDs:	Christina Isakoglou		
Other team members:	Christian Beckmann	Marius Braunsdorf	Clara Ekerdt
	Guillén Fernandez	Simon Fisher	Stephanie Forkel
	Peter Hagoort	Gabriele Janzen	Tamar Johnson
	Jiska Koemans	Merel Koning	Willeke Menks
	Kristin Lemhöfer	Janay Monen	Ingrid Szilagyi
	Atsuko Takashima	Nina Wyman	
Collaborators	Rogier Kievit	Andre Marquand	

KEY PUBLICATIONS (2022):

1. Corps, R. E., Knudsen, B., & **Meyer, A. S.** (2022). Overrated gaps: Inter-speaker gaps provide limited information about the timing of turns in conversation. Cognition, 223: 105037. doi:10.1016/j.cognition.2022.105037.
2. Strauß, A., Wu, T., **McQueen, J.** M., Scharenborg, O., & **Hintz, F.*** (2022). The differential roles of lexical and sublexical processing during spoken-word recognition in clear and in noise. Cortex, 151, 70-88.
3. **Menks, W. M., Ekerdt, C., Janzen, G., Kidd, E., Lemhöfer, K., Fernández, G., & McQueen, J. M. (2022)**. Study protocol: A comprehensive multi-method neuroimaging approach to disentangle developmental effects and individual differences in second language learning. BMC Psychology, 10: 169

BIG QUESTION 4: AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS

1. **Florian Hintz** was appointed Senior Investigator at the Max Planck Institute for Psycholinguistics.
2. **Florian Hintz** became a member of DFG-funded Research Network for the Interdisciplinary Study of Predictive Processing in Memory and Perception (PPiMP)

BIG QUESTION 4 - HIGHLIGHTS

BQ4 - Highlight 1

Specific neural networks underlie age-related variability in grammar learning success.

Willeke Menks, Clara Ekerdt, Guillen Fernández, Gabriele Janzen, Evan Kidd, Kristin Lemhöfer and James McQueen

This project used the fMRI dataset from the grammar sub-project of strand B (1) to investigate age-related variability in grammar learning success during the initial learning phase and (2) to explore the neural mechanism underlying this age-related grammar learning variability within a large developmental sample of 165 typically developing individuals aged 8-25 years.

Behaviourally, we observed a strong linear correlation between age and grammar learning success until 16.2 years of age. Above that point, age was not predictive any more for grammar learning success. This turning point is in line with previous behavioural studies, and this study is the first that is able to investigate the underlying neural correlates.

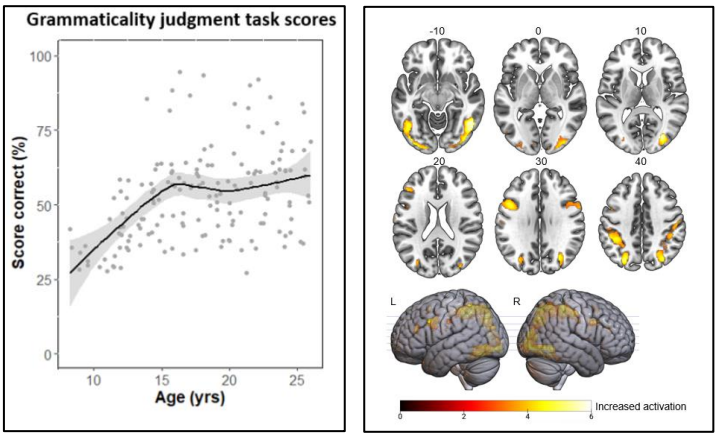


Figure 6. *LEFT: GJT scores plotted against age overlaid with a fitted line by a LOESS function (black). The shaded areas indicate the confidence interval (95%) of the estimated curve. RIGHT: Statistical parametric map (cluster-level, p < .05 FWE-corrected) displaying whole-brain increased (red-yellow) activation during grammar processing in relation to the LOESS fitted curve, that is, the combined effects of age(-related) and grammar learning success during the pre-training session.*

On the neural level, age-related grammar learning success was reflected by increased activation in language-specific and domain-general brain areas, such as the bilateral inferior frontal gyrus, inferior parietal gyrus, and inferior temporal gyrus. A group comparison—split at the turning point—showed that older participants recruited these networks more compared to children and young adolescents, which suggests that maturation of these networks could explain the observed age-related grammar learning differences. Overall, these novel findings suggest that grammar learning success is dependent on age till late adolescence and that those differences are linked to the maturation of language and working memory networks.

This work contributes to the overarching quest of Language in Interaction through its interdisciplinary approach, across psycholinguistics, memory, and (neuro)development within a large-scale developmental sample. These novel findings provide evidence for a direct link between age and grammar learning success and its neural correlates. Close collaboration and team science within the language in Interaction consortium teams of BQ4 made our interdisciplinary approach possible. We hope this work will motivate and guide future research to continue to investigate the underlying mechanisms of age-related variability in second language acquisition.

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 making 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.

Progress in 2022

In 2022, two key members of the BQ5 left the team due to personal reasons. The team also welcomed members: Postdoc Marieke Woensdregt, who jointly leads one of the subprojects, and RAs Anna Aumeistere and Lisa Horstman. Two MA students are writing their theses within BQ5. BQ5 held monthly meetings which invited both internal and external speakers, discussed their research findings and discussed BQ5-related general issues such as the BQ's position paper and the preparation for the upcoming SAB visit (January 2023). The entire team jointly worked on the position paper, led by Rene Terporten, Xiaochen Zheng and Roshan Cools.

The interactive potential of BQ5 is also illustrated by the collaborative efforts between subprojects, who jointly set up a large pharmacological-fMRI study investigating (1) the dopaminergic mechanisms of context-dependent representations of word meanings and (2) compositional inference in language.

TEAM MEMBERS

Coordinators and steering group: Roshan Cools (*coordinator*), Andrea Martin (*coordinator)* Xiaochen Zheng (*coordinating postdoc*)

PhDs:	Elena Mainetto		
Other team members:	Silvy Collin	Rene Terporten	Hanneke den Ouden
	Ioanna Zioga	Iris van Rooij	Ashley Lewis
	Stefan Frank	Marieke Woensdregt	Anna Aumeistere
	Lisa Horstman		
Collaborators:	Mark Blokpoel	Monique Flecken	Anya Petukhova
	Saskia Haegens	Mona Garvert	Roel Willems
	Katarina Labancova		

KEY PUBLICATIONS (2022):

1. Adolfi, F., Wareham, T., & van **Rooij, I**. (2022). A computational complexity perspective on segmentation as a cognitive subcomputation. Topics in Cognitive Science.
2. Dai, B., **McQueen, J. M., Terporten, R., Hagoort, P.**, & Kösem, A. (2022). Distracting Linguistic Information Impairs Neural Tracking of Attended Speech. Current Research in Neurobiology, 100043
3. **Zheng, X. Y**., Hebart, M. N., Dolan, R. J., **Doeller, C. F., Cools, R.**, & **Garvert, M. M.** (2022). Parallel cognitive maps for short-term statistical and long-term semantic relationships in the hippocampal formation. bioRxiv
4. **Zheng, X. Y.** & **Piai, V.** (2022). Neural oscillations of interference control in the aging brain: evidence from picture-word interference. bioRxiv
5. **Zioga, I.**, Weissbart, H., **Lewis, A.** G., **Haegens, S.**, & **Martin, A. E.** (2022). Naturalistic language comprehension is supported by alpha and beta oscillations linked to domain-general inhibition and reactivation. bioRxiv.

