Localization of Clinical Syndromes in Neuropsychology and Neuroscience
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## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td></td>
<td>xv</td>
</tr>
</tbody>
</table>

### 1 Disturbances of Brain Information Processing and Localization Studies
- Localizationist Approach
- Holistic Approach
- Modern Approaches: Interfacing Localization with Holistic Perspectives
- Sizes of Lesions and Compensatory Mechanisms of Brain Information Processing
- Types of Lesions
- Summary

### 2 Disorders of Recognition in the Physical World: Visual Agnosia
- Visual Agnosia
- Color Agnosia

### 3 Disorders of Recognition in the Physical World: Other Types of Agnosia
- Visuospatial Agnosia
CONTENTS

Loss of Visual Imagery ............................................. 109
Auditory Agnosia .................................................. 113
Tactile Agnosia, Astereognosis ................................ 129
Somatoagnosia and Disturbances of Somatic Self-Image .............................................. 136
Disturbances in the Recognition of Motion and Action in the Physical World ...................... 157

4 Disorders of Recognition in the Physical World: Illusions and Hallucinations .............. 187
   Illusions .................................................. 187
   Hallucinations ........................................... 191

5 Disturbances of Recognition of the Social World .............................................. 221
   Social Agnosia ........................................... 221
   Agnosia of Social Actions ................................ 254
   Delusions ................................................ 272

6 Disturbances of Actions ........................................... 291
   Motor Apraxia .......................................... 291
   Social Apraxia: Disorganization of Goal-Directed Behavior in the Social World ............... 324

7 Communication Disorders ........................................ 335
   Aphasia Syndromes and Other Language Disorders ............................................. 335
   Alexia and Agraphia ...................................... 406
   Amusia .................................................. 419

8 Memory Disorders: Disturbances of the Major Supportive System of Brain Information Processing ........................................... 427
   Amnestic Syndromes ..................................... 433
   Disturbances of Modular Memory for Recognition and Action .................................... 455
   Working Memory and Its Disturbances .......................................................... 466

9 Disturbances of Regulatory Activity: Impairment of Visually Guided Attention .............. 483
   Disturbances of Visually Guided Attention and Visual Agnosia ................................ 484
10 Disturbances of Regulatory Activity: Impairments of Volition. .......................... 501
   Avolition, Akinesia, and Negative Symptoms ........ 501
   Apathy, Avolition, Akinesia, and Disturbances of Brain Information Processing ........ 524

11 Disturbances of Regulatory Activity: Impairments of Emotion .................... 529
   Mood Disorders ........................................ 529
   Anxiety Disorders .................................... 566
   Mood Disorders and Disturbances of Brain Information Processing ................ 599

12 Generalized Cognitive Disturbances .......... 607
   Delirium .............................................. 607
   Dementia ............................................. 621

13 Neuropsychological Testing of Clinical Syndromes ................................. 667
   Neuropsychological Testing and Brain Imaging ........ 667
   Psychometric System Based on Normative Data of Normal Individuals ........ 668
   Psychometric Neuropsychological System Based on Clinical Normative Data ...... 672
   Neuropsychological Testing of Clinical Syndromes .................................. 673
   Use of Diagnostic Algorithms in Neuropsychological Testing of Clinical Syndromes .... 688

Appendix ..................................................... 693

References ................................................ 705
Clinical medicine and health care has based its diagnostic decision making on the concept of syndromes—peculiar combinations of signs and symptoms often underlined by common causes, pathogenesis, or localization of lesions. This pattern was, similarly, followed in the early days of neuropsychology. However, a constantly growing number of neuropsychological studies—clinical, experimental, and anatomical—are focusing less on clinical descriptions of major neuropsychological syndromes and are focusing instead on the studies and analyses of simple signs and symptoms, which often reflect impairments of single operations rather than disturbances in particular functional goals manifesting as clinical syndromes. This new approach has resulted in controversies concerning clinical patterns and localization of lesions even in such well-established syndromes as various types of aphasia, agnosia, and apraxia. The shift in approach is further complicated by discrepancies between the old so-called lesion data and the findings brought to the field of clinical neuropsychology by the explosion of new data obtained through the use of powerful technology such as single-cell recording and functional brain imaging as well as the expansion of the empirical foundation of clinical neuropsychology and neuroscience.

For many years, the clinico-anatomical approach remained one of the major methods in the study of brain information processing in normal and pathological conditions. In many respects, clinico-anatomical data remains pertinent to the new data and to subsequent theoretical explanation based on current methods of cognitive neuroscience, neuropsychology, and neuropsychiatry. The goal of this book
is to systematize the historical clinico-anatomical neuropsychological and neuropsychiatric data and to present those data in such a way as to make them more compatible with recent findings based on the modern methods of cognitive neuroscience, especially single-cell recording and brain imaging. It is important to consider both types of data within the frameworks of concepts developed by modern computer science and the construction of artificial cognitive devices. Approaches are also discussed in relation to new types of neuropsychological testing conducted by the authors and their colleagues. This book offers systematic descriptions of the clinical manifestations, anatomical data, and history of studies of the various neuropsychological syndromes; in fact, the text may be used as a frame of reference for clinical signs and syndromes and localization for research and clinical practice in neuropsychology, neuropsychiatry, and cognitive neuroscience.

Also analyzed are findings that exhibit the types of brain information processing that influence the single versus multiple sites of lesion localization that then lead to similar types of disturbances, for example, various sites of lesion that may each cause a similar impairment in one’s working memory. These analyses help to present localizationist versus anti-localizationist approaches as perhaps two sides of the same issue. While one side is based on differences in the functional structure of modules for simpler, well-learned, and relatively strictly localized conventional information processing, the other is based on modules for more complicated and unconventional information processing, requiring the use of operations that are localized in several brain areas. It is the entire issue, rather one perspective versus another, that is particularly intriguing, robust and most important. In essence, one cannot leave the role of localization to neuroradiology nor can one simply be content with understanding neuropsychological patterns of performance. It is the interface between localization and functional analysis that is the future of brain study.

