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Editorial Overview
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Angela Friederici's group studies the functional neuroanatomy of language processing, in both the adult and the developing brain. Their aim is not only to describe the neural network underlying language functions, but, moreover, to understand the interplay of the different brain areas that unfolds over time.

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Leslie Ungerleider's research group focuses on the neural mechanisms of visual perception, attention, learning and memory, conducting single-cell recordings in non-human primates and functional magnetic resonance imaging (fMRI) in humans.

Introduction
In this issue of *Current Opinion in Neurobiology*, we include reviews covering a wide spectrum of topics in cognitive neuroscience. Many of the articles deal with traditional topics in the field, such as the neural basis of visual and auditory perception, multisensory integration, attention, and learning and memory, in which clear links can be made between human and non-human primate findings. Other reviews deal with distinctively human abilities, such as the processing of language, music comprehension and reading. The focus of these articles is on interactions among a distributed network of areas and, in particular, the part played by the prefrontal cortex. The prefrontal cortex and its interactions with more posterior cortical regions are also the focus of the review on the biological basis of autism, in which a disordered prefrontal cortex is postulated to be the source of the disease. Finally, we present here reviews of recent studies on the developing and aging brain, in which changes in prefrontal function are also emphasized. Overall, the emerging picture seems to be that more intensive investigations both on monkey–human homologies of brain function and on those neural mechanisms that mediate distinctively human abilities are taking place. We wish to thank the authors for their thoughtful contributions to this issue.

Visual processing and multisensory integration: from monkeys to humans
Given our extensive knowledge of the functional architecture of the monkey brain, one might ask to what extent can we establish homologies across primate species? As Sereno and Tootell point out, although macaque monkeys are the natural model system for humans, the last common ancestor of macaques and humans dates to more than 30 million years ago, and their independent evolution since that time has resulted in a complex mixture of shared and unique features. Still, with the advent of fMRI in humans, one can begin to make extrapolations, especially with regard to retinotopically organized visual areas. In their treatment of this subject, the authors first consider the methodological problems one faces in mapping visual areas in humans and then review the current status of evidence for possible homologies. They conclude that, with the exception of V1, V2 and MT in monkeys and humans, considerable uncertainty exists for homologies among most of the other retinotopically mapped areas.

In his article, Beauchamp tackles the question of which cortical regions integrate information across sensory modalities. He reviews the imaging data in humans indicating that regions of lateral occipito-temporal cortex contribute to multisensory integration. The emphasis here is on the superior temporal sulcus (STS), in which a patchy organization of visual, auditory and multisensory responsive regions has been described. In this regard, the STS in humans resembles area temporal–parietal–occipital (TPO) in the fundus of the STS of monkeys, where multisensory responses have been recorded. Additional functional evidence that the STS in monkeys and humans might be homologous is the finding that this region integrates information not only across sensory modalities but also within modalities; in both species, the STS integrates visual form with visual motion information.

Perceptual and motor skill learning

In contrast to declarative memories, which are retrieved through the explicit recall of events and facts, non-declarative (procedural) memories are typically retrieved implicitly through the performance of a perceptual or motor skill. Such memories are often acquired incrementally over time with practice and can be extremely long lasting, even without further practice. Importantly, skill learning is a clear demonstration of brain plasticity that can occur throughout one's lifetime. In his review of perceptual learning, Fahle notes that the specificity of the training-induced improvements (e.g. training to perceive a given line orientation does not transfer to other orientations) indicates neural changes in early sensory processing areas. At the same time, perceptual learning also appears to be under the control of top-down influences, such as task complexity and attention, which can greatly influence the degree to which such improvements generalize.

With regard to the acquisition of motor skills, Doyon and Benali distinguish between two categories: first, motor sequence learning, in which one incrementally learns movements to form a well-executed automatic behavior, and second, motor adaptation, in which one compensates for environmental changes. The authors present neuroimaging data, bolstered by behavioral results in both normal subjects and patients with cerebellar damage or Parkinson's disease, indicating that, during the early ('fast') stages of learning, the acquisition of both types of motor skills recruit cortico–striatal (CS) and cortico–cerebellar (CC) circuits. However, once the skill is automatic, its representation is distributed within the regions of a single circuit: motor sequences in CS regions and motor adaptations in CC regions. As the authors point out, recent findings indicate that this model of motor skill learning might require further refinement.

