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# WHAT CAN BE LOCALIZED IN THE BRAIN? TOWARD A "FACTOR" THEORY ON BRAIN ORGANIZATION OF COGNITION

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A theoretical integration attempt among the lesional (neuropsychological), physiological (functional), and psychometric models of cognition is presented in this article. Recent neuroimaging techniques particularly fMRI have shown that there are some brain functions (i.e., simple) that can be localized into single brain areas whereas there are others (i.e., complex) that cannot. Clinical neuropsychology has been able to propose some "cognitive factors" based on empirical observations in patients with brain lesions. Factor analysis in psychometry may provide an additional tool to extract some constitutive elements of psychological functions (factors). "Factors" in factor analysis, however, may have different levels of specificity. Some times they refer to functional systems (complex cognition); in other occasions to elements of cognition ("cognitive factors"). It is emphasized that the very same brain areas (and cognitive factors) may be potentially involved in different types of cognition. It is proposed that complex cognition depends on specific patterns of activation of different brain areas and specific circuitries ("modules"), each one making its own contribution to the whole system (functional

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system). Impairment in a specific cognitive factor, on the other hand, may result in diverse types of impairments. At the moment, it seems feasible to suppose some cognitive factors responsible for normal neuropsychological performance. Theoretically, the impairment in any of these factors could be responsible for some specific neuropsychological syndromes.

**Keyword** brain imaging, brain localization, cognition, cognitive testing, factor analysis, factor theory, fMRI, neuropsychology



## INTRODUCTION

The localization of the brain cortical functions has been a major endeavor since the first work of Paul Broca (1861), who associated a left inferior frontal gyrus lesion to an expressive language deficit. Based on this correlation between neurological deficits and cerebral post-mortem findings, the nineteen-century neuroanatomists developed the brain function localization model. This model basically stated that a "brain function is performed by a given region of the brain." Korvinian Brodmann gave a strong support to this model in 1909 by describing 50 pair areas of different laminar organization of the cerebral cortex. These areas would provide the bases for discrete localization of several brain functions. It was not clear enough, however, what exactly the term "brain function" meant. Is "language comprehension"—as an example, a "brain function"? Certainly it is, but such a complex function seems to demand several localized areas at least to account for different input forms. Primary sensory and motor functions have been found to be localizable in rather specific brain regions across different subjects. Nevertheless, complex functions, like naming, have been found disperse in different brain areas in studies of electrocortical stimulation in patients worked up for epilepsy surgery (Ojemman, 1979; Ojemann & Mateer, 1979; Ojemann et al., 2002). From these findings, it appears that there are some brain functions (i.e., simple) that can be localized into single brain areas and others (i.e., complex) that cannot. "Complex" functions are the result of a multistage integration of different components contributing to the whole function. If one accepts a wide meaning for "brain function," then what elements of the complex function can be "localized"? In other words, which elements of the complex functions could be assigned to a specific region of the brain?

This article presents a theoretical integration attempt among the lesional (neuropsychological), physiological (functional), and psychometric approaches to cognition. An effort is made to discern those localizable elements contributing to more complex systems. Lesional model refers to the information derived from the neuropsychological clinical observation of individuals presenting a brain pathology; that is, the cognitive sequelae resulting from focal brain damage. The neurophysiological model refers to the contribution given by modern neuroradiological techniques—particularly functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET), when performing different intellectual tasks. Finally, the psychometric studies on cognition refer to the knowledge yielded by standardized measures of cognition, that is, psychological and neuropsychological tests.

During recent decades, modular theories of cognition have been particularly influential in neuropsychology (e.g., Caplan, 1981; Caramazza, 1992; Fodor, 1983; Humphreys & Riddoch, 1987; Moscovitch & Ulmitá, 1990; Shallice, 1988). These theories have attempted to find out the architectural organization of cognition, and the elements, steps, or "modules" required in specific forms of complex cognition (e.g., reading). The proposal that we are presenting here represents—at least in some points—an extension of these modular theories of cognition.

This article shall use the term "factor" to mean an element of cognition. It can be related with a specific pattern of brain activity. The same word will be used with the statistical meaning (factor analysis); that is, communality (shared variance) among different tests. Although they can overlap at some extent, it does not happen in all cases. For example "Verbal comprehension" may appear as a "factor" when analyzing the psychometric tests, but it refers to something ampler than the "specific pattern of brain activity" in the sense aforementioned.

Three departing points will be taken:

1. The results of neuropsychological assessments, seeking in particular for association ("communality") existing among different measures of psychological and neuropsychological tests. Factor analysis, a statistical technique aimed to discover patterns among variations in the values of multiple variables, has been applied to neuropsychological studies. These studies will be reviewed, pointing out that factor analysis may contribute to find out basic elements in cognition.
2. The neuropsychological theories about brain organization of cognition, in particular, Luria's (1966, 1970, 1973, 1976) interpretation of psychological processes as "functional systems." The idea of "functional system" has been directly or indirectly taken by different contemporary authors to explain cognition, even without a direct reference to its origin. For instance, Lieberman (2000) refers to a "functional language system" to explain how the language is organized in the brain and how a diversity of cortical and subcortical structures contributes to this "functional language system."

3. Contemporary data provided by modern neuroimaging techniques about brain activation. Neuroimaging includes different techniques to see the working regions of the brain over an anatomical framework. Two main types are considered: PET and fMRI. The findings of brain activation during simple and complex tasks will be reviewed focusing on descriptions of "core" and ancillary centers to specific cognitive tasks.

## MEASURING COGNITION

There are two different sets of instruments directed to the appraisal of cognitive abilities: psychometric intelligence tests (e.g., Wechsler Adult Intelligence Scale in its different versions), and neuropsychological assessment tests (e.g., Wisconsin Card Sorting Test, Boston Diagnostic Aphasia Examination, Halstead-Reitan Battery). It is assumed that psychometric intelligence tests are directed to normal populations, whereas neuropsychological instruments are directed to brain−damaged populations (e.g., Lezak, 1995). There is, however, a significant overlap between both. In general, neuropsychological tests have a lower ceiling and are more appropriate to detect abnormalities in cognition (e.g., naming defects, perceptual impairments). Neuropsychological, but not intelligence, tests were developed specifically to detect brain integrity, departing from the observation of the deficits found in diverse types of brain abnormalities. During recent decades, a significant effort has been directed in neuropsychology to establish clinical/anatomical correlations (i.e., correlating impaired performance in a particular test with anatomical abnormalities) (e.g., Damasio & Damasio, 1989; Kertesz, 1994). Neuropsychology evaluation, for instance, analyzes how different abilities contributing to the arithmetical test performance can be impaired with left angular, left prefrontal, right parietal, pathology, and so on (Ardila & Rosselli, 2002).

Localization by means of a non-anatomical-imaging strategy (i.e., neuropsychological tests) is a fuzzy concept. How precise can a localization diagnosis be? Reading can illustrate the complexity of brain localization of any psychological process ("functional system") (Price et al. 1994). Reading is based in certain fundamental abilities (or elements of cognition or simply "factors") (e.g., complex shape perception, cross−modal learns) already existing 8,000 years ago, and of course, existing in illiterate individuals. What might be "localizable" in the brain is not reading *per se*, but certain basic abilities or elements of cognition or "factors (information processing levels) required to read—albeit not only to read (Ardila, 2004). Learning to read may be supposed to involve the activation and long−term potentiation (Levy

& Steward, 1983; Perkins & Teyler, 1988) of several high order modules, using some particular types of information (visual information related with the perception of letter shapes, cross–modal association between letters and language sounds, etc.).

