

Biological and Psychological Development of Executive Functions

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The purpose of this overview is to provide a background for understanding the relation between the biological maturation of the frontal lobes and the development of the psychological concept of executive functions. In the first section, an interactive hierarchical feedback model is presented as a heuristic way of conceptualizing the relationship of the frontal lobes and executive functions to other brain regions and abilities. The following two sections present a synopsis of research on biological maturation and the psychological development of executive functions. © 1992 Academic Press, Inc.

INTRODUCTION

In recent years, there has been a revitalization of interest in the frontal lobes and their associated functions. Outcomes of this renewed enthusiasm have included advances in conceptual models, experimental paradigms that have isolated component processes, and an increased understanding of the brain mechanisms underlying these functions. There has been a concomitant burgeoning interest in the life-span development of these abilities. The importance of frontal lobe and executive function development in childhood maturation was emphasized by Russell (1948), who proposed that the frontal regions were most important during childhood years. The frontal lobes serve to condition patterns of behavior for the rest of the brain, a molding completed by early or middle life in many

An excellent summary of the biological maturation research is provided by Fuster (1989). Primary references may be obtained from this source. I thank the following for their assistance: P. Mathews for typing the manuscript; J. Pogue for preparation of the figure; S. Segalowitz, L. Rose-Krasnor, and an unidentified reviewer for helpful comments on an early draft. Research funding provided during the preparation of the manuscript was provided by the Ontario Mental Health Foundation. Address correspondence and reprint requests to Donald T. Stuss, Director of Research, Rotman Research Institute of Baycrest Centre, 3560 Bathurst Street, North York, Ontario, Canada M6A 2E1.

individuals. If Russell's proposition is correct, injury to the prefrontal lobes of children would result in significant failure in mental development. It would also imply the necessity of understanding and nurturing the development of the functions associated with this cortical region.

Definition of basic terms is a necessary prerequisite before investigating the functional and biological development of the frontal lobes. Certain behaviors which are exhibited in novel or demanding situations have been commonly labeled "frontal lobe functions." These include such abilities as planning, decision making, directed goal selection, and monitoring of ongoing behaviors. The reason for attributing these abilities to the frontal lobes is obvious: focal lesions in this cortical region result in often striking impairment of these functions (Damasio, 1985; Fuster, 1989; Stuss & Benson, 1986). A strict localizationist approach, however, is inappropriate. The term "frontal lobes" defines a structural entity, the anterior one-third of the brain, but does not emphasize that the brain is an integrated functioning unit. The term "frontal systems" reflects a more interactive concept, but again emphasizes the anatomical base. There is a growing awareness that frontal lobe mental processes may be described as psychological constructs rather than as anatomically localized functions. For example, individuals who have suffered a head injury will exhibit significant dysfunction in "frontal" abilities, but attribution to the frontal lobes exclusively or even primarily is not possible or necessary (Stuss & Gow, *in press*). The aging process may result in apparently impaired abilities in planning, selective attention, and other higher order abilities. These problems have been attributed both to focal frontal dysfunction and to diffuse degeneration (Albert & Kaplan, 1980; Kinsbourne, 1977). The dysfunctions appear to be real; the underlying pathophysiology, however, is uncertain.

Terms such as "executive control function" (Lezak, 1983; Milner & Petrides, 1984; Stuss & Benson, 1986; Stuss & Gow, 1992), "supervisory system" (Shallice, 1988), or "dysexecutive syndrome" (Baddelcy & Wilson, 1988) relate more directly to the psychological concept of frontal system function and can be used regardless of the underlying anatomical disturbance. In the developmental literature, this distinction may be particularly relevant since the development of "frontal functions" may relate not only to anatomical/biochemical maturation of the frontal lobes but also to the integrative demands of tasks on multiple brain regions.

