LANGUAGE in INTERACTION

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Crossing the Boundaries: Language in Interaction

Symposium Abstracts

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Neural System Identification with Cortical Information Flow

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Cortical information flow (CIF) is a new framework for system identification in neuroscience. CIF models represent neural systems as coupled brain regions that each embody neural computations. These brain regions are coupled to observed data specific to that region. Neural computations are estimated via stochastic gradient descent. We show using a large-scale fMRI dataset that, in this manner, we can estimate models that learn meaningful neural computations. Our framework is general in the sense that it can be used in conjunction with any (combination of) neural recording techniques. It is also scalable, providing neuroscientists with a principled approach to make sense of the high-dimensional neural datasets.

On the Evaluation of Structural Similarity between Brain and Computational Models

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Much progress has been made in representing the meaning of linguistic units such as words, sentences and phrases due to powerful neural network architectures [1], [2]. These computational representations are high dimensional vectors that are learned such that units with similar meaning are grouped together more closely in the vector space. As a result, they capture the meaning of concepts without explicitly being informed about what these concepts entail. These computational representations have improved performances on a variety of downstream NLP tasks. The question to what extent they are similar to semantic representations in the human brain has drawn the attention of researchers that are trying to gain insight into human language processing.

Two main approaches for comparing computational representations with human brain activation are encoding/decoding experiments and representational similarity analysis. Both methods attempt to evaluate whether computational models and the brain use similar organizational principles to process language by trying to capture similar patterns in their semantic representations. Finding a correlation between the structures of computational and brain representations may contribute to linguistic, computational, and cognitive science. Computational models can operationalize and test cognitive hypotheses for human language understanding. Simultaneously, a better understanding of the human brain enables us to derive more cognitively plausible models [3].

A current issue is that there is no conventionalized way to evaluate the analysis results. Therefore, we compared different evaluation methods, using state-of-the-art deep learning models, and tested them on a number of fMRI datasets in order to allow for a robust comparison. We found that different methods could lead to vastly different results. For example, the way in which pairwise accuracy is defined could make a difference of 30% in accuracy. These inconsistent results could lead to misleading assumptions of structural similarity between both models. It is therefore important to make evaluation procedures more transparent.

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Continuous Speech Tracking in Dorsal Premotor Cortex during Audiovisual Speech Perception

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There has been a long-standing debate about the role of premotor cortex in speech perception. So far, the experimental work has shown that ventral premotor cortex may be involved in tracking syllabic structure[1], encoding of articulatory gestures[2], phoneme categorization[3] or forward predictions of speech[4]. Involvement of dorsal premotor cortex has been reported less frequently and has so far been implicated in tracking of the rhythmic structure of the phrase[5]. In the present study, we recorded brain responses to a long-duration audiovisual film, in which naturalistic dialogues took place between characters, similarly to the situations in real life. The brain responses were collected directly from the (pre-)motor cortices of two patients using high-density electrocorticography recordings. This way we were able to collect high-quality, long-duration neural data at high temporal and spatial resolution to help elucidate the role of premotor cortex in naturalistic speech perception. Using a cross-correlation analysis, we found that patches of premotor cortex were tracking the speech envelope significantly more compared to non-speech sounds and silences. The involved regions were located in dorsal premotor cortex, anterior to the hand localizer maps and superior to mouth/tongue localizer maps in both patients. This region also exhibited significant correlation with the electrodes over the auditory areas (superior temporal gyrus). Finally, we observed that the tracking was still present even when the largest source of variance (speech vs pauses) was regressed out from both the brain and audio signals. Significant tracking of the speech residuals in this region indicates that it follows speech features above and beyond the associated rhythmic structure of the phrase. These findings outline the specific role of dorsal premotor cortex in naturalistic speech perception.

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Bilinguals Already Know: Reducing Internal Control Leads to Faster Task-Switching Performance.

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Rapid Instructed Task Learning (RITL) involves rapid switching between instructions and stimuli. In a previous RITL experiment by Stocco and Prat (2014), bilingual and monolingual participants solved sets of arithmetic operations. Monolinguals executed novel sets 500 ms slower than practiced sets, while bilinguals executed both novel and practiced sets at the same pace. In other words, bilinguals may not have changed their execution strategy; they may already know how to efficiently switch between task instructions and information. Bilingualism increases an individual's linguistic demands. Bilinguals may therefore reduce internal control in exchange for faster information routing, resulting in more fluent language use at the expense of accuracy. This effect might spill over in non-linguistic task-switching, resulting in lower reaction times in task-switching paradigms. To investigate this hypothesis, we looked at the computational steps that bilinguals and monolinguals take during a RITL trial. We created computational models of monolinguals and bilinguals for the RITL paradigm as seen in Stocco and Prat (2014), using the Adaptive Control of Thought–Rational (ACT–R) architecture. This allows us to observe RITL task performance as an adaptive step-by-step process. The "monolingual" model performs each step in the task separately. With experience, these steps merge into habitual sequences of actions, in which multiple computations are performed at once. The "bilingual" model has these compiled sequences by design and internal control checks have been removed. This reduces execution time and eliminates learning effects. The models correctly reproduce the behavioral pattern observed in Stocco and Prat over a wide parameter space. These results suggest that the additional linguistic demands of bilingualism are met by reducing internal control in exchange for faster information routing between cortical areas, and that this effect carries over to non-linguistic rule-switching as well.

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From genes to language: how CNTNAP2 affects sentence processing in human neural networks

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Specific neural networks are essential for the human capacity of language. These networks implement the context-dependent and compositional computations necessary to produce and understand language. Genes are strong mediators of the development and function of neural networks and have also shown to be involved in variation in language abilities. We investigate how the language-related gene *CNTNAP2* affects language processing at the network level.
To address this question, we use data from *in vitro* human neural networks to constrain *in silico* models of neural networks that perform core aspects of sentence comprehension.
We generate *in vitro* neural networks from human stem cells with a knockout mutation in *CNTNAP2* and matched control cells. Using synapse staining and calcium imaging, we quantify synapse properties, functional connectivity and firing regularity to compare knockout and control networks. From these data, we estimate network parameters via an interface that we are developing. These parameters allow us to match inhibition-excitation ratio, connectivity patterns and spiking statistics between the *in vitro* models and *in silico* models. The *in silico* models are recurrent networks of adaptive-exponential integrate-and-fire neurons, which have been shown to reliably reproduce spiking behavior of real cortical neurons.
The *in silico* models corresponding to knockout and control networks are exposed to sequences of word input. We calibrate a decoder that maps internal network dynamics onto the semantic and syntactic structure of input sentences. By comparing simulated knockout and control networks in this comprehension task, we expect to observe differences in performance between both networks and identify the underlying computational characteristics.
This project integrates language research across multiple levels, from genes to neural networks to sentence processing. We combine the power of two advanced models of human neural networks to their mutual benefit, in an effort to gain novel insights in how genetic factors shape the computational make-up of cortical circuits and affect core aspects of language processing.