Furthermore, the same information processing level may be useful for apparently different types of cognition. As example, it has been pointed out that mathematics, painting, playing chess, reading and writing, mechanics, and music abilities may be impaired in cases of right hemisphere damage of those very same areas that in an Eskimo or Amazonian Indian could simply imply an impossibility to move around the snow or the jungle (Ardila, 1993 a). Brain assemblies (“basic circuitry”) or modules able to perform a specific information processing level can be potentially useful for many different types of cognition. Any type of complex cognition will require the participation of multiple cognitive elements.

Individual differences in cognition have to be recognized. Visual areas in blind people are activated with auditory stimulation, haptic stimulation (Rosler et al., 1993) or Braille reading (Uhl et al., 1993). The pattern of activation (and the recruited brain area) observed when moving the little finger of the left hand is more complex and extensive in professional musicians playing a string instrument (Elbert et al., 1995). Learning to read supposes significant changes in the language processing activity in the brain (Castro-Caldas et al., 1998; Petterson et al., 2000). Practicing a specific ability, in consequence, results in changing the pattern of brain activity and even increasing the size of that cortical brain area (Levin & Grafman, 2000). Every individual has a unique set of experiences. Individual experiences are different not only between overtly different people living in overtly different conditions (e.g., the Amazonian Indians and New York dwellers), but also between any two individuals. Even the performance of a relatively simple task (e.g., telling animal names) may be carried out using quite different individual strategies (e.g., imagining moving around the zoo; selecting specific categories such as mammals; finding the animal names beginning with a specific letter) and depends on the personal experiences with animals. Personal experience with animals may be sensory based (i.e., obtaining through the senses in a direct—visual, auditory, olfactory, tactile or any combination, or indirect—pictures, way) or conceptually based (i.e., reading about a particular animal). It is not surprising that the pattern of brain of different people when telling animal names will not be totally coincidental. There is something in common, but there is also something variable depending on the individual experiences.

A neuropsychological test result may point to a hemisphere or gyrus activity, although usually the results of neuropsychological tests point to systems ("functional systems"), subsystems, or "functions," that may involve one or several lobes. They usually yield performance results as scalar magnitudes (usually compared to standards) but without a precise anatomical direction. Frequently, the abnormal test result may be due to multiple causes and even multiple regions of lesion. Neuropsychological test localization was an enormous contribution in the past. Nowadays with the advent of neuroimaging, the neuropsychology-test localization is challenged. Neuroimaging techniques, nonetheless, have generally supported the findings of the clinical neuropsychology; they have shown that many intervening cognitive factors, as units of localizable brain functions, can account for the same or similar deficits. These factors should be understood as "units of functional brain localization" related to specific tasks. They should be able to be demonstrated as isolated elements involved in systems but independent to be recruited in different tasks.

Although neither the results, nor the usual methodology of the neuropsychological or psychometric tests yield information about the discrete factors involved, there are methods to extract them, and ways to validate the resulting conclusions.

Before tackling the analysis of the psychometric assessments it is important to define what this article is referring to with "functional system," "brain function", "module," and "factor." The authors are naming the pattern of cognitive abilities participating in complex psychological processes (complex cognition; e.g., reading) as "functional system," following the Lurian tradition. This article shall refer to the brain activity supporting the functional system as "brain system." The authors are referring to the elements of the functional systems or complex forms of cognition as "cognitive factors." The cognitive factors would be related with a specific way of processing information, associated with an integrate activity of a specific brain module or supramodule. Thence, "factor" will be understood as an element of cognition. "Module" will be used to refer to a brain assembly performing a particular operation (specific way of processing information). The article shall be arguing that the elements of cognition ("cognitive factors") may be potentially analyzed and pinpointed using three different procedures: neuropsychologic, neuroradiologic, and psychometric. Theoretically, a coincidence among the three approaches should exist.

The term "factor" has been extensively used in psychometry ("factor analysis"), but psychometric procedures can just suggest the existence of some

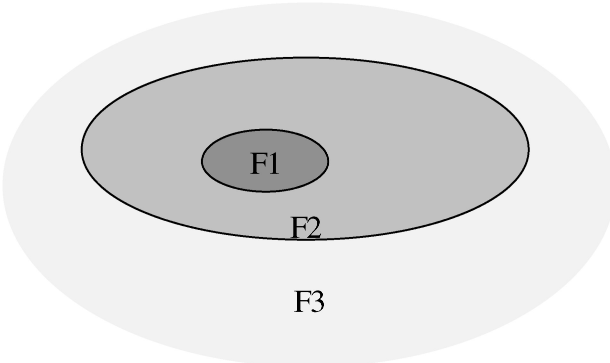


**Figure 1.** Cognitive factors may include subfactors.

general "cognitive factors" (elements of cognition). The factors found in factor analytic studies are frequently too broad (frequently they indeed represent functional systems), and obviously depend on the tests included in that specific factor analytic study. Comparing diverse factor analytic studies, however, converging results may shed light on basic elements of cognition (cognitive factors). The use of the term "cognitive factor" (i.e., element of cognition) is only partially equated with the meaning usually given in psychometry. Finally, the existence of factors of different levels (subfactors, suprafactors) will be assumed. An example taken from clinical neuropsychology can be illustrative. Finger naming may be a particular case of body-parts naming defects. Finger naming, however, may be impaired without generalized defects in body-parts naming; but, when body-parts naming impairments are found, finger naming is always defective (Hécaen & Albert, 1978). In consequence, there is a single dissociation, not a double dissociation. A double dissociation would mean two different syndromes depending on the activity of two different brain areas. Therefore, a kind of hierarchy can be assumed. Certain specific brain modules can participate in naming fingers (factor). Naming body parts requires the recruitment of more extended brain areas (supramodules) representing a higher level ability (suprafactor) (Figure 1)

## ANATOMICAL CORRELATES OF LOCALIZATION

Brain localization is a term intimately related to anatomical landmarks. Following a macro-to-micro order the first localization category is given by the lateralization of functions. For instance, motor function is lateralized to the opposite hemisphere. In a more precise categorization, the brain is divided into lobes and further into gyri yielding a smaller regionalization of the cortex. Heschl's gyrus, for example, is a well defined anatomical structure of the temporal lobe; it is the seat for the primary auditory cortex. In a smaller level of division, the brain cortex is regionalized according to the laminar organization of its six constitutive layers of neurons. Differences in these histological properties convey, as expected, differences in function. The visual area located in both lips of the calcarine fissure has particularities not shared by any other region of the cortex. This area is, therefore, tuned up to serve as the cortical first processor for visual inputs. Beyond this anatomical subdivision it is found a columnar organization of the function. This is, at least represented in the visual cortex, where Hubel and Wiesel (1961, 1962, 1963, 1965) demonstrated a columnar organization responsible only for lines specifically oriented. These columns are the unit of function response and are also called modules. Thus, a decrescendo chain will have:

Hemisphere → Lobe → Gyrus → Brodmann area → Module

It is expected that a similar progression of complexity can be described with respect to different brain functions. However, there is a lack of such functional stepwise categorization. One is constrained to a simple chain between a global level of "Functional System" to a rather basic level of "minimal discrimination" or minimal "unit of output" probably yielded by modules. Intermediate levels of processing should exist. For instance, in anomia it has been traditionally recognized that naming body-parts, external objects and colors depend (and are altered) upon the activity of different brain areas (Hécaen & Albert 1978). It has also been found that finer distinctions can be made with regard to naming defects, which can be limited to a rather specific semantic category (e.g., people's names, living things, geographical names) (e.g., Harris & Kay, 1995; Goodglass et al., 1986; Lyons et al., 2002; Warrington & Shallice, 1984) and even as specific as "medical terms" (Crosson et al., 1997). The "factor" theory presented here represents a development of the classical modular explanations creating a transitional link between "functional systems" (that supposedly encompass larger structural areas), and the minute modular level.