In summary, the use of the term frontal functions is a reflection of the historical development of these concepts and the intimate connection of these abilities to the prefrontal cortex. The understanding of the term and its implications must extend beyond a concept limited to localization; nevertheless this review, while retaining the psychological construct foremost, does emphasize the biological development of the prefrontal cortex.

This introduction to the development of frontal functions will be pre-

sented in three sections. The first section presents a concept of hierarchical brain functioning. A cybernetic feedback model based on ideas of previous researchers such as Pribram and colleagues (Miller, Galanter, & Pribram, 1960; Pribram, 1971), Powers (1973), and Carver and Scheier (1982) was selected for several reasons. The general model is compatible with general concepts of brain organization, including the frontal lobes (Mesulam, 1981; Stuss & Benson, 1986; Teuber, 1964). A comparable format has been used in social psychology in relation to the development of self (Carver & Scheier, 1982), providing some generalizability of the model. It has also been used to explain alterations in self and awareness after focal brain damage, particularly in the frontal lobes (Stuss, 1991, in press a). The model therefore provides a structure for reviewing the research on the biological development of the frontal lobes and the psychological concepts of executive functions.

The second section outlines research on the biological maturation of the brain, emphasizing differences in development within the frontal lobes and the importance of the interaction of different brain regions. The final section describes research on the psychological development of executive functions, with suggested parallels to the biological research.

A HIERARCHICAL FEEDBACK–FEEDFORWARD MODEL

This model represents a hierarchy of brain abilities, meaning that there are “higher” and “lower” order functions. While hierarchical, it should not be considered solely or even primarily linear. Knowledge of anatomical connections and current processing models indicate the complexities of processing. An important component of the model is the feedback loop present at each level. Incoming information is forwarded to a comparator which analyzes in a pattern-recognition format the incoming specific fact or group of facts. These comparator values have been developed through previous experience, modeling, and training. If there is no difference between the input and comparator values, no adjustment is necessary. If they are different, a change output is automatically triggered. Depending on the level or the demand, this could be action to change the environment, a call for increased information from the environment, or a requirement for direction from higher levels and alteration of the comparator. A feedforward system is postulated to preset the system in an anticipatory manner.

Three levels of monitoring or feedback–feedforward systems are proposed (see Fig. 1). The lower level(s), at least, may be considered as modules as described in cognitive psychology (e.g., Moscovitch & Umiltà, 1990). One could postulate more levels or smaller feedback loops within particular systems. The three levels proposed are satisfactory as a skeleton outline for the specific needs of this paper.

Neuropsychological input at the lowest level presented is sensory/

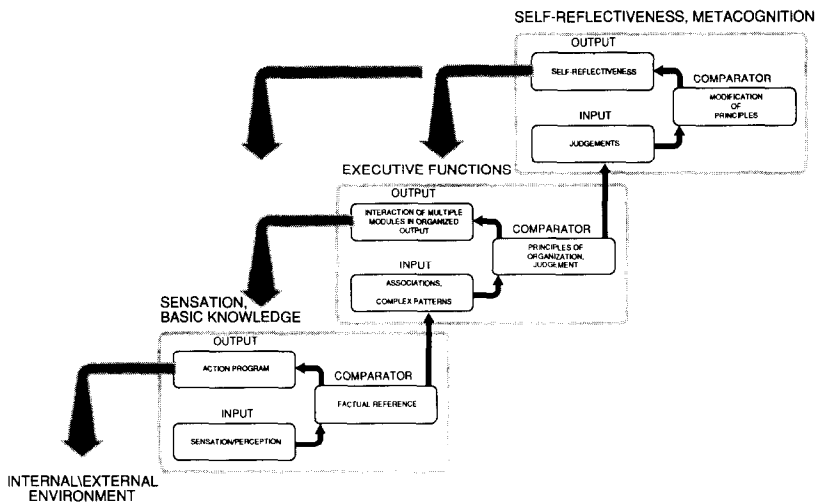


FIG. 1. This figure illustrates three hierarchical levels of processing: sensory-perceptual, executive control, and self-reflectiveness. Monitoring occurs within a feedback loop. Reprinted with permission of the publisher from Stuss (1991b).