The content of this book is based on the taxonomy of neuropsychological syndromes underlined by the functional goals of the various parts of the intermediate and high levels of brain information processing. The text also attempts to incorporate neuropsychological clinico-anatomical syndromes such as agnosia, aphasia, apraxia, and amnesia into the new taxonomy, incorporating a reflection of disturbances in the particular functional goals. Accordingly, the book consists of 13 chapters that describe disturbances of several systems involved in the intermediate and high levels of brain information processing, including recognition, action, communication, and supportive and regulatory functions. These disturbances are described and analyzed within the framework of four major themes explored in the book.
The first theme focuses on the differentiation of syndromes underlined by disturbances of conventional versus unconventional information processing, which helps to outline the conventional syndromes in relation to localized circumscribed brain lesions and to bring attention to the localization problems in the unconventional syndromes. Conventional information processing consists of high frequency and well-known items that may be processed using a limited store of representations as compared to well-learned complex features. Such modules may be tuned to the processing of a particular type of information, for example, the recognition of high frequency objects or faces, or the performance of typical actions. As this processing requires a relatively small amount of brain space, damage to the area may result in the development of clearly defined clinical syndromes that have been described in detail through years of neuropsychological, behavioral neurological, and neuropsychiatric studies. Conversely, unconventional information processing deals with more complicated information, including a large number of typically low frequency items that may be completely absent in and/or between the stored representations. Unconventional information processing requires the use of various additional operations to process new items or items with an incomplete set of information, for example, objects partly occluded by background “noise” or overlapping objects. Processing of such information depends on a wide range of operations performed by multiple structures in various areas of the brain. Damage to these structures may result in disturbances of unconventional information processing, for example, an impairment in the recognition of incomplete objects caused by lesions in multiple different brain sites, lacking a clearly defined, narrow lesion localization in one specific area of the brain. It is especially important to take this into account as increasingly more sophisticated cognitive tests are often directed toward the evaluation of unconventional information processing, making quite difficult the use of such tests for purposes of localization. Problems arising from studies of single-cell recording are often based on tests directed toward unconventional information processing. Results of these studies have often exhibited a lack of support from the clinico-anatomical cases studied with the use of clinical features of disturbances in conventional information processing.

The second theme presented is related to the information processing approach based on the use of features that describe the common invariant properties of the same items, such as a particular object in various positions or actions. The common properties may include simple and complex features as well as the semantic meaning of the item, which may be used for comparison with similar features of representations stored in the memory (Ullman, 1996). This text describes and analyzes disturbances as they are related to the processing of simple
and complex features of various types of items in the course of brain information processing, especially the role of the impairment of complex features analysis in the development of the major syndromes of disturbances in the intermediate and high levels of brain information processing.

The third theme gives special attention to disturbances of recognition in both the physical and social worlds. The concepts of agnosia and apraxia as defined in neuropsychological and neurological literature are explored in relation to the physical world, with descriptions and analyses of disturbances in recognition and in social actions being considered. In general, disturbances of recognition and of actions in the social world have been traditionally characterized by vague terms such as social incompetence, and may be better defined and studied within the concepts of social agnosia and social apraxia. We attempt to systematize these issues in accordance with the already well-studied disturbances of prosopagnosia and agnosia of emotions and to outline the current status of the studies and their future directions. The book also includes descriptions of the clinico-anatomical syndromes underlined by disturbances of the social self as a module independent from the body image or somatic self-image; the book then discusses the roles of disturbances of the somatic self-image and social self in the formation of neuropsychological syndromes.

The fourth theme brings attention to disturbances in the recognition of dynamic components of the world. Agnosia is usually described in relation to disturbances of recognition in the physical world of such static items as objects and space; dynamic actions in the physical world are typically excluded from the major studies of recognition. The text emphasizes the role of impairments of recognition and of actions in the constantly changing dynamic environment via literature-based descriptions of various types of agnosia of action in the physical and social worlds and via an outline of the symptoms of social agnosia and social apraxia. Also discussed are ways to adjust current clinical neuropsychological testing to meet the needs of research and of everyday clinical practice as based on an evaluation of neuropsychological syndromes.
The syndromological and localization approaches reflected in this book have been originally discussed by Joseph Tonkonogy with Alexander Luria, one of the founders of neuropsychology. We are grateful to Alexander Luria for his inspiration to continue the efforts in those directions that represented the backbone of the neuropsychology approach at the early stages of its development. The efforts have been later enhanced by help of Ilya Tsukkerman, the eminent physicist and enthusiastic supporter of strong connections between computer science, especially in the area of incomplete information processing, and studies of brain pathology and behavior. We owe a debt of gratitude to Ilya Tsukkerman for his instruction and collaboration.

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Disturbances of Brain Information Processing and Localization Studies

The role of brain scientists and clinicians has historically been focused on localization of brain function. More recently, the advent of sophisticated brain imaging, such as computerized axial tomography and magnetic resonance imaging, has resulted in a significant shift in the understanding of brain structure and function. This shift has resulted in an increasing focus on pattern analysis of cognitive disorder for neurological diseases. However, increasing evidence is suggesting that the correlation between function and neuroradiological studies is weak at best. Thus, interfacing known information about disturbances of brain information processing with localization studies should provide new opportunities for a more robust understanding of brain disorders.

Localizationist Approach

At the turn of the nineteenth century, the ideas of undivided mental processes were challenged by suggestions that mental processes might be divided into relatively isolated mental “abilities” with specific locations in the brain. At that time, Gall (Gall & Spurzheim, 1810–1819) tried to suggest the localization of isolated mental abilities
in the various regions of the cortex. He was first to point to the localization of speech abilities in the frontal regions of the brain. Though Bouillaud, who by 1825 had reached a position of great influence in the Paris medical community, was a supporter of Gall’s ideas, neither Gall nor Bouillaud had any real evidence in support of their point of view.

Such evidence was first presented by Broca, a surgeon and anthropologist, who observed a patient with peculiar speech disturbances related, as Broca stressed, to a lesion in the posterior part of F3. The patient, Leborgne, was able to say only the word “tan” and a few obscenities. However, the muscles needed for speech appeared to be preserved, as the patient was able to eat and to drink, and no disturbances in comprehension of spoken language were observed. Broca concluded that the patient had a specific disorder in his ability to articulate language, a disorder that he termed aphemie. Broca presented the patient’s brain on April 18, 1861, just one day after the patient’s death, at a meeting of the Paris Anthropological Society. During his presentation, Broca (1861a) exhibited his finding of a cerebral infarction in the left hemisphere that extended from the posterior part of the third frontal gyrus, through the lower part of the central gyrus, to the anterior part of the first temporal gyrus. His observations of a sequenced progression of language disturbances in the patient allowed Broca to conclude first that the disturbances were related to the posterior F3 lesion and subsequently that the posterior F3 area represented a center for articulate language. Broca eagerly informed Bouillaud, Broca’s teacher and mentor, who supported the idea previously (Bouillaud, 1825) (for details, see chapter 7, section entitled “Aphasia Syndromes and Other Language Disorders”).