White-matter bottleneck in small vessel disease: A lesion-symptom mapping study of language-executive functions.

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Objective

Cerebral small vessel disease (CSVD), characterized by the presence of white matter lesions (WML), is among the main causes of vascular cognitive impairment. The most studied cognitive domains showing impairment in CSVD are executive functioning and processing speed, which are correlated with total WML volume (1,2). By contrast, the domain of language has received less attention (3,4). The present study investigates whether WML location is associated with poorer performance in language-executive tasks, analyzed at a single task level.

Methods

This study included a cohort of 445 CSVD patients without dementia, with varying burden of WML. The Stroop and the verbal fluency tests were used as measures of language production with varying degrees of executive demands. The symbol digit modality (SDMT) was used as a control task as it does not require verbal abilities. A voxel-based lesion symptom mapping (VLSM) approach (5) was used. All VLSM analyses were corrected for age, gender, education, and lesion size. Additionally, to control for the processing speed component in all tasks, the VLSM analyses were corrected by a "processing speed" score.

Results

The VLSM analyses revealed statistically significant clusters for verbal fluency, and Stroop word reading, color naming and color-word naming, but not for SDMT. Worse scores in all tests were associated with WML predominantly in the forceps minor, bilateral thalamic radiations and the caudate nuclei. Symptom-lesion location associations remained once the scores of the verbal fluency and Stroop color-word naming tests were corrected for processing speed.

Conclusions

A relationship was found between WML in a core fronto-striatal network and language-executive functioning in CSVD independent of lesion size. This circuitry formed by the caudate nuclei, forceps minor and thalamic radiations, seems to underlie language-executive functioning beyond the role of processing speed. The contribution of this circuitry seems stronger for tasks requiring language functioning.

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The interpretation of noun phrases and their structure: Views from constituency vs. dependency grammars

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The adjective ordering in *big green ball* is much preferred over the one in *green big ball*. Syntactic analyses within Constituency Grammar (CG; 1) argue that these restrictions reflect hierarchical modification within noun phrases [2,3], while Dependency Grammars (DG; 4) posit that each adjective independently modifies the noun via parallel modification [5,6]. The critical difference between both analyses of the phrase *big green ball* is that CG treats *green ball* as a constituent, whereas DG does not.

We approached this theoretical debate using a language-mediated visual search task. In two experiments, 80 Dutch participants read a description of a target, which was either phrased in a subordinate structure (*big green ball* (Exp.1)/*green big ball* (Exp.2)) or in a predicate structure (*ball that is big and green* (Exp.1)/*green and big* (Exp.2)), and subsequently searched a visual display. Displays either had fewer distractors that overlapped with the target on the two adjectives than distractors that overlapped with the target on the second adjective and the noun (Adjective-Adjective<Adjective-Noun), or the other way around (Adjective-Noun<Adjective-Adjective).

In both experiments participants were faster for targets with a subordinate structure than for those with a predicate structure. In experiment 1 participants were faster on AN<AA displays than on AA<AN displays, while this effect of display type was reversed in experiment 2. The latter effect was driven by target-absent responses, suggesting that the pragmatically odd adjective order of *green big ball* affects search strategy only in cases of uncertainty. Crucially, the effect of display type in experiment 1 suggests that when reading *big green ball*, participants created a subset of *green balls*, from which they picked the *big* one. This finding can only be explained by an account that treats *green ball* as a separately analyzable constituent, thus providing experimental evidence for the theoretical representations of CG.

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Investigating the semantic control network and its structural decline in mild cognitive impairment and mild dementia

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During concept retrieval, semantic control tailors automatic spreading activation between highly related concepts to suit the current context and goals.
Patients with mild cognitive impairment and mild dementia show episodic memory deficits due to medial temporal lobe (MTL) atrophy. Some patients show additional language impairment and executive dysfunction, but it is unknown whether semantic control deficits contribute to the observed language impairment.
Recent literature has revealed that episodic and semantic memory share neural substrates, including the MTL. Most evidence of the semantic control network comes from stroke patients with lesions to perisylvian language areas or healthy participants undergoing stimulation of these areas, which has led to a cortico-centric neuroanatomical model of semantic control. Accordingly, little is known about the role of the MTL and ventral language pathways, such as the inferior fronto-occipital fasciculus and the uncinate fasciculus, in semantic control.
The present study proposes a possible extension of the semantic control network by investigating a pre-dementia patient group with varying MTL and white-matter atrophy. Behavioral and diffusion-weighted imaging data acquisition is ongoing. Semantic control is investigated with a word-picture verification task. Participants indicate whether a picture matches a word as quickly and accurately as possible. Word and picture are semantically related ("pilot" – "airplane") or unrelated ("pilot" – "knife"). Preliminary results of healthy controls (n = 14; aged 65 – 82) confirm longer processing times and a larger number of errors made in related trials, illustrating increased need for control. A preliminary comparison between controls and patients (n = 5) supports the hypothesized semantic control deficits in pre-dementia patients, with one patient scoring 2 standard deviations below the mean accuracy rates of controls. These results tentatively indicate a contribution of semantic control deficits towards the language impairment in pre-dementia patients and place the MTL as a potential node in the semantic control network.

Selective routing and integration of speech and gestural information studied by rapid invisible frequency tagging

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During communication in real-life settings, the brain integrates information from auditory and visual modalities to form a unified percept of our environment. In the current MEG study, we used rapid invisible frequency tagging (RIFT) to generate steady-state evoked fields and investigate the integration of and interactions between these different modalities in a multimodal, semantic context. Until now, technical limitations have prevented the use of higher frequencies in frequency tagging studies. Here, we used a new projector with a 1440 Hz refresh rate to present participants with videos of an actress uttering action verbs (tagged at 61Hz) accompanied by a gesture (tagged at 68Hz). Integration ease was manipulated by auditory factors (clear/degraded speech) and visual factors (congruent/incongruent gesture). We reliably identified an enhanced intermodulation frequency of the auditory and visually tagged signals at 7 Hz (f2-f1) when integration was easiest (i.e., when speech was clear and accompanied by a congruent gesture). This signature of non-linear audiovisual integration was strongest in left inferior frontal gyrus and left-temporal regions, areas known to be involved in speech-gesture integration. We suggest that this enhanced power at the intermodulation frequency reflects the ease of integration and that speech-gesture information interacts in higher-order areas. Furthermore, we provide a proof-of-principle of the use of RIFT to study the integration of and interactions between audiovisual stimuli in a semantic context.

