How **Language** Hits a Nerve

"It's quite old and takes different forms; it can be tender but also angry, both gentle and brutal; it can proclaim love, but also declare war. We all know it – but somehow not all that well. We're confronted with it every day, but we'd be hard pressed to describe it if we had to. It comes to us, and becomes part of us, but we don't know how." With this riddle (the answer is "language") **PROF. ANGELA FRIEDERICI**, *Director of the* **MAX PLANCK INSTITUTE OF COGNITIVE NEUROSCIENCE**, *introduced her public lecture at the General Meeting of the Max Planck Society in Halle this year. The following article describes the current status of knowledge about the neural basis of language comprehension.*

While philosophers and other intellectuals have long reflected on language, it appeared to elude the natural sciences – until about 140 years ago, that is, when French neurologist and anthropologist Paul Broca presented the first evidence that language, like other mental phenomena, is bound to physical substance. Broca reported the case of a patient who had lost the ability to produce language with the exception of a single syllable, "tan". The patient remained well able to understand simple questions, however, and signalled his responses through affirmative or negative inflections of "tan".

Two years later the patient died. The autopsy revealed a brain lesion in the left hemisphere at the base of the third frontal convolution. As chance would have it, the patient's brain resurfaced in its original condition a hundred years later in an anatomical institute in Paris. The brain exhibits the lesion Broca described in the third frontal convolution (fig. 1 a). Interestingly, Broca had preserved the organ intact and not undertaken the customary dissection for in-depth examination – as if he had sensed intuitively that more than a century later a technique would be developed which permitted imaging the brain's internal structure without cutting, namely computer tomography. A substantial lesion can be seen in the anterior left hemisphere; the damage is far greater than one would assume from a surface examination (Fig. 1 b).

The external appearance of the lesion originally caused Broca to view the inferior portion of the third frontal convolution as the seat of language production; even today this portion of the left brain hemisphere is referred to as Broca's area. Several years later, in 1874, Breslau neurologist Carl Wernicke reported a series of patients who were able to produce speech but not understand it. These patients exhibited lesions in the superior convolution of the temporal lobe. From that time onward, language comprehension was attributed to this area of the brain, a localization which represented accepted scientific opinion for many years (fig. 2).

Today, however, we can specify the neural basis of language in much greater detail. This can be attributed to three factors. First, there is the formulation of basic theories of language and language processing. These models describe – sometimes in very precise terms – what it is that we wish to investigate, namely language and its individual components. The second factor is the rapid development of so-called imaging technologies which allow us to depict brain activity during cognitive tasks – both with respect to which areas of the brain are activated when it is put to work as well as how various portions of the brain work together in time. The third and perhaps most important factor, however, goes by the name of interdisciplinarity. Researchers from diverse backgrounds – the human sciences as well as the natural sciences – collaborate closely to probe the nature of language and the mind. What follows is the story of their adventure.