BIG QUESTION 5 – AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. Roshan Cools was awarded an ERC advanced Grant: CHEMCONTROL "Balancing brain chemicals for boosting meta-control"

BIG QUESTION 5 - HIGHLIGHTS

BQ 5 - Highlight 1

Generalization and representation of novel compositional word meanings

Xiaochen Zheng, Mona Garvert, Hanneke den Ouden, Roshan Cools

The ability to generalize previously learned information to novel situations is key for adaptive behavior. The team investigated the neural mechanisms underlying the ability to infer novel compositional word meanings using a novel behavioral paradigm in fMRI. Results suggest that generative inference in language recruits a domain-general network shared with action planning, compositional vision and constructive relational memory, while the newly inferred meanings are represented in more language-specific regions.

Participants were taught the meaning of artificial compositional words from an artificial language comprising extant stems ("good") and novel affixes ("kla"). The meaning of the compositional words depended on the position of the novel affix ("goodkla = bad", "klahorse = pony"). They were then asked to infer the meaning of novel compositional words ("whitekla =?", "klacat =?") which were either congruent or incongruent with the rule ("klawhite" is incongruent because a small version of "white" does not exist). To do this, they had to generalize the sequential order rule they inferred during training (e.g., if kla occurs after the stem, then it reverses the meaning of the stem). During fMRI, participants performed a semantic priming task in which the novel words served as congruent or incongruent primes ("whitekla") and their synonyms ("black") served as targets. Faster responses on congruent than incongruent targets show that people are able to generate novel compositional meanings on the fly, successfully inferring meanings of congruent versus incongruent words. Neural repetition suppression effects at target were greater when primed with congruent than incongruent words in the left inferior frontal gyrus, suggesting the novel meanings to be derived at this linguistic "building" hub. Analysis of congruent versus incongruent prime-related activity revealed a broad frontal-parietal network, including hippocampus, the brain area commonly associated with the generalization process of abstract, generalizable, structural relationships.

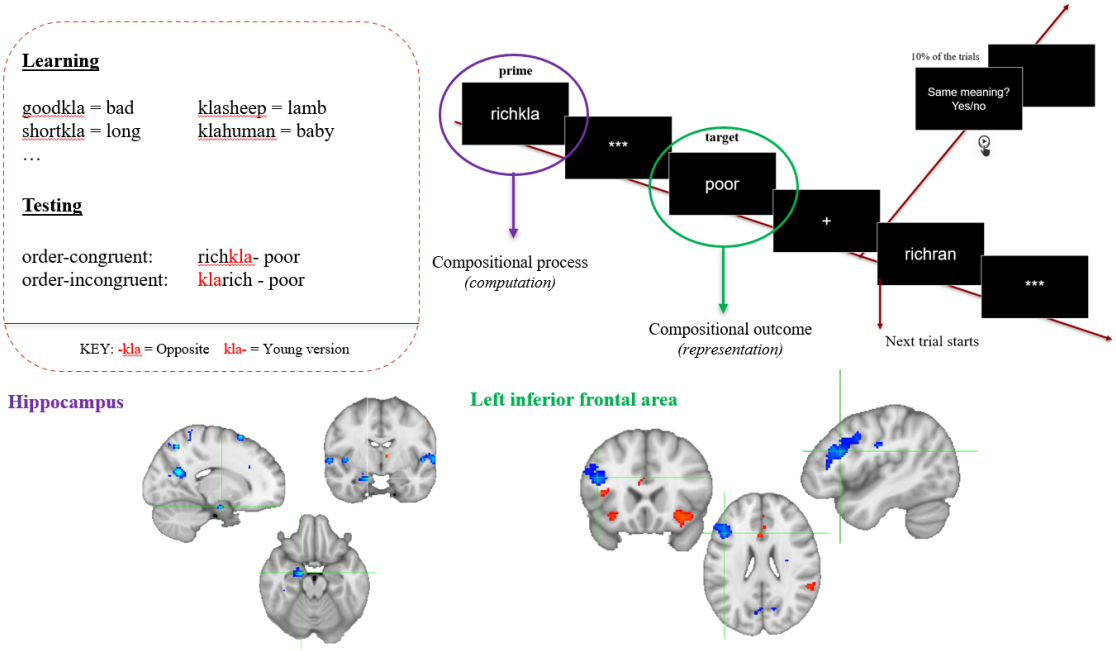


Figure 7. *Experimental paradigm and main fMRI findings. Participants learned compositional pseudo-words consisting of a known stem (e.g., "good" in "good-kla") and an unknown affix (e.g., "kla"). The affix alters the word meaning depending on its position (e.g., "-kla" as a suffix means the opposite, whereas "kla-" as a prefix means "young version"). We tested participants' knowledge with novel, compositional pseudo-words using a fMRI adaptation paradigm where they viewed pseudo-words which is either congruent in sequential order (e.g., "rich-kla", where "-kla" means "opposite"), or incongruent in order (e.g., "kla-rich", where "-kla" but not "kla-" means "opposite") as in the learning, followed by a matched or unmatched target synonym word. Repetition suppression effects at target were greater when primed with congruent than incongruent words in the left inferior frontal area. Analysis of congruent versus incongruent prime-related activity revealed a broad frontal-parietal network, including hippocampus.*

The current project investigates structural inference in language and leverages knowledge from vision, memory and planning. It not only extends our understanding of the flexible and efficient nature of language processing – the key question addressed by BQ5 – , but also probes its possibly shared mechanisms with other cognitive domains. The current project is challenging because of the different languages spoken by and common conceptual misalignment between the psycholinguists versus neuroscientists on learning and decision making. Nevertheless, through active, resilient and well-coordinated team science, an integrative novel design, unique ideas and preliminary advance in understanding were achieved not otherwise possible.

BQ 5 - Highlight 2

Parallel cognitive maps for short-term statistical and long-term semantic relationships in the hippocampal formation

Xiaochen Zheng, Roshan Cools, Mona Garvert, Martin Hebart, Raymond Dolan, Christian Doeller

The hippocampal-entorhinal system uses cognitive maps to represent spatial knowledge and other types of relational information. We investigated how the hippocampal formation handles the embedding of stimuli in multiple relational structures that differ vastly in terms of their mode and timescale of acquisition (e.g., semantic similarities learned over the course of one's lifetime versus transitions experienced over a brief timeframe in an experimental setting).