The development of neural mechanisms underlying word learning

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To date, it is unknown if the neural mechanisms supporting word learning change over the course of development. While evidence from diverse disciplines suggest that how the brain learns words changes with age, however, these observations have not been connected. Memory research has uncovered that when new information is learned, a distinction can be made between information that fits into a pre-existing schema, and information that does not. In this context, the medial prefrontal cortex (mPFC) has been suggested to play a role in the learning of schema-related information (van Kesteren et al., 2013). Separately, evidence that schema effects exist in word learning have been reported in studies showing that access to previous knowledge affects word learning ability (e.g. James, Gaskell, & Henderson, 2018). Finally, research on brain development from developmental cognitive neuroscience provides evidence that the brain continues developing well into the third decade of life. Interestingly, the PFC is one of the areas of the brain that shows the most protracted development (Gogtay et al., 2004; Shaw et al., 2008).
In this study, we aim to bring together these findings from memory, language, and developmental research through an interdisciplinary project on the development and maturation-related changes that take place in word learning between the ages of 8 and 30. We employ two experimental fMRI paradigms. In the first, we investigate the effects of prior knowledge and consolidation on second language (L2) word learning. We will compare BOLD responses to L2 labels for known and unknown objects learned either remotely or recently, and ask how the pattern of responses changes with maturation. In the second paradigm, online knowledge acquisition and updating will be probed in an artificial language learning fMRI task (adapted from Berkers et al., 2018). Taking this interdisciplinary approach, we will shed further light on how word learning is supported by different mechanisms and brain structures at different stages of development.

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The Perception-Production Interface: Insights from Cumulative Semantic Effects

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Picture naming time increases linearly as a function of the number of previously named pictures from a semantic category (e.g., fork, spoon, cup, etc.), whereas picture categorization time (living vs. non-living) decreases linearly. These cumulative semantic effects have not yet been studied in speech comprehension. Different feedforward-only computational models (e.g., Oppenheim et al., 2010; Howard et al., 2006) have been proposed to account for these effects in word production, but do not include mechanisms for spoken word comprehension. Only the WEAVER++ model (Levelt et al., 1999) makes the relation between word perception and production explicit, and indicates how syntactic properties of words are accessed. Recently, it has been successfully applied to cumulative semantic effects (Roelofs, 2018).
In this study, we investigated cumulative semantic effects in spoken word production and comprehension using tasks that do or do not involve retrieval of syntactic properties, such as gender, associated with the word. Our aim was to test for cumulative semantic effects across production and comprehension and hence address the nature of their relation.
We used four tasks (two production and two comprehension tasks) in a within-subject (N=32) experimental paradigm. One task from each modality involved retrieval of the determiner associated with the word while the other did not. The tasks were: bare picture naming, determiner-marked picture naming, and two button-press tasks, semantic judgement and determiner judgement on auditorily presented words. The stimuli set for each task had nine semantic categories with four items each, four filler items and twenty pseudo items. We analyzed the data obtained using linear mixed models to investigate the effect of ordinal position within a category on naming and button press latencies as well as on errors.
Our analyses reveal that a cumulative semantic interference effect was replicated on the bare picture naming task (slowing down by 30ms from ordinal position one to four). A cumulative semantic facilitation effect was found in the semantic judgement task (speeding up by 40ms from ordinal position one to four). Trends towards cumulative semantic interference and facilitation were found in the determiner-marked picture-naming task and determiner-judgement task respectively but these were not statistically significant.
Computer simulations revealed that WEAVER++ accounts for the cumulative semantic interference and facilitation effects. The findings on spoken word comprehension challenge other computational models (Oppenheim et al., 2010; Howard et al., 2006),

which need to make the perception-production interface explicit to be able to account for our findings.

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The effect of brain development on grammar learning ability

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Acquiring a new language is easier, more automatic and ultimately more successful early in life, and by implication becomes progressively more difficult as we age. This is especially the case for grammar, where second language outcomes gradually decrease the later an individual begins acquiring their second language. One potential causal factor in this process is neural maturation. However, while we know a significant amount about which brain regions support grammatical processing in adults (e.g., medial temporal lobes, prefrontal cortex), we know very little about how the maturation of these regions influences second language grammar learning. The current study aims to bridge this gap using a novel, interdisciplinary approach that brings together the fields of second language learning, psycholinguistics, human memory, and functional and structural neuroimaging. Specifically, we aim to study age-related differences in brain activation patterns and their effect on grammar learning in typically developing individuals within a broad age range from 8 – 30 years old. We will use a new natural grammar learning paradigm that allows the investigation of training-induced neural plasticity changes. Structural and functional brain characteristics will be related to training effects, as well as to age and grammar learning skills within the whole sample. The results of the study will provide us with better insight into the age-related effects on neural mechanisms underlying grammar learning, which could be informative in educational strategies for language learning.

Oscillatory Mechanisms Underlying Word Planning Following Semantic Processing of Verbal versus Nonverbal Material: The relevance of stimulus modality

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Producing speech requires accessing information from long-term memory as well as motor plan preparation and execution. This study investigates the neural mechanisms underlying both of these processes following verbal and nonverbal semantic contexts. Verbal semantic contexts have been studied with the verbal-context picture-naming task, where the goal is to name pictures that complete sentences with constraining and nonconstraining contexts (Piai, Roelofs, & Maris, 2014). Constraining sentences have a strong bias towards one completion ("The farmer milked the", picture: COW), while the nonconstraining sentences do not ("The child drew a"). Word planning and speech preparation can start prior to the picture onset in the constraining context, which has been associated with more desynchronization in the alpha and beta bands in previous research. What happens if such semantic context is provided in a nonverbal modality? To test this, we developed a nonverbal-context picture-naming task. In this task, three pictures appear consecutively on the screen. The first two pictures provide either constraining context (e.g. nest, feather, bird) or nonconstraining context (e.g. flower, TV, church). The participants' task is to name the third picture. Twenty participants will take part in both the verbal-context and the nonverbal-context picture-naming tasks. We expect that naming will be faster following the constraining context in both tasks. Brain oscillations will be recorded using EEG throughout the experiment to examine underlying neural processes. We will compare the oscillatory differences in the alpha and beta bands between the constraining and nonconstraining contexts in both tasks. Furthermore, we will investigate how the sources of these oscillatory effects differ depending on the modality in which the semantic context is provided. The new paradigm developed in this study could be utilized for monitoring the recovery process of patients with left-hemisphere brain lesions who have problems processing semantic information in the verbal domain.