## FROM "COGNITIVE FACTORS" TO "BRAIN FUNCTIONS"

The problems of finding the constituent parts of a given brain function are exemplified by this question: Is "naming ability" due to a non-reducible factor (element) of brain activity or is it the result of a subsystem consisting of several functional modules susceptible to be affected at different levels with similar deficit in the output? If the answer points to a non-reducible element, the brain localization would be circumscribed to a specific region, whereas if the answer is inclined to a subsystem, the brain localization would be circumscribed to a sort of circuitry showing different participating elements. These are two different approaches of brain localization. Furthermore, what exactly does the term "brain function" mean? Is language comprehension a "brain function"? Certainly it is, but such complex function seems to demand the participation of several localized areas. Cortical electrical stimulation in patients worked up for epilepsy surgery have shown that each subject has several areas that respond with "anomia" when stimulated (Ojemman, 1979; Ojemann & Mateer, 1979; Ojemann et al., 2002). A diversity of category specific anomia have been observed in clinical practice (e.g., Harris & Kay, 1995; Goodglass et al., 1986; Lyons et al., 2002; Warrington & Shallice, 1984). Consequently, it may be inferred that naming—as brain function—is the resultant sum of several "intervening" cortical areas, and cannot be explained as the output of a single "naming module." A more rational way to look at the localization concept may be taking it in a brain system level, involving a diversity of supramodules, active according to the task demand, and following a specific activation pattern.

## FACTOR ANALYSIS

Neuropsychological inventories and psychometric tests may be refined to provide clues of brain function localization if their results are factorized to extract their constitutive elements. The results will be named also as "factors" but as pointed out earlier, they do not necessarily refer to non-reducible units of brain function as "cognitive factor" does. Often, they are closer to a functional system (e.g., verbal comprehension factor).

Factor analysis represents a strong and relatively sophisticated statistical tool in measurement research. Factor analysis allows deducing underlying factors accounting for variance in individual tests. Communality, and in consequence, "relative distance" among different subtests can be deduced. Departing from correlation matrixes among different measures, factors responsible for observed dispersions can be deduced.

Factor analysis has been extensively used in psychological measurement sphere, and different factorial studies of "general intelligence" have been presented in psychological literature (e.g., Carroll, 1993; Cattell, 1971; Guilford, 1967; Matarazzo, 1972, 1992; Wechsler, 1997).

Using factor analysis, it has been attempted to determine which could be considered as the "basic," "primary," or "fundamental" cognitive abilities.

For instance, Thurstone (1947) proposed that seven "primary mental abilities" existed: verbal, reasoning, numeric, spatial, perceptual speed, memory, and verbal fluency. Guilford (Guilford, 1967, 1968; Guilford & Hoepfner, 1971) proposed a three−dimensional classification of intelligence, including: contents (letters, numbers, words, and behavioral descriptions); operations (memory, evaluation, convergent thinking, and divergent thinking); and products (units, classes, relations, systems, transformations, and implications). In consequence, according to Guildford 120 different intellectual abilities could be distinguished.

The Wechsler Intelligence Scale–Revised (Wechsler, 1987) represents a good example of an assessment instrument used not only in psychological but also in neuropsychological evaluation. Most often, a three−factor structure has been found in the WAIS (Matarazzo, 1972). Factor I ("Verbal Comprehension") is measured by Information, Vocabulary, Similarities, and Comprehension subtests. Factor II ("Perceptual Organization") is measured with Object Assembly, Block Design, Picture Completion, and Picture Arrangement subtests. Factor III ("Freedom of Distractibility") is specially measured with Digit−Symbol subtest. A fourth (albeit weaker) factor has been sometimes reported, measured with Arithmetic subtest (Cohen, 1957). From a neuropsychological perspective, the distinction between verbal ("Verbal Comprehension") and visuoperceptual ("Perceptual Organization") abilities simply represents the most evident dichotomy for left and right hemisphere activity. "Freedom of Distractibility" is just an attentional factor, often conforming an independent factor in factor analytic studies (Bornstein & Chelune, 1988; Roid et al., 1988; Wechsler, 1987; Ardila & Rosselli, 1994). From a neuropsychological perspective, attention may be altered in cases of frontal pathology (Luria, 1966; Stuss & Benson, 1986).

The factor analysis of the WAIS-III (Wechsler, 1997) resulted in a more complex factor solution. New tests were included in the WAIS-III, not existing in the previous versions (Matrix Reasoning, Letter-Number Sequencing, Symbol Search). According to the Manual of the WAIS-IIII, and using a sample of 2,450 16–89-year-old adult participants, the following factors were disclosed: Verbal Comprehension, Perceptual Organization, Working Memory and Processing Speed (Table 1). A fifth factor (Arithmetic) defined by only one subtest (Arithmetic) was also suggested. This factor solution has been in general confirmed by other authors (e.g., Burton et al., 2001; Ryan & Paulo, 2002).

Tulsky and Price (2003) further presented a series of confirmatory factor analyses to determine the joint WAIS-III and WMS-III factor structure. Using

**Table 1.** WAIS-III factor analysis (Wechsler, 1997)

| Factor | Subtests |
|---|---|
| Verbal comprehension | Vocabulary |
| | Similarities |
| | Information |
| | Comprehension |
| Perceptual organization | Block design |
| | Matrix reasoning |
| | Picture completion |
| | Picture arrangement |
| Working memory | Digit span |
| | Letter-Number sequencing |
| | Arithmetic |
| Processing speed | Digit symbol |
| | Symbol search |

a structural equation modeling approach, a 6-factor model that included verbal, perceptual, processing speed, working memory, auditory memory, and visual memory constructs provided the best model fit to the data. Allowing select subtests to load simultaneously on 2 factors improved model fit and indicated that some subtests are multifaceted. The results were then replicated in a large cross-validation sample ($n = 858$).

Carroll (1993) analyzed 461 factor−analytic studies presented in the literature up to date. He observed that some factors tend to appear with a significant frequency across different factorial studies. This is observed in different cognitive domains: reasoning, language, memory, visual perception abilities, and so on. Table 2 presents a summary of these relatively constant factors found across different factor analytic studies. That is, regardless of the diversity of tests included in the different 461 factor analyses, an importance convergence in the factor structures is observed. These common factors found across diverse studies may represent general and fundamental elements of cognition. From a neuropsychological perspective, these factors (fundamental elements of cognition) are potentially impaired in cases of brain pathology. Some neuropsychological syndromes may be conjectured to be found in cases of disruption of these basic cognitive factors.