We reanalysed functional magnetic resonance imaging (fMRI) data from Garvert et al. (2017)

that had previously revealed an entorhinal map which coded for newly learnt statistical regularities. We used a triplet odd-one-out task to construct a semantic distance matrix for presented items and applied fMRI adaptation analysis to show that the degree of similarity of representations in bilateral hippocampus decreases as a function of semantic distance between presented objects. Importantly, while both maps localize to the hippocampal formation, this semantic map is anatomically distinct from the originally described entorhinal map. This finding supports the idea that the hippocampal-entorhinal system forms parallel cognitive maps reflecting the embedding of objects in diverse relational structures.

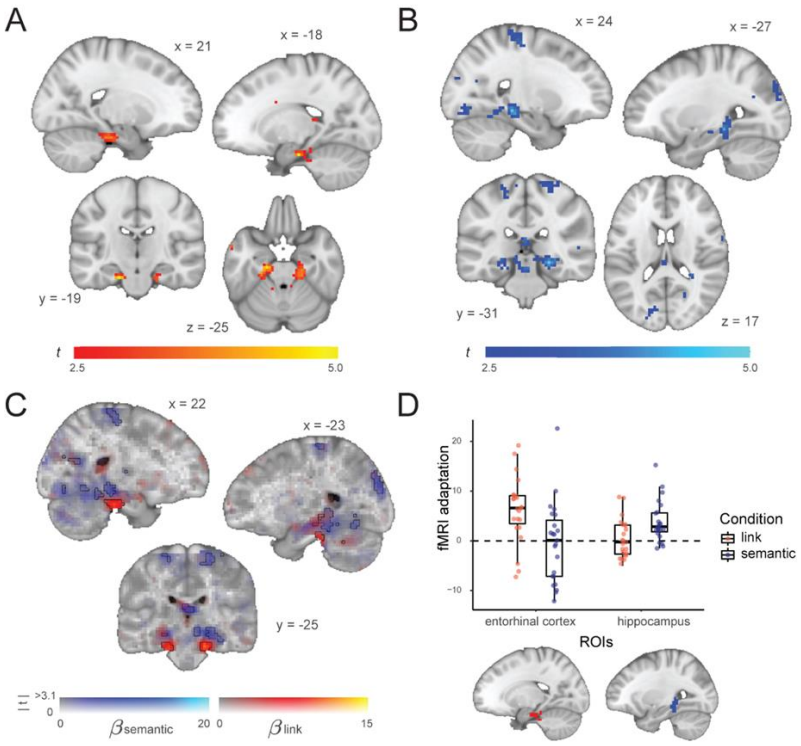


Figure 8. *Statistical and semantic relationships are represented in non-overlapping clusters in the hippocampal-entorhinal system. (A) Whole-brain analysis showing a decrease in fMRI adaptation with link distance in the entorhinal cortex, when link distance, semantic distance and residual distance are included in the model. (B) Whole-brain analysis showing a decrease in fMRI adaptation with semantic distance in the hippocampus, when link distance, semantic distance and residual distance are included in the model. (C) Link distance effect (red) and semantic distance effect (blue) are represented in non-overlapping clusters. Whole-brain results are displayed using Slice Display (Zandbelt, 2017) using a dual-coding data visualization approach (Allen, Erhardt, & Calhoun, 2012), with color indicating the parameter estimates and opacity the associated t statistics. Solid and dotted contours outline statistically significant clusters for the link and the semantic effects, respectively. (D) Bottom: The two ROIs defined based on the link distance effect in the entorhinal cortex (in red) and the semantic distance effect in the hippocampus (in blue). Top: boxplot of the parameter estimates for the link distance and semantic distance effects extracted from the two ROIs. The thick horizontal line inside the box indicates the median, and the bottom and top of the box indicate the first and third quartiles of each condition. Each dot represents one participant. The plot is for visualization only, since the contrast used for defining the ROIs is not independent from the interaction effect of interest here. Both (A) and (B) are thresholded at p < .01, uncorrected for visualization.*

This work contributes significantly to current theorizing about how our brain organizes knowledge of the world, and imposes new constraints on the cognitive computations the brain can perform to make novel inferences and support flexible behaviour. This project is closely

related to the original BQ5 proposal on map-like encoding for integrated cognitive representation. Knowledge gained from this project also supports multiple BQ5 projects such as meaning representation and structural inference (SP1 & SP5). This work concerns interdisciplinary team work (e.g., language, memory, and decision making) from three international institutes (MPI Leipzig, UCL, Donders). We also took an open science approach, re-using an existing fMRI dataset to address a novel question.

BQ 5 - Highlight 3

Computational modelling to explain flexible linguistic inference

Marieke Woensdregt, Andrea E. Martin, Iris van Rooij and Mark Blokpoel

Language comprehension involves fast and flexible inference (e.g., we can infer the meaning of a novel phrase like "mask-shaming" on first encounter). This requires two foundational abilities: (i) understanding of compositionality, and (ii) integration of context. In this project, we use computational modelling to develop an explanation of the cognitive process that combines these two abilities in order to infer linguistic meaning.

We take meaning inference of novel compound words as a test case (e.g., anderhalvemetersamenleving in Dutch, which means "one-and-a-half metre society"). We are in the process of developing a computational-level model of this inference process by building on work by Blokpoel et al. (2019), which models the cognitive ability of coming up with novel hypotheses to explain a given observation, by finding analogical matches between (transformed) representations of the observation and (transformed) representations of knowledge. Figure 9 illustrates how this computational model could be adapted for the case of inferring the meaning of novel compound words, where various constraints (lexical meaning, grammar, and background knowledge) could influence either which higher-level representations are formed, or which get selected as a plausible interpretation (through a process of inference-to-the-best-explanation).