Photo: Wolfgang Filser / Fig.: MPI of Cognitive Neuroscience

Fig. 1a Fig. 1b

Photo Computer tomography

Brain of Paul Broca's patient, deceased in 1865

Classical Language Areas in the Left Hemisphere

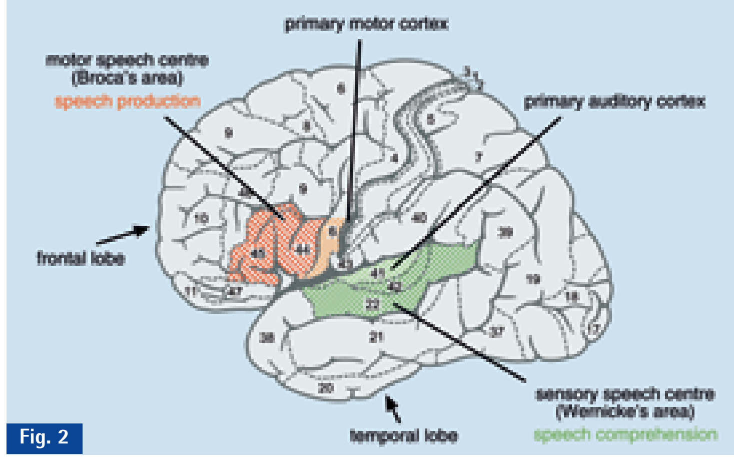


Fig. 2

Fig. 3

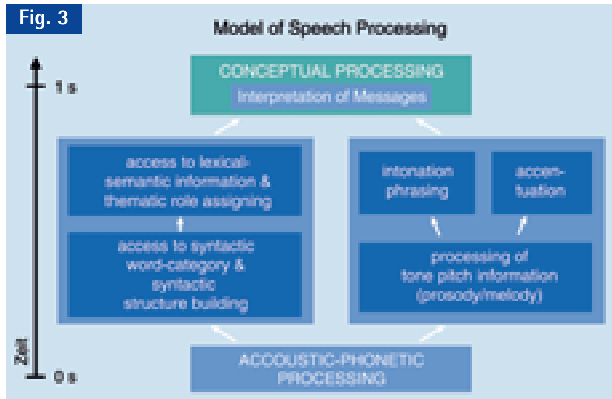
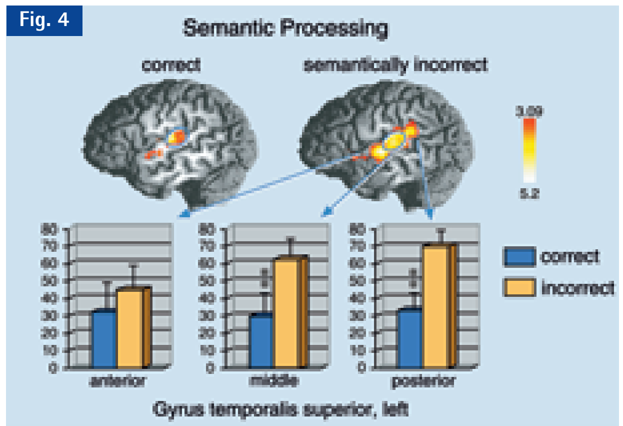


Fig. 4



Some people will ask whether it is actually possible to investigate the phenomenon of language, with its potential associations of Goethe or Schiller, using natural scientific methods. The answer is 'yes' when the object is not to interpret poetry but rather to probe the biological foundations of the human ability to comprehend language.

What then are the processes that transpire when we hear and comprehend language, from the acoustic input to the moment we arrive at an interpretation of the spoken word? Figure 3 shows a schematic rendering of these processes. First, the system must conduct an acoustic/phonetic analysis of the utterance. Subsequently, additional information must be filtered out along two paths. Along the one processing path access to lexical category and syntactic (grammatical) structure building occurs; only then are semantic features (meaning) accessed. During the semantic access phase thematic roles are assigned: it is determined "who is doing what to whom," and following that, the utterance is interpreted.

In addition to syntactic and semantic information, however, spoken language also contains prosodic information, in other words information pertaining to pitch modulations, or "sentence melody" as it is commonly called. This information is processed along the second pathway. Prosody can also signal sentence structure. For example, it allows us to distinguish between statements and questions, and to know whether the speaker is happy or sad. The system processes all this information at a very fast pace, from word to word in far less than a second – 600 milliseconds, to be more exact.

To understand how the brain accomplishes this, we must examine two questions. First, which areas of the brain support sentence processing, in particular the syntactic, semantic and prosodic aspects? Secondly, how are the individual subprocesses coordinated in time? Today we have various methods at our disposal to shed light on these issues by recording the activities of the brain "at work." One of the approaches entails event related brain potentials. Here, an electroencephalogram (EEG) records the summed action potential produced by synchronous activation of a large number of neurons. While the temporal resolution of this method is approximately 1 millisecond, spatial resolution is fairly inaccurate even using a large number of electrodes.

The other method, functional magnetic resonance imaging (fMRI), offers excellent spatial resolution of roughly 2 millimetres but less satisfactory temporal resolution. The functional MRI method records blood oxygen levels and changes during neural activity. Utilizing a combination of both techniques allows us to describe brain activity related to language processing with considerable temporal and spatial accuracy.

Let us first address the question of where syntactic and semantic processes occur in the brain. To this end, we conducted a series of experiments using functional magnetic resonance tomography (fig. 4). In one of the experiments, we presented sentences which were either correct ("Die Gans wurde gefüttert." – "The goose was fed."); contained a semantic error, that is an incorrect meaning ("Das Lineal wurde gefüttert." – "The ruler was fed."); or contained a syntactic error, incorrect grammar ("Die Kuh wurde im gefüttert." – "The cow was into fed.")