In neuropsychology, factor analysis has been specially applied to some specific tests and scales directed to measure single cognitive abilities. The Wechsler Memory Scale (WMS) represents a good example. To date, several factor−analytic studies with the WMS have been published, usually reporting

**Table 2.** Some relatively constant factors found across different factor–analytic studies (Carroll, 1993), and the neuropsychological syndromes with which they could be associated

| Factors | Neuropsychological syndrome |
|---|---|
| Language | |
| Lexical knowledge | Wernicke aphasia |
| Grammatical sensitivity | Broca aphasia |
| Communication ability | Prefrontal syndrome |
| Oral production | Verbal apraxia? |
| Speech sound discrimination | Word–deafness |
| Naming facility | Anomia |
| Expressional and word fluency | Extransylvian (transcortical) motor aphasia |
| Reasoning | |
| Sequential reasoning | Prefrontal syndrome |
| Inductive reasoning | Prefrontal syndrome |
| Quantitative reasoning | Frontal acalculia |
| Visual perception | |
| Spatial relations | Spatial agnosia |
| Serial perceptual integration | Topographic agnosia? |
| Perceptual speed | Visual agnosia |
| Numerical | |
| Number facility | Acalculia |
| Attention and concentration abilities | |
| Attention and Concentration | Prefrontal syndrome |

a two–factor structure (General Memory and Attention factors) (Bornstein & Chelune, 1988; Roid et al., 1988; Wechsler, 1987; Ardila & Rosselli, 1994). However, Elwood (1991) analyzed the factor structure of the WMS–Revised in a clinical sample and observed that only one general memory component accounted for 54% of the variance; a second factor that contributed 9.4% of the total variance was found only after IQ scores were included. Ardila and Rosselli (1994) used the original WMS version, but included delayed recall for the Logical Memory, Visual Reproduction, and Associative Learning subtests. One general memory component accounted for 51% of the variance. The same second factor reported by Wechsler (1987) as an "Attentional Factor" was also found. Finally, Ardila and Rosselli (1994) observed a third, and indeed very weak factor, related with verbal memory, specially measured by means of the Associative Learning subtests ("Verbal Memory" factor). These results with the WMS were very similar to the results obtained by Wechsler; Bornstein and Chelune (1988); and Elwood (1991) using the WMS–R. In consequence, seemingly here is not too much difference between the WMS and the WMS–R factor structure.

Ardila and Pineda (2000) analyzed the factor structure of nonverbal cognition. A neuropsychological test battery for assessing different nonverbal cognitive domains (attention, memory, visuoperceptual and visuoconstructive abilities, executive functions, praxis abilities, and written calculation abilities) was administered. Initially, independent factor analyses were carried out for each domain. Three attention factors (Sustained Attention, Divided Attention, and Processing Speed, 73.1% of the variance); two memory factors (Categorical and Non-Categorical Memory, 59.7% of the variance); two visuoperceptual and visuoconstructive factors (Sequential and Simultaneous, 54.0% of the variance); and two executive function factors (Categorization and Trial/Error, 82.0% of the variance) were found. Subsequently, several sequential factor analyses using Varimax orthogonal rotations for noncorrelated variables were performed. The 32 test variables were included, but progressively some variables were removed. This procedure finally selected 13 variables corresponding to five factors accounting for 72.6% of variance. Factor 1 was an Executive Function factor (30% of variance). Factor 2 corresponded to a Sequential-Constructional factor (14.7%). Factor 3 represented a Processing Speed factor and accounted for 10.6% of the variance. Factor 4 was a Visuoperceptual factor (9.5% of the variance). Finally, Factor 5 (7.8% of the variance) was a Nonverbal Memory factor. It was concluded that several different cognitive dimensions are included in nonverbal cognition.

Only a few factorial analyses of extensive neuropsychological test batteries have been occasionally presented in literature (e.g., Ardila et al., 1994, 1998; Haut et al., 1992; Wilhem & Franzen, 1992; Loewenstein et al., 2001; Ostrosky et al., 1985, 1986; Livingston et al., 2000; Pontón et al., 1994, 2000). Thus, Pontón et al. (1994) gave a test battery to 300 normal subjects; which included 10 different neuropsychological tests. A factor analysis yielded five factors: a Verbal Factor (measured with Verbal fluency, Naming, and Digit span); a Learning Factor (measured specially with the Auditory Verbal Learning test); a Speeded Processing Factor (including the Digit−Symbol, Color Trails, and the Block Design), a Visual Processing Factor (measured with the Rey−Osterrieth Complex Figure and the Raven test), and a Psychomotor Speed Factor (measured with the Pin Test). Ardila et al. (1994) used a neuropsychological test battery, including 10 basic and common neuropsychological tests. Twenty−five different scores were calculated. A factor analysis with varimax rotation disclosed nine different factors, accounting for about 70% of the variance (Table 3).

**Table 3.** Factors observed in Ardila et al. (1994) neuropsychological test battery, tests most saturated by these factors, and probable neuropsychological syndromes theoretically associated with impairments in those factors

| Factor | Tests | Probable neuropsychological syndromes |
|---|---|---|
| I Verbal Production | Verbal fluency | Convexital left prefrontal syndrome |
| II Constructional–Visuospatial | Rey–Osterrieth Figure<br>Visual memory WMS | Constructional apraxia<br>Spatial agnosia |
| III Verbal Memory | Logical memory | Verbal amnesia<br>Wernicke aphasia |
| IV Fine Movements | Tapping test | Premotor syndrome<br>Kinetic apraxia |
| V Verbal Knowledge | Information<br>Boston Naming Test | Wernicke aphasia<br>anomia |
| VI Praxis Ability | Ideomotor apraxia test | Ideomotor apraxia |
| VII Delayed Associative Learning | Delayed Associative Learning WMS | Hippocampus amnesia |
| VIII Arithmetic | Digits | Acalculia |
| IX Attentional | Mental control WMS | Orbital prefrontal syndrome |

In another study, an extensive neuropsychological test battery was assembled and individually administered to a relatively homogenous 300–subject sample (Ardila et al., 1998). The participants were 17–25-year-old right–handed middle socioeconomic status male university students. The battery included some basic neuropsychological tests directed to assess language, calculation abilities, spatial cognition, praxis abilities, memory, perceptual abilities, and executive functions. In addition, the Wechsler Adult Intelligence Scale was also administered. Forty–one different scores were calculated. Correlations among the different test scores were analyzed. It was found that some of the tests presented a quite complex intecorrelation system, whereas other tests did present few or no significant correlations. Mathematical ability tests and orthography knowledge represented the best predictors of Full Scale IQ. A factor analysis with varimax rotation of the neuropsychological battery tests was performed. Five different factors with an eigenvalue higher than 1.00 were disclosed. These five factors accounted for 63.6% of the total variance. The first factor accounted for about one–fourth of the total variance. Table 4 presents the general results of the factor analysis.