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The Temporal Structure of Intonation Units

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Neuroscientific studies of speech processing investigate the relationship of temporal structure in speech stimuli and neural activity (Giraud & Poeppel, 2012; Gross et al., 2013; Park, Ince, Schyns, Thut, & Gross, 2015). The speech envelope, a representation of speech that captures amplitude fluctuations in the acoustic speech signal, is a central tool with which investigators probe this temporal relationship. The envelope is widely considered to capture the sequence of syllables in the speech stream: across languages, it has been shown to reflect syllable boundaries and their succession in time (Ding et al., 2017). This conception of the envelope is prevalent in the neuroscientific literature, and only few studies acknowledged the possibility that the envelope captures other linguistic information in addition to the syllable level.

Here, we focus on Intonation Units (IUs) and analyze their temporal structure as captured in the speech envelope. IUs are prosodic units that are hypothesized to be structurally and functionally comparable across languages (Chafe, 1994; Himmelmann, Sandler, Strunk, & Unterladstetter, 2018). Structurally, they are defined by a unified set of rhythmic, melodic and articulatory criteria. Functionally, they appear to pace new information in the course of language use.

We study the relation between IU onsets and the periodic components of the speech envelope in four languages (Hebrew, Russian, French, and English). We use recordings of interactions and narratives from every-day speech contexts, and analysis methods adapted from investigations of neural synchronization (Vinck, Battaglia, Womelsdorf, & Pennartz, 2012). This analysis thus offers a fuller account of the temporal structure of the envelope used in neuroscientific inquiries, and concurrently broadens the scope of linguistic analyses by including temporal information. We find that IUs are expected to occur in a 1-Hz cycle. Our results suggest that not only syllables but also IUs may drive rhythmic brain activity during speech processing. This view challenges neuroscientific investigations that relate low-frequency neural activity in the context of speech to purely syntactic units (Ding, Melloni, Zhang, Tian, & Poeppel, 2016; Nelson et al., 2017).

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Differentiation of primary progressive aphasia variants

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Primary progressive aphasia (PPA) is an acquired language deficit, with aphasia being the most prominent symptom, due to progressive neurodegenerative disease. PPA comprises three main subtypes, varying in clinical presentation, pattern of brain atrophy, and underlying pathology: non-fluent/agrammatic (nfv-PPA), logopenic (lv-PPA), and semantic dementia (sv-PPA). Differentiation of these subtypes is important for treatment and planning. However, the distinction between PPA variants remains challenging for clinicians, especially for the nfv-PPA and the lv-PPA variants. To overcome this problem and to assist clinicians in better diagnosing PPA variants, we have started to validate and use two Dutch language tests in clinical practice, the SYDBAT-NL and the newly developed SynTest. The SYDBAT-NL is a brief language battery that measures naming, single-word comprehension, semantic association, and repetition abilities. The SynTest measures comprehension of sentences that vary in syntactical complexity and length. Preliminary results are promising: Results suggest distinct patterns of impairments on the SYDBAT-NL subtests across PPA variants. Furthermore, the SynTest provides a fast and simple tool for assessing syntactic processing, which could assist in differentiating nfv- and lv-PPA subtypes. In the non-language domain, the results of a meta-analysis we performed shows that both episodic and working memory deficits are more pronounced in lv-PPA than in nfv-PPA. This suggests that in addition to language tests, measures of episodic and working memory may also be helpful to distinguish between these PPA variants. In our PPA sample, we used diffusion-weighted MRI to assess the topography of microstructural damage along dorsal and ventral language pathways by combining probabilistic tractography and localized statistical testing of tract integrity. This enabled us to investigate the correlation between both language and memory tests, and tract integrity measures of the dorsal and ventral language in these patients in order to aid in the diagnostic process of PPA.

Lapses of attention explain the distributional dynamics of semantic interference in word production: Evidence from computational simulations

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The tail of reaction time (RT) distributions in speech production tasks has been shown to be modulated by differences in sustained and executive attention (e.g. Shao et al., 2012; Jongman et al., 2015). In this study, we focused on picture-word interference, where participants name pictures (e.g., say cat) while ignoring semantically related (e.g., dog) or unrelated (e.g., tree) written distractor words. Relative to unrelated distractors, related distractors yield a delay in RT: the semantic interference effect. Using ex-Gaussian analyses, Scaltritti et al. (2015) found this effect to be present only in the tail of the RT distribution (τ), while Roelofs and Piai (2017) found it in both the distribution's tail (τ) and its leading edge (μ). We provide a computational account that explains the distributional effects as arising from interruptions of top-down executive attention related to occasional lapses of goal maintenance (Kane & Engle, 2002; Unsworth et al., 2010). Simulation results show how the difference between studies in the distributional locus of the semantic interference effect can be explained by a difference in attentional performance between participant groups; namely, in the rate and duration of the lapses they experienced. The model provides a causal link between fluctuations in attentional processes and variations in ex-Gaussian parameters and offers proof-of-principle insight into the interpretation of distributional analyses.

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Gene Expression Correlates of the Cortical Network Underlying Sentence Processing

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A pivotal question in modern neuroscience is which genes regulate brain circuits that underlie cognitive functions. However, the field is still in its infancy. Here we report an integrated investigation of the high-level language network (i.e., sentence processing network) in the human cerebral cortex, combining regional gene expression profiles, task fMRI, large-scale neuroimaging meta-analysis, and resting-state functional network approaches. Genes that made consistent individual contributions to an overall transcriptome-functional connectivity correlation within the sentence processing network were then analyzed using bioinformatics to characterize their biological roles, and also tested for an enrichment of signals in genome-wide association scan data for autism, schizophrenia and intelligence. We revealed reliable gene expression-functional network correlations using multiple datasets and network definition strategies, and identified a consensus set of genes (N = 41) related to connectivity within the sentence-processing network. The genes involved showed enrichment for neural development 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, and also suggest a genetic link between this functional infrastructure and susceptibility to autism. The integrative approach described here will be useful to study other complex cognitive traits. A preprint of this work is available at BioRxiv (Kong et al., 2018).