Such incorrect sentences can be used to test whether the brain reacts differently to each of the two error types – either the semantic or the syntactic information. The semantically correct and incorrect sentence conditions (fig. 4) elicit pronounced activation of the superior temporal gyrus. The differences between the semantically correct and incorrect conditions are greatest in the posterior and middle superior temporal gyrus. The syntactic condition (fig. 5) produces less pronounced activation primarily of the middle portion of the superior temporal gyrus. In contrast, the anterior portion of the superior temporal gyrus shows marked activation. Here, the difference between the syntactically correct and incorrect conditions is greatest. These findings substantiate that different areas of the superior temporal gyrus are specifically and independently activated by syntactic and semantic processes. The anterior portion of this gyrus is active primarily in processing syntactic aspects, while the middle portion is involved with semantics. The posterior portion of this gyrus appears to be equally activated in both processes, and therefore plays a role integrating semantics and syntax.

Syntactic and semantic conditions differ further in the activation of the frontal area. The syntactic – in contrast to the semantic – "violation condition" additionally activates the left frontal operculum located near Broca's area. This and a number of similar fMRI experiments demonstrate that different processes – primarily auditory, syntactic or semantic – are supported by different portions of the brain. It is interesting to note that a single area does not bear exclusive responsibility for either semantic or syntactic processes. Rather, one process simultaneously activates portions of the temporal as well as the frontal lobes, both of which form a specific mini-network. In the left hemisphere the networks for syntactic processes (fig. 6, marked in red) can be clearly distinguished from those utilized by the semantic processes (marked in orange). Frequently, there is pronounced activation of the frontal regions of the mini-networks only if semantic and syntactic processes require greater effort, in other words when the sentences are more complex than in the experiment reported here.

Based on these experiments we can now identify the areas of the brain in which the processing of syntactic and semantic features occurs. But what about the temporal parameters? Is syntactic information – as the theoretical model suggests – really processed before semantic information? To investigate this question we employ the method of event-related brain potentials (ERP) which provides temporal resolution in the millisecond range. Since only little specific brain activity is discernable from an ongoing EEG (fig. 7, top) due to the relatively large background activity of the brain at the time individual stimuli are presented (marked "S"), brain activity associated with a series of stimuli of a certain class is averaged. The averaging yields an interpretable brain wave, the event-correlated brain potential (fig. 7, bottom).

The stimulus material used in the ERP experiment was identical with that used in the previously described fMRI experiment and comprised correct, semantically incorrect, and syntactically incorrect sentences. Brain responses to the semantically and syntactically incorrect sentence conditions show marked differences. The brain response to the last word in the semantically incorrect sentence is shown for one electrode ("Cz") in the upper half of figure 8. The solid line represents the correct condition, the dotted line the incorrect condition. Both curves diverge at approximately 400 milliseconds and then reconverge at roughly 700 milliseconds. In keeping with its temporal occurrence, this negative component is called N400. From this experiment it is obvious how the brain reacts to the semantic error in the sentence.

The lower section of figure 8 shows the topographical difference between the correct and semantically incorrect conditions measured at electrodes distributed over the