Declarative memory systems in non-human and human primates

Declarative memories are those that are accessible to consciousness and include memories for facts and knowledge (semantic memories) and for personally experienced events (episodic memories). The dependence of declarative memories on the hippocampus is reviewed by Bachevalier and Vargha-Khadem. Evidence from non-human primates indicates that there is a maturational gradient within the hippocampus; a profound and persistent memory loss resulting from hippocampal removal in infancy becomes evident only later in life. Importantly, the presence of an enduring global amnesia after early hippocampal insult indicates that no other brain structure can serve as a substitute. Recent neuropsychological data from case studies of children with developmental amnesia, for whom MRIs show severe hippocampal volume reduction, indicate a dissociation between semantic memory, which is largely intact, and episodic memory, which is severely and chronically impaired. Thus, one intriguing possibility is that the hippocampus is especially important for context-rich memory (i.e. episodes), whereas the surrounding cortical tissue subserves context-free memory (i.e. facts and knowledge).

The role of the hippocampus is further explored in the review by Ranganath and D'Esposito in the context of working memory, the ability to maintain and manipulate information 'on-line' for brief periods of time. Initially, the authors review the evidence that visual object working memory is accomplished via sustained activation of object-selective neurons in the inferior temporal (IT) cortex, and then highlight the roles played by the hippocampus and prefrontal cortex to support such sustained activity. For example, the hippocampus appears to have an especially important role in working memory for novel objects, presumably because these objects do not have a pre-existing representation in IT cortex. The role of the prefrontal cortex in working memory, by contrast, appears to be in top-down control processes, for example, in maintaining working memories in the face of distraction.

The role of attention and awareness in the processing of visual stimuli

Because of the limited processing capacity of the visual system, not all objects present in a visual scene can be processed at any given moment in time. Therefore, many objects compete for neural representation. The object that wins this competition then becomes the object that is processed, reaches consciousness, and is perceived. In their review, Hopf *et al*. report how attention can bias the processing in favor of relevant compared with irrelevant information, presumably through top-down feedback projections from frontal and parietal cortices. In particular, they present evidence that location-based, feature-based, and object-based selective attention mechanisms are coordinated dynamically and flexibly in visual cortex according to specific task demands.

Unlike attentional modulation of neural responses to neutral stimuli, it is now thought that the processing of stimuli with emotional valence (e.g. fearful faces) is automatic, immune to the effects of attention, and might even take place without awareness. The basis for this line of thinking comes from recent reports of responses in the amygdala to emotional stimuli under some unattended conditions, during visual masking and during binocular suppression. However, as Pessoa points out, the effects of attention are highly dependent on attentional load; when attentional resources are completely depleted, valence effects in the amygdala are not observed. Moreover, whether one is 'aware' or not depends on whether one uses an objective measurement (signal detection methods) or a subjective one (the individual's report). A key question in this ongoing debate is the extent to which a putative subcortical pathway to the amygdala can support the processing of emotional stimuli in the absence of inputs from the visual cortex.

Auditory processing

Our knowledge concerning the functional neuroanatomy of auditory processing in humans has gained considerably from studies on basic processes of audition in non-human primates [1]. In this issue, Scott discusses recent functional neuroimaging studies of audition in humans with reference to the auditory neurosciences of non-human primates. Similar to the situation with vision, a functional distinction between a 'what' pathway and a 'where' pathway is suggested. Whereas the primary auditory cortex supports the processing of pure tones, more complex sounds recruit adjacent regions. The more posterior auditory/inferior parietal cortex, as part of the 'where' pathway, responds to spatial characteristics of sounds. Anterior portions of the superior temporal gyrus and sulcus, as part of the 'what' pathway, respond, instead, to auditory objects and to lexical and syntactic aspects of speech.

Language, music, action and the prefrontal cortex

Whereas basic auditory processes are located in areas of the temporal lobe, in particular the superior temporal gyrus, higher order processes such as language and music comprehension additionally include areas of the prefrontal cortex, in particular the so-called Broca's area in the inferior frontal gyrus [2].