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Sushi or Waffle: Modelling Orthographic Perception of Loanwords

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A loanword is formed in a process of different languages contact. In this adaptive process, their word form and sound would be modified for adapting a new (native) language system. For example, Romanisation of Chinese characters "tài jí" has been loaned to English as "Tai chi". Nevertheless, Peperkamp, Vendelin and Nakamura (2008) have found that native language speakers are more sensitive to loanwords than native vocabulary in sound.

In this case, can native speakers also distinguish loanwords via word form? In fact, previous studies of the lexical decision (Samson & Pillon, 2004), which is a popular laboratory task that participants are required to differentiate whether a string of letters is regular words or pseudo-words, have provided some evidence to show that humans are capable of discovering encoding patterns in letters. Because participants spent a longer reaction time to make a choice for pseudo-words.

However, a traditional behavioural experiment is difficult to test the hypothesis in the perception of loanwords because it is unlikely to cover as many as possible loanwords in the experiment. In this respect, however, machine learning shows a predictive power based on big data. Thus an RNN-based (Recurrent neural network) framework is applied to simulate a cognitive process of orthographic perception of loanwords. Firstly, for each training word, its cognitive representation of orthography (Grainger, & Ziegler, 2011) and its reaction time in the lexical decision task (Van Heuven, Mandera, Keuleers & Brysbaert, 2014) would be as input data for a training step. Next, the model could predict whether a loanword can be identified. The results indicate that the orthographic perception of loanwords can be simulated in this framework.

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Processing of visuospatial perspective-taking and communicative demands during referential pointing

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Communicative pointing is one of the simpler instances of human referential behavior, yet such action is cognitively complex as it compels a communicator to consider the presumed knowledge of that addressee. Previous work has shown how communicators plan a pointing movement by taking into account the location in space of the addressee. However, the mental representations of space frequently differ according to the visual perspectives of the interacting agents. Here, we investigate whether and how an agent's visuospatial perspective is integrated with the sensorimotor processes controlling communicative pointing. We developed a communicative game in which a Communicator points at an object on a horizontal plane, either to instruct an Addressee to choose a target-object (communicative condition) or to predict which target-object the Addressee would choose (non-communicative condition). Two types of visuospatial demands were embedded in the game, level-1 perspective-taking (i.e., knowledge about which object can be seen by another person) and level-2 perspective taking (i.e., knowledge about how another person sees the object). Communicative movements had a longer trajectory length on the vertical axis than non-communicative movements, an indication that communicative demands influence of movement control. In addition, trials requiring level-2 perspective taking had a longer trajectory length on the transverse axis, an indication that perspective-taking influences movement control even after target selection. The results also revealed a dynamic modulation of perspective-taking and communicative intent along the trial course, i.e. perspective-taking showed an effect earlier than communicative intent did. These findings suggest that the sensorimotor system can temporally and spatially organize communicative movements according to task demands in a flexible manner.

Dependency parsing with your eyes: Dependency structure predicts eye regressions during reading

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Backward saccades during reading have been hypothesized to be involved in structural reanalysis, or to be related to the level of text difficulty. We test the hypothesis that backward saccades are involved in online syntactic analysis. If this is the case we expect that saccades will coincide, at least partially, with the edges of the relations computed by a dependency parser. In order to test this, we analysed a large eye-tracking dataset collected while 102 participants read three short narrative texts. Our results show a relation between backward saccades and the syntactic structure of sentences.

Directionality in translation: A compound account for a complex phenomenon

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This poster provides a psycholinguistic outline of translation as a process that integrates features of language production with language comprehension in the context on native and medium- to high-proficiency non-native language – strands of linguistic research that have long co-existed in relative separation. A compound model that results from aggregation of relevant accounts (Levelt 1989, Kroll & Stewart 1994, Levelt et al. 1999, Pickering & Branigan 1998, Hartsuiker & Pickering 2008) permits predictions about an impact of language direction on translation processing. This is corroborated by quantitative empirical evidence; findings are in line with long-standing axiomatic claims by translation professionals that have only seen qualitative support so far.

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The role of the ventral fiber pathway in language production in health and disease

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While neuroimaging research on language production has traditionally focused primarily on grey matter, several recent studies highlight the involvement of ventral and dorsal white matter pathways. A debated issue concerns the exact functional role of these pathways. The ventral pathway has been suggested to underlie top-down control in language production, but the functional roles of each specific white matter tract within this pathway, like the inferior fronto-occipital fasciculus (IFOF) and uncinate fasciculus (UF), have not yet been elucidated. To investigate the involvement of the IFOF and UF in top-down control, 17 patients with primary progressive aphasia (PPA), an acquired language deficit due to neurodegenerative disease, and 22 age-matched healthy controls performed a picture-word inference (PWI) experiment, which served as a behavioral measure of the participants' top-down lexical and semantic interference control. Furthermore, with diffusion tensor MRI and tractography, the microstructural integrity of the IFOF and UF was calculated as a neuroanatomical measure, expressed in Fractional Anisotropy (FA) values. Regression analyses will reveal the relationship between tract integrity (FA values) and top-down control performance in the PWI task, and group differences will be assessed. The outcome of this study will provide new insights in the mechanisms involved in language production and top-down interference control, and could aid in the diagnosis of PPA.

Learning semantic sentence representations from visually grounded language without lexical knowledge

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Current approaches to learning semantic representations of sentences often use prior word-level knowledge. The current study aims to leverage visual information in order to capture sentence level semantics without the need for word embeddings. We use a multimodal sentence encoder trained on a corpus of images with matching text captions to produce visually grounded sentence embeddings. Deep Neural Networks are trained to map the two modalities to a common embedding space such that for an image the corresponding caption can be retrieved and vice versa. We show that our model achieves results comparable to the current state-of-the-art on two popular image-caption retrieval benchmark data sets: MSCOCO and Flickr8k. We evaluate the semantic content of the resulting sentence embeddings using the data from the Semantic Textual Similarity benchmark task and show that the multimodal embeddings correlate well with human semantic similarity judgements. The system achieves state-of-the-art results on several of these benchmarks, which shows that a system trained solely on multimodal data, without assuming any word representations, is able to capture sentence level semantics. Importantly, this result shows that we do not need prior knowledge of lexical level semantics in order to model sentence level semantics. These findings demonstrate the importance of visual information in semantics.

