Chateaubriand Application

Applicant: Teon Brooks

Project Title: Decoding Semantics: Mending the Gap on Eye Movements and ERP research in semantic processing

Proposed international research collaborator(s): Telecom ParisTech / CNRS LTCI, INSERM-CEA Cognitive Neuroimaging Unit

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Proposed Dates and Duration of Visit: July 15th, 2014 – December 15th, 2014 (Total: 5 months)

Introduction

My project aim is to innovate new techniques to decode semantic processing in on-line language comprehension in a naturalistic reading paradigm. Chiefly, I would like to tackle a problem plaguing the field: what is the linking hypothesis between the behavioral effects shown in eye-movement research and the physiological effects seen in the EEG and MEG literature.

Although there are several decades of studies on reading, we still don't know what is happening neurally when we read naturally. Language research has made significant progress in understanding visual word recognition by focusing on two powerful techniques: eye-tracking and neurophysiology recording. These two techniques work in different empirical domains, eye-movements and neurophysiological brain responses, in hopes of describing cognitive processes underlying word recognition. The eye-movement literature has provided detailed models for the behaviors evoked when reading: skipping, regressions, fixation durations, but it hasn't been able to suggest a solid linking hypothesis between the these behaviors and their cognitive underpinnings. There is still contention over the linking assumption of whether we don't move the eyes until we have finished processing (E-Z Reading serial model: Reichle et al., 1998) or that we have distributed parallel processing (SWIFT parallel model: Engbert et al., 2002), allowing movement prior to completion of lexical access. Neurophysiology models have provided insight to regions that may be implicated in lexical access (Lau et al., 2008) but the neural timing seems to lag behavioral results.

Neurophysiological research in reading overwhelmingly restricts the possible eye movements of participants to reduce the induced large motor artifacts. Due to these potential artifacts in the data, neurophysiological experiments generally employ a non-natural task of rapid serial visual presentation (RSVP), which can impose processing constraints (Rayner, 1998). These constraints include a processing load limit that is not present in normal reading, a lack of parafoveal preview benefit that aids in reading, and the inability to regress back to previous word when additional processing and repair are needed (Rayner, 1998). Given the contrast in experimental tasks between behavioral and ERP studies, it is not possible to distinguish whether differences in timing estimates for processing are a symptom of the imposed processing limits or if these measures could be reflecting different stages of lexical processing. There have only been a few studies that have tried to couple the two techniques (Kretzschmar et al., 2009; Kliegl et al., 2012), but currently, there is no strong evidence showing that the variance in eye-movements we see in reading corresponds to the variance in ERPs we see in RSVP reading tasks. Combining these two methodologies with an appropriate linking hypothesis could help tie the eye-movement data to the underlying processes that lead to them.

Sereno & Rayner (2003) points out how these two complementary methodologies contend for the title of "holy grail" in visual word recognition as they aim to solve the problems of when, where, and why recognition occurs. Developing a method to marry eye-movement research with neurophysiological recording would be a considerable advancement to field by providing the framework to addressing the apparent timing discrepancies between the methods while clearly linking the behavior to neural computations.

To strengthen the validity across these complementary methodologies in language comprehension, we plan to devise a method for simultaneously recording eye-movements and neurophysiological responses. Our approach for resolving eye movements while reading will work based on the following: 1. we model ocular globes with electrical dipoles whose orientations can be inferred from the eye tracking data. 2. we compute forward models of these dipole using realistic head volume conductor models. 3. we use the computed predicted MEG signals as regressors to inform the estimation of eye movement and regress out the noise. We plan to validate this model using a robust Cloze-probability language task where we will seek to identify correspondent behavioral effects concurrent with neurophysiological measures.

Design

Four-word simple sentences will be constructed to minimally contrast Cloze probability and semantic relatedness. Each sentence will be constructed with the first word being an animate entity and the third word describing a quality of this entity. We will use Latent Semantic Analysis Landauer et al. (1998) to calculate high and low semantic relationships between these words for our semantic relatedness contrast.

High Semantic Relatedness

(1) Birds can fly quickly.

(2) Birds can tweet quickly.

Low Semantic Relatedness

(3) Birds can fall quickly.

(4) Birds can die quickly.

We will then calculate high and low probable continuations from the two words to the verb in each sentence, which is the target word for the ERP analysis. 3-gram frequency information from the Corpus of Contemporary American English Davies (008) would serve to quantify the expectation for the verb, given the subject, yielding our Cloze probability contrast at the verb (the final word in each sentence will be equi-probable given the first 3 words across the contrast (1-4)). In the example, (1) presents a much more expected continuation from the first two words than (2), and (3) is more expected than (4).

Task

Participants are asked to read a series of sentence, each of which is followed by a comprehension question. A gaze-contingent, moving window paradigm will be implemented to control for visual input (Just et al., 1982).

Method

We will use the fixation measures mentioned above from Clifton et al. (2007) to define time regions of interest in eye-tracking data. To interpret our MEG data, we will use our approach to resolving eye movements while reading. This will involve modeling dipoles generated the eye-movements inferring its orientations from the eye-tracking data, computing a forward model of how these dipoles would manifest as an MEG signal, then regressing out the movements from the forward model's estimation. The MEG response surrounding the saccade to and from the verb is the crucial dependent neurophysiological measure.

Predictions

We will evaluate the response to reading the third word in these sentences. Given the findings in prior research, we expect to replicate findings of gaze duration reduction for increasing Cloze-probability and for increasing semantic relatedness independently. Of interest for models of prediction in reading is whether semantic relatedness significantly modulates gaze duration in situations of high and low prediction, or whether semantic relatedness is only relevant in cases of high prediction.

To link the eye-tracking and MEG results, we would ask what MEG signal time-locked to the saccade to the verb shows an amplitude modulation that correlates with the behavioral reduction in gaze duration. If gaze reduction and the N400 really reflect that same processing – lexical access, for example – in this paradigm we would expect an early N400-type effect that parallels the latency of the saccade. However, if the N400-type response modulation occurs later, after the saccade from the verb, the cognitive trigger for the saccade might not be reflected in the N400-type response. Rather, we might expect to find correlations of gaze reduction with modulation of MEG responses from other, non-N400-type, brain areas and latencies. For example, if prediction for the verb pre-activates aspects of the orthographic form of the verb, gaze duration might correlate with modulation of the MEG M170 response.

Summary

The research proposed seeks to bring together two separate lines of research, eye-tracking and neurophysiology, by combining both methodologies simultaneously. Correlations between the two types of data in the same experiment should lead to a linking hypothesis tying eye movements to underlying cognitive and neurocognitive processing in real-time. Neurophysiology would be benefit from an explanation of the apparent lag of event-related responses with respect to eye movements. These techniques could finally solve questions about levels of processing in word recognition and their sequential or parallel computation by providing reliable time-course information about processing at different levels of analysis. This collaboration would become the springboard for my dissertation research as it would culminate a body of my research on lexical processing of compound words while expanding my research topic to semantic processing of sentences.

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