**CREST Workshop**

**on**

# Language Acquisition and Brain Functional Imaging

The University of Tokyo, Komaba, Japan

June 10-12, 1999

## Program

**June 10 (Thursday)**

10:00 – 10:10 Opening address

Shunichi Amari

*Director, Brain-Style Information Systems Research Group, RIKEN Brain Science Institute, Japan*

10:10 – 11:00 Introduction to functional imaging studies of language information processing

Kuniyoshi L. Sakai

*Department of Cognitive and Behavioral Science, The University of Tokyo, Komaba, Japan*

11:00 – 12:00 The anatomical organization of the brain for language

Albert M. Galaburda

*Emily Fisher Landau Professor of Neurology and Neuroscience, Harvard Medical School, U.S.A.*

12:00 – 13:30 < Lunch Break >

13:30 – 14:30 Cognitive neuroscience of speech sound processing

Alec Marantz

*Department of Linguistics and Philosophy, Massachusetts Institute of Technology, U.S.A.*

14:30 – 15:30 From speech perception to word learning

Janet F. Werker

*Department of Psychology, The University of British Columbia, Canada*

15:30 – 16:00 < Coffee Break >

16:00 – 17:00 Bilingualism: Learning and mastery of two languages

Núria Sebastián Gallés

*Dept. de Psicologia Basica, Universitat de Barcelona, Spain*

17:00 – 18:00 Cortical Activity and Language Acquisition

Jacques Mehler

*Directeur d'Etudes l'Ecole des Hautes Etudes en Sciences Sociales, Paris, France*

18:00 – 19:30 < Welcome Reception >

**June 11 (Friday)**

10:00 – 17:00 Meeting of the "Cortical Plasticity and Linguistic Constraints" project group (closed), phase one

**June 12 (Saturday)**

10:00 – 17:00 Meeting of the "Cortical Plasticity and Linguistic Constraints" project group (closed), phase two

*This workshop is under the auspices of Japan Science and Technology Corporation (JST), Tokyo, Japan.*

# Introduction to functional imaging studies of language information processing

Kuniyoshi L. Sakai

*Department of Cognitive and Behavioral Science, The University of Tokyo, Komaba, Japan*

In this introductory talk, I will summarize relative advantages of functional imaging techniques and their possible application to language studies. Because none of these techniques are "perfect," we have to combine multiple techniques to overcome their limitations. For example, functional magnetic resonance imaging (fMRI) is useful for functional localization only in adults, whereas optical topography (OT) can be applied to infants. Moreover, these imaging techniques should be combined with anatomical studies for understanding both structural and functional bases of language information processing.

My current working hypothesis is that the human auditory cortex is specially designed to work as a part of Language Acquisition Device. Therefore it is essential to study the auditory cortex to elucidate language information processing. Here I will present our recent fMRI study, which demonstrates attentional influence on multiple auditory areas using the dichotic speech recognition paradigm. We tested two experimental conditions: diotic listening (DIO) and dichotic listening (DIC). In a single run, DIO and DIC blocks were alternately presented and those blocks were intervened by a control condition, in which white noise and tone were presented. We have identified at least nine auditory areas in the left superior temporal cortex. Speech sound-selective cortical responses emerge even in A1, as well as A2 and Wernicke's area. We found clear differential effects of attention on these multiple auditory areas. The degrees of attentional modulation of cortical activity indicate the progressive stages of speech recognition in the auditory cortex, which are further segregated into multiple pathways.

# The anatomical organization of the brain for language

Albert M. Galaburda

*Emily Fisher Landau Professor of Neurology and Neuroscience, Harvard Medical School, U.S.A.*

Although in the past few years there have been no paradigmatic changes in our knowledge of how the cerebral cortex is organized, our understanding of how language maps on to this anatomy has indeed changed. This is due to a large extent to findings made by functional imaging in normal subjects. In this lecture I will review what is known about the organization of the cerebral cortex and relevant subcortical structures with respect to language function. In hearing subjects the auditory system figures importantly in this organization; the extension of the auditory system includes most of the superior temporal gyrus, a far greater area that depicted in classical maps. Auditory areas on the superior temporal gyrus, including some quite anterior near the temporal pole, maintain orderly relations with visual areas in the middle and inferior temporal gyri, as well as with a number of parietal and frontal areas. Furthermore, there is a special interrelation between the perisylvian areas involved in language and dorsomedial fronto-parietal regions involved in motivation for and initiation of linguistic activity. Relations between the cortical auditory areas and the thalamus are also more widespread than commonly understood. Finally, interhemispheric connectivity plays a role in the interindividual variability seen in cerebral dominance for language. When this broader anatomical picture is taken into account, it is easier to understand why functional studies activate areas that fall outside the 'classical' language areas.

