ESF - Short Visit Grant - Final Report

Ref. Number: 4792

Applicant's name: Dr. Dirk Koester, Bielefeld, Germany

17 September 2012

Dates of visit: 28/07 - 04/08/2012

Title of the proposed research project:

The neural basis of internal word structure: Integrating temporal and neuroanatomical characteristics of compound word processing

Purpose of the visit

This short research visit was used to analyse fMRI and ERP data acquired for the processing of polymorphemic words. In particular German compound words consisting of three constituent morphemes. Each initial constituent was used to form 4 experimental stimuli; it was either followed by a plausible or a less plausible non-head constituent (by non-head constituent we will refer to the second constituent throughout). Each of these was then again followed by a plausible or less plausible head constituent. As a shorthand for the experimental conditions, we will use ”LL” (both constituents of low plausibility), ”LH” (non-head of low, head of higher plausibility), ”HL” (non-head of higher, head of low plausibility), and ”HH” (both constituents of higher plausibility). Based on this procedure, the compounds are assumed to have an AB-C structure where the initial two constituents (A+B) modify the head constituent (C). For example, “chicken leg dinner” is interpreted as a dinner where chicken legs are served (AB-C) as compared with “chicken wallpaper” which could be a wallpaper with chickens on it (A-BC). The primary aim was to determine the functional neural correlates of the comprehension performance by means of functional magnetic resonance imaging (fMRI). The outcome may serve as the basis to integrate neuroanatomical knowledge with the temporal knowledge gained from the event-related potentials (ERP; Koester et al., 2009) due to their high temporal resolution.

Background information

The experimental protocol involved a structural and functional MRI scan. Both were performed on a Siemens Magnetom Trio scanner with a magnetic field strength of 3.0 Tesla. Functional data were collected with an echo planar imaging sequence in 30 transversal slices in an interleaved fashion (with no inter-slice gap; repetition time [TR] = 2,000 ms; echo time [TE] = 30 ms; flip angle = 80 °; slice thickness = 3.0 mm; field of view [FoV] = 224 mm; in-plane resolution = 3.5 × 3.5 mm). The functional run began with presentation of the instruction (for 4 TRs) incl. four additional filler trials to allow for magnetic saturation. High-resolution anatomical images (structural scan) were collected before the functional run using a T1-weigthed 3D-MPRAGE sequence (TR = 2,300 ms; TE = 3.03 ms; flip angle = 8 °; slice thickness = 1 mm; FoV = 256 mm; voxel resolution = 1.0 × 1.0 × 1.0 mm) covering the whole brain.

The experimental procedure was as follows. Participants received a block of twelve trainings trials which were not used in the experiment. Two pseudo randomised lists were created with no more than two successive presentations of any experimental condition. The presentation side of the test word was counterbalanced which resulted in a total of four experimental lists one of which was randomly assigned to each subject. The experiment consisted of four blocks, and the whole session lasted about 60 min.

Each trial began with a cross-hair presentation for 1000 ms. Next the compound was presented via loudspeakers while the cross-hair remained on the screen. The cross-hair was replaced by two words 500 ms after compound offset for the semantic similarity judgement. To ensure that the compounds were processed on a semantic/conceptual level, participants decided via a push-button response which of the two visually presented words was semantically related to the compound.

The fMRI data will provide evidence for the functionally necessary cortical areas for the auditory comprehension of morphologically complex word that are made up of free morphemes, i.e. compound words. The fMRI signal provides information of increase cerebral blood flow which is correlated with neural activity. The advantage of fMRI data is the high spatial resolution. However, fMRI has a reduced temporal resolution. Since language processes are very fast, the findings from the functional neural correlates (fMRI) should be complemented by ERPs with their high temporal resolution (Koester et al., 2009). Given both sources of data, the ERP data will be modelled using the spatial distribution of the underlying neural correlates. Thus, the fMRI data provide primarily evidence for the localisation of brain activation and, second, help to construct an inverse model of the temporal brain processes during compound comprehension by constraining the inverse solution anatomically.

Increased brain activity was expected for implausible (e.g. LL) vs. plausible compounds (e.g. HH) in the left middle temporal lobe and possibly in the left inferior frontal lobe as these areas are often reported in language comprehension (Martin & Chao, 2001; Hagoort et al., 2004; 2005; Meinzer et al., 2009 for derivations). However, most of the previous work was based on sentence comprehension (e.g. Friederici, 2002; 2006). We are not aware of any work investigating the neural correlates of auditory compound comprehension. Of particular interest was the question of whether right-hemispheric areas would be activated by the increased processing demands of lexico-semantic integration (implausibility) because research findings pointing toward a right-hemispheric involvement for prosodic processing which plays an important role in compound comprehension (Koester et al., 2004; Eckstein & Friederici, 2006).

The major question of the fMRI work was to determine whether there is a neural area or network that is responsible for lexico-semantic integration, i.e. semantic integration "below" the sentence level. In particular, activations in temporal regions would suggest lexical retrieval processes as the content of the mental lexicon has been located in temporal regions (e.g. Mummery et al., 1999). That is, one might surmise whether the complex words are stored in lexical memory. In contrast, activation in left inferior frontal areas would be an indication of integration processes (e.g. Hagoort, 2005). Such a view might assume that the same integration processes are used regardless of whether the language input is lexical or phrasal (i.e. sentence level). A theoretically more interesting finding would be activation in both temporal and frontal areas. Such a result may point toward an more sophisticated network of storage and integration processes. The temporal processes in such a network will then be investigated by means of ERP data. Such a neuroanatomical model could, for example, indicated whether or not lexical retrieval and (lexico) semantic integration processed interactively or unidirectionally.