perceptual and is domain- or module-specific; consequently, multiple systems relating to specific functions may exist. At this level operations may range from simple to complex. Regardless of their complexity, they are overlearned and routinized. The processes are thus virtually automatic—speed of operations is rapid. From a behavioral/anatomical perspective, this level is equivalent to the posterior/basal functional systems described by Stuss and Benson (1986). Such functional systems have roles, content, and organization which are relatively hard-wired. The routinized activity is not conscious or easily changed by conscious effort. The process of routine selection of routine actions or thought processes has been labeled “contention scheduling” by Norman and Shallice (1986; Shallice, 1988). The processes here are the basis of daily ongoing behavior. They provide facilitation for all levels of behavior that are needed on a repetitive, relatively unchanging basis.

The second level described is associated with the executive control or supervisory functions of the frontal lobes (Stuss & Benson, 1986). The neural input for this second level derives primarily from the information elaborated by the sensory/perceptual level. The neural substrate for this second level is the well-documented reciprocal connections of the frontal regions with all posterior multimodal and basic limbic structures (Nauta, 1971; Pandya & Barnes, 1987). The primary role of this level is the conscious direction of the lower level systems toward a selected goal. This control is higher order, an adjustment of the ongoing activities of lower modules (Shallice, 1988; Stuss, 1991b). This control may well be divided

into specific functions such as anticipation, goal selection, plan formulation, evaluation and monitoring of behavior, and anterior attentional functions such as selectivity and possibly persistence (Shallice & Burgess, *in press*; Stuss & Benson, 1986; Stuss, 1991c). Research investigating the specificity of function in the frontal lobes of monkeys seems to corroborate such distinctions (Petrides, 1987).

At this level, the feedback loop is slower, deliberate, effortful, and required in the processing of new or complex material where routine responses or knowledge are not available. With repetition, the new complex behaviors requiring active conscious deliberation may eventually become automatic in the sense that control of these behaviors in ordinary circumstances is transferred to a lower level.

The highest level described is consciousness—the ability to be aware of oneself and the relation of self to the environment. This prefrontal self-awareness appears to be similar to the concept of metacognition, the ability to reflect on any process itself. This level implies a self-reflectiveness of all levels, including its own. Inputs are presumably the abstract mental representations of the executive's alternative choices. The primary anatomical representation of this highest level has been postulated as the prefrontal region (Stuss, 1991a,b; Stuss & Benson, 1986). The abstract representation of this concept, however, necessitates involvement of all functionally lower levels (of the brain).

The concept of the feedback loop promotes the possibility of alteration (for better or worse) of the basic processing of a system. The important developmental implication is the means by which this upgrading is accomplished. Is this a passive phenomenon, totally bound by biological readiness and occurring primarily by experience? Is the process “bottom-up,” “top-down,” or both? If both, is the developmental timing parallel? The hierarchy of systems suggests differences in development for different levels. The lower levels, representing faster routine processes, perhaps indicate the importance of rote learning and practice. Fact is emphasized. The higher levels are more flexible, process is more relevant, and localization to specific brain regions is perhaps less specific. The relationship of the proposed levels to different brain regions implies the importance of biological maturation and the timing of such maturation, as well as the possibility of developmental lag or focal neurological disturbance as a possible explanation for specific developmental problems. The following sections review the biological and psychological development of the higher processing levels, with a focus on the role of the frontal lobes.

BIOLOGICAL MATURATION

Knowledge of postnatal maturation of human brain is confounded by several issues (Stuss & Benson, 1986). These include the shortage of human specimens in the early stages, the variation in maturity depending

on which anatomical aspect is being studied, and the existence of anatomical individual differences.