# Cognitive neuroscience of speech sound processing

Alec Marantz

*Department of Linguistics and Philosophy, Massachusetts Institute of Technology, U.S.A.*

I will report the results from two recent MEG studies on speech perception.

## Magnetic Mismatch Field elicited by phonological feature contrast

Colin Phillips, Thomas Pellathy, Alec Marantz

Phonological theory shows that the phonemes of a language are not primitives, but are composed of subphonemic units known as features. The phonemes /b/, /d/, and /g/ differ in place of articulation but share the feature [+voice], which distinguishes them from the phonemes /p/, /t/, /k/, which are all [-voice]. Existing research has shown that the generator of the Magnetic Mismatch Field (MMF) in human auditory cortex accesses representations of both the discontinuous acoustic sensitivity which underlies speech perception (Näätänen et al. 1997), and phonemic categories themselves (Phillips et al. 1998). The current study investigates whether the generator of the MMF can also access subphonemic feature representations, specifically the feature [voice].

Evoked magnetic fields were recorded using a 64-channel whole head magnetometer while subjects passively listened to sequences of standard and oddball stimuli. [+voice] stimuli were chosen randomly from a set of 12 synthetic syllables, consisting of /ba/, /da/, and /ga/ each with 4 different voice onset times (VOT); [-voice] stimuli were chosen randomly from a corresponding set of examples of /pa/, /ta/ and /ka/. There was no many-to-one ratio among stimuli at either the acoustic or phonemic level, but there was at the level of phonological features.

Comparison of responses to standard and deviant stimuli revealed a MMF component which could only be accounted for if the generator of the MMF has access to phonological feature representations. The MMF was statistically significant only in the left hemisphere.

## Is speech mode of auditory cortex related to knowledge of articulation/acoustic mappings?

David Poeppel, Colin Phillips, David Embick, Krishna Govindarajan, Alec Marantz

The sound categories of language are simultaneously perceptual and articulatory. There is much evidence that we hear according to the way that sounds are made and that we articulate speech sounds to create reliable acoustic categories. The sound categories of speech, then are well suited to the human articulatory and auditory/perceptual systems. Much of the research on the initial state of a child and on brain plasticity for speech perception has explored the sound space of actual human languages, i.e., the sounds that are within the articulatory and perceptual borders of language. We must ask whether the learning mechanisms used by the child are tuned to the sounds within a space delimited by properties of the human articulatory tract or whether any sounds with a formant structure and with timing properties similar to human speech will trigger the same category and contrast learning as speech.

As background to investigating these questions about the initial state of the child, the present study examines whether the adult auditory cortex is specially tuned to sounds that could be produced by a human articulatory system. Previous research from our group has suggested that the M100 latency in the auditory evoked MEG response correlates with the speech vs. non-speech status of the stimuli: for speech sounds, M100 latency is a function of the formant structure of the sounds while for non-speech, M100 latency is a function of the fundamental frequency. The present experiment tests the scope of this generalization and also tests whether the speech/non-speech distinction for auditory cortex is related to ecological plausibility, i.e., to what a human vocal tract can produce. Subjects are presented with sounds from a continuum between a 2-formant /a/ and a non-speech perceived-pitch stimulus with energy concentrated at what corresponds to F2 of the vowel. The continuum is produced by raising the relative energy at F2 over F1 for the vowel, simultaneously spreading the bandwidth of F2. As the energy at F2 increases, the sound becomes impossible for a human vocal tract to produce (and is perceived as a complex tone with a pitch at the fundamental frequency of the vowel). We predict a shift in M100 latency from a latency determined by F1 to a latency determined by F0 at the point in the continuum where the sound stops being perceived as a vowel.

# From speech perception to word learning

Janet F. Werker

*Department of Psychology, The University of British Columbia, Canada*

During the first year of life, infants become exquisitely tuned to just those phonetic differences which are used to distinguish meaning in their native language. This language-specific tuning would seem to ideally prepare the infant for the task of mapping sound on to meaning. However, in recent work we reported that although infants of 14-months who are in the initial stages of word learning are easily able to discriminate native-language contrasts in simple perception tasks, when they attempt to associate minimal pair words to two different objects, they become confused. This suggests a functional reorganization in the use of phonetic detail at the onset of word-learning. In ongoing work, we have been using both behavioural and ERP methods to ascertain whether this lack of sensitivity at 14-months reflects a deficit in the phonetic detail in the representation of words, or instead if it simply reflects a difficulty in access. As well, we have been probing to see whether older infants, who are more proficient word learners, can learn to associate minimal pair nonsense words to different objects.