**Table 4.** Factor analysis of an extensive neuropsychological test battery (Ardila et al., 1998)

| Factor | Pct. of variance | Most saturated tests |
|---|---|---|
| Verbal | 26.7% | WAIS Similarities |
| Visuoperceptual | 12.5% | Hidden Figures |
| Executive function | 9.8% | WCST Categories |
| Fine movements (fluency) | 7.9% | Finger Tapping Test |
| Memory | 6.9% | Serial Verbal Learning |



It could be supposed that some shared "brain systems" may underlie to the performance of those tests measuring common factors. For example, in Ardila et al. (1994) factor analysis, Factor II ("Nonverbal Memory and Constructional" factor) represented a quite independent and isolated factor. It could be proposed that the two tests saturated by this factor (Visual Reproduction from the Wechsler Memory Scale, and Rey–Osterrieth Complex Figure) were the only two tests associated with the activity of certain specific "brain systems" (according to current neuropsychological knowledge, most likely related with the activity of some right hemisphere areas). It could be further expected their performance were impaired in cases of pathology of this "brain system" (i.e., some right–hemisphere pathology). Correlations between these two tests and other tests were low and non-significant. The brain activity supporting the performance in these two tests should be quite independent of the brain activity supporting the performance in the rest of the battery. But both tests share the same "brain system." "Functional distance" between them is very low. Conversely, "functional distance" between these two tests and the rest of the test battery is high. "Functional distance" should be understood as the commonality in the brain organization of the cognitive processes supporting their performance. Excepting Visual Reproduction and Rey–Osterrieth Complex Figure scores, for the rest of the tests a quite complex matrix of intercorrelations was obtained. Nonetheless, albeit correlated, different factors were extracted. These tests were not homogenous in their scores; and likely, they depended on somehow different (but relatively "close" and partially overlapped) "brain systems." For example, it could be hypothesized that performance in the Boston Naming Test and the Information subtest of the Wechsler Intelligence Scale (highly correlated, and grouped into a single factor: "Verbal Knowledge" factor) depend on "closer" brain systems, than the Boston Naming Test and, say, the Orientation subtest of

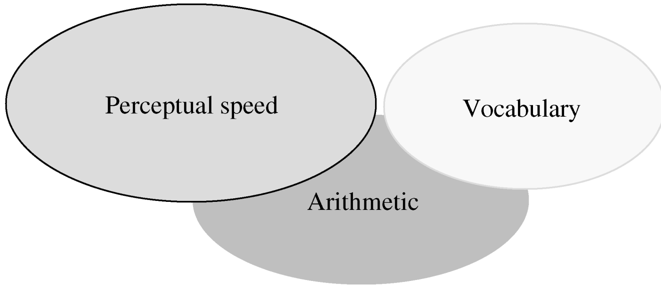


**Figure 2.** High correlations (high communality) and low or none communality can be observed among different cognitive abilities.

the Wechsler Memory Scale (with a correlation close to zero). It could be supposed that the stronger the correlation between two tests, the higher the commonality of the brain activity supporting their performance. The lower the correlation, the higher the "functional distance" in the brain organization of those cognitive abilities required for the correct performance. Figure 2 illustrates how arithmetic can be significantly associated with vocabulary and perceptual speed, but vocabulary and perceptual speed represent independent factors, associated with different brain systems.

A factor might be somehow interpreted as a kind of "information processing type" or "information processing level." A specific "information processing level" can be incorporated and required for the performance of different tests. In a psychometric language, a factor can be saturating different tests. In consequence, it would seem reasonable to attempt establishing correlations between brain pathology and disturbances at specific information processing levels (correlations between brain pathology and factors), rather than attempting to correlate brain pathology with performance in specific tests.

However, when different factor analyses are applied, it does not seem necessary to expect a fixed and limited number of factors responsible for psychological activity. Depending on the included tests, factor structure can eventually vary (Carroll, 1993). Besides, not all factors have the same weight (eigenvalue); they account for different percentages of the total variance. Furthermore, subfactors can exist, as usually it is recognized in the psychometric tradition (Anastasi, 1982; Cronbach, 1990). So, if a verbal factor were found (e.g., Factor V: "Verbal knowledge"; Ardila et al., 1994), it seems reasonable to expect that, when carrying out a sufficiently extensive language evaluation, some subfactors included in this general verbal factor would eventually emerge. These verbal subfactors eventually found, would correspond to different language processing levels, or "language elements" (factors of cognition).

Moreover, if the conditions of the tests were changed, the level of performance can also change. For example, performance in verbal fluency tasks (to search for words according to certain characteristics) varies depending on the category that is used (words beginning with a particular letter, animals, flowers, chemical elements, abstract words, etc.). With regard to naming, as it was mentioned earlier, brain organization of different naming categories can be partially different (Benson & Ardila, 1996).

Comparing different factor analytic studies in neuropsychology, some factors can appear to be relatively constant and stable throughout various analyses. Verbal knowledge (Naming, Information, Vocabulary) usually appears as a single factor across various factor−analytic studies. Constructional and perceptual abilities usually appear conforming a single factor, quite independent from others—verbally based, factors. Attention (measured in diverse ways) also appears to represent an independent factor. Verbal fluency could be also considered as another relatively constant and independent factor. If each one of these factors were correlated with a focal neuropsychological syndrome, a notorious approximation between psychometric results and clinical data would be achieved. Conversely, if the specific factor responsible for every neuropsychological syndrome could be pinpointed and further, a statistical demonstration of its existence in normal populations were obtained, no doubt, a solid mathematical ground for clinical observations would be provided.

As it was stated before, the factors yielded by the factorial analysis of the psychometric tests frequently correspond to "functional systems" rather than "elements of cognition." So, they can be subdivided into more simple elements approaching the level of "units of brain function localization" (modules). In order to dissect the functional systems given by the factorial analysis into "cognitive factors" one needs the theoretical input provided by the lesional model and the empirical validation given by the neuroimages.

## THE NEUROPSYCHOLOGICAL APPROACH (LESIONAL MODEL. A. R. LURIA'S THEORETICAL APPROACH)

For Luria, psychological processes represent "functional systems." The concept of functional system was taken from Anokhin (1974), and is understood as a group of interconnected biological operations that produce a particular biological effect. The functional system is based on a complex dynamic constellation of stages, situated at different levels of the nervous system, which in performing an adaptive task, may be changed without the task itself being changed. Writing, for instance, represents a complex psychological process (functional system) that requires the participation of multiple areas of the brain; each of these areas making its particular contribution to the whole system. A focal lesion of the brain will disrupt the ability to write at a particular level (e.g., the ability to perform the skilled movements required for writing, the spatial organization of writing, the selection of words, the ability of sequencing graphemes). However, such particular brain focal damage will also disrupt all the functional systems for which that particular operation is required. For instance, the patient will not only have spatial organization of writing difficulties, but also, difficulties in spatial organization of numbers, figures, drawings, and so on. In all the functional systems in which such ability is included, the defect will be apparent.

The brain damage does not produce the loss of a specific cognitive process (functional system), which is poorly localized, but its disturbance at a specific level. This implies that neuropsychological assessment will be aimed at disclosing the fundamental defects underlying the apparent deficits ("syndromatic analysis"). For this purpose and according to Luria, it will be necessary to administer to the patients different types of tasks and to analyze how the particular difficulties in performing each one of them are manifested.

For Luria, the most important observation when testing a patient refers to the nature of deviations or errors, and how such mistakes could be explained. This implies that the pass/fail criterion is not enough, or at best, it is simply an initial gross approximation to the characteristics of the deficit. The qualitative analysis of errors will be particularly informative as concerns the underlying deficit of the patient. It is not enough to know that a patient cannot understand language, or cannot write. For Luria, the most important information is the precise nature of the patient's inability to understand language or to write, and the specification of the level in the functional system that is disrupted. What are the actual mistakes the patient presents when trying to understand language or trying to write? The errors produced by patients with frontal, parietal, or temporal lesions when performing calculation tasks are quite different, although all of them may present a certain degree of acalculia (Ardila & Rosselli, 1990, 2002; Rosselli & Ardila, 1989). All these patients can fail in exactly the same tasks, but because of totally different reasons. Their errors will be the key clues for understanding the underlying deficit.