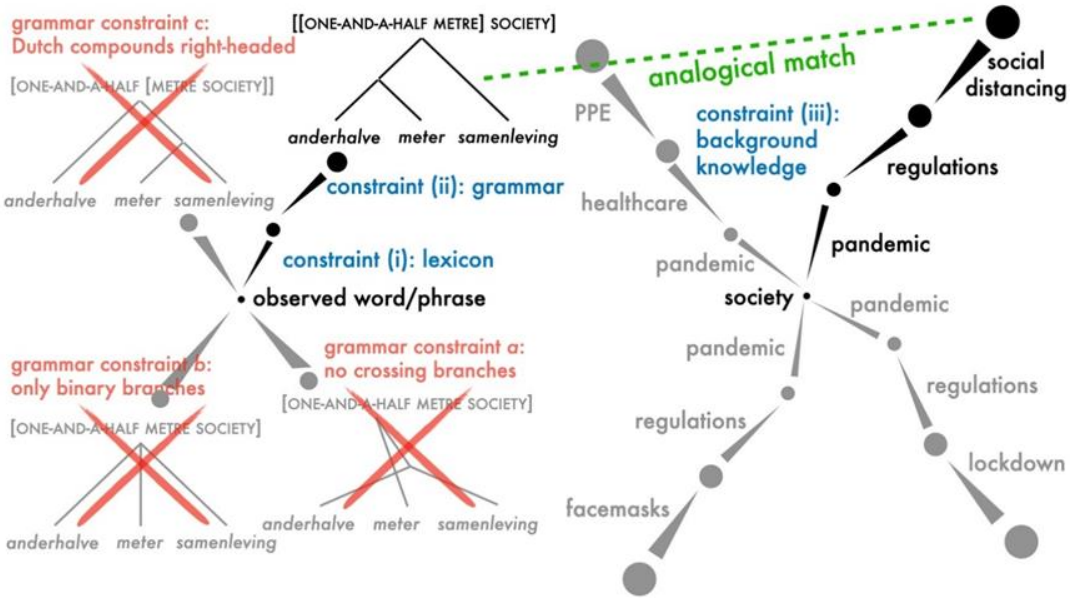


Figure 9 *Illustrative example of analogical matching process for inferring meaning of novel compounds, based on Deep Analogical Inference model of Blokpoel et al. (2019). Certain transformed representations of the observed word are excluded based on grammatical constraints, and certain transformed representations of the background knowledge are excluded because they do not form a good analogical match with (transformed representation of) the observed word.*

Language is a dynamic phenomenon, and humans are remarkably flexible in using it. This project

contributes theoretical work that aims to explain the cognitive processes that make this possible, by bringing together knowledge from linguistics, computational complexity theory and systems neuroscience, through computational modelling. Interaction with the BQ5 team has helped sharpen our formulation of the explanandum for this subproject. Furthermore, this subproject benefits greatly from discussion and collaboration within the research groups of PIs Andrea Martin (Language and Computation in Neural Systems) and Iris van Rooij (Computational Cognitive Science).

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 behaviours. 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 2022

The four-year Synergy project has entered its third year in 2022, with data collection underway for the two CMO-approved fMRI studies central to the main goal of the project: Communication in Context: Social interaction in Autism Spectrum Disorder, 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). As of December 2022, the ASD group data acquisition is completed, and the remaining 8 neurotypical and 8 SAD pairs are scheduled until May 2023. Data analysis of the various parts of these projects is

underway, with preliminary results presented at an international conference.

TEAM MEMBERS:

Coordinators:	Arjen Stolk (*coordinator*)	Jana Bašnáková (*coordinator*)	
PhDs:	Margot Mangnus		
Other team members:	Saskia Koch Bas Schippers	Maartje Grauwmans	Jordy van Langen

KEY PUBLICATIONS (2022):

1. **Stolk, A., Bašnáková, J., & Toni, I.** (2022). Joint epistemic engineering: The neglected process in human communication. In The Routledge Handbook of Semiosis and the Brain (pp. 259-278). Routledge.

2. Chu, M., Tobin, P., Ioannidou, F., & **Bašnáková, J.** (2022). Encoding and decoding hidden meanings in face-to-face communication: Understanding the role of verbal and nonverbal behaviors in indirect replies. Journal of Experimental Psychology: General.

Synergy – AWARD / RESEARCH HIGHLIGHTS

AWARD HIGHLIGHTS:

1. **Saskia Koch** was awarded a Brain and Behavior Research Foundation Young Investigator grant: "Multimodal Biomarkers of Communicative Deficits in Autism and Social Anxiety

Synergy - Highlight 1

On the integration of stereotypes and factual evidence in interpersonal communication* *Saskia B. J. Koch, Anna Tyborowska , Hannah C. M. Niermann, Antonius H. N. Cillessen, Karin Roelofs, Jana Bašnáková, Ivan Toni & Arjen Stolk*

One of the critical features of everyday language use is that it is always adapted to a partner. This project provided an analysis of communicative exchanges of adolescents from the tacit communicative game, in order to elucidate the mechanisms of such communicative adjustments, as well as the neuroanatomical variability and early social life experiences related to this adjustment.

Using precisely quantified communicative exchanges in 95 adolescents followed since infancy, this longitudinal study shows that there are two sources of knowledge informing real-time communicative adjustment: generalizable stereotypical knowledge about the interlocutor and interaction-based evidence. These make complementary, yet neuroanatomically and developmentally dissociable, contributions to understanding other minds in social interaction. Contributions from stereotypes were prominent at the onset of interactions, and individual variation in stereotype-driven effects correlated with variation in volume and surface of gray matter in the right anterior cingulate gyrus. Contributions from interaction-based evidence gradually reduced the influence of stereotypes, and the rate of this modulation was predicted by the degree of exposure to social interactions during the first few years of life, over and above effects of familial environment and late social experience. These findings unify previously disparate theories of human social understanding, and suggest that early-life social experiences have long-term consequences on how an understanding of mind is constructed in social interaction.

This study is among the first ones quantifying the relative contribution of two sources of evidence to communicative adjustment during unfolding interaction. In addition, we were able to directly relate the relative contribution of both sources of knowledge to individual difference in early social experience, as well as to neuroanatomical variations in brain structure. The findings lend support to the notion of a sensitive developmental period, showing that early-life social interactions, particularly those outside of the family environment, are crucial in shaping an individual's ability to tailor communication to an individual partner.