Work carried out

As planned the fMRI dataset was pre-processed using multiple parameter settings to optimise the statistical power of the analyses. The second level analyses determined the coordinates and the extent of the functional activations related to lexical-semantic integration. The latter were done using different analysis strategies (comparisons of single conditions and parametric analyses). The magnitude of conditions specific activations were related to behavioural performance. The coordinates for source localisations (for the ERP data) were determined. Finally, the analyses and findings were documented and a data back-up was compiled.

All analyses were performed using MATLAB 7.2 (http://www.mathworks.co.uk/) and SPM8 (http://www.fil.ion.ucl.ack.uk/spm/). The first 4 volumes of each functional run were discarded to minimize T1-saturation effects. Pre-processing included the standard procedures of realignment (rigid body transformation of all volumes to the first volume), co-registration with the corresponding structural MR images for normalization to the Montreal Neurological Institute (MNI) space. Subsequently, the functional MR images were spatially smoothed with an isotropic 3D Gaussian filter kernel of 8 mm full-width at half maximum (Xiong et al., 2000).

The fMRI data were statistically analyzed in a two-step approach using the general linear model (Friston et al., 1995). At the participant level (N=21), all stimuli according to the four experimental conditions were included as explanatory variables and modeled as separate events before they were convolved with the canonical hemodynamic response function. Each participant’s movement parameters (translation and rotation) from the motion correction algorithm were included as regressors of no interest to account for small head movements. At the group level, the average activation levels (beta weights) were entered into a random effects analysis. The estimated activation levels per participant and condition were tested in paired t-tests (df = 12) in the a priori constructed ROIs.

Main results

The main result are different activation foci distributed across the brain. The areas are consistent with previously described distributed networks of neural areas involved in language processing in general. All areas show increased neural activity with increased processing demands of lexical-semantic integration within compound words. A novel finding is the involvement of the right inferior frontal gyrus (IFG) for constituent integration. The main areas and coordinates for source localisation are listed below.

Comparison	Activated area	Coordinates
LL> HH	Left middle temporal gyrus	-60 -22 1
LH > HH	No activation	
HL > HH	Right superior temporal gyrus (bilateral)	60 2 -11
		60 -7 -8
Parametric contrast		
LL > HL > LH > HH	Right IFG p. triangularis (40% BA 45)	48 23 19
	Left IFG (svc; anatomical BA 45 as search volume)	-57 23 19
	Left superior temporal gyrus	-63 -22 1
		-57 -10 -5
		-57 -37 10
		-48 -40 10

Note: intensity threshold: p < 0.006; cluster size k = 20

References

Eckstein, Korinna & Friederici, Angela D. (2006). It's Early: Event-related Potential Evidence for Initial Interaction of Syntax and Prosody in Speech Comprehension. *Journal of Cognitive Neuroscience, 18*, 1696-1711.

Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6*, 78-84.

Friederici, A. D. (2006). Broca's area and the ventral premotor cortex in language: functional differentiation and specificity. *Cortex, 42*, 472-475.

Friston, K., Holmes, A., Worsley, K., Poline, J. B., Frith, C., & Frackowiak, R. (1995). Statistical parametric maps in functional imaging: A general linear approach. *Human Brain Mapping, 2,* 189-210.

Hagoort, P. (2005). On Broca, brain, and binding: a new framework. *Trends in Cognitive Sciences, 9,* 416-423.

Hagoort, P., Hald, L., Bastiaansen, M., & Petersson, K. M. (2004). Integration of word meaning and world knowledge in language comprehension. *Science, 304*, 438-441.

Koester, D., Gunter, T. C., Wagner, S., & Friederici, A. D. (2004). Morphosyntax, Prosody, and Linking Elements: The Auditory Processing of German Nominal Compounds. *Journal of Cognitive Neuroscience, 16*, 1647–1668.

Koester D, Holle H, & Gunter TC. (2009). Electrophysiological evidence for incremental lexical-semantic integration in auditory compound comprehension. *Neuropsychologia, 47,* 1854-1864.

Martin, A. & Chao, L. L. (2001). Semantic memory and the brain: structure and processes. *Current Opinion in Neurobiology, 11*, 194-201.

Meinzer, M., Lahiri, A., Flaisch, T., Hannemann, R., & Eulitz, C. (2009). Opaque for the reader but transparent for the brain: Neural signatures of morphological complexity. *Neuropsychologia, 47*, 1964-1971.

Mummery, C. J., Patterson, K., Wise, R., Vandenbergh, R., Price, C. J. & Hodges, J. R. (1999). Disrupted temporal lobe connections in semantic dementia. *Brain, 122*, 61–73.

Xiong, J., Rao, S., Jerabek, P., Zamarripa, F., Woldorff, M., Lancaster, J., et al. (2000). Intersubject variability in cortical activations during a complex language task. *NeuroImage, 12*, 326-339.

Future collaboration with host institution

At present I am continuously in contact with the host (H Holle) regarding additional, further analyses. Also, the preparation of presentations and writing of the associated publication proceeds in a collaborative fashion. In the near future, it is planned to invite Dr. Holle for a research visit to Bielefeld University, Germany where further collaborative experiments can be designed (e.g. to follow up on the novel finding of right IFG activity).

Projected publications

The results of the short visit research will be presented at national and international conferences. Furthermore, the present work should be published as a research paper in the international, peer-reviewed journal *NeuroImage* (impact factor 5.895).