Project title

The neurocognitive architecture of individual word reading: mapping visual inputs onto meaning.

Project supervisors

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Project summary

Despite a century of research into visual word recognition, basic questions remain unresolved about the neurocognitive architecture of the process that maps visual inputs from orthographic analysis onto lexical form and meaning and about the units of analysis in terms of which these processes are conducted. The goal of the proposed project is to address this question using a novel interdisciplinary approach, examining how visual input is segmented into linguistic substrings (so-called 'morphemes') that trigger lexical access. We propose to combine the logic of behavioral masked priming with the neurophysiological phenomena of electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) to provide some initial insights into spatio-temporal underpinnings of single word reading within the human brain.

Aims and background

"Literacy is a bridge from misery to hope." (Kofi Annan, former UN Secretary-General)

This project will investigate a core cognitive mechanism of the reading system: the rapid mapping of printed letters onto meaning. Written language is one of our main means of communicating with people and is arguably even more vital today due to the increased use of text in electronic communication. Reading is a basic skill, which many take for granted. However, despite the educational systems and structures we have put in place, many children still leave school without sufficient literacy skills and often fail to make up for this deficit in adulthood (Sept 2012, EU High Level Group of Experts on Literacy). A reasonable number of adults in France fail to achieve adequate levels of literacy. A recent report by the European Commission showed how pervasive this problem is, and suggested that "an estimated 20% of adults lack the literacy skills they need to function fully in a modern society". Understanding the mechanisms involved in reading is therefore of great practical relevance and theoretical interest.

This project addresses this research gap by examining the spatio-temporal constraints of individual word reading in French adults, using EEG and fMRI. Past research has focused on the mapping between letter strings and their pronunciations [1], but the role of units that carry meaning ("morphemes") has often been ignored. They are of particular interest as they pose a challenge to the reader in that they require the combined mapping of all morphemes onto one meaningful representation. This is a significant problem, because approximately 90% of all words comprise multiple morphemes (*walker, walking walked, etc.*), yet there is very little understanding of how adults process these words [2]. Thus, the focus of my research will be on words comprising multiple morphemes.

Mechanisms of morphological decomposition

Previous research, including my own, suggests that adults rapidly "decompose" words with multiple morphemes into their morphemic subunits (*teach* + *e*r) during reading [3-12]. Much evidence comes from the masked priming paradigm, where a target (*teach*) is preceded by a masked prime (*teacher*), which is presented so briefly that it is invisible to the reader; nevertheless effects on target performance can be measured (see also Methodology section below). Two key mechanisms have been proposed that enable adult readers to rapidly and unconsciously identify morphological information. The first mechanism operates on the basis of orthographically defined morphemic units (morpho-orthographic units) which 'blindly' decomposes any letter string, independently of whether stem and whole-word are semantically related (*teach-er*) or not (*corn-er*). Such accounts are primarily based on evidence from masked priming, showing that both truly suffixed (*teacher-TEACH*) and pseudo-suffixed (*corner-CORN*) words produce priming to the stem target, relative to an orthographic control (*scandal-SCAN*), suggesting that morpho-orthographic decomposition takes place independently of semantic and syntactic constraints [for a review, see 11]. The decomposition of words like *corner* is particularly revealing as it reflects a highly automatised form of language processing, and so represents the fundamental ability of rapid, unconscious word reading. The second mechanism is based on semantically defined morphemic units (morpho-semantic units), which is true for semantically transparent words (*teach-er*) [12]. Morpho-semantic decomposition is typically evidenced by increased masked priming effects for truly suffixed as compared to pseudo-suffixed prime-target pairs.

Limitations of previous research

A neurocognitive account of visual word recognition - the core process underpinning human reading - needs to address two basic questions: What are the spatio-temporal dynamics of the recognition process, whereby visual inputs are mapped onto representations of lexical form and meaning, and what are the units of analysis - lexical or sublexical - in terms of which these processes are conducted? Despite an enormous research effort over the last 100 years, involving behavioral, neuropsychological, and neuroimaging techniques, there is no agreed answer to these questions [13]. Although it is generally accepted that the initial analysis of visual form and orthography engages occipitotemporal cortex, most strongly on the left [14-16], and that later stages of lexical access and interpretation involve middle temporal and frontotemporal regions, also primarily on the left [14,17,18], the central properties of this process remain unclear.