Isochronous rhythmic structure of learned animal vocalizations

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The evolutionary path that led to music as we know it today is difficult to trace. Cross-species comparative research can help us uncover the biological substrates that enabled humans to develop this peculiar behavior. Rhythm, the organization of events in time, is a central component in the structure of all forms of music. Oftentimes musical rhythm gives rise to a perceptionally isochronous beat, or pulse. Learned vocalizations of non-human animals, such as birdsong, show striking parallels to vocal music (i.e. human song). This study investigates birdsong for the presence of an isochronous rhythmic structure that could allow a conspecific listener to perceive such a beat. To this end, I have developed a generate-and-test (GAT) method to extract an isochronous pulse from a temporal sequence of events, such as note onsets. The application of this approach to the songs of zebra finches (Taeniopygia guttata) revealed a hierarchical, isochronous structure that is reminiscent of the metrical structure of many types of music. We report the effect of genetic manipulations on the song learning success of zebra finches. The expression of FoxP2, a gene involved in speech acquisition and birdsong learning, as well as of two related genes, FoxP1 and FoxP4, was experimentally reduced in juvenile birds during their learning period. Among other effects, the adult birds produced song with an impaired isochronous structure. Surprisingly, control animals, whose FoxP levels were not reduced, showed a similar effect in this regard. I discuss possible interpretations of this result in the light of current knowledge about neural mechanisms and behavioral processes of song learning and production.

Complexity and learnability in the explanation of semantic universals

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Despite wide variation among natural languages, there are linguistic properties universal to all (or nearly all) languages. An important challenge is to explain why these linguistic universals hold. One explanation employs a learnability argument: semantic universals hold because expressions that satisfy them are easier to learn than those that do not. We investigate the relation between learnability and complexity and whether the presence of semantic universals for quantifiers can also be explained by differences in complexity. We develop a novel application of (approximate) Kolmogorov complexity to measure fine-grained distinctions in complexity between different quantifiers. Our results indicate that the monotonicity universal can be explained by complexity while the quantity and conservativity universals cannot. We also find that the learnability and complexity of quantifiers do not necessarily pattern together. This suggests that complexity and learnability may be two independent forces shaping the structure of natural languages.

The speech production system is reconfigured to change speaking rate

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It is evident that speakers can freely vary stylistic features of their speech, such as speech rate, but how they accomplish this has hardly been studied, let alone implemented in a formal model of speech production. Much as in walking and running, where qualitatively different gaits are required cover the gamut of different speeds, we might predict there to be multiple qualitatively distinct configurations, or 'gaits', in the speech planning system that speakers must switch between to alter their speaking rate or style. Alternatively, control might involve continuous modulation of a single 'gait'. We investigate these possibilities by simulation of a connectionist computational model which mimics the temporal characteristics of observed speech. Different 'regimes' (combinations of parameter settings) can be engaged to achieve different speaking rates.

The model was trained separately for each speaking rate, by an evolutionary optimisation algorithm. The training identified parameter values that resulted in the model to best approximate syllable duration distributions characteristic of each speaking rate.
In one gait system, the regimes used to achieve fast and slow speech are qualitatively similar, but quantitatively different. In parameter space, they would be arranged along a straight line. Different points along this axis correspond to different speaking rates. In a multiple gait system, this linearity would be missing. Instead, the arrangement of the regimes would be triangular, with no obvious relationship between the regions associated with each gait, and an abrupt shift in parameter values to move from speeds associated with 'walk-speaking' to 'run-speaking'.
Our model achieved good fits in all three speaking rates. In parameter space, the arrangement of the parameter settings selected for the different speaking rates is non-axial, suggesting that 'gaits' are present in the speech planning system.

A computational account of progressive and post-stroke aphasias: Integrating psycholinguistic, neuroimaging, and clinical findings

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Aphasia concerns language impairment due to brain damage. Causes include stroke and neurodegenerative disease. Post-stroke aphasias were investigated intensively over the past 150 years. Evidence on impaired word production, comprehension, and repetition informed the classic model of Wernicke and the model of Geschwind a century later. However, post-stroke language impairments typically go beyond words and also may involve syntax. Moreover, progressive aphasias due to neurodegenerative disease show resemblances but also differences with post-stroke aphasias. Although some implemented models address word-level deficits in both post-stroke and progressive aphasias, a unified computational account of language impairments beyond single words is lacking. Here, such an account is presented, the WEAVER++/ARC model extended with syntax, which integrates behavioral psycholinguistic, functional neuroimaging, tractography, and aphasiological evidence. The model addresses the clinical and neuroanatomical features of the three major primary progressive aphasia syndromes (i.e., nonfluent/agrammatic, semantic, and logopenic) and classic post-stroke aphasia syndromes (i.e., Broca, Wernicke, conduction). Computer simulations revealed that the model accounts for the typical patterns of impaired and spared language production, comprehension, and repetition, at word and syntactic levels. Ongoing work is testing the model in targeted behavioral psycholinguistic, functional neuroimaging, tractography, and neuropsychological studies.

EEG alpha power desynchronization during sentence planning is linked to partial overlap in syntactic configurations

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Virtually all theories of grammar assume that linguistic expressions share partial syntactic configurations, modeled by derivation [1] or inheritance [2] mechanisms. Sentences like "The rabbits eat carrots" and "The cat sleeps" share the initial structure NP V… and thus exhibit partial overlap in their syntactic configurations. It remains open whether these partial overlapss are only computationally or whether they are also neurally relevant [3,4]. To explore whether partial overlaps are neurophysiologically detectable during sentence production, we conducted a combined eye tracking and EEG experiment [5] in Hindi. Here, we focus on event-related desynchronization (ERD) in the alpha band (8-13 Hz) during relational and structural encoding [6]. Alpha ERD is associated with syntactic processing during comprehension [7,8] and general attentional processes [9,10]. Our study constitutes the first exploration of the role of alpha ERD in sentence planning. In Hindi, subjects of transitive sentences are unmarked (NP-Ø, nominative) in imperfective aspect, but carry overt case (NP-ne, ergative) in perfective aspect. While nominatives share the initial configuration NP-ØNOM… with intransitive sentences and passives, the ergative configuration NP-neERG… is limited to transitive perfective sentences. We hypothesized that alpha ERD during structure planning should be sensitive to this difference in initial partial overlaps if they are neurally implemented. Fifty Hindi speakers described pictures of events using SOV sentences with nominative or ergative subjects (between subjects, N = 25 per group). Central and posterior alpha ERD responses were stronger when a sentence's initial syntactic configuration overlapped with that of other sentence structures (NP-ØNOM…) than when it was unique (NP-neERG…). We demonstrate that partial overlaps between syntactic configurations are relevant for the neurocognitive processes underlying sentence planning, possibly because planning configurations that exhibit more partial overlap with other configurations increases attentional and selectional demands on speakers [11] compared to planning configurations with no initial overlap.