Several months later, in November 1861, Broca (1861b) presented his second case at a meeting of the Paris Anthropological Society. Lelong, the patient presented, had resided at the Bicetre hospital since 1853, with manifestations of senile dementia. In April 1853, Lelong experienced a stroke; what followed was a development of prominent speech disturbances—the patient was able to utter no more than several words and could do so only with laborious articulation. However, Lelong was able to understand almost everything that was said to him, and no disturbances were observed in the movements of his extremities. On October 27, 1861, Lelong experienced a fall during which he suffered a fracture of the left hip; he died 12 days later. An external overview of the brain revealed the destruction of one half of the posterior F3 in the left hemisphere. This damage was connected with tissue loss in the second F2, an area that was almost completely destroyed. The central gyrus and F1 areas, however, had been completely preserved.

In addition to the clinical significance of lesion localization in patients with speech disorders, the data presented by Broca were
probably the first to demonstrate the role of the clinico-anatomical method in the study of isolated mental abilities. Soon after Broca’s presentation, similar cases were reported by a number of authors. Later, in 1864, Trouseau pointed out that the word infamy in the modern Greek language may be translated as aphemia, and suggested the replacement of the word aphemia with the word aphasis. Despite Broca’s objection, Trouseau’s suggestion was widely accepted. Thus, the term aphasis became accepted and became widely used in the literature.

Ten years later, in 1874, Karl Wernicke published a book in which he provided 10 case studies and described patients with disturbances in the comprehension of spoken language as well as in expressive speech, naming, reading, and writing. Wernicke called these disturbances sensory aphasis. Following the deaths of two patients, brain autopsies were performed, revealing extensive brain lesions. An autopsy performed in the only case with a circumscribed lesion showed an infarction in the posterior part of T1 and in adjacent areas of T2 in the left hemisphere. Based on these findings, Wernicke attributed the development of sensory aphasis to a lesion in the “auditory speech center” in the posterior T1. He suggested that a lesion in the left posterior T1 resulted in sensory aphasis, while a lesion in the left posterior F3 produced motor aphasis. The interruption of the connection between the centers of “auditory speech images” and “motor speech images” led, according to Wernicke, to the development of conduction speech aphasis with disturbances of speech repetition.

Lichtheim presented the idea of a “center of concepts” in 1884 and suggested that the development of transcortical motor aphasis was the result of an interruption of the connection between the center of concepts and the motor speech center, while transcortical sensory aphasis occurred when the connections between the center of concepts and the sensory speech center were disturbed. Based on Lichtheim’s suggestions, a classification of aphasis was developed (Lichtheim, 1884); it is still currently used (for more details, see chapter 7, section entitled “Aphasis Syndromes and Other Language Disorders”).

The studies of Broca and Wernicke may be considered to be important milestones for the series of subsequent works and great successes of localizationists at the end of the nineteenth century and at the turn of the twentieth century. In 1881, Munk showed that following the removal of its occipital lobes, a dog preserved its ability to see but was no longer able to recognize objects. Several years later, Wilbrand (1887) and Charcot (1883) described cases in which visual agnosia resulted from cerebral infarctions involving the second occipital gyrus (Wilbrand, 1892). In 1890, Lissauer was the first to describe the apperceptive and associative types of visual object agnosia. Disturbances of writing related to a lesion of the posterior F2 area were reported by Exner in
1881, while in 1877 Kussmaul presented cases of isolated reading disturbances under the name wordblindness, or "Wortblindheit." Various types of visual spatial agnosia reported at that time included disturbances of topographic disorientation (Wilbrand, 1887) and visual neglect of hemispace (Anton, 1898; Balint, 1909). Tactile agnosia was described and called astereognosia by Hoffman in 1885. Motor and sensory amusia was observed by Steinhal in 1871 and later by Oppenheim in 1888. In addition to the disturbances of recognition of the outside world, disturbances of recognition in the "somatic Myself" (Pick, 1908), also known as somatoagnosia, were defined by cases with anosognosia of blindness (Anton, 1898, 1899) and anosognosia of hemiplegia (Babinsky, 1914). The majority of the studies were limited to neurological patients who suffered primarily from circumscribed focal lesions often caused by cerebral infarctions, and in some patients by tumors and head injuries.

The clinico-anatomical approach was more difficult to apply in the field of psychiatry, due to the absence of significant anatomical and localized changes in cases with primary psychiatric illnesses such as schizophrenia and bipolar disorder. However, some cases in which psychiatric manifestations of clearly defined neurological conditions, resulting from head injuries, brain tumors, encephalitis, and degenerative brain diseases, were present allowed for the use of the clinico-anatomical approach.

A classic example is the celebrated case report of Phineas Gage (Harlow, 1868). Gage exhibited profound personality changes following a severe frontal lobe injury caused by an explosion that sent a metal rod through his skull. The rod traveled upward from the left maxilla and through the frontal lobe, exiting to the left of the frontal skull’s midline (similar personality changes were later observed in other patients with frontal lobe injuries). Another example is given in a description by Korsakoff (1887) of the peculiar amnestic disorders caused by chronic alcoholism, later found to be related to lesions in the mamillary bodies and medial dorsal nuclei of the thalamus (Gamper, 1928; Victor, Adams, & Collins, 1971).

A series of psychiatric studies based on the clinico-anatomical approach was begun in the 1920s and 1930s during the aftermath of World War I. The main data were provided by evaluations of World War I veterans with various head injuries acquired during battle. Further studies were performed in the 1940s and 1950s involving psychiatric manifestations of brain tumors and epilepsy as well as head injuries sustained in action during World War II. It was demonstrated that apathy, or flatness of affect, often developed after frontal lobe injuries, especially following injuries to the dorso-lateral prefrontal cortex, the thalamus, and the globus pallidus (Feuchtwanger, 1923; Kleist, 1934). A melancholic type of depression was frequently observed in cases with temporal lobe tu-
Disturbances of Brain Information Processing and Localization Studies

E. Mors (Hécaen & de Ajuriaguerra, 1956). Electrical stimulation of the T1 area led to the development of verbal auditory hallucinations and, in some cases, visual hallucinations (Penfield & Erickson, 1941). Peculiar personality changes were observed and studied in patients with temporal lobe epilepsy (Bear & Fedio, 1977; Waxman & Geschwind, 1975), and caudate and frontal lobe lesions were reported in cases of obsessive-compulsive disorder, and so on.