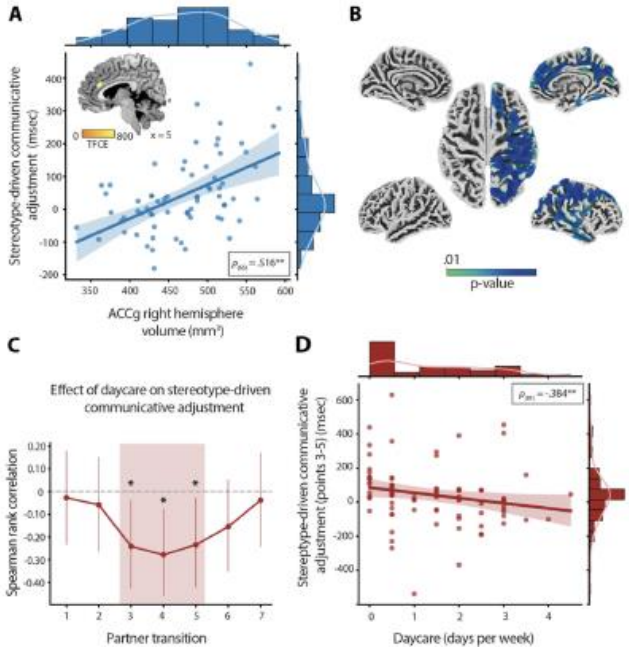


Figure 10. *Neuroanatomical and socio-developmental contributions to stereotype- and interaction-based adjustments. (A) Contributions from stereotypes correlated with gray matter volume in the right anterior cingulate gyrus (ACCg). Statistical effects thresholded at pFWE < 0.05. (B) Contributions from stereotypes also covaried with cortical thickness in ACCg as well as in a distributed right-hemispheric cortical network showing a degree of overlap with the theory-of-mind network. Statistical effects thresholded at pFWE < 0.01. (C) Diminishing contributions from stereotypes during partner transitions 3 through 5 correlated with time spent in daycare during the first few years of life. As seen in Fig. C, this effect coincides with a reduction in stereotype-driven adjustments across the group, with individuals who spent more time in daycare showing a faster rate of communicative convergence toward the understanding of both partners. Error bars indicate 95% confidence intervals. (D) Scatterplot of the inverse relationship between daycare attendance and stereotype-driven communicative adjustment averaged across partner transitions 3 through 5 for all participants. Shaded area indicates 95% confidence intervals.*

The findings of this project are built on the interdisciplinary Nijmegen longitudinal study following the development of a cohort of children from 1998 until present. The NLS itself is a collaborative project, with this analysis making a unique contribution to understanding language in interaction.

* This study has been submitted for publication in February 2023. The figure and its caption are part of the submitted manuscript.

SOCIETAL IMPACT

Our consortium aims at implementing research outcomes directly in society. As staying in the lead in science imposes high demands on researchers, 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*)	
	Esther Steenbeek (*societal impact coordinator*)	
Other team members:	Annemarie van Dooren	Carmen Marseille

Progress in 2022

To be of added value to solving current societal challenges and to make impact with our consortium's knowledge, WP7 implemented a new structure for its activities. Facilitating knowledge exchange in the long run for our fundamental SSH consortium requires a more profound transdisciplinary approach. Moreover, the consortium's potential lays at the group level: the overarching understanding of human communication is complementary to the consortium's individual and small group fine-grained expertise. Therefore, innovation-driven projects at the individual level were no longer be financially supported (researchers can turn to their hosting institute's department for valorisation and business development). Instead, the focus is on Team Science; input from a larger group of scientists will be facilitated related to specific societal topics. WP7 created two new positions to support the consortium 2022 - 2024: overarching postdoc Annemarie van Dooren was appointed with the task to work towards using the consortium's knowledge in a transdisciplinary approach aimed at societal challenges. Management assistant Carmen Marseille was appointed to assist researchers to topic-wise team up and to take part in collaborative grants.

1. COLLABORATIVE GRANTS

In order to achieve knowledge utilization of our consortium and increase societal impact of our research, we facilitate applications for collaborative grants between (groups of) LiI researchers, societal and business parties. In Spring 2022 the team interviewed ten Principal Investigators of

the consortium who would be able to lead a large-scale collaborative project. We provided personalized advice for them, including a list of potential European Grants tailored to their specialisations. The focus was on Horizon Europe Grants, including topic-centred grants (Clusters), technology development grants (EIC) and network-centred grants (COST Actions), suiting the different ambitions of the Principal Investigators. By the end of 2022, the team set appointments with the PIs to discuss possible grant applications.

2. READING GAME LETTERPRINS

The decline in literacy skills and lack of mastery among certain groups has become a growing concern in European societies. The existing fragmented market, including schools, libraries, parents, and educational care systems, has struggled to reverse this trend and support children in their reading journey. Language in Interaction proudly launched the reading game Letterprins, which aims to improve reading motivation, promote literacy, and boost reading competency. Letterprins was successfully launched during the National Week of Children's Books [Kinderboekenweek] in October 2022 by Princess Laurentien of the Netherlands. The game quickly attracted a large pool of loyal users. After three weeks, 5056 accounts were created. Six months later, the number of accounts doubled to nearly 10,000, of which 3000 are used at least weekly. Letterprins is a collaboration between consortium researchers (Esther Steenbeek, David Neville, Boris Konrad, Marco van de Ven) and societal and private partners (Orthopedagogenmaatschap Nijmegen, Stichting Lezen, Sardes, IJsfontein, Vertigo6, Boekwijzer, Biblion). The development was financially supported by Stichting IT Projecten and Stichting LOM. Letterprins is a unique innovation in reading education, combining reading motivation, promotion of literacy, and competence of reading in children. The game is adaptive with algorithms keeping track of a child's competence and thereby personalizing the exercises presented to the user. It is designed for children in Grade 1 [Groep 3] to practice reading at home, 15 minutes a day. The game is free, accessible on all devices, and gives all parents/caretakers the opportunity to practice with their children, regardless of their own literacy level, Dutch proficiency or dyslexia. Preliminary results of (anonymized) user data confirm the linguistic adaptive structure, that is, each gaming level builds up in increasing difficulty. Moreover, children progress in reading competency day by day. In 2023 DNA research will be initiated and connected to the production data.

Letterprins is a successful example the WP7's ambition of Team Science and collaborating with societal and private partners to achieve societal impact, which will remain the focus of the WP until the end of the consortium.

3. CIRKELS PROJECT – NEMO KENNISLINK

In September Language in Interaction launched a new initiative in collaboration with NEMO Kennislink, the "Cirkels" project. NEMO Kennislink writes articles accessible to wider audience about topics addressed by Language in Interaction researchers, often including interviews with the relevant LiI members. In the Cirkels project, these articles are connected to each other in a web, allowing the reader to dive further into related topics, learning more about language, brain and society in the process.

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 first two tenure tracks have ended with the graduation of their corresponding PhD candidates. The PhD candidate of Tenure Track 3 has also graduated in September 2022. This Annual Report gives an update on relevant output in 2022 stemming from the work in the tenure track. For Tenure Track 3, an update is given on the progress in 2022.

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)

This tenure track concluded in 2021. Stefan Frank is also the coordinator of BQ1 and a co-investigator in BQ5, where he advised on some of the modelling work.

KEY PUBLICATIONS FROM THE TENURE TRACK:

1. **Frank, S. L.** (2021). Toward computational models of multilingual sentence processing. *Language Learning, 71*(S1), 193-218.
2. **Frank, S. L.**, & **Willems, R. M.** (2017). Word predictability and semantic similarity show distinct patterns of brain activity during language comprehension. *Language, Cognition and Neuroscience, 32*(9), 1192-1203.
3. **Tsoukala, C.**, **Frank, S. L.**, Van Den Bosch, A., Kroff, J. V., & Broersma, M. (2021). Modeling the auxiliary phrase asymmetry in code-switched Spanish–English. *Bilingualism: Language and Cognition, 24*(2), 271-280.

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)

This tenure track concluded in 2020. Jelle Zuidema remains part of the Language in Interaction consortium as member of the steering group of BQ1.