Clinical/anatomical correlations were widely developed by Luria. As a matter of fact, he pioneered the method of the superimposition of lesions to disclose critical areas in a particular type of disorder. His study of 800 patients to determine the critical brain area for phonemic discrimination deficits, has become classic (Luria, 1947/1970). This procedure of superimposing lesions to highlight critical areas responsible for clinical syndromes is extensively used in the present day neuropsychological research (e.g., Ardila & Ostrosky, 1989; Damasio & Damasio, 1989; Kertesz 1983, 1994).

Luria strived to establish correlations between brain pathology and disturbances at specific levels of information processing (e.g., phonemic discrimination)—not to correlate brain pathology with performance in specific tests. Tests may be changed, but while some specific level of information processing will still be required, impairment will be manifested. Besides, the performance on even apparently very simple tests can require the participation of different brain areas. Hence, even performance on simple tests can be altered as a consequence of very different brain pathology, although the specific error patters will be different. Many different types of brain pathology can alter for instance calculation abilities (Ardila & Rosselli, 2002); however, in each case the difficulty (and the errors) will be the result of a disturbance at a different level in the calculation process. Patients with frontal lobe damage and patients with angular gyrus damage can both present serious difficulties in simple calculation tests. However, the underlying impaired mechanism and the type of errors manifested are quite different (Rosselli & Ardila, 1989). Consequently, the validity derived from correlating the site of the brain pathology with performance on a particular test appears, in Luria's interpretation, as a very preliminary and crude approximation.

Luria's interpretation of semantic aphasia and acalculia represents a good illustration of what a "cognitive factor" is, according to Luria's approach. For him, both syndromes are just two clinical manifestations of the very same disrupted component (i.e., a defect in the ability to understand logical–grammatical relationships holding a quasi−spatial content). It would be reasonable according to this interpretation, to expect a virtually perfect correlation between both syndromes. Furthermore, if one assumed that acalculia and semantic aphasia are also associated with finger agnosia and right left disorientation (Ardila et al., 2000), one may conjecture that they represent specific manifestations of an impaired "cognitive factor" (Figure 3).

Cognitive factors would, in consequence, represent the basic elements of cognition, or the "basic cognitive abilities," the functional counterpart of the anatomical modules. Luria discussed this question with some detail only with regard to language. In his last book, *Basic Problems of Neurolinguistics* (1976), Luria analyzed the cognitive factors that can underlie to the different

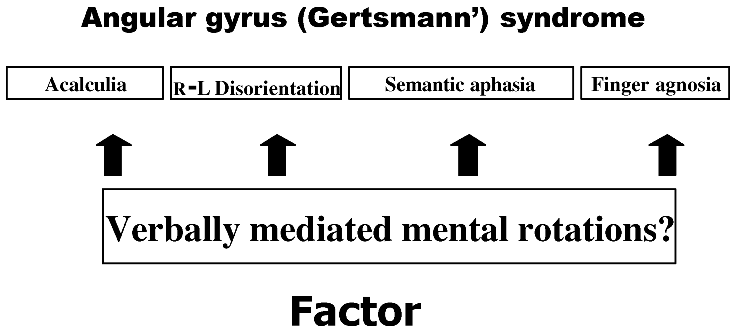


**Figure 3.** The impairment in a common cognitive factor (verbal mediated mental rotations?) may account for the different manifestations observed in case of left angular damage.

aphasic syndromes (Table 5). However, it is not easy to deduce the impaired "cognitive factors" in other neuropsychological syndromes (e.g., agnostic or apraxic disorders). This "cognitive factor theory" represents one of the most interesting and outstanding ideas in Luria's neuropsychological perspective. Unfortunately, Luria left his "cognitive factor theory" of psychological activity without a complete development.

Evidently, the core problem is how to determine those fundamental components underlying normal cognition. Correlation procedure among performance in different cognitive tasks seems to represent a provocative possibility.

## THE NEUROIMAGING APPROACH (FUNCTIONAL MODEL)

In contrast to the lesional model that derives assumptions from neuropsychological deficits in patients with brain lesions, the neuroimaging approach explores

**Table 5.** Factors underlying different aphasia syndromes, according to Luria (1976)

| Aphasia type | Impaired factor |
|---|---|
| Acoustic-Agnosic | Phoneme discrimination |
| Acoustic-Amnesic | Verbal memory |
| Amnesic | Semantic structure of words |
| Semantic | Understanding logical-grammatical (quasi-spatial) structures |
| Afferent Motor | Articuleme discrimination |
| Efferent Motor | Disturbances in speech kinetic structure |
| Dynamic | Verbal initiative |

normal or abnormal brain activity associated with a specific task. A reasonable expectancy for the neuroscientist is that, both the lesional and the functional models were totally convergent. However, they are not. Such divergence is seen in other neurological fields contrasting lesional and functional models. For example, in the creation of maps of dermatomes there are two models that are not entirely coincidental. One model is derived from the area of anesthesia after a lesion or anesthetic blockage of one spinal root (Keegan & Garret, 1948). The other is based in the area that remains with sensitivity after the rest of roots are blocked, or the area responding with electrical stimulation of the dorsal root (Foerster, 1933). The explanation for this phenomenon is "functional overlapping." A simpler example is demonstrated with the visual field. What does the right eye see? If only the right eye is closed (lesional model), a small portion of the far lateral vision is lost. If only the right eye is opened (functional model) the entire visual field of the right eye is revealed. The lesional model points more to proprietary functions but could underestimate the extent of function of a given structure. On the other hand, functional models may fail to isolate critical nodes of a distributed circuitry or overlapped function. Functional neuroimaging procedures are in essence functional models.

The understanding of these differences is important when deriving assumptions from exploratory models that neither rely on lesional experiences nor on functional examinations, but on normalization data, as it happens with the psychometric tests.

The two most important functional neuroimaging procedures are positron emission tomography (PET), and functional magnetic resonance imaging (fMRI). These techniques have provided the most valuable information about brain activity during performance of different cognitive tasks. PET images are based on metabolic and regional perfusion changes and require radiotracers. fMRI is based in minute regional changes of oxyhemoglobin/deoxyhemoglobin blood levels that influence the magnetic signal. Both techniques allow visualizing levels of brain activity and focal involvement during different conditions. The procedures entail typically a probe task and a control condition that are repeated several times accounting for their small magnitude and noise.

A common characteristic of PET and fMRI is the possibility of "cognitive subtraction." This is a modeling technique of the experiments that allow the researcher to "isolate" a target function. For example, the experimenter can target the areas involved in verbal comprehension, when the subject is reading. To accomplish it, the session is divided into two blocks. During one block (condition A), the subject reads a normal text from a screen. In a second block (condition B), the subject is presented with a meaningless arrangement of letters. The subject will search for a specific letter during this block to control visual, attention and working memory loads. The rest of the conditions are kept the same. Then, a subtraction is made between the constitutive "elements." Condition A = Attention + visual processing + ocular movement + working memory + decoding of letters + grammar comprehension. Condition B = Attention + visual processing + ocular movement + working memory + decoding of letters. Grammar comprehension is derived by subtracting B from A.