HOLISTIC APPROACH

From the early years of localization studies, the idea of strict localization was criticized by anti-localizationists who stressed that mental functions cannot be localized in particular areas of the brain. Flourens (1824, 1842) insisted that the brain is a homogenous substance that is similar to, for instance, the liver in its physiological functioning. Flourens based his ideas on experiments involving the removal of various parts of the cerebral hemisphere in birds. The birds’ behaviors were completely restored after a certain amount of postsurgery recovery time, regardless of the localization of the removed parts. Goltz (1876–1884) observed only a transient disturbance of behavior after a surgical removal of various parts of the cerebral hemisphere in dogs, an outcome he considered to be a result of the brain’s reaction as a whole. Subsequently, the dogs showed a “general decline of intellect,” which Goltz correlated with the size of the removed brain tissue but not with the localization of the lesion.

The idea of a general intellectual decline was explored further by a number of authors. Finkelenburg, in 1870, was probably the first to suggest that damage to the cortex of cerebral hemispheres results in asymbolia, a disturbance in one’s ability to use symbols, leading to impairments in speech, recognition, and actions. Marie (1906a, 1906b) later brought these ideas to the study of aphasia in 1906, suggesting that the main disturbance in aphasia is a “partial intellectual disturbance” manifesting in impairments of speech comprehension and presenting itself as Wernicke’s sensory aphasia—what Marie termed a “true” aphasia.

Subsequently, Head (1926) considered the basic disturbance in aphasia an impairment in “symbol formulation and expression,” which represents a part of “general intellectual ability” and cannot be strictly localized in any definite area of the brain. Goldstein (1948) later outlined the differences between the peripheral and central cortices. According to the anatomical principle in which cortical structure leads to disorders of the instrumentalities of speech, such as peripheral motor aphasia and peripheral sensory aphasia, lesions in the periphery result in
more elemental neurological manifestations in comparison to more centrally located lesions.

According to Goldstein, the central part of the cortex has the property of equipotentiality. A lesion in any part of this central cortex leads to a disorder in one’s ability to form abstractions and to perform categorization; the severity of this disorder depends only on the size of the damaged cerebral tissue. Goldstein considered anomic aphasia to be a typical example of aphasia produced by a disorder of “abstract language.” Goldstein’s idea was closely linked to Lashley’s conception of brain tissue equipotentiality. Lashley (1929) studied the role of extirpations of particular types of cerebral hemispheres on the behavior of rats. He observed that the degree of disturbances in the behavior of rats in the labyrinth did not depend on the localization of the extirpations but rather reflected the size of the removed brain tissue.

Several other studies pointed to the correlation of the development and severity of aphasia with lesion size. Through the years, a series of cases has been described in which small lesions in Broca’s area of posterior F3 result in either a transient aphasia or no aphasia at all. Such cases have been collected from both literature and experience, being originally described by Marie (1906a, 1906b), Moutier (1908), Von Meyendorf (1930). Mohr et al. (1978) observed that an infarct limited to the posterior part of the left F3 resulted in transient mutism with subsequent recovery to almost normal speech, though with some mild articulation difficulties, within a few days or weeks following a stroke.

A transient form of Broca’s aphasia was also described in cases with symmetrical destruction of Broca’s areas in both hemispheres (Tonkonogy & Goodglass, 1981). Tonkonogy (1968b, 1986) demonstrated that in Broca’s aphasia the severity and persistence of the deficit is proportionate to the size and distribution of the infarction over the opercular, insular, and adjacent cortical and subcortical regions. The effect of the lesion size on the severity of language impairment was later exhibited by Selnes, Knapman, Niccum, Rubens, and Larson (1983) and Knapman, Selnes, Niccum, and Rubens (1984).

It has also been stressed that the particular symptoms of aphasia, such as a disturbance in comprehension, may be observed in patients with various anterior and posterior lesions within the large perisylvian region in the left hemisphere (Selnes et al., 1983).

Another example against a strict localizationism is a disturbance in one’s ability to classify visual stimuli in accordance with a changing target category during the course of testing. For instance, in the Wisconsin Card Sorting Test (WCST), the subject is required to classify the 64 cards according to color, form, number, and again color as the test progresses (Berg, 1948; Grant & Berg, 1948). In Halstead’s
Category Test (Halstead, 1947), the subject must classify 208 items into seven sets organized according to different categories—number of objects, ordinal position of an odd stimulus, and so forth. It was suggested that disturbances of categorization revealed by the WCST or by Halstead’s Category Test might be related to lesions of the frontal lobe (Halstead, 1947; Milner, 1963; Weinberger, Berman, & Zec, 1988). However, several studies failed to observe any consistent relationship between the results of the category test and any specific location or laterality of brain damage (Doehring & Reitan, 1962; Reitan & Wolfson, 1985), or any differences in WCST performance between groups of patients with local frontal versus nonfrontal lesions (Anderson, Damasio, Jones, & Tranel, 1991; Axelrod et al., 1996). It should be emphasized that Goldstein (1934, 1948), who originally introduced the card sorting tests for studies of “abstract attitude,” held that impairments in one’s ability to form abstractions cannot be strictly localized in particular cortical areas.

MODERN APPROACHES: INTERFACING LOCALIZATION WITH HOLISTIC PERSPECTIVES

Clinico-anatomical studies have been markedly advanced in recent decades by the advent of brain imaging, especially head computerized tomography (CT) scans and brain magnetic resonance imaging (MRI) scans, providing the tools necessary to study the anatomy of lesions in patients. These studies have helped to refine the detection of clinical symptoms, classifications, and anatomical findings in the syndromes previously described using the historical clinico-anatomical approach based on a comparison of clinical and autopsy findings. The new data are discussed and compared with the original findings in this book. The role of functional brain-imaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans in studies of localization is also discussed.