Fig. 5

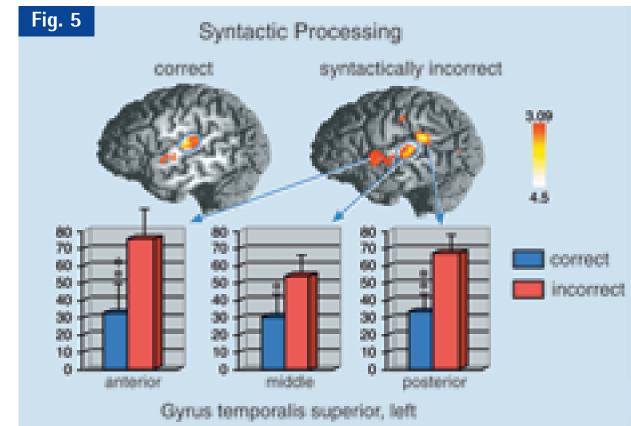


Fig. 6

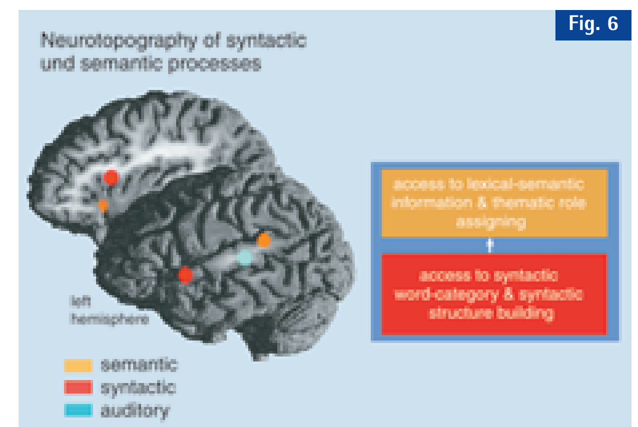
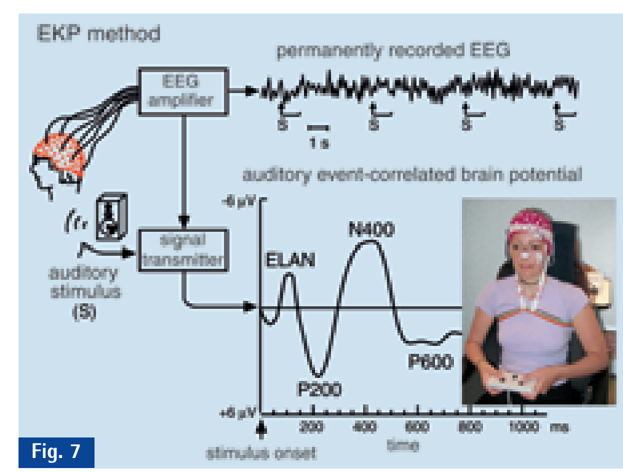


Fig. 7



surface of the head. Negativity is coded orange, and it can be seen that N400 spreads across the posterior portion of the head.

The syntactic violation (fig. 9, upper left, dotted line) elicits a very early brain response with an onset around 160 milliseconds. We named this component ELAN (Early Left Anterior Negativity). Figure 9, lower left, shows the topography of this component: it occurs in the anterior portion only and is somewhat more pronounced on the left than on the right. This implies that syntactic information is indeed processed earlier than semantic information. The distribution points to the activation of specific brain areas for syntactic as opposed to semantic processing. Syntactic errors elicit a second, later component, namely a positivity around 600 milliseconds which is therefore called P600 (fig. 9, upper right). In the lower right, figure 9 shows the distribution of this component over the head. It is clearly different from the early syntactic ELAN component.

The data support a precise temporal coordination between syntactic and semantic processes which is divided into three phases (fig. 10). First, a syntactic structure is rapidly and automatically built. Then, lexical-semantic information is retrieved and integrated (N400). If neither of the first two processes encounters a problem, the message can be interpreted. If problems arise, however, the system enters a reanalysis phase1 (P600) with the goal of finding an adequate interpretation.

These two experiments allow us to describe the neural aspects of the auditory input pathway within the left half of the model and to specify the temporal sequence of the spatially precise but initially static brain activity model (cf. fig. 6). First, acoustic information is processed bilaterally in the primary auditory cortex. This is followed by rapid syntactic processing in a temporal-frontal network and finally by semantic processing in a differently distributed temporal-frontal network. Successful integration of these different information types is essential for interpretation.

An additional experiment using a magnetoencephalograph (MEG) with a total of 148 channels supported the idea that the early syntactic process already activates the temporal-frontal network. The same stimuli were used as in the preceding experiments, and the sources of brain activity in the early time window around 160 milliseconds were calculated individually for five subjects. Interestingly, two sources emerged for this early time window, a temporal and a frontal dipole. This implies that the defined mini-network is already active in the early phase of syntactic processing.