KEY PUBLICATIONS FROM THE TENURE TRACK:

1. **Hupkes, D.**, Veldhoen, S., & **Zuidema, W.** (2018). Visualisation and'diagnostic classifiers' reveal how recurrent and recursive neural networks process hierarchical structure. *Journal of Artificial Intelligence Research, 61*, 907-926.
2. **Abnar, S.**, & **Zuidema, W.** (2020). Quantifying attention flow in transformers. *arXiv preprint arXiv:2005.00928.*

3. Giulianelli, M., Harding, J., Mohnert, F., **Hupkes, D.**, & **Zuidema, W.** (2018). Under the hood: Using diagnostic classifiers to investigate and improve how language models track agreement information.

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 (PhD defense date: September 27th, 2022)

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 2022

The PhD candidate successfully defended her thesis in September 2022. Previously established collaborations with different groups from RUMC (Neurosurgery, Neurology, Audiology, and Otorhinolaryngology) and other medical centres were continued, with scientific publications resulting from them over the course of 2021. A new collaboration with mathematician dr. Maria-Carla Piastra, and with dr. Jan Mathijs Schoffelen and dr. Robert Oostenveld was initiated. The following projects made especially notable progress in 2021, resulting in scientific publications:

1. Language research with intracranial EEG (Piai, de Zubicaray, Chauvel (QUT, Australia and Cleveland Clinic, USA)

An international collaboration has been established for a research programme on language based on intracranial EEG data. Knowledge from this research programme will not only deepen the theoretical understanding of language functions, but also help to predict language and memory dysfunction in epilepsy. A PhD candidate at QUT co-supervised by the tenure tracker successfully defended his thesis this year.

2. Within- and across-session consistency of MEG and fMRI measures of language (Roos, Piai, Takashima)

A study by the tenure track researcher in collaboration with a PhD candidate concluded that tests suitable for longitudinal studies focusing on neuroplastic changes following brain damage should be concise and have high across-session consistency. This study in the healthy population highlights the high test-retest reliability for MEG with a well-studied language task, i.e., sentence completion. This study has resulted in a scientific publication in 2022.

3. "Reorganising language: Neuroplasticity after left-hemisphere stroke through right-hemisphere recruitment". (Piai, Schoffelen, Oostenveld, Piastra (University of Twente)

The role of the right hemisphere is investigated in supporting language in patients who suffered a left-hemisphere stroke and suffer from (mild) aphasia. The project addresses structure-function relationships that shape brain organisation and contribute to developing personalised language-treatment strategies that make maximal use of a patient's neuroplastic potential. The study combines MEG during language tasks for functional lateralisation and white-matter tractography

for quantification of interhemispheric connections. In order to achieve high-quality source localisation of the patients' MEG data, given the stroke-filled lesions, a FEM-based method needed to be implemented. Two scientific publications have resulted from this study in 2022.

4. "Just about the arcuate fasciculus?: A reassessment of human/chimpanzee differences in connectivity of the temporal lobe language hubs" (Sierpowska and Rogier Mars' group, BQ2).

We investigated the patterns of white matter connectivity of two specific areas (posterior middle temporal gyrus and anterior temporal lobe) within the left temporal lobe. Both of these brain portions are claimed to be involved in semantic processing and/or semantic learning. To understand the possibly human-unique connectivity of these regions, we used a probabilistic single region of interest tractography approach in humans and chimpanzees and compared the results between the two species. In 2022, a scientific paper was published on this research.

KEY PUBLICATIONS (2022):

1. **Sierpowska, J**. and Bryant, K. L., **Janssen, N**., **Blazquez Freches, G.,** Römkens, M., **Mangnus, M**., **Mars, R**. B., & **Piai, V**. (2022). Comparing human and chimpanzee temporal lobe neuroanatomy reveals modifications to human language hubs beyond the frontotemporal arcuate fasciculus. Proceedings of the National Academy of Sciences, 119(28), e2118295119. doi:10.1073/pnas.2118295119

2. Chupina, I., **Sierpowska, J**., **Zheng, X**. Y., Dewenter, A., Piastra, M., & **Piai, V**. (2022). Time course of right-hemisphere recruitment during word production following left-hemisphere damage: A single case of young stroke. European Journal of Neuroscience. doi:10.1111/ejn.15813

AWARDS:

1. Vidi (Netherlands Organisation for Scientific Research, NWO), "Fingerprints of language: towards a neurophysiological theory of retrieval from memory in speaking"
2. Small Projects for NWA routes (Netherlands Organisation for Scientific Research, NWO), "Dynamic Assessment of Everyday Communication using Virtual Reality: proof of concept for persons with aphasia (DCOM-VR)", main applicant: dr. M. Ruiter

INDEPENDENT POSTDOCS

INDEPENDENT POSTDOC 1: NATALIA LEVSHINA

Natalia Levshina is the consortium's go-to expert on (corpus) linguistics. 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 interlocutors use language efficiently, which with time percolates into language grammar and lexicon. She addresses the following questions:

1. Do efficient systems of differential subject and object marking emerge in artificial language communication?
2. Do informativity or frequency correlate more strongly with word length in typologically diverse languages?
3. What are correlations and causal relationships between available linguistic cues to Subject and Object in typologically diverse languages and other parameters, such as freedom of valency alternations (e.g., break intransitive vs. break transitive)?
4. Are differential argument marking systems communicatively efficient across languages?
5. How do manifestations of the Principle of Communicative Efficiency interact with the Principle of No Synonymy and the likes, which are based on Gricean and Neo-Gricean pragmatics? Is there competition between the two? A case study of want to/ wanna in the British National Corpus.

Progress in 2022

In 2022 Natalia Levshina's main effort has been on finishing data analysis and disseminating the results. In connection to the questions mentioned above, she has analysed data and published papers on the correlation between word length and informativity or frequency in typologically diverse languages (2), the correlations and causal relationships between available linguistic cues to Subject and Object (3)and the Principle of Communicative Efficiency and its interactions with the Principle of No Synonymy and the likes (5). On the efficient systems of differential subject and object marking emerging in artificial language communication (1) Natalia is currently writing a journal article. She has added more languages to the cross-linguistic database regarding the efficiency of differential argument marking systems across languages (4), and is preparing a second version for publication.

KEY PUBLICATIONS (2022):

1. **Levshina, N.** (2023). Communicative efficiency: Language structure and use. Cambridge: Cambridge University Press.

2. Levshina, N. (2022). Frequency, informativity and word length: Insights from typologically diverse corpora. Entropy, 24(2): 280. doi:10.3390/e24020280.

3. Levshina, N., & Lorenz, D. (2022). Communicative efficiency and the Principle of No Synonymy: Predictability effects and the variation of want to and wanna. Language and Cognition, 14(2), 249-274. doi:10.1017/langcog.2022.7. Corpus.