Special attention should be paid to modern approaches based on the theory and models of information processing developed in studies of artificial intelligence. These approaches bring a new dimension to the understanding of brain information processing by outlining the particular goals of recognition and action, the operations needed for the achievement of these goals, and the roles of the supportive and regulatory systems, which may then be compared with the functional structures of corresponding artificial devices. The artificial devices of recognition or action cannot be considered to be identical to the functional structure of brain information processing, but they may be
compared, especially in defining some of the important principles and operations required for the successful achievement of particular tasks in the course of such processing. Some of the principles of artificial intelligence have already found their way into modern neuropsychology and neuropsychiatry. They include the application of such terms as module, circuitry, operation, working memory (operational memory in artificial intelligence), signal recognition from background noise, and so forth.

Modularity and Disturbances of Brain Information Processing

General Concept

The term module has been used in the technical description of various devices to outline individual parts with relatively independent tasks and separate functional capabilities that also contribute to the overall goals of the device’s function. The conception of modules as the major components of brain information processing represents a further development of the old localizationist approach to brain function. Similar to Gall’s “organs” and “centers,” the term “module” implies that information processing in the brain is conducted by relatively functionally independent units, each with a special purpose of application. It is reasonable to assume that the system of modules is highly efficient in terms of brain space economy. The system of modules also seems to be reliable, as the particular module processes a certain type of information requiring a relatively small number of stored representations for objects, faces, and actions. The volume of information processed in the course of recognition or action would become prohibitively large and virtually impossible to process without relatively independent modules tuned to a particular type of information.

The conception of modularity was introduced into the modern theory of the mind/brain functions by Fodor in Modularity and Mind (1983). Fodor considered the module to be composed of domain-specific, stimulus-driven, autonomous units that assess information via bottom-up processing rather than via top-down processing. According to Fodor, the neural architecture of modules is genetically fixed, hardwired, and prespecified. It is suggested that the independent units are minimally interactive with one another, a view that is reflected in Chomsky’s “organology” as well as in Fodor’s Modularity. This point of view is supported by observations that patients with aphasia suffer from impairments of language, while their cognitive abilities are relatively well preserved; in other words, there is a dissociation of disturbances between the impaired space and preserved object recognition.
The number of such examples may be greatly expanded by the inclusion of the many specific types of agnosia, apraxia, aphasia, and amnesia observed and described since Broca’s initial observations. These examples may be considered to reflect impairments in the domain-specific information processing of particular modules. A list of brain modules may thus be composed by using the described types of recognition and action disturbances as confirmation of the existence of certain modules. Such a list may include the modules for recognition and action in the physical world, such as visual object recognition, space orientation, body image orientation, speech production and comprehension, recognition of actions, motor praxis, and other types of modules that have been revealed in clinical and neuropsychological studies based on the strict localizationist approach.

Special attention should be given to the modules that provide recognition of social actions and social praxis, which have been largely omitted from past studies as a target of neuropsychological testing. An example of a module with the purpose of processing social information is facial recognition. A disturbance in this module may be manifested as an impairment in the recognition of known faces or prosopagnosia. Another module may be involved in the recognition of emotional expressions, and disturbances in this condition are known as sensory aprosodia. Disturbances of brain information processing in these modules are discussed in subsequent chapters of this book.

The structures of recognition and action modules are based on a set of both simple and complex features. This set is used for descriptions of target objects or actions and their meanings, either in the process of comparison with the stored models for recognition or in the process of evoking a course of action. Other types of modules may be used by supportive and regulatory systems of attention, memory, and emotion, and may be used for central control and support of recognition and action. They may include, for instance, an ability to assign a negative or positive score to the result of an action or an ability to anticipate planned actions using emotions as score indexes. For a module of episodic memory, a special structure is required, probably based on the directory used for selecting the needed information in the memory archive. An attention module helps to direct recognition or action modules to their specific targets.

Modules may have the ability to communicate for the purpose of translating information from the language of one module to the language of another module, for example, from visual to auditory types of languages. Some of the modules may be able to work as multilingual devices able to use different languages of the brain, most likely by translating modality-specific languages into a modality-neutral language. In the studies of present authors and their colleagues, for instance, it was
found that parietal lesions were manifested by disturbances of recognition of both visual and auditory sequences, while posterior-superior temporal lobe lesions produced selective impairments in the recognition of auditory sequences, and occipital lesions resulted in disturbances of recognition of visual sequences (for more details, see chapter 2, section entitled “Visual Agnosia”).

The most prominent criticism of the claim of modularity has been concentrated on the notion that modular units are informationally independent. Such a criticism may be supported by the findings of informational interdependence in information processing by a particular model: for example, word recognition is markedly improved when a patient with aphasia is asked to point to objects in the same semantic environment, such as the kitchen. Word recognition significantly worsens if the patient is asked to point to objects not found in the kitchen, but rather in a different semantic environment, such as a street scene. Critics also stress their claim that the formation of modules may result from a gradual developmental process rather than from a prespecified modular architecture (Elman et al., 1996; Karmiloff-Smith, 1992; Rose, 1997).

The idea that modules are fully independent in their functions is difficult to imagine, especially since they represent a part of the general system of brain information processing underlying goal-directed behavior. The types and degrees of such interdependency require further exploration, especially for the processing of novel, unconventional information. In addition to bottom-up processing, the role of top-down processing in the functioning of modules warrants further investigation.

Modules for Conventional and Unconventional Information Processing

Based on clinical and neuropsychological studies, it is reasonable to suggest that special modules must exist for the processing of conventional, frequently used information and unconventional, new, and incomplete information processing. The modules for conventional information processing are characteristically similar to Fodor’s description of modules as units that are domain specific, stimulus driven, and autonomous. The processing of items such as objects or actions that require a short list of predefined features and a limited number of models is represented in memory storage for comparison with a particular set of features. The comparison with features of real items or selection of plan of actions is well learned and may be processed quickly. Such a system allows for substantial conservation through the use of a stable set of features predefined by a learning process and limited in its number of features. The approach also allows for the building of a
storage model that consists of a relatively small number of frequently used items and reflects the main features assigned to the modules. The conventional modules are fairly simple, occupy relatively small cortical areas, and may be built with substantial redundancy so as to be protected from brain damage, especially from small lesions. Larger lesions in such areas may lead to the development of a clinical syndrome that reflects a disturbance in the set of operations in a particular domain-specific module, as characterized by the specific localization of the lesion. For example, consider the development of Broca’s aphasia as an impairment of a specific module for expressive speech, resulting primarily from a lesion in the inferior-posterior frontal lobe and the inferior central gyri (for more details, see chapter 7, section entitled “Aphasias Syndromes and Other Language Disorders”).