Nevertheless, several facts appear consistent. Many reports suggest a hierarchical model of cortical development, from primary motor and sensory areas to adjacent secondary areas, with association regions (including prefrontal) developing last. The major cortical gyri are present and distinguishable at birth (Chi, Dooling, & Gills, 1977). The laminar structure of the prefrontal cortex is virtually complete by birth. Connective apparatus appear to be largely present in the newborn, ready for connections. Shaping of the cortical surface by means of tertiary sulcation, however, appears to continue through life.

Morphological development in the frontal cortex is incomplete at birth (Orzhekhovskaya, 1981). Even by age 4, prefrontal areas nine and ten lack complete pyramidization. While morphological maturation of prefrontal cortex is reached around puberty, quantitative and qualitative changes may continue into later years (Orzhekhovskaya, 1981; Yakovlev, 1962). Age-related prefrontal RNA development matures by approximately age 9 and remains constant until a gradual decline starts in the retirement years (Uemura & Hartmann, 1978). Metabolic activity and levels of various enzymes also suggest a hierarchical model of development (Kennedy, Sakurada, Shinohara, & Miyaoka, 1982).

Hierarchical development is also suggested by electroencephalography measurements (Hudspeth, 1987). Hudspeth reported that the electrophysiological maturity of the brain appears to start at the back and move forward to the frontal regions. Studies of the degree of myelination also indicate that the prefrontal cortex is among the last areas to develop (Yakovlev, 1962; Yakovlev & Lecours, 1967). The supralimbic zones, comprised of frontal, parietal, and temporal association areas, have a slow but continuing progressive myelination past the middle years. Yakovlev (1962) suggested that "the longer cycle of differentiation of the more plastic eulaminar supralimbic cortex [might correlate] with the slower exponential gain in the insight, understanding and maturity of judgement 'learned' from conscious experience through decades of later life" (p. 39).

The hierarchical concept of development, even if correct, serves only to explain certain phenomena. It does not explain the entire pattern of biological development. For example, columnar organization of the frontal association area appears to mature earlier, not later, than similar organization in the optic radiation fibres (Goldman & Nauta, 1977; Goldman-Rakic, 1984). A comparison of synaptogenesis in multiple areas of cortex indicates that the initial development of synaptogenesis is simultaneous and equivalent in all the areas and layers of cortex studied (Rakic, Bourgeois, Eckenhoff, Zecevic, & Goldman-Rakic, 1986). These data suggest that principles in addition to one of hierarchical development are important and that perhaps these principles interact: thus development of spe-

cific regions related to a defined functional capacity may be achieved not only through regulation of the initial formation (as would be proposed in a pure hierarchical model), but also perhaps by selective survival of certain synapses. The interaction of behavior and biology may be important in this latter type of development, as well as others.

There is selectivity and specificity of development even within the frontal cortex. The orbital prefrontal regions appear to mature before the dorsolateral, perhaps underlying the varied development of different behavioral correlates (Yakovlev, 1962). Glucose utilization has a unique representation within the medial orbitofrontal cortex (Kennedy *et al.*, 1982). When one considers that the infantile cerebral metabolic rate exceeds that of maturity, some early modulatory function must be considered. The specificity may be revealed in myriad ways. Schade and Van Groenigen (1961) showed that there were different developmental periods for different biological parameters. For example, nerve cell body volume in layers III and V has two periods of growth separated by an interphase. Huttenlocher (1979) stated that synaptic density in the middle frontal gyrus showed a gradual increase during the early infant years, and then a gradual decline between ages 2 and 16 until adult level is reached. Neuronal density, on the other hand, was highest in the neonatal brain, with a rapid drop in the first 6 months of life and a slower decline between age 2 years and maturity.

There are no neurotransmitters unique to the frontal cortex, although different neurotransmitters vary in their importance to this region (see Brown & Goldman, 1977; Goldman-Rakic & Brown, 1982). There are three frontal dopamine systems, indicating a disproportionate amount of dopamine innervation to the frontal cortex (Lindvall, Bjorklund, & Divac, 1978). Norepinephrine fibers transverse the frontal cortex en route to posterior regions. At birth, this adult pattern of monoamine distribution is already present. The subsequent development shows some variation. Norepinephrine progressively increases to adult level from birth to 3 years. The dopamine distribution, however, is almost adult level at birth, falls off in infancy, and then reattains the former level at 2 to 3 years of age.