INDEPENDENT POSTDOC 2: FRANCESCA CAROTA

Francesca is one of the overarching, independent postdocs of the consortium, connecting all the Big Questions. She studies the cross-linguistic processing of information structure, in its linguistic manifestations at the interface between intonation, syntax and discourse.

RESEARCH AIMS

Francesca Carota's research work fits the aims and content of the overarching question with its focus on the computational bases of language comprehension and production, particularly in relation to semantic representation and processing, and the interplay with visual processes and action. She adopts an interdisciplinary approach to study language-specific and universal mechanisms in the distribution of linguistic and semantic information across brain regions, from a cross-linguistic and developmental perspective. Her interdisciplinary research interests embrace questions and topics from different BQs:

BQ1: Models of the mental lexicon that explain behavioural and neuroimaging data. Using high-dimensional numerical vectors, neurobiological and computational (psycho)linguistic models of the mental lexicon are integrated and methods are developed for comparing model predictions to large-scale neuroimaging data.

BQ2: Investigating the neurobiological infrastructure that allows us to acquire and process language, and that co-determines the characteristics of spoken (and sign) and written language to address the question "What are the characteristics and consequences of internal brain organization for language?"

BQ3: The temporal structure of communicative interactions and the functional dynamics of real-life communicative interactions.

Progress in 2022

The scientific work was performed along the following directions:

1. With the goal to test competing hypotheses on the cascading vs. parallel computations underlying language production. The results brought evidence for early semantic access and later phonological encoding, consistent with cascading models. The interdisciplinary study applies innovative research methods (magnetoencephalography combined with pattern classification) to elucidate a longstanding question in psycholinguistics.
2. Abstract semantic representations in children (project in the context of the MPI Levelt Innovation Award, in collaboration with Tineke Snijders). The project investigates the differences between abstract and concrete word processing in children, using electroencephalography. It employs a combination of corpus-based analyses, computational linguistic methods, and psycholinguistics.
3. Information structure in Italian. The interdisciplinary project investigates crosslinguistically the role of intonation and syntax as attentional cues directing attention of the interlocutors, and the underlying neural processes and time course using electroencephalography.

The projects contribute to the overarching question of the Lil in elucidating aspects of the interplay between different levels of linguistic processes, and between the language system and vision, attention, and memory.

KEY PUBLICATIONS (2022):

1. **Carota, F.**, Schoffelen, J.-M., R. Oostenveld, Indefrey, P. (2022). The neural dynamics of language production as revealed by pattern classification of MEG data. Journal of Neuroscience.
2. Shebani, Z., **Carota, F.,** Hauk, O., Rowe, B. J., Tomasello, R., Pulvermüller, F. (2022). Brain correlates of action word memory revealed by fMRI. Sci. Reports 12:16053.
3. **Carota, F.**, Van Zwet, J., Snijders, T. (2022). AsPredicted #94262, titled "Abstract words - Levelt Award", MPI, Nijmegen, 2022
4. **Carota, F.**, Schoeffelen, J.-M., R. Oostenveld, Indefrey, P. (under review). Spatio-temporal dynamics of language production: evidence from MEG MVPA in source space. Special Issue on Cognitive Neuropsychology on Language production.
5. **Carota, F.**, Kriegeskorte, N., Nili., H., Pulvermüller, F. (under review in Language, Cognition, and Neuroscience) Integrating distributional and experiential semantic vectors to decode conceptual categories.

INDEPENDENT POSTDOC 3: MARIA SPYCHALSKA

Maria Spychalska is an overarching, independent postdoc of the consortium. Her research is placed at the interface between psycholinguistics, philosophy of language and experimental pragmatics.

RESEARCH AIMS

Maria's research within the Language in Interaction consortium focuses on the question of how pragmatic inferences are dependent on both the speaker and hearer epistemic perspectives.

Progress in 2022

The current focus of Maria's research is on:

1. The investigation of the role of theory of mind reasoning in the processing of implicatures. To this aim, she combines EEG and Virtual Reality to test how scalar implicatures are inferred depending on the speaker's and hearer's epistemic state.

2. The processing of temporal implicatures, i.e., inferences concerning the order of events, that arise in relation to past tense conjunctive sentences. Specifically, she tests whether temporal implicatures arise at the level of sentence meaning or discourse structure, and what role our knowledge about the usual order of real-life events plays in inferring temporal implicatures.

OVERVIEW OF PHD PROJECTS

PHDS WHO DEFENDED THEIR DISSERTATION IN 2022

1. Singing is silver, hearing is gold: impacts of local FoxP1 knockdowns on auditory perception and gene expression in female zebra finches
PhD Candidate: Fabian Heim (*PIs: Carel Ten Cate and Simon Fisher)*
DEFENSE DATE: May 12, 2022

KEY PUBLICATION:
Heim, F., Fisher, S. E., Scharff, C., **Ten Cate, C.,** & Riebel, K. (2023). Effects of cortical FoxP1 knockdowns on learned song preference in female zebra finches. eNeuro, 10(3): ENEURO.0328-22.2023. doi:10.1523/ENEURO.0328-22.2023.

2. White matter tracts associated with executive aspects of language production in small vessel disease and stroke
PhD Candidate: Ileana Camerino *(PIs: Vitória Piai, Roy Kessels, and Erik de Leeuw)*
DEFENSE DATE: September 27, 2022

KEY PUBLICATION:
Camerino, I., **Ferreira**, J., Vonk, J. M., **Kessels**, R. P., de Leeuw, F. E., **Roelofs**, A., David Copland, & **Piai**, V. (2022). Systematic Review and Meta-Analyses of Word Production Abilities in Dysfunction of the Basal Ganglia: Stroke, Small Vessel Disease, Parkinson's Disease, and Huntington's Disease. Neuropsychology Review, 1-26.

3. Modelling multi-modal language learning: from sentence to words
PhD Candidate: Danny Merkx (*PIs: Stefan Frank, Mirjam Ernestus, and Raquel Fernández)*
DEFENSE DATE: November 7, 2022

KEY PUBLICATION:
Merkx, D., Scholten, S., **Frank, S.L., Ernestus, M.,** & Scharenborg, O. (in press). Modelling word learning and recognition using visually grounded speech. Cognitive Computation..

ONGOING PHD PROJECTS IN 2022

4. 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.*

5. 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., & **Zuidema, W.** (2020). Quantifying attention flow in transformers. *arXiv preprint arXiv:2005.00928.*

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

KEY PUBLICATION:

Eijk, L., Rasenberg, M., Arnese, F., Blokpoel, M., Dingemanse, M., Doeller, C. F., Ernestus, M., Holler, J., Milivojevic, B., Özyürek, A., Pouw, W., van Rooij, I., Schriefers, H., Toni, I., Trujillo, J.P., & Bögels, S. (2022). The CABB dataset: A multimodal corpus of communicative interactions for behavioural and neural analyses. NeuroImage, 264, 119734.