PET results are based in series and do not account for intra-subject variability. Its spatial resolution is poorer than fMRI's, and assumptions derived from the technique are applicable to populations, not to individuals. This advantage in terms of normalization turns out to be a disadvantage in clinical practice.

fMRI does not require pooling data from subject series. Its results are applicable to individuals and the exam may be repeated as many times as deemed necessary since it is not based on ionizing radiation. PET and fMRI show great reproducibility (Casey et al., 1998; Carey et al. 2000) both among subjects and groups. Reproducibility, resolution, and localization are better in fMRI because there is no risk for re-exposing the subject to the MR environment and because its matrix of reconstruction is more precise. However, the reproducibility of findings differs according with the complexity of the tasks.

Neuroimaging, particularly fMRI, has shown, for instance, a total reproducibility of activation in groups and subjects when mapping primary visual areas (Engel et al., 1994; Thulborn et al., 1997; Moradi et al., 2003). Several tasks have been used. Passive viewing of a black and white checkerboard, for example, actives regions along the boundary of the calcarine fissure (primary visual area) (Hirsch, 1994).

Primary auditory area has also been consistently mapped using tones (Wessinger et al., 1997), chords (Bernal et al., 2004), music (Li et al., 2000; Bernal & Altman, 2001), noise (Colder & Tannenbaum, 1999), etc. (for a review see Bernal et al., 2004). The same reproducibility shows the primary motor-sensory cortex (Freund, 2002; Lotze, 2000; Fera et al., 2004). In all of these cases the activation takes place in restricted areas common to different subjects with minimal variations. Recognition of syllables, for example, activates very restricted areas of the left temporal lobe corresponding to the primary auditory cortex (Black & Behrmann, 1994). Viewing nouns, hearing nouns, and generating verbs activate the left occipital, temporal, and frontal areas, respectively (Raichle, 1994). In all cases, activation is limited to some rather specific brain areas.

In contrast to the restricted and limited activation of the primary areas elicited by simple tasks, complex tasks produce activation of a circuitry in which different brain areas participate holding specific contributions to the whole performance. Figure 4 shows the activation elicited by a silent word generation task. In addition to the Broca's area (main target of this paradigm), involved in speech production, activation is also seen in the left premotor area accounting for motor planning; supplementary motor area (SMA) accounting for initiation, and probably effort; left auditory association areas most like related to some semantic analysis; visual areas related to picturing; and left thalamus. The involvement of thalamus in this task is not well understood, but it is congruent with cases reported of aphasia resulting from thalamic lesions (Crosson et al., 1986; Ozeren et al., 1994). In the experience of one of the authors of this paper (BB), Broca's and lateral frontal areas are consistently activated across subjects (core areas), whereas SMA, thalamus, caudate nucleus, and temporal areas may vary. This has also been described by Friedman et al. (1998). Although some of the ancillary activation findings may be explained because of the different individual strategies chosen on the basis of personal skills, word generation in groups demonstrated that core areas are not restricted to speech areas (Holland et al., 2001). Similar circuitry distribution is also seen in many other cognitive tasks. Calculation tasks, for example, may activate a constellation of different cortical places (Figure 5) depending on their complexity (Bernal et al., 2003). Core areas of cognitive tasks are revealed in averaging of groups. Figure 6, for example, is the averaging of activation of a group of 16 right handed volunteers realizing a Color Stroop task. In total, 16 subjects activated 13 different areas, but after group analysis only 6–7 areas of the left hemisphere proven communality in this task supporting a "core circuitry."

In an effort to isolate these core centers (modules?) in high complex tasks Cabeza and Nyberg (2000) reviewed 275 PET and fMRI studies on 5 different categories of cognitive tasks: language, memory, attention, imagery, and perception. Each category was divided in subgroups. For language, it was considered written/spoken word recognition, with and without spoken responses. For memory, they included studies on working memory, semantic memory, episodic memory encoding, episodic memory retrieval (rather fluency tasks), and procedural memory.

Attention was subdivided into sustained, selective, Stroop, orientation, and divided. Imagery encompasses the subgroups of object and navigation. For perception, subgroups were objects, faces, and space/motion. In all these studies there was an extended participation of different brain regions. Pooled data of receptive language tasks showed activation in 25 different Brodmann's

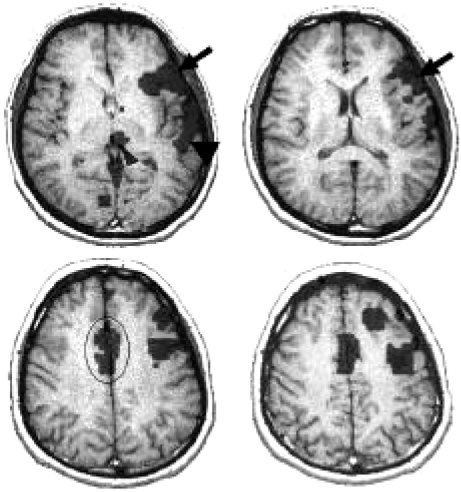

**Figure 4.** Demonstrative example of a functional MRI on a right-handed subject performing a semantic fluency task. The axial images appear in radiological conventional orientation with left hemisphere on the right. The ON condition consisted of silently retrieval of words belonging to a given category auditory presented. The OFF (control) condition consisted of thinking of "a blue sky." The subject kept his eyes closed and remained still, while hearing the magnet's gradient noise throughout the task subtracting the primary auditory area activation. The task elicits a complex activation pattern. The circuitry includes: left Brodmann's 44 area (long arrows), left Brodmann's 6 and 8 areas (short arrows), left Brodmann's area 22 (arrow head); and supplementary motor area (encircled). In addition there are some activation in the inferior aspect of the right occipital lobe (small cluster in the lower left image), left thalamus (thin arrow head), and left middle frontal gyrus (round bubble in lower right image). (Images from the Department of Radiology, Miami Children's Hospital.)

areas and 3 subcortical structures. Some tasks activated up to 17 different areas (naming), whereas 11 of 36 tasks activated 3 or less areas. Areas more frequently activated were left Brodmann's 22 and 21 (in 24 and 10, respectively of 36 experiments), more frequently with left dominance. Brodmann's 47 and 45 areas were activated in 11 and 10 studies also with left dominance. Obviously, the tasks pooled had different designs, and thresholding, and some of them had more auditory load whereas others were more visually clued. However, evident differences appear when comparing a number of areas involved in tasks like hearing words and reading. The former activated an average of 3.4 areas in 9 studies, whereas the latter activated 8 areas in average, having more frontal areas involved. The authors pooled expressive language tasks within the category of semantic memory retrieval. Twenty studies of word generation were analyzed. Twenty different areas activated at least in 3 studies. In average

**Figure 5.** Activation circuitry elicited by a calculation task. The subject subtracts 7 from one hundred, and over again from each subsequent obtained result. Several areas activated. Brodmann's area 44 appears activated bilaterally, more on the left (arrows, left image), extensive activation is seen in the left parietal lobe encompassing both banks of the intraparietal sulcus, and the posterior inferior parietal lobule (encircled). In addition there are activation in right Brodmann's 22 area, SMA, and prefrontal areas. Interestingly there are two symmetrical activations occurring in the posterior third of the superior frontal sulcus (short arrows). (Images from the Department of Radiology, Miami Children's Hospital.)

**Figure 6.** Activation circuitry obtained with a Stroop color task. The image is an average of activation of a group of 16 right-handed subjects. The task consisted of names of colors printed in congruent color ink (for example, "Blue" in blue ink), for the ON condition, and incongruently ("Blue" in red ink) for the OFF condition. The subject was asked to silently name the ink color. Thus, visual stimuli, reading, inner speech, attention, ocular motion, and working memory are controlled. Activation is seen in different areas of the left hemisphere: Brodmann's area 37 (encircled), Brodmann's area 44 (long arrow), and Brodmann's areas 22, 39, and 40 involving the supramarginal gyrus (short arrows). There are also activation in left thalamus, left striattum, left cerebellum, and anterior cingulate gyrus with left predominance. (Images from the Department of Radiology, Miami Children's Hospital.)