This brings us to the processing of prosodic information (cf. fig. 3, right side of the model). The question of where prosodic information is processed in the brain was investigated using functional MRI. In order to analyze prosody separately from semantics and syntax, spectral information was filtered out of a normally spoken sentence (fig. 11, top), while pitch modulation was retained (fig. 11, bottom). The specific activation for the processing of prosody becomes clear when brain activation is compared for the filtered sentences – which contain prosody alone – and the sentences spoken normally, which conveyed both prosodic and spectral information. In the latter sentences, however, no content but only syntactic structure was recognizable because all content words had been replaced with pseudo-words. The findings support a dominant involvement of the right hemisphere in prosodic information processing (fig. 12).

The functional brain model depicts the processing of spoken language as follows (fig. 13). Homologous areas in the superior temporal gyrus and the inferior frontal gyrus of the left and right hemispheres are activated. Syntax and semantics are processed in domain-specific mini-networks, primarily in the left hemisphere, while prosody is principally processed in the right. We suspect that the left and right hemispheres collaborate in real-time to ensure effective processing of spoken language.

But how are syntax and semantics combined with prosody? To ascertain the interaction between syntax and prosody, subjects are presented with sentences containing so-called incorrect prosody, for example, "Peter verspricht, Anna zu arbeiten und das Büro zu putzen" ("Peter promises to work Anna and clean the office") instead of "Peter verspricht Anna, zu arbeiten und ..." ("Peter promises Anna to work and ...") or, "Peter verspricht, Anna zu entlasten und ..." ("Peter promises to relieve Anna and ..."). And indeed, the brain initially reacts to such misleading information with an N400 response indicating that it cannot integrate the inappropriate verb "to work" into the syntax of the sentence – as opposed to the correct verb "to relieve." Then, however, a P600 component follows as an expression of a reanalysis process – and so in the end the sentence is understood after all.

Shedding light on the interaction between semantics and prosody is a more difficult task. To accomplish this, one uses sentences containing words with positive or negative emotional connotations and presents each sentence in an emotionally appropriate or inappropriate tone of voice. Contrary to all other experiments, a difference between men and women emerges. Male brains respond to mismatched information more slowly than female brains, which react to prosodic emotional information very quickly – as early as 200 milliseconds. This could account for some of the misunderstandings between men and women.

This interesting aspect notwithstanding, we can state summarily for all brains that the path of acoustic input travels through spatially separated mini-networks. They process specific information from what has been heard separately and then communicate with each other within one second regarding the content. This applies to mature brains. But how do children learn to understand language between birth and age six? Currently, the relationship between language development and brain development is being studied on 250 children we are following from birth. At this time, the children are only one year old and there is as yet little to report. The study will require patience, a virtue every scientist needs.