Modules for unconventional information processing may be connected with the same domain-specific conventional module, but the processing of new or incomplete information requires the use of a more detailed set of features and an extended capacity for memory storage. Furthermore, the speed may be significantly slowed by the increased volume and complexity of information that must be processed. The unconventional module may not satisfy in its structure all of the features included in Fedor’s more strict definition of modules as being less autonomous and more interconnected with other modules.

The role of the module in unconventional information processing may be demonstrated via a comparison of the processes of recognition of conventional and unconventional spoken language. This process may be provided by operations based on the alphabet of features that include single phonemes, syllables, words, and even sentences. The program for conventional information processing may be based on a conventional module composed of a limited number of well-known, frequently used words and sentences—the features of the model. Impairments in this conventional module would lead to significant disturbances in the comprehension of conventional language used in everyday conversation, as observed in patients experiencing Wernicke’s aphasia. At the same time, recognition of low-frequency words or words of a more complex syntactical structure may be provided by the module for unconventional information processing, based on phonological and semantic analyses of the speech as well as on special operations for streamlining inverted sequences into a more direct order that is much easier to comprehend: for example, “the lion killed the tiger” than “the tiger was killed by a lion.”

Conventional information processing for language comprehension may be strictly located in a particular area of the brain, namely, in the posterior T1 of the dominant hemisphere—Wernicke’s area. Thus a lesion in the specified area manifests as aphasia with disturbances
in the comprehension of conventional spoken language—Wernicke’s aphasia. The lesion must certainly involve adjacent areas and must be relatively large to cause disturbances in the set of operations involved in conventional language comprehension. In a case of unconventional information processing, such as the comprehension of an inverted and more complicated syntactical structure, the set of operations used for language comprehension is significantly larger and may be localized in many areas around the Sylvian fissure, including the posterior F3, the operculum of the central gyri, and the insula. Thus, lesions in these areas may produce similar disturbances in unconventional language comprehension, for instance, in the comprehension of inverted sentences. While the comprehension of everyday language may be preserved in such cases, the use of special tests, such as inverted sentences and other types of unconventional language, reveals disturbances in this language comprehension (for more details, see chapter 7, section entitled “Aphasia Syndromes and Other Language Disorders”). This observation is often used as evidence against the argument for the strict localization of particular language disturbances.

Similarly, the recognition of real objects based on conventional information processing may be preserved in patients with prominent disturbances in the recognition of incomplete pictures or with decreases in object exposition from less than 2–3 seconds to 100–200 milliseconds. The localization of lesions in such cases may involve the inferior temporal lobe as well as the occipital lobe, as usually observed in patients with visual agnosia of real objects.

Various tasks may require the application of the programs for unconventional information processing. One such task is the recognition of objects or actions with incomplete sets of features, as in cases of object occlusion, in which a part of the object or the entire object is hidden in the midst of background noise. Disturbances in the performance of such tasks may be related to impairments of special programs used for the recognition of signals from noise based on a limited number of features (for more details, see chapter 2, section entitled “Visual Object Agnosia”). Such disturbances may also be observed in the recognition of actions, including social actions, with incomplete sets of features.

Another type of unconventional task requires an ability to overcome the standardized, conventional set of information processing. Such tasks are often described as executive functions and are mainly related to the processing of unconventional information by modules for unconventional sequences recognition. For instance, in the Trail Making Test, Part B (Reitan & Wolfson, 1985), the subject has to alternate between two standard sequences—numbers and letters of the alphabet—thus overcoming the well-learned automatic sequences of 1, 2, 3 . . . and A, B, C . . . . In our test entitled “Number Tracking,” the
Alternation is required between automatic sequences of upward and backward number counting—for example, 1, 12, 2, 11, 3, 10, and so forth (Tonkonogy, 1997).

The ability to overcome the distraction caused by the established type of recognition is also tested by the popular Stroop Test (Stroop, 1935). In this particular test, the subject has to read various color names while simultaneously ignoring the color of the print, which never corresponds with the color names.

Various category tests usually contain two types of unconventional tasks. In the Wisconsin Card Sorting Test (Grant & Berg, 1948), for instance, the first task is to recognize a category or pattern, as predefined by the test procedure, from among sequences of cards with figures composed of different features such as color, form, and number, for example, organization via color. The second task is to overcome the previously learned category once the pattern to be recognized is switched to another leading feature during the course of testing. Finally, the subject is asked to replicate a number of figures as they are displayed on the cards, and then to switch back to organization via color. In such tasks, the main feature of the sequence continues to change throughout the course of testing and is intended to reflect real conditions as they require new actions in the outside world, whether physical or social. It is possible that this ability is interconnected via two different modules—one for the physical world and another for the social world.

**Localization of Operations and Syndromes**

**Operations**

Some of the operations performed within the various modules must be similar, if not identical. For instance, operations conducted by working memory are needed for information processing in various modules and thus may be represented in every module. Therefore, similar clinical manifestations of particular operations may be observed as the result of lesions in various sites, giving the impression of the equipotentiality of brain functioning. For example, working memory disturbances have been ascribed to various sites of lesions in the frontal, parietal, temporal, and occipital lobes. On the other hand, auditory working memory disturbances have been observed in patients with temporal lobe lesions, and visual working memory impairments have been attributed to damage to the occipital lobe (for more details, see chapter 8, section entitled “Amnestic Syndromes”).

The idea that there exists a wider distribution of operations not strictly localized in one cortical area is further supported by studies of anosognosia. Anosognosia, also known as loss of insight, has been attributed to a wide variety of lesion sites, including lesions in the frontal, parietal, temporal, and occipital areas as well as in subcortical
structures. However, anosognosia of paralysis or aphasia was observed in patients with a corresponding right parietal lesion or left temporal lesion, while anosognosia of cortical blindness was found to be related to the presence of an occipital lesion, and loss of insight in psychiatric illnesses is often connected with frontal lobe involvement, and so on.