The following facts may be extracted from this review of biological development. Development appears largely hierarchical, with tertiary association areas (including frontal) maturing last, most markers reaching maturation by the age of puberty. This may have some relevance to the hierarchical model of brain organization. Functions associated with the tertiary association regions would not be considered fully developed until between ages 10 and 12, a profile that appears to be compatible with the development of formal operational reasoning (Piaget, 1963). Shute and Huertas (1990) reported that a measure of formal operational processing was most strongly related to tasks that have been associated with frontal lobe functioning. This does not imply that the psychological development

of executive abilities is uniquely secondary to frontal lobe maturation. The efficient interaction of all tertiary zones, including those that mediate transmission of information from frontal to posterior regions, is certainly relevant. Perhaps even more important to development are the iterative feedback functions occurring between neural substrates and behavior.

An important concept is that biological development should not be considered totally hierarchical. In addition, there appears to be distinctiveness of development within the frontal cortex. Considering our present knowledge of the heterogeneity of the prefrontal cortex as well as individual differences, the importance of correlating specific functions with biological properties is an important avenue of future research.

While much of the biological maturation is complete by puberty, there is evidence of continuing development into later years. This extended development relates not only to prefrontal but also to parietal and to temporal association areas. The corresponding psychological functions associated with these biological changes have not yet been definitely documented.

PSYCHOLOGICAL DEVELOPMENT

Concepts which appear similar to those proposed for certain executive functions have been proposed by certain developmental psychologists. Recently, however, developmental neuropsychologists and others have turned their attention to functions defined in the adult neuropsychological literature as those primarily attributed to the frontal lobes. This section reviews some of the pertinent research on the development of these "frontal lobe" abilities. The review indirectly reflects the present inadequacies of the definition of "frontal" abilities. Some researchers study specific functions (e.g., control of motor response), while others base their research on a test-oriented approach (e.g., Wisconsin Card Sorting Test), and still others address more abstract concepts such as self-awareness.

The control of motor responses has been frequently reported as impaired after frontal lobe lesions in adults (Luria, 1973). One aspect studied in children, the verbal regulation of motor responses, moves in a developmental sequence from overt to internal control, particularly during ages 2 to 5 (e.g., Luria, 1959; Tinsley & Waters, 1982). Children are able to use speech covertly to direct action effectively only around age 5 (Conrad, 1971). Even when children are older, they often revert to overt regulation to perform more difficult tasks. This technique of verbal regulation has been used successfully in therapeutic approaches (e.g., Meichenbaum & Goodman, 1971).

Becker, Isaac, and Hynd (1987) examined more complex motor skills, such as inhibition of motor reactions, in tasks varying in stimulus modality and difficulty. The most significant development of the defined motor tasks was observed between ages 6 and 8 with some behaviors attributed

to frontal functioning still not mastered by age 12. These authors also observed the classic frontal lobe sign of dissociation between correct verbalization and incorrect action described by Luria (1973). While children of all ages could verbalize task demands, younger children were impaired in the inhibition of inappropriate responses. What they said and what they were able to do were not equivalent in certain circumstances.