Fig. 8

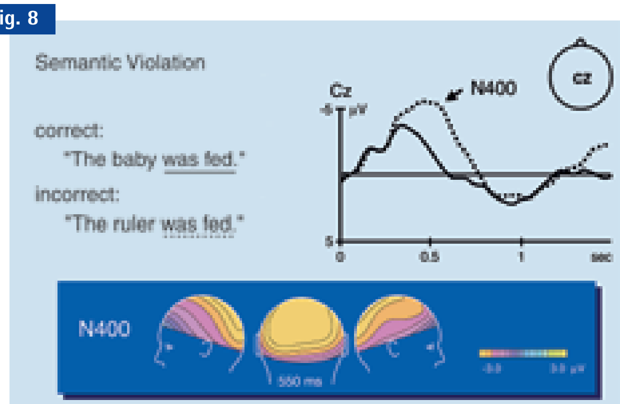


Fig. 9

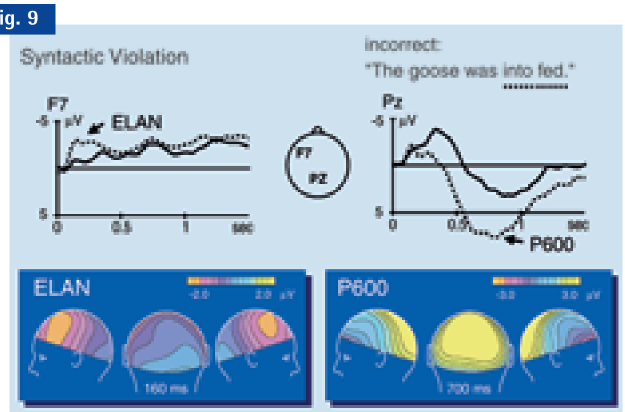
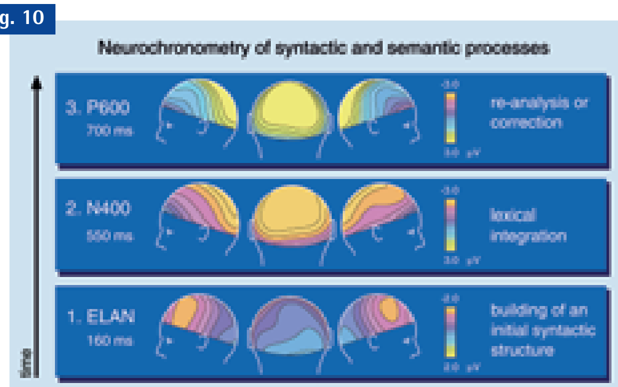


Fig. 10



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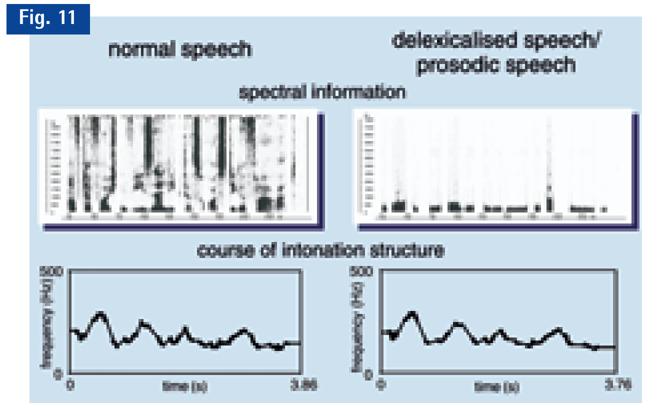


Fig. 12

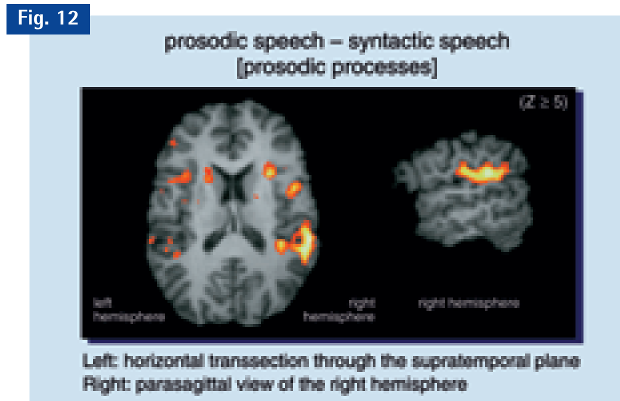
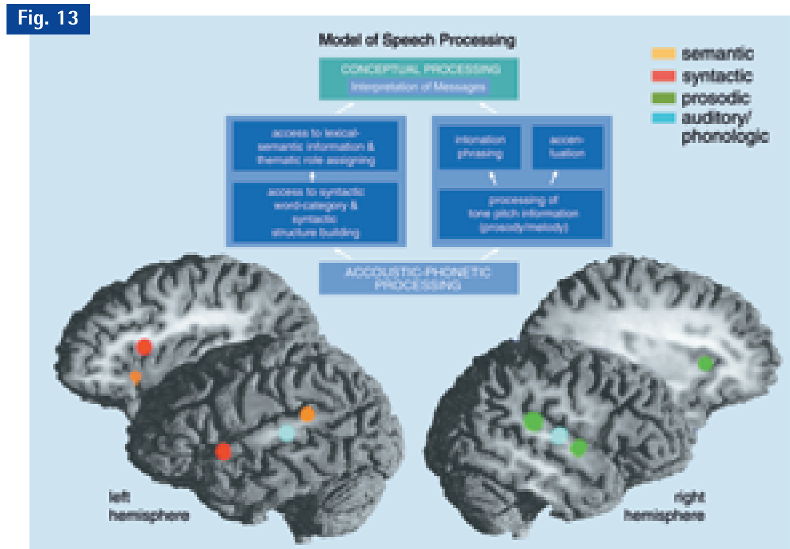


Fig. 13



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