Particular modules may use the operations provided by specific types of insight typical for that module. It is difficult to imagine that the brain is constructed in such a way that the same operation is performed in many areas of the brain, thus seemingly wasting the large amount of brain tissue needed for so many operations. It is possible that operations such as working memory or insight are included in the set of operations that are performed independently inside the various modules in order to facilitate and speed up the functioning of particular modules. It is further possible that these operations performed by working memory or by insight differ between modules. For instance, visual working memory was found to be disturbed in the task of angle differentiation in patients with occipital lobe lesions and in the task of angle sequences in patients with temporal and parietal lobe lesions. Disturbances of the auditory working memory, as in one’s ability to differentiate between single tones and tone sequences, were observed in patients with posterior T1 lesions. Parietal lobe lesions, on the other hand, led to impairments of working memory for tone sequences (Meerson, 1986; Tonkonogy, 1973) (for more details, see chapter 8, section entitled “Amnestic Syndromes”).

In some cases, the particular working memory operations may be copied in another site in order to bring the processing closer to the site of subsequent operations, for example, using single-cell recording. Goldman-Rakic, Scalaidhe, and Chafee (2000) showed that in rhesus monkeys, areas in the inferior convexity of the prefrontal cortex were involved in the visual working memory of faces and objects. Selective neuronal activity was recorded following the presentation of a stimulus: a face followed by a delay. This pattern was also observed in the neuronal activity of the inferior temporal cortex, pointing to the possibility that neuronal activity in the prefrontal cortex copied the information transmitted from the primarily sensory temporal cortex areas for further use in the tasks typical for frontal neuronal activity, such as various executive functions in the physical and social worlds.

Rizzolatti, Fogassi, and Gallese (2000) carried out a study further supporting the idea that one area of the cortex may make copies of neuronal activity occurring in another area of the cortex. Using single-cell recording, the authors identified mirrored neuronal activity in the F5 frontal area while a monkey performed or observed hand-object interactions. Mirrored neurons were also found to be active in the superior temporal sulcus (STS) in response to movements with real objects.
It is possible that neuronal activity in the STS closely connected with visual areas in the posterior cortex was transmitted and copied into the F5 area for probable use in the course of motor action initiated by neurons in this area (for more details, see chapter 6, section entitled “Motor Apraxia”).

**Syndromes**

While operations such as working memory may be performed by various modules, there are sets of conventional operations that are specific to particular modules. Lesions in these sets may result in the development of unique clinical syndromes with typical sites of lesion localization. Consider, for example, Broca’s aphasia, a clinical syndrome that consists of unique and complex conventional disturbances in expressive speech. These disturbances include difficulties in word finding as well as laborious, effortful speech, which is often characterized by a prevalence of nouns, combined with disturbances of unconventional types of speech comprehension, such as impairments in reading and writing. Broca’s aphasia is characterized by a lesion in the posterior F3, the operculum of the central sulci, the insula, and the subcortical nuclei. Another clinical syndrome, known as Wernicke’s aphasia, is marked by severe impairments in speech comprehension with a peculiar disorder of expressive speech quite different from Broca’s aphasia; contrary to Broca’s aphasia, Wernicke’s aphasia is characterized by fluency, a prevalence of verbs and functional words, combined with impairments in reading and writing abilities. The syndrome is marked by a lesion both in the posterior T1 and in adjacent structures (for more details, see chapter 7, section entitled “Aphasia Syndromes and Other Language Disorders”).

However, some of the symptoms of one particular clinical syndrome may also be present in other syndromes, especially symptoms reflecting disturbances of unconventional information processing. For instance, impairments of more complex types of speech comprehension may be observed in various types of aphasia, both anterior and posterior, thus supporting the holistic approach to the problem of localization. Another example of a single symptom reflecting multiple possible syndromes is anomia (also known as optic aphasia)—a condition that has been described in cases with lesions found throughout the cortex of the left hemisphere in the frontal, temporal, and parietal lobes as well as far back in the occipital lobe.

In most cases, the presence of anomia is indicative of a part of a particular syndrome, such as Broca’s or Wernicke’s aphasia, conduction aphasia, transcortical aphasia, and so on. Some differences are indicative of anomia in the various plausible syndromes. For instance,
anomia in Wernicke’s aphasia is characterized by hyperactive speech, with the production of a series of examples of verbal and literal paraphasia in an attempt to find the proper word. On the other hand, a patient suffering from Broca’s aphasia is unable to produce any speech at all while attempting to find the appropriate word. Efforts have been made to identify and categorize differences in the words most often found to be disturbed in patients with anomia and to relate these differences to particular lesion locations.

As in cases of aphasia syndrome, disturbances of auditory or visual working memory may represent a component of a particular clinical syndrome reflecting the malfunction of a corresponding module, as is the case for visual object agnosia, prosopagnosia, spatial agnosia, and auditory agnosia, in which more strictly localized sites of lesions are associated with each of the various syndromes. Conventional and unconventional modules, especially domain-specific modules, may be closely interconnected (e.g., for object recognition).

The modules for conventional information processing may provide the initial stage in the operations of the modules for unconventional information processing, serving as an important component in the hierarchical functional structure for that processing, as in the operations underlying the executive functions.

CIRCUIT AND CIRCUITRY

The terms circuit and circuitry are typically defined technologically as being part of an electrical scheme. As described in neuropsychiatric literature, the terms were initially used in studies of functional connections between various cortical and subcortical structures. For instance, depression has been described as being the result of lesions in various areas of cortical and subcortical structures and in the diencephalo-hypothalamic region of the brain, with the two areas being connected by cortico-subcortical circuits. It seems possible that the core of the clinical syndrome of depression is underlined by a lesion in the module for emotions and is thus primarily localized in a particular area, namely, the amygdala. This area is turned on via different areas of the brain that receive negative information from both the outside and inside worlds as transmitted through the circuitry, which serves to connect the various regions of the brain involved in the processing of emotions. It is also possible that circuits may be an important part of the operations inside one particular module, or over several connected modules. Specifically, the modules of social recognition and actions include a circuitry of emotion regulating the assessment of situations in the outer and inner worlds so that the various nodes of the emotional circuitry receive input inciting or inhibiting a particular emotion, for example,
depression or anxiety (for more details, see chapter 11, section entitled "Mood Disorders").