5.7 areas were involved. Left Brodmann's 45 and 44 (except one study that reports bilateral), are reported in 13 and 10 studies, respectively. Brodmann's area 21, 6 and SMA (3 cingulate gyrus areas) are reported in 13 studies.

Verbal working memory activated between 4 and 11 different areas with a mean of 7.6. Brodmann's area 44 was reported activated in 14 of 18 studies, 11 of them in the left side, and the rest bilaterally. Brodmann's area 6 is reported in 15 studies, 11 of them bilaterally. Area 40, in 15 studies, 8 bilaterally. Area 7 appears 11 times. Interestingly, the cerebellum appears activating in 10 studies. No study found less than four different areas involved.

Results are similar for the rest of the pooled study categories: several areas are simultaneously involved in complex tasks with some core areas that appear in more than 80% of the studies. An interesting corollary of this study is finding several of Brodmann's areas participating in different types of tasks. For example Brodmann's area 9 appears activated in sustained attention (right), verbal and spatial working memory tasks (bilaterally), episodic memory encoding (left), and episodic memory retrieval. Area 46 is found activated in all types of working memory, episodic memory encoding (left) and episodic memory retrieval (right). Left Brodmann's area 45 is activated in tasks of verbal comprehension, word generation, episodic memory encoding and conceptual priming. Brodmann's area 6 activates in orientation, divided attention, space/motion perception, reading, verbal and spatial working memory (bilaterally), problem solving, and learning of motor schemes. Similar involvement is seen for Brodmann's area 7 without lateralization. Brodmann's area 40 is activated in orientation, space/motion perception, space/motion imaginery (left), verbal working memory (left), spatial working memory (bilateral), spatial episodic memory encoding (left), verbal retrieval, and motor skill learning. Brodmann's area 19 and cerebellum, bilaterally, are also involved in several different types of tasks.

In conclusion, it could be stated that: (1) during relatively simple tasks (e.g., listening syllables, watching a checkerboard), brain activity changes are restricted to somehow specific brain areas; and (2) during complex cognitive tasks (reading, speaking, memory encoding), a participation of multiple brain areas is observed. Each of these areas makes its particular contribution to the whole system.

## TOWARD A SYNTHESIS

It has been assumed that the cerebral cortex is organized in modules, which probably range in size from a hundred thousand to a few million neurons

(Carlson, 1994). Each module receives information from other modules, performs certain processing and then passes the results to other or others modules (De Valois & De Valois, 1988; Livingstone & Hubel, 1988). In the primary visual cortex it has been proposed some 2,500 modules, each approximately 0.5 × 0.7 mm. The neurons in each module are devoted the analysis of various features in one specific portion of the visual field. Basic similarities in the brain organization of different perceptual systems have been proposed, and neural organization for different sensory systems is assumed to be alike (Konorski, 1967). In consequence, the very same principles (neural operations) required for visual pattern recognition (Hubel & Wiesel, 1961, 1962, 1963, 1965) can be also expected for auditory pattern recognition, for example, phoneme perception (Ardila, 1993b). Although the comprehension of how these modules work and are organized is of the utmost importance for neurocognitive sciences, it is of poor aid for clinical research, and has no medical decision impact. Indeed, there is no neurological condition affecting single modules. Tumors, infarcts, trauma, degenerative diseases, and infections injure the brain, affecting areas larger than modules. Even when they are small as a module can get, it is very unlikely that the location matches exactly that one of a single module. For this reason, in clinical practice, the observed deficit is due to impairments of small units of processing, usually greater than a module.

Clinical observation has shown that apparently rather different tasks (e.g., solving numerical problems and recognizing fingers) can be altered as a consequence of the very same brain pathology. Certain "common cognitive factors" should underlie in those apparently different, but simultaneously altered tasks (e.g., to solve numerical problems and to recognize fingers).

Evidently, the higher the correlation between performance in two different tasks, the higher the probability should be that the abilities tapped by these two tasks will be simultaneously impaired in case of focal brain pathology. Broca aphasia can represent an illustrative example. It is usually recognized that Broca aphasia has two different distinguishing features: (a) a motor component (lack of fluency, disintegration of the speech kinetic melodies, verbal–articulatory defects, etc., that is, apraxia of speech); and (b) agrammatism (e.g., Benson & Ardila, 1996; Luria, 1976; Goodglass, 1993; Kertesz, 1985). If both defects are simultaneously observed (i.e., they are very highly correlated), it simply means they both are just two different manifestations of a single underlying defect. It is not easy to understand which one could be the single factor responsible for these two clinical manifestations; it may be kind of an "inability to sequence expressive elements" (Figure 7). But, anyhow, a single common factor underlying both defects should be assumed. Broca's area, most likely, is

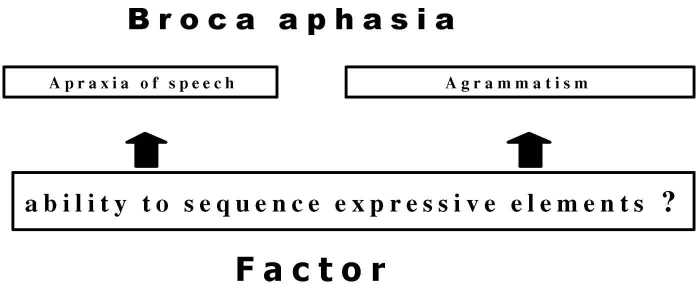


**Figure 7.** The impairment in a common cognitive factor (ability to sequence expressive elements?) may account for the different manifestations observed in case of Broca aphasia.

not specialized in producing language, but in certain activity that can fundament not only skilled movements required for speech, but also morphosyntax. It is interesting to note that deaf–mute subjects (who, in consequence have not ever produced verbal articulatory movements) present a virtually total impossibility to learn, understand, and use language grammar (Poizner et., 1987). Probably, the lack of verbal articulatory normal development is necessarily associated with a lack of normal grammatical development.

Tentatively, it could be concluded that,

1. Recent neuroimaging techniques show that cognitive functions are yielded by a distributed brain activity involving several discrete areas ("modules") arranged into circuitries. These areas are presenting a specific contribution to the whole system.
2. Clinical neuropsychology has been able to propose some "cognitive factors" based on empirical observations in patients with brain lesions.
3. Neuropsychology inventories can provide rough approximation about the localization of different functional systems.
4. Factor analysis may provide an additional tool to extract some constitutive elements of functions (factors). "Factor" in factor analysis may have different levels of specificity. Some times it refers to a functional system; in other occasions to elements of cognition.
5. The very same brain areas (and cognitive factors) may be potentially involved in different types of cognition (functional systems). Thus, phoneme discrimination is required for language understanding, speaking, writing, and so on.
6. Impairment in a specific cognitive factor may result in diverse types of impairments. Thus, the ability to sequence expressive movements, for

example, may be associated with agrammatism and also with apraxia of speech.

7. Currently, it seems feasible to suppose that some cognitive factors are responsible for normal neuropsychological performance. Theoretically, the impairment in any of these factors could be responsible for some specific neuropsychological syndromes.

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