Perani and Abutalebi specify the neural network underlying the processing of language, both in monolinguals and bilinguals. Within a network comprising temporal, parietal, inferior frontal and subcortical structures, different areas are functionally related to phonological (speech sound), semantic (meaning) and syntactic (grammar) processes. With respect to second language processing, the crucial question is whether or not it is based on the same neural mechanisms and to what extent the age of second language acquisition determines the underlying neural basis.

In his review, Koelsch describes the neural network underlying music processing, thereby highlighting the large overlap of brain regions involved in music processing and the temporo-frontal network of auditory language processing. Moreover, when considering the time structure of music processing, different electroencephalographic (EEG) and magnetoencephalographic (MEG) studies suggest that structural aspects of music (music-syntax) and aspects of meaning (music-semantics) are processed in a temporal relationship quite similar to that of syntactic and semantic processing in language.

Both language and music processing involve not only sensory systems but also regions in the prefrontal cortex. Thompson-Schill *et al.* discuss whether different subareas of the prefrontal cortex can be interpreted to be domain-specific (as assumed by several studies), or whether the prefrontal cortex should rather be attributed domain-general functions of regulatory control. The authors stress the regulatory function of the prefrontal cortex across domains, but note that domain-specific processing might emerge through this area's connectivity to posterior brain regions.

The contribution of Fadiga *et al.* addresses this issue by discussing the role of premotor cortex in action perception. Motivated by findings showing that premotor neurons in non-human primates discharge when viewing an action, data are presented from human subjects who observed similar stimuli as those used in the primate studies, while transcranial magnetic stimulation is applied. The functional relation between sensory and premotor regions is considered, and the notion of mirror neurons is incorporated into a model for language processing.

Autism as a special case of frontal abnormality

The central role of the frontal cortex for higher cognitive functions is highlighted by the contribution of Courchesne and Pierce on autism. A functional anatomical model of autism is put forth on the basis of the results of studies using gray and white matter volumetry and diffusion tension imaging (DTI), which enables examination of fiber tract organization. The authors suggest that autism might be characterized by over-connectivity in frontal cortex that is accompanied by a lack of connectivity between the frontal cortex on the one hand and sensory and other long-distance regions on the other hand. From this it appears that it is the intact function of frontal cortex in addition to the intact function of the sensory systems that guarantees normal social, emotional and cognitive functions.

Reading and reading disturbances

Reading abilities are secondary to auditory language functions both in phylogenesis and in ontogenesis. Reading requires the translation of visual codes (written letter combinations) and pronunciation (spoken syllables and words). Price and Mechelli describe the neural mechanisms underlying this process and highlight the observed double dissociation between reading real words associated with a particular meaning and reading pronounceable letter strings that are not associated with any meaning (pseudowords). This dissociation between lexical and sublexical processes is not only observed in the functioning reading system, but seems relevant also for the understanding of reading disturbances.

Cerebral changes in cognitive development and aging

Brain anatomy and function change during an individual's life span. Casey *et al*. review the recently emerging studies that use functional brain imaging to investigate changes in neuroanatomy, connectivity and function from childhood and adulthood. Convincing evidence from structural MRI, functional MRI and DTI studies is provided indicating that brain systems subserving motor and sensory functions mature earliest, whereas brain areas supporting functions, located in the prefrontal cortex, mature later. The reviewed studies point towards a close linkage between cognitive changes and changes in neuroanatomy and in neurophysiology.

Reuter-Lorenz and Lustig focus on cognitive development in later life, that is, aging and the resulting socio-affective consequences. Reviewing the literature on aging, it becomes obvious that there is shrinkage of the gray and white matter, in particular in the prefrontal cortex, in addition to cholinergic and dopaminergic decline. These facts are confronted with data suggesting that plasticity exists during aging, leading to a more positive view of aging than the dominant view, which has been one of irreversible decline.

Conclusions

This collection of reviews demonstrates that a combination of different methods, from functional imaging, electro- and magnetophysiology, transcranial magnetic stimulation, in addition to single-cell recording to structural methods such as gray and white matter volumetry and diffusion tensor imaging provides a novel and more complete view of the functional neuroanatomy of cognitive processes.

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References

1. Rauschecker JP, Tian B: **Mechanisms and streams for processing of "what" and "where" in auditory cortex**. *Proc Nat Acad Sci USA* 2000, **97**:11800-11806.

2. Friederici AD: **Towards a neural basis of auditory sentence processing**. *Trends Cog Sci* 2002, **6**:78-84.