The circuits and circuitries may very well be an important component in the functional structure of brain information processing, though more in-depth, detailed, definitive descriptions are needed. Still, the words circuit and circuitry are avoided in the major literature related to clinical neuroscience. It has been suggested that electrical schemes of the circuits in computer chips may be used as an initial model for further exploration of the role of circuitry in brain information processing and its disturbances.

**Sizes of Lesions and Compensatory Mechanisms of Brain Information Processing**

Clinically significant disturbances of conventional and unconventional information processing are usually observed in cases with relatively large lesions involving the cortical and often subcortical areas of the cerebral hemispheres. For instance, the development of Broca's aphasia is underlined by lesions involving the posterior F3, the lower parts of the central gyri, and the insula, with frequent extensions into the adjacent subcortical areas. Small lesions limited to the parts of those areas such as posterior F3 result only in transient aphasia or do not cause any language disturbances (see review by Tonkonogy, 1986). This effect may be explained by the existence of special mechanisms protecting the uninterrupted functioning of brain information processing. One of the mechanisms may be the presentation and processing of information in a parallel, distributed form, which continues to function even when a portion is damaged by a small lesion. McClelland and Rumelhart (1986) discussed the role of distributed memory in amnesia and suggested a distributed, developmental model for word recognition and naming.

Another mechanism may be related to the possibility that the same functional task may be accomplished by different programs within particular domain-specific conventional and unconventional modules, so that in the event of the impairment of one program, another program may overtake the functional task of the damaged program. A typical example of such a substitution is the use of unconventional information processing when conventional processing is disturbed. A patient with a small posterior T1 lesion may be able to comprehend the language spoken with regular speed, but may show disturbances of comprehension of faster conversational speech, making it impossible to use conventional simplified information processing based on the
alphabet of words and phrases. In such cases, comprehension of spoken language may require the use of relatively complex, slow unconventional information processing provided by the alphabet of phonemes and syllables.

Some role may also be played by programs that use probability assessment to restrict the amount of information that has to be processed by the brain. This semantic assessment helps to reduce the number of choices so that the alphabet of the processing message consists of 10–15 items, for instance, when a subject is asked to name an object in the kitchen. In fact, when asked to point to the table and then to the window, the subject makes the determination of a high probability that the next question will be related to objects located in the same room. The same is true for the comprehension of conversational speech dealing with the patient’s health or family conditions. However, if the semantic field is suddenly changed, for example, from objects in the room to body parts, a patient with mild aphasia caused by a small lesion will exhibit substantially increased difficulties in comprehension. It is also of interest that the number of errors may increase significantly when the patient is repeatedly asked to show the same objects in the kitchen or office, since probability of such repetitions in questions is, in normal conditions, usually quite low.

**TYPES OF LESIONS**

**Circumscribed Large Lesions and Generalized Extended Lesions**

Various types of aphasia, agnosia, and apraxia have been described in studies of patients with circumscribed but large lesions caused by stroke or, in some cases, by tumors and head injuries. In such cases, the brain tissue is destroyed in particular areas, resulting in the loss of certain operations and leading to the development of specific clinical symptoms and syndromes reflecting the “minus tissue,” or negative effect, of brain damage. The severity of the negative functional impairment becomes more prominent when the lesion is larger. Certainly, the localization and the size of lesions as well as other factors influence the clinical manifestations of these circumscribed losses of brain tissue. These factors include brain edema surrounding the destroyed brain area, or the so-called ischemic penumbra, caused by diminishing blood flow in the cortex when the cerebral infarction is primarily in the subcortical region. The particular disturbances are often transient in such cases, developing in the acute period of stroke or head injury and subsiding in the course of recovery.
Disturbances of modules for recognition and action underlined by relatively local and circumscribed loss of brain tissue are clinically manifested as aphasia, agnosia, and apraxia. In addition, the loss of brain tissue in a particular brain region may result in impairments of supportive and regulatory modules such as memory, attention, or emotion in the operations of activation of brain information processing for recognition and action. When the loss of tissue is large, extending through the many areas of cortex and subcortical nuclei and white matter, dementia develops, representing the peculiar multimodular combination of many clinical syndromes attributed to the lesions, with tissue loss in the various areas of the brain underlying the functioning of the various modules.

**Small Excitatory Lesions**

Another type of lesion consists of small lesions that cause an excitation of the preserved brain tissue. This is true in cases of epilepsy with the preictal in the course of aura, the ictal, and in some cases the interictal psychiatric manifestations. They may include illusions, hallucinations, delusions, and anger with episodes of rage and other changes in mood and behavior. However, lesions with small tissue loss and with the source of excitation in particular brain areas responsible for those psychiatric manifestations being very often difficult to find, even when using the modern method of brain imaging, and especially in patients with primary psychiatric illnesses such as schizophrenia and bipolar disorder. Such disturbances may be mediated by a neurochemical imbalance, particularly at the synaptic level. The disturbances have been intensively and extensively studied over the course of recent decades, leading to the fascinating series of successes in the treatment of psychiatric patients.

However, some important mechanisms related to the excitatory role of small lesions in the formation of psychiatric syndromes and symptoms have been excluded from mainstream studies of diagnoses and treatments of psychiatric disturbances. These mechanisms are directly related to the understanding of the brain as primarily an electrical device with the crucial participation of neurochemically mediated activity. In such cases, a malfunction of the electrical part of the device per se may be responsible for the development of some of the psychiatric problems that, in turn, require treatment approaches based on understanding that an electrical malfunction may be responsible. For example, the intermittent psychiatric problems caused by excitation resulting in aggressive episodes such as rage outbursts may be underlined by subclinical seizure activity with only an indirect relation to the neurochemical imbalance.
Certainly, further studies may elucidate the importance of the direct role of electrical mechanisms in the development, diagnosis, and treatment of psychiatric disturbances and their relationships to neurochemical abnormalities.

**SUMMARY**

The addition of localization information to neuroradiological and neuropsychological studies provides for the field a newer generation of thinking. Historically, neuropsychological studies existed without reference to brain-imaging studies and vice versa. Over the last decade the two have interfaced, resulting in exciting discoveries and a greater understanding of brain dysfunction. However, the relationship between the two remains relatively weak. The integration of the historic roots of neuropsychology brings an even stronger presence to the role that neuroradiological and neuropsychological studies, alone and combined, may add to the understanding and treatment of neurological and neuropsychological disorders.