To examine the question of representation vs. access, we chose to conduct an ERP study in collaboration with the labs of Neville and Mills. In previous work, Coffey-Corrina, Mills, and Neville (1995) found that infants of both 13-17 and 20-months show different infant ERP responses to known and unknown words. In our work, we tested infants of 14- and 20-months of age on their ERP response to known, phonetically dissimilar unknown, and minimal pair nonsense words. At 14-months the ERPs to the minimal pair unknown words patterned like the ERPs to known words, indicating that in its earliest stages, the lexicon may not include fine phonetic detail. By 20-months, the ERPs to the phonetically similar unknown words looked like those of the phonetically dissimilar unknown words, indicating that the brain was able to use fine phonetic detail to distinguish comprehended from unknown words. On the basis of these ERP results, we conducted a behavioural word-object association task with infants aged 20-months. As predicted by the ERP results, we found that infants of 20-months have no difficulty mapping minimal pair words to two different objects. The match between the behavioural and ERP work points to exciting new directions for study.

# Bilingualism: Learning and mastery of two languages

Núria Sebastián Gallés

*Dept. de Psicologia Basica, Universitat de Barcelona, Spain*

Research performed cross-linguistically has shown that speakers of different languages process the speech signal in quite different, language-specific ways. Moreover, they seem to apply maternal language knowledge when listening to foreign languages. But, what is it this "maternal language knowledge" for individuals raised in bilingual environments? In this talk, I will present some data analyzing the way in which people become bilinguals and how these people process and represent the two languages they have.

Though there are different lines of research dealing with this issue, I will concentrate my exposition on two specific domains. The two topics that I will expand both refer to phonological processing:

(a) tuning to the maternal language:

- language discrimination abilities in young infants (4 month olds) by monolingual and bilinguals
- acquisition of phonotactic constraints (10 month olds) by monolingual and bilinguals

(b) phonemic representation in adult bilinguals.

There are many different types of bilinguals, but we are interested in studying two types of them:

(1) people who during the first years of their lives had only been exposed to one language and that from age 3-4 onwards, they have been intensively exposed to two languages (and who currently use both languages in their everyday life)

(2) people who have been exposed to both languages from birth

Our hope is that the first type of bilinguals will allow us to address the issue: to which extent can a second language be learnt when early + intensive exposure to a second language is produced (but the first one has already been established)? Can L2 override (modify) the initial values of L1? The second type can allow us to address a different issue: is it possible to learn two languages at the same time (or our language learning "device" is designed to learn just one? Is it the same to learn one and two languages from the beginning?

# Cortical Activity and Language Acquisition

Jacques Mehler

*Directeur d'Etudes l'Ecole des Hautes Etudes en Sciences Sociales, Paris, France*

During language acquisition the first observable adjustment to the infant’s perceptual processing system is determined by the prosodic features of the parental language. In the last ten years several studies have established that at birth infants discriminate any two languages that have very different prosodic structures. How can the prosodic differences between two languages be measured? Phonologists and psycholinguists postulated that languages instantiate different timing properties, like syllable-timing, stress-timing, and so forth. Recently a more general hypothesis called the phonological class hypothesis (PCH) has been formulated. This hypothesis asserts that the languages of the world cluster into a few groups giving rise to perceptual classes. We will present evidence compatible with PCH. Clearly, PCH becomes interesting if it can be shown that some of the essential parameters that have to be fixed to learn the syntactic properties of one's language, can be correlated with the prosodic properties that characterize these classes or clusters.

Over time some of the abilities present at birth change. Two month old infants do not discriminate two languages if neither is the native language. However, two month olds have no trouble discriminating their native language from languages that belong to a different class even though they no longer distinguish it from other languages in the same class.

By the age of five months, infants have made considerable progress. Indeed, they now can distinguish their maternal language from other languages in the same class showing that they have assimilated properties other than the prosodic ones that characterize the class. It is known that it is about at this time that babies begin to move from a phonological to a phonetic characterization of language. Learning is very important during this period. To illustrate this point I will present results from studies of infants raised in bilingual environments. I will argue that similar studies on bilingual infants who are learning two very different languages are necessary if we are to understand whether one can generalize from the study of Spanish/Catalan bilinguals to say English/Mandarin bilinguals.

In the second part of the talk, I will first show that the vertebrate brain is very plastic and that re-mapping of the somatosensory cortex can be observed even in adults. Next I will show that language behavior is far more rigid than the cortical representation underlying behavior. I will review results from brain-imaging studies showing that the cortical representation of language changes with the degree of proficiency with which the language is spoken. In particular, I will show that the greater the proficiency of a bilingual with L2, the more extensive the overlap between the cortical representations of L1 and L2. Moreover, degree of proficiency is more important for our understanding of the macro-representation of L2 than age of acquisition.  We will discuss results obtained using PET and fMRI over the last five years.

To conclude, I will argue that we still need to study the stable state of the language used in conjunction with the linguistic dispositions of the human infant in order to be able to understand how language learning takes place. Moreover, it is important to compare the infants' dispositions with those in other higher vertebrates to gain a better understanding of the biological foundations of language.