Another motor phenomenon tested in children was motor persistence—the ability to sustain motor acts such as eye closure and tongue protrusion (Chadwick & Rutter, 1983; Garfield, 1964). The inability to sustain a motor act, motor *impersistence*, has been proposed as a sign of frontal lobe disturbance (Kertesz, Nicholson, Cancelliere, Kassa, & Black, 1985; Stuss, Delgado, & Guzman, 1987). A rapid improvement was noted between the ages 5 and 7 in the sustaining of specific motor acts, with relatively stable performance thereafter. Chadwick and Rutter (1983) concluded that motor persistence appears to be a developmental phenomenon that can be reliably measured. Garfield (1964) also examined 25 brain-damaged children on this variable. Greater impairment was noted when the children had documented bilateral or diffuse damage, in comparison to children with more focal brain pathology. Unfortunately, the authors did not address the comparative effects of brain damage in anterior versus posterior brain regions. The literature on motor *impersistence* in adult patients has suggested diffuse or frontal (primarily right) pathology as most pertinent (Kertesz et al., 1985). The developing brain, however, is not directly comparable to the adult brain.

The development of attentional functions has been investigated by several authors. Humphrey (1982) proposed that the ability to attend selectively and to disregard distractions followed a developmental sequence from ages 5 to 9. Passler, Isaac, and Hynd (1985) administered several attentional tasks increasing in difficulty to children who ranged in age from 6 to 12. Some of the tests requiring selective attention were mastered between the 6th and 8th year, but complete mastery of all skills was not universally obtained even by age 12. Miller and Weiss (1981, 1982) examined children from Grades 2, 5, and 8 on two tests: allocation of attention and incidental learning. The students revealed maximum improvement on the intentional allocation between Grades 2 and 5. Incidental learning, on the other hand, improved the most between Grades 5 and 8. The authors suggested that incidental learning requires allocation of attention plus additional skills. In essence, we must first learn strategies and then learn how to use them, a metacognitive skill. These attentional studies indicate the importance of precise definition of task demands. Even within the umbrella term “attention,” different functions mature at different times. The experimental work by Tipper, Bourque, Anderson, and Brehart (1989) differentiating the maturation of the cognitive processes of habituation and inhibition suggests that these attentional pro-

cesses that have been described as related to frontal lobe function can be separated in children.

Other researchers investigating the development of executive abilities have adopted the procedure of using standard psychological tests of "frontal functions" developed for adults and administering them to children of different ages. Chelune and colleagues (Chelune & Baer, 1986; Chelune & Thompson, 1987) evaluated the sensitivity of the Wisconsin Card Sorting Test, a measure frequently considered sensitive to focal frontal pathology (Milner, 1963). Children of average intelligence (overall IQ of 108) from Grades 1 to 6 were assessed. The authors concluded that "... the ability to use environmental feedback in the development of problem-solving strategies, the capacity to shift set and suppress inappropriate responding, and the ability to selectively attend to relevant stimulus dimensions without distraction are developmental tasks that appear to reach adult levels of maturity by the age of ten years" (p. 225). When children aged 4 to 13 were compared on "frontal" and "posterior" tests, differences in performances were noted overall, with better performance on the posterior tests (Kirk & Kelly, 1985). These posterior tests would be hypothetically related to the first level described in the conceptual schema. Errors on the frontal executive tests diminished over time between ages 6 to 10. Adolescents performed like normal adults. Welsh, Groisser, and Pennington (1988) (see also Welsh & Pennington, 1988) tested 140 subjects from ages 3 to 28 on their ability to complete several executive function tests. They concluded that such abilities are mostly independent of IQ. In addition, they found that the sequential development of these abilities was prominent. Adult level performance of executive functions seemed to be reached in three stages: (1) simple planning and organized visual search by 6 years; (2) set maintenance, hypotheses testing, and impulse control by age 10; (3) complex planning, motor sequencing, and verbal fluency during adolescence. Finally, temporal ordering, a process impaired in adults after focal frontal lobe damage (Milner, Petrides, & Smith, 1985), follows a developmental pattern from age 6 to 12 (Becker et al., 1987). The task could not be successfully performed by children 6 years of age. By age 12, appropriate strategies were employed, and the children performed significantly better. The labeling of tests as anterior or posterior is understood as a conceptual shortcut; the fact that these tests may vary in a number of dimensions and that strict localization is not possible is acknowledged.