A second limitation is that although differences have been observed behaviourally between the processing of prefixed and suffixed words [19-22], the neurocognitive representations of affixes remain largely unexplored. Recent behavioral evidence from a letter search study [23] suggests that prefixes (*re* as in *rename*) and suffixes (*er* as in *teacher*) have a different status in the reading system, with suffixes being 'chunked' pre-lexically *and* post-lexically, but prefixes being anlaysed post-lexically only [see also 24]. Prefixes may have a different status to suffixes, due to (i) an obligatory beginning-to-end processing bias in spoken word recognition, (ii) because prefixes, contrary to suffixes, have an exclusively semantic function that is predominantly compositional, (iii) because prefixes never modify the orthographic form of their stem. However, little is known regarding the neurocognitive architecture of the process that maps prefixed and suffixed letter strings onto meaning. As a result, it is not clear *how*, *when* and *where* morphemic substrings are processed in the human brain.

A third limitation is that despite this extensive body of research in written language, we still know very little about to what extent visual processing inherits properties from the auditory system. Previously observed differences between prefixed and suffixed letter strings may originate from a beginning-to-end processing bias from spoken language processing. Virtually all of the literature is based on studies examining visual word recognition [11]. This is unfortunate, because to fully understand how morphological knowledge is used during skilled word recognition, we need to understand the commonalities and differences between the spoken and written language system.

Methodology and Hypotheses

Here, we propose to use EEG and fMRI to delineate the specific spatiotemporal patterns of neural activity elicited by a psycholinguistically rich set of morphologically structured words and nonwords. We aim to determine the spatio-temporal dynamics of mappings of prefixed and suffixed letter strings onto lexical-level representations (**Aim 1**), and to dissociate the neurocognitive mechanisms involved in the auditory and visual word processing system (**Aim 2**). In doing so, we will integrate behavioural data about the performance characteristics of the system with direct EEG- and fMRI-based evidence about its underlying neural dynamics. EEG and fMRI make it possible to study unconscious effects that are too short-lived or transient in order to show up with classic behavioural measures [11]. EEG in particular displays exceptional high temporal resolution and can be used to study a chain of processing stages rather than just examining the participant's final response, thus presenting an important extension of reaction-time based research. fMRI complements EEG by providing a good spatial resolution, making it possible to study the location of the generators that produce the effects in the brain.

To target Aim 1, we will use *masked priming* to study the automatic mechanisms of adult's reading, while recording participants' neural correlates using EEG (Experiment 1) and fMRI (Experiment 2). Words are presented so briefly (50 ms) that participants are not aware of their existence, yet they influence their reading performance. It thus provides an important window into unconscious reading mechanisms, assisting my goal of exploring the automaticity of morphemic processing. Extending my own initial findings [23], I will examine how and when adults rapidly decompose affixed words like *tristesse* or affixed nonwords like *tristerie*. To target Aim 2, we will use *auditory* and *visual lexical decision* to study spoken language effects during adult's word reading, while recording participants' neural correlates using EEG (Experiment 3) and fMRI (Experiment 4).

Participants: We will test 20 adults per experiment, who will be recruited from the LPC participant pool.