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

KEY PUBLICATION:

Sierpowska, J., Bryant, K. L., **Janssen, N., Blazquez Freches, G**., Römkens, M., **Mangnus, M.,Mars, R.,** & **Piai, V.** (2022). Comparing human and chimpanzee temporal lobe neuroanatomy reveals modifications to human language hubs beyond the frontotemporal arcuate fasciculus. Proceedings of the National Academy of Sciences, 119(28), e2118295119.

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

KEY PUBLICATION:

Camerino, I., **Ferreira**, J., Vonk, J. M., **Kessels**, R. P., de Leeuw, F. E., **Roelofs**, A., David Copland, & **Piai**, V. (2022). Systematic Review and Meta-Analyses of Word Production Abilities in Dysfunction of the Basal Ganglia: Stroke, Small Vessel Disease, Parkinson's Disease, and Huntington's Disease. Neuropsychology Review, 1-26.

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

KEY PUBLICATION:

Rasenberg, M., Pouw, W., Özyürek, A., & Dingemanse, M. (2022). The multimodal nature of communicative efficiency in social interaction. Scientific Reports, 12(1), 19111.

10. 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).*

11. 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., Fitz, H., Duarte, R**.,** van den Broek, D**., Hagoort, P.,** and **Petersson, K.M.** (2022). The Tripod neuron: A minimal structural reduction of the dendritic tree. Journal of Physiology, 58.

12. Communication in context: Language use in Autism Spectrum Disorder
PhD Candidate: Margot Mangnus (*PIs: Jana Bašnáková and Arjen Stolk*)

KEY PUBLICATION:

Sierpowska, J., Bryant, K. L., **Janssen, N., Blazquez Freches, G**., Römkens, M., **Mangnus, M.,Mars, R.,** & **Piai, V.** (2022). Comparing human and chimpanzee temporal lobe neuroanatomy reveals modifications to human language hubs beyond the frontotemporal arcuate fasciculus. Proceedings of the National Academy of Sciences, 119(28), e2118295119.

13. 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.

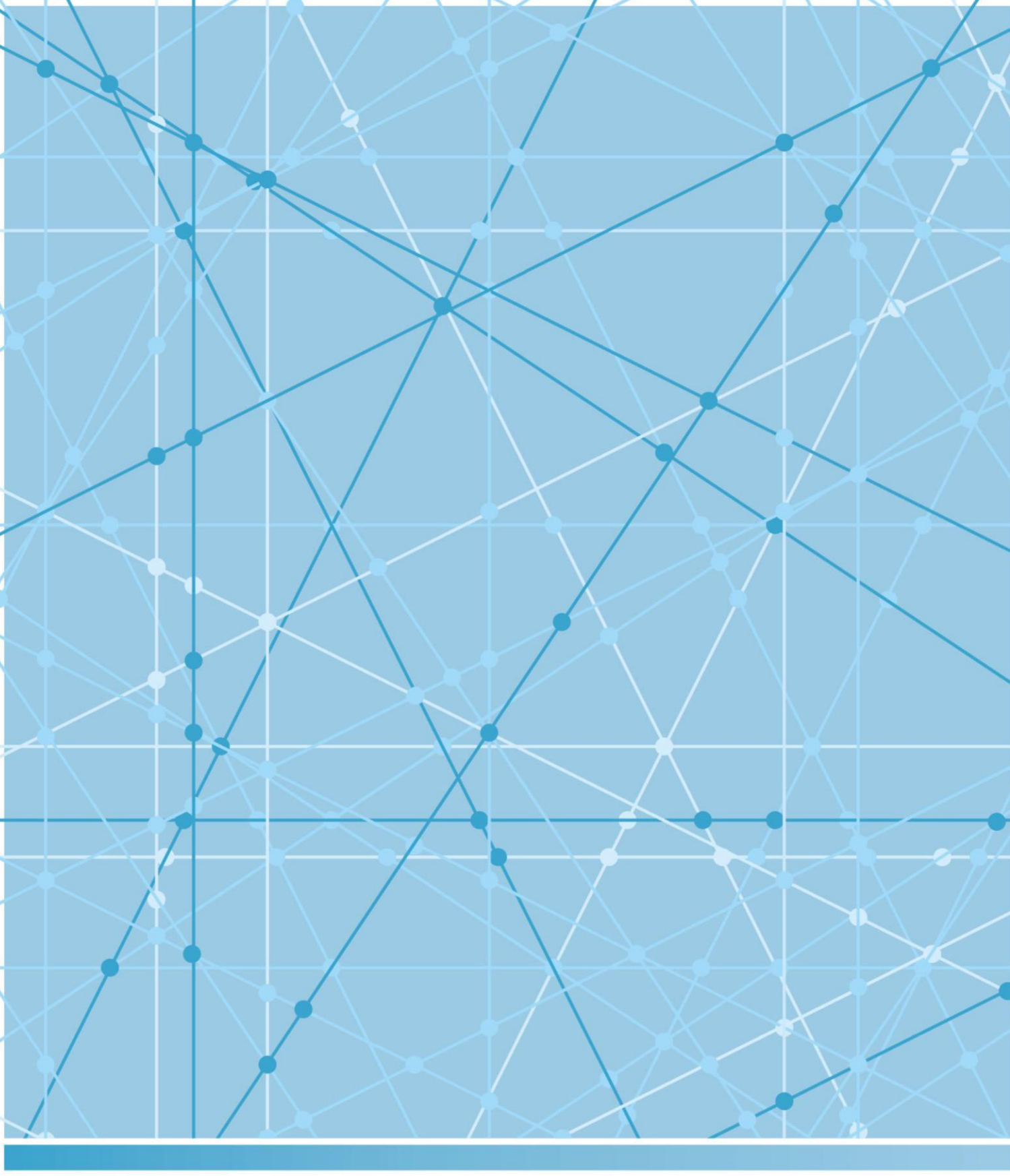
14. The connection between language model representations and neural image data.
PhD Candidate: Marianne de Heer Kloots (*PI: Jelle Zuidema)*

KEY PUBLICATION:

Cosma, R.A., Knobel, L., **De Heer Kloots, M.,** & Van der Wal, O. (2022).Seeing the bigger picture: Can deep neural agents learn higher-level concepts in crossmodal referential games? Proceeding ML4Evolang 2022 Workshop.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ASD	Autism Spectrum Disorder
BQ(s)	Big Question(s)
CLS	Centre for Language Studies
CMO	Commissie Mensgebonden Onderzoek
EEG	ElectroEncephaloGraphy
fMRI	functional Magnetic Resonance Imaging
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
PI	Principal Investigator
RT(s)	Reaction Time(s)
RU	Radboud University
RUMC	Radboud University Medical Center
VGS	Visually Grounded Speech
WP	Work Package



LANGUAGE
in INTERACTION

NWO
Netherlands Organisation for Scientific Research