A more abstract concept apparently related to frontal cortex is that of self or self-awareness (self-consciousness). We (Stuss & Benson, 1986) suggested earlier that this self-reflectiveness is the highest of frontal functions. More recently (Stuss, 1991a,b), I proposed at least three levels of self-awareness, two of these related to frontal functions. Initial research into the developmental aspects of self and self-awareness has been sub-

lished. Welsh and Pennington (1988), reviewing previous literature, stated that self-control or self-regulation followed a protracted period of development from infancy through childhood. Gallup and Suarez (1986) reported gradual development of self-awareness in children, a development they interpreted as coincidental with a period of rapid growth in the frontal lobes. Developmental progression of higher levels of self-awareness has not been studied. Since hierarchic levels of self-awareness have been proposed (Freeman & Watts, 1948; Stuss, 1991b), this may be an important area of future research.

Evidence for the development of executive abilities has also derived from studies in various childhood disorders. Hyperactivity, many characteristics of which appear similar to the deficits described after focal frontal lesions, has been considered to be related to frontal lobe dysfunction, perhaps due to a maturational lag (Shue, 1989; Stamm & Kreder, 1979). It is also possible that certain deficits in dyslexia may relate to abnormal development of executive abilities. Children with a reading disability were compared in their performance on "prefrontal" and "posterior" neuropsychological tests (Kelly, Best, & Kirk, 1989). The measures of executive abilities differentiated the dyslexics from matched normal readers better than the posterior function tests. It therefore appears that certain aspects of reading may be dependent on executive functions such as verbal mediation. The hypothesis that abnormal executive abilities are related to certain dyslexic symptoms may be considered compatible with other research. Electrophysiological differences between dyslexic and non-dyslexic boys were found in both left posterior and prefrontal regions (Duffy, Denckla, Bartels, & Sandini, 1980). Autopsy examination of five young men diagnosed dyslexic as children revealed cellular abnormalities in both left posterior and left anterior regions (Galaburda, 1983, 1986). Both the electrophysiological and the anatomical evidence imply some correlation of the reading functions assessed and the development of frontal regions.

This review on the development of executive supervisory functions has arbitrarily emphasized the possible relation of these abilities to the biological maturation of the frontal cortex. The biological maturation research suggests that there is an orderly if not uniform progression of development, with differences in development dependent upon the biological marker measured and the region and cortex in question. The psychological data on the development of executive functions parallels the main concepts of the research on biological maturation. Functional development of executive abilities may be considered a multistage process, with different functions maturing in different ways, at different times (Passler et al., 1985). That these apparently parallel developmental sequences may somehow be interrelated in their development should be considered.

The model presented in the first section can be adapted to fit the biological and psychological developmental data. There does appear to be differential timing in the development of specific functions that relates to some degree to the hierarchical order of the schema. At level 1, the basic content is sensory-perceptual basic facts or grouping of facts. There is some suggestion that the anatomical regions underlying some of these simpler functions mature earlier. Level 2 is the level of executive functions. At this higher order, the abilities to plan, establish goals, generate alternatives, and monitor programs are relevant. Biological and psychological development data are consistent with the concept of separate executive functions, which develop differentially over time. There is also some suggestion that these functions can be taught or modified. The feedback loop presents the conceptual opportunity for modification of the executive abilities, a potential suggested by both the psychological and the biological maturational data. Apparently 5- and 6-year-old children can plan better if tasks and goals are made more concrete (Klahr & Robinson, 1981). The possible interaction of behavior and biological substrates through feedback is again emphasized. Little research has been done on the development of the third tier, self-awareness. It is possible that self-awareness as assessed by Gallup and Suarez operates at a lower level. If so, higher aspects of self-awareness should be investigated developmentally.

This paper is meant to provide a background for the other papers in this volume. Some of these illustrate specific features of the normal development of the frontal lobes and executive functions; others examine impaired executive abilities after frontal lobe damage. An understanding of the biological base and the general corresponding principles in the behavioral literature serves as an introduction to these data.

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