Experiment 1 (masked primed lexical decision + EEG). Experiment 1 asks *how* and *when* the skilled reading system decomposes prefixed and suffixed words like *rename* and *teacher*. A forward mask is displayed at the centre of the computer screen for 500 ms, followed by the prime (50 ms), and then the target word (until response). Participants are instructed to decide as quickly and accurately as possible if the presented item is a real word or a nonword. EEG is acquired from 64 scalp locations and analyzed for three time-windows: 100-250ms (P200) and 250-450 (early N400), because pre-lexical morphological priming has previously been indexed by a reduction of the P200 and early N400 ERP component, and 500-650ms (late N400), because post-lexical morphological priming by a reduction of the late N400 ERP component [9]. While behavioural priming will be reflected in faster response latencies, neural priming will be measured as the degree of attenuation of various components, in particular the P200 and N400 components. Each target word is preceded by 6 different primes: (i) A *prefixed nonword* and (ii) *suffixed nonword* which do not share a semantic relationship with the stem (*préamour-AMOUR/*amouresse-AMOUR). (iii) A *non-prefixed nonword* and (iv) a *non-suffixed nonword* which comprise stem+non-morphemic endings (*brosamour-AMOUR/amourugne-AMOUR*). (v) An *unrelated non-prefixed* and (vi) and *unrelated non-suffixed* which are all letter different from the target (*brossirgle-AMOUR/broncugne-AMOUR*). We predict morphological priming of suffixed nonwords (cond 2 < cond 4 = cond 6), but not of prefixed nonwords (cond 1 = cond 3 = cond 5). We also predict that suffixed priming should be reflected by an early reduction of the P200, early N400, and late N400, whereas prefixed priming should only result in a reduction of the late N400 component.

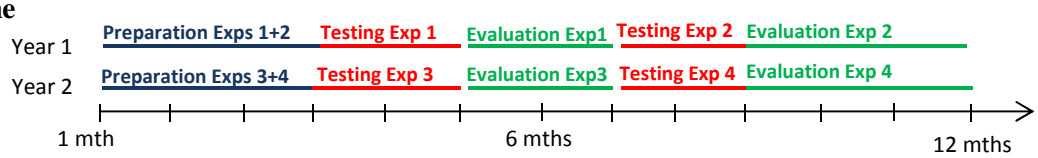
Experiment 2 (masked primed lexical decision + fMRI). Experiment 2 asks *where* the neural reading system decomposes prefixed and suffixed words like *rename* and *teacher*. The same masked priming materials from Experiment 1 will be used. fMRI data will be collected on a 3-T Siemens Magnetom Trio MRI scanner. We expect to see evidence for the pre-lexical processing of suffixed words in posterior-temporal regions [i.e. the left-laterised

occipito-temporal lobe; e.g. 25], and evidence for the post-lexical processing of both prefixed and suffixed words in frontal language areas [i.e. the Broca's region; e.g., 26].

Experiment 3 (auditory and visual lexical decision + EEG). Experiment 3 asks *if* and *when* during visual word recognition the lexical representations of spoken morphemic units and written morphemic units can be dissociated. The primes of Experiment 1 will be used as targets. Targets will be presented auditorily in Experiment 3a and visually in Experiment 3b. EEG recordings follow the same principles as in Experiment 1. We are the first to apply this innovative paradigm to the domain of spoken language recognition. Given that this task uses overtly presented targets, the observed effects will tap into later, less automatized processing stages compared to Experiments 1 and 2. Behaviourally, we expect to find an effect of morphological complexity within the two modalities. However, within the ERP data, the auditory modality should reveal an early segmentation effect in the prefixed condition (evidenced by a reduction of the P200 and the early N400), and a later effect in the suffixed condition (evidenced by a reduction of the late N400), due to a beginning-to-end processing bias during spoken language processing.

Experiment 4 (auditory and visual lexical decision + fMRI). Experiment 4 asks *where* the neural reading system processes spoken and written morphemic units. The same materials from Experiment 3 will be used. The results will identify a neural dissociation between a spoken and written module of morphological processing.

Timeline



In Year 1, I will prepare, conduct and evaluate Experiments 1 and 2, whereas in Year 2, I will prepare, conduct and evaluate Experiments 3 and 4. Data evaluation will comprise data cleaning, data analyses, collaborative data evaluation, joint meeting, publication of cross-sectional and longitudinal findings and computational modelling.

Expected results

Expected results are an expanded understanding of fundamental processes of reading, which have the potential to be of great value to adults and children with language and reading deficits, speech pathologists, psychiatrists and educational psychologists. This project will produce publications in high-impact journals and conferences.

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