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Contribution of frontal aslant white matter tract to morphological processing

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The frontal aslant tract (FAT) is a white matter structure joining the anterior supplementary and pre-supplementary motor area (SMA and pre-SMA) to the inferior and middle frontal gyri. FAT is left lateralized (Catani et al., 2012), which suggests its role in language processing. Although previous studies showed the contribution of FAT in speech motor control (Kinoshita at al., 2015; Kemerdere et al., 2016), the exact character of FAT as a functional connection remains poorly understood. In our previous work (Sierpowska et al., 2015), we reported that direct electrical stimulation applied at the level of the left FAT during brain surgery provoked morphological processing errors (overregularization) in a verb generation task. This case study motivated us to search for similar relationships between the microstructural properties of FAT and a more demanding verb generation task in a healthy population.
50 healthy subjects (mean age=43.7±21.6) were scanned with high-resolution diffusion-weighted imaging (DWI) and underwent behavioral testing using a verb generation task. Stimuli consisted of 100 high-frequency concrete Dutch nouns (e.g."hond" [dog]) and the possible noun-to-verb pairs did not share the morphological stem.
Based on the responses given by the 50 participants, we sorted the items into high and low response agreement. Further, all the individual participants' responses were categorized as: correct, no answer, unrelated verb, noun instead of a verb, cue repetition, cue to response blending (e.g., "boot" [boat] to "bood-schappen" [groceries]), overregulzarization (e.g., "kwast" [brush] to "kwasten" [neologism]), or ambiguous given the cue (e.g., "muis" [both computer mouse and animal]).
We hypothesize that (1) the microstructural properties of the left FAT will correlate with the accuracy in verb generation and that (2) this relationship will be more pronounced for verbs with low response agreement. We will also explore (3) if we can find a similar effect for the right FAT.

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Can Language Cue the Visual Detection of Biological Motion?

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In this study, we employ signal detection theory to investigate the interaction between language and perception within the domain of (biological) motion. Motion perception is an evolutionarily salient part of our visual system, with a robust processing dichotomy between general and biological motion, reflected both behaviourally and neurally (Howard et al., 1996). The saliency of motion is also reflected in language, with fine-grained distinctions in motion type and level of specificity. We investigate the extent to which the detection of biological motion (Do you see human motion, yes or no?) in a multistable, dynamic environment can be cued by language. Specifically, we test the degree of specificity required to achieve a linguistic cueing effect for biological motion detection. We report two experiments (N=40 each) using a pre-cuing paradigm to probe the detection of a point-light figure (PLF; walker, rower, etc.), concealed within a random dot motion (RDM; predominantly upward or downward motion) mask. Linguistic cues varied in terms of specificity regarding features of (biological) motion: (in)congruent biological motion (rower, dancer); biological form (brother, father); general motion (snow, smoke). Before each experiment, individual biological motion detection thresholds were obtained using a Bayesian adaptive staircase procedure. Results show that only linguistic cues congruent with the biological motion of the masked PLFs enhanced motion detection (accuracy, RT, Criterion). Furthermore, general motion cues, reminiscent of general motion patterns of the RDM mask itself, diminished the detection of biological motion (accuracy, Criterion). Findings suggest that motion language is capable of triggering our highly specialised biological motion detection mechanism, enhancing recognition of human-like stimuli in a dynamic and noisy setting. Specifically, we show that such effects are only obtained when the language overlaps in degree of specificity on core biological motion features: kinematics and (human) form.

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Imitating unfamiliar languages vs. accents: No acoustic evidence that people vary in "phonetic talent"

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Why are some people better than others at acquiring a native-like accent in a non-native language? This question has led some researchers to propose that people vary in the general ability "phonetic talent" (e.g., [1]). If the construct of phonetic talent truly exists, one would expect that talented people would demonstrate an advantage with any new sound system they encounter. However, support for phonetic talent so far has come from studies showing that speech imitation ability is related to L2 pronunciation [2, 3]. Stronger evidence for phonetic talent would be provided by evidence that imitation ability in one completely unfamiliar sound system predicts imitation in another such system. Here we tested the strong claim of a general phonetic talent by using two imitation tasks: imitation of an unfamiliar language (L0) and an unfamiliar accent in the L1. Native Dutch speakers imitated words with target vowels in Basque (/a/ and /e/) and Greek-accented Dutch (/i/ and /u/). Spectral and durational analyses of the target vowels revealed no relationship between the success of L0 and L1 imitation. Rather, it may be that, as some theories suggest [4, 5], the relationship of new sounds to native phonological categories explains performance better than phonetic talent. It may be the case, however, that our participants imitated features that were not captured by our acoustic measures. As previous studies have used more global, perceptual ratings, a current line of research will address this question by obtaining ratings of the imitations. The acoustic analyses, however, offer no support for the concept of phonetic talent.

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Modulation of Context Effects by Selective Attention in a "Cocktail Party" Setting

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Temporal characteristics are fundamental to speech comprehension. Differences in duration cues, such as in stressed vs. unstressed syllables, can sometimes result in the perception of entirely different concepts. This perception is often relative to contextual information rather than absolute. For example, following Dutch sentences spoken at a fast rate, people are more likely to report hearing the ambiguous word [x.xa:n] as the longer instance /xə.xa:n/ *gegaan* "gone", but as shorter /xa:n/ *gaan* "to go" after a slow speech rate. This temporal normalisation appears to be supported by entrainment of neural oscillations to the fast vs. slow syllabic rhythms. However, in natural environments we often find ourselves surrounded by multiple speakers ("cocktail party" settings), requiring that we "tune in" to relevant speech while inhibiting attention towards distracting speakers. So do listeners normalise words only for the speech rate of an attended talker, or does an unattended speech rate also influence speech comprehension? In an MEG experiment, listeners were concurrently presented two rate-manipulated context sentences, one in each ear, followed by ambiguous target words (e.g., midway between *gegaan* and *gaan*). In block 1, participants were instructed to attend to one ear; in block 2, to listen to the same stimuli but attend the other ear. As a neural signature of success in selective auditory attention we compute an alpha power lateralisation index: lower left lateralised alpha power indicates greater attention to the speech stream presented on the right, and vice versa. If attention modulates temporal normalisation, we should find that when participants are better at attending a fast sentence and ignoring a slow competing sentence (as indexed by greater alpha lateralisation), they report more long *gegaan* responses. Thus, outcomes will contribute to the investigation into whether context effects operate at a level preceding attentional stream segregation within the hierarchically organised auditory system.

Modality Effects in Novel Picture-Word Form Associations

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It is not known whether modality affects the efficiency with which humans learn novel word forms and their meanings, with previous studies reporting both written and auditory advantages. The current study implements several controls, whose absence in previous work likely explains these contradictory findings. In two implicit learning experiments, participants were trained and tested on pseudoword - novel object pairs, controlling for modality of test, modality of meaning, transparency of word form and duration of exposure. In both experiments word forms were paired with a pictorial meaning (an unknown novel object). Word forms were presented in either their written or spoken form. After a 20-minute filler task, participants were tested on their ability to identify the picture-word form they had to learn. A between subjects design generated four participant groups: 1) written training, written test; 2) written training, spoken test; 3) spoken training, written test; 4) spoken training, spoken test. In experiment 1 the written stimulus was presented for a time period equal to the duration of the spoken form (*M* = 860 ms). It was found that when providing equal exposure duration, a written learning benefit was found. Given words can be read faster than the time taken for the spoken form to unfold, in a second experiment exposure to the written form reduced with 65% to 300 ms. This was still sufficient time to read the word. No modality effect was observed under these conditions. These results indicate that, for proficient readers, the efficiency with which word form-meaning associations are learnt does not differ when exposure to the word form is equivalent across modalities. Our results therefore suggest that, even though all humans begin as aural-only word learners, our learning mechanisms ultimately converge on learning equally efficiently from written and spoken materials.

Processing single words in idiomatic expressions: Anticipation of word forms and word meanings?

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Prediction is currently seen as one of the core mechanisms in language comprehension, and many studies have shown that speakers anticipate semantic features of upcoming words (Federmeier & Kutas, 1999; Federmeier et al., 2002; Altmann & Kamide, 1999). However, semantic expectancy may be reduced when the context renders this unnecessary, e.g. when reading idiomatic expressions for which individual word meanings are semantically unrelated to the idiom as a whole (Rommers, Dijkstra, & Bastiaansen, 2013). It has been suggested that after an idiom is recognized, semantic retrieval of individual words becomes less important and focus is shifted to the matching of incoming strings to an idiom template (Vespignani et al., 2009). If this is the case, we expect word forms, but not necessarily word meanings, to become pre-activated during idiom processing. In two experiments – with and without a preceding context sentence – we tested 160 Dutch native speakers, using a novel idiom verification paradigm, i.e. asking participants directly whether the sentence they just read contained an idiomatic expression or not. Sentences were manipulated in such a way that the final word was either part of an idiom (he spilled the BEANS), semantically related to the correct target word (CORN), orthographically related (BEARS) or unrelated (DRESS). If word forms, but not word meanings, are predicted during idiom processing, we expected response times to be slower for the orthographically related (ORT) – but not for the semantically (SEM) related – words, as compared to the unrelated words (UNREL). Without a preceding context, we found slower reactions to ORT as compared to UNREL, but response times for SEM did not significantly differ from either ORT or UNREL. With a preceding context, we found that SEM and ORT significantly differed from UNREL, but not from each other. This seems to suggest that both word form and meaning are anticipated, even in an idiomatically biasing context in which the individual word meanings do not contribute to the idiomatic reading.

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Two-stage operation of multi-level chunking in reading

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Chunking in language processing refers to partitioning continuous linguistic input into smaller pieces. Effective chunking during reading facilitates disambiguation and enhances efficiency for comprehension. However, the mechanisms of chunking remain elusive, especially in reading given that information arrives simultaneously yet the written systems may not have explicit cues for labeling boundaries such as Chinese. What is the mechanism of chunking operation that mediates reading of text that contains multiple levels of hierarchical information?

In this study, we used Chinese four-character strings to investigate the chunking operation in reading. Chinese written system is a good model for the multi-level chunking because it does not have explicit word boundaries, and each Chinese character is a basic lexical unit with similar length and four characters can form two levels of chunks -- chunks with 2 characters (hereafter as local level chunks) and a chunk with 4 characters (a global level chunk). The lexicality was manipulated at both levels. We conducted a behavioral experiment to investigate the interaction of global and local chunks in reading. Moreover, an EEG experiment was carried out to test our hypotheses regarding the dynamics of multi-level chunking operation.

The behavioral results showed that the lexical decision of lexicalized two-character local chunks was influenced by the lexical status of the four-character global chunk, but not vice versa, which indicated that the judgement of global chunks possessed priority over the local chunks. EEG results revealed that nested chunks were detected simultaneously at both levels and further processed in different temporal order -- the onset of lexical access for the global chunks was earlier than that of local chunks. These behavioral and EEG results suggest that chunking in reading occurs at multiple levels via a two-stage operation of simultaneous detection and global-first recognition.

Interpretable Machine Learning for Predicting Brain Activation in Language Processing

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Machine learning models for estimating the probabilities of potential next words (and hence, for predicting the next word) in a running text have seen enormous improvements in performance over the last few years (Merity et al., 2018). These newer models – all based on deep learning techniques such as LSTMs – allow some language technologies, such as speech recognizers, to reach 'human parity'. From their high accuracy and from further analysis, it is clear that LSTM-based language models have learned a great deal about both short and long distance predictive relations in sentences and discourse.

For understanding how humans process and learn language, however, these models are currently less useful, given (i) the lack of understanding of how LSTMs actually solve the task, (ii) the lack of a mapping from components of the model to components of the human brain and mind; and (iii) the massive amounts of data needed to train them.

We report on progress on the first two of these challenges. We open up the 'black box' that LSTMs often are, using a methodology we call 'diagnostic classification'. Using this methodology, we can determine how LSTMs process hierarchical structure and represent logical inference relations between sentences in artificial tasks; applying this same methodology to large scale natural language tasks and specific linguistic phenomena is part of our current work.

We study the mapping from components of the LSTMs to brain activation, by training a separate machine learning model to predict brain activation, as measured using fMRI, from the internal variables (hidden layers and gate values) of the LSTM. Using this approach, and applying it to the fMRI dataset of Wehbe et al. 2014, we can predict, with better accuracy than existing baselines in the literature, the brain activation associated with words when participants are reading a chapter from Harry Potter. Moreover, we can track which parts of the brain show activity that is best or least predictable from components of the LSTM.

Integrating the two legs of this research project is also a key focus of our work, as this holds the promise of providing a novel way of linking brain activation to linguistic function. The project thus uses the latest advances in deep language modelling, and (multi-voxel) brain image analysis, to provide a novel link between computational linguistics and psycholinguistics. The next step will be to explore whether the results from this new link or the learning stages that the used LSTMs go through, offer new clues for language acquisition research as well.

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