Severe traumatic brain injury remains one of the main causes of severe disabilities in children. The state of cognitive functions, which largely determines the quality of a child’s life after a brain injury, is one of the significant parameters used to assess the outcomes of severe traumatic brain injuries [1]. Early identification of the disorder the higher mental function allows one to develop rehabilitation programs and to increase intervention effectiveness. The current concepts of neurorehabilitation with emphasis placed on early intervention impose absolutely new requirements both on instrumentation of neuropsychological assessment and on techniques of neuropsychological recovery training.

A conventional neuropsychological examination aimed at finding the mechanisms of disorders in certain mental processes implies verbal contact with patients. Neuropsychological work with a child experiencing long-term depression of consciousness has different aims: assessment of the dynamics of consciousness recovery with early neuropsychological diagnosis and early intervention effectiveness. The current concepts of neurorehabilitation with emphasis placed on early intervention impose absolutely new requirements both on instrumentation of neuropsychological assessment and on techniques of neuropsychological recovery training.

A. R. Luria has proposed the structural–functional model of brain activity, in which the brain is regarded as a substrate for mental processes (see Figure). The model separates the brain into three units: the first unit is the energy-related unit responsible for nonspecific activation; the second unit is associated with reception and processing of exteroceptive information; while the third one is responsible for programming, regulation, and control of the complex forms of mental activity, which control certain types of mental activity and execute behavioral programming [11, 12]. Severe traumatic brain injury with focal and diffuse brain lesions can lead to a situation when all three functional units of the brain are injured to a certain extent. Hence, a path of recovery and the contribution of each unit to consciousness recovery are the most significant issues. Normalization of the sleep—wake cycle, along with self-awakening and opening of eyes without regard to external stimuli, are typical steps in the common path of mental functions recovery. These components are supported by functions of the first unit of the brain (activation). In the further recovery process (according to the neuroimaging data available from literature), the auditory cortex is activated in response to verbal stimuli, which may be indicative of partial involvement of the second unit in maintaining the reception of external information (stimuli) [20].

Alterations in the subcortical—cortical—subcortical and cortical—cortical links in the course of consciousness recovery have been demonstrated in a number of studies. According to O. M. Grindel (cited by [7, 8]), recovery of
the electrophysiological activity of the brain is somewhat
regular to some extent: from the total absence of any in-
teraction between hemispheres at the stage of depressed
consciousness to its partial formation at mental confu-
sion and complete formation at the beginning of patient’s
orientation. Cortical links are commonly recovered from
the dorsal (occipital) to frontal lobes. According to neu-
rophysiological data, inter- and intrahemispheric rela-
tions in the frontal lobes are the last ones to recover; only
at this stage a patient becomes able to execute instruc-
tions and his/her executive function recovers to the ex-
tent that is possible according to the primary defect. Ac-

According to the L.S. Vygotsky’s concept about
sense and systemic structure of consciousness, “human
consciousness has... different sense structure at different
stages of its development ... and is executed by different
systems of mental processes” (cited by [12]). For ex-
ample, development of consciousness in child’s ontogen-
esis progresses from the leading role of immediate emo-
tional impressions and diffuse motion reactions in in-
fancy to complex forms of information processing based
on subjective motions, actions, perception in toddler-
hood, and to the leading role of speech and executive
notion regulation [2, 12]. Although children recover
after severe traumatic brain injury according to the same
main vector (executive function component is en-
hanced), ontogenesis is not completely repeated after
recovering from coma. Complete development since
birth through acquisition of new skills is never repro-
duced; “recovery” (formation of something new) takes
place under conditions of a disturbed system, lost links
of the system of the brain mechanisms, each of which
considerably contributes to execution of the child’s con-
scious activity and mental processes.

Among various neurobehavioral scales that have
been successfully used in Russian and foreign practice
to assess the dynamics of conscious recovery, the param-
eters that are maximally important for neuropsycho-

Structural and functional model of the brain integrative function [12, 16].
a) first unit: 1 — corpus callosum; 2 — mesencephalon; 3 — parietooccipital fissure; 4 — cerebellum; 5 — brainstem reticular formation; 6 — uncinate girus; 7 — hy-
pothalamus; 8 — thalamus;
b) second unit: 1 — premotor cortex; 2 — anterior central gyrus; 3 — central gyrus; 4 — motor cortex; 5 — prefrontal cortex area;
c) third unit: legend is the same as that in Fig. b.
logical monitoring should be mentioned. One of the main parameters in recovery of children with severe traumatic brain injury is the executiveness, which determines a possibility to recover patient’s cognitive functions and potentialities of neuropsychological rehabilitation training during further cognitive rehabilitation. What is executiveness? While one sense aspect of executiveness is the capability of conscious target behavior and conscious control over one’s own mental processes, executiveness in general implies complete recovery of patient’s consciousness. According to L.S. Vygotsky’s culture-historical approach [3, 4], ontogenetic development of child’s consciousness is tightly related to executive processes mediated by a sign. Hence, the mindfulness criterion cannot be totally eliminated from discussion of executiveness of the mental processes, movements and actions. A.V. Zaporozhets [10] demonstrated the development of executive movements when nonexecutive movements of a person acquire signaling meaning and become perceptible and, hence, executive and conscious. M.I. Lisina’s experiments (cited by [10]) in healthy individuals verified this idea and demonstrated that an individual needs orientation/exploration activity to express his/her signaling activity.

Nonexecutive spontaneous activity beyond targeted stimulation and the ability to perform any purposeless self-activity or activity independent of its adequacy are an important basis and a measurable parameter during the recovery of child’s consciousness. Gaze fixation and visual tracking, being signs of emergence from a vegetative state, are a purposeless self-activity of a patient [6, 8]. Orienting responses during patient’s recovery can be implemented within the main modalities: visual (object tracking, human figures and faces, etc.), auditory (turning one’s head/eyes/hands to a sound), motor (palpation, grabbing things within a bed, etc.) and their combinations. Therefore, the nonexecutive level of mental processes should be included in behavioral study of a patient during the recovery of his/her mental activity.

In clinical aspect, both executive and nonexecutive responses to internal and external stimuli are typical of the vegetative state of mental activity recovery. According to the classification proposed by T.A. Dobrokhотовa [6, 8] and used in Russia, distinct gaze fixation and differential response to a stimulus of any modality (verbal or nonverbal emotional), distinct, non-generalized localization of noxious stimuli are typical of the stage of akinetic mutism with emotional reactions. Minimally conscious state is a term used in the foreign classification [19]; the negative minimally conscious state, (MCS–) is currently used to describe this patient group [20].

A number of behavioral manifestations important for observations during a neurobehavioral study, although containing formal nonexecutive activity, can be listed:

- nonexecutive attention to any stimulus;
- attention to a stimulus and its duration (seconds); concentration on a task or a problem;
- independent turn of the head/eyes towards a speaker, indicating focus on the contact;
- orienting responses (tracking the emotionally significant stimuli, relatives’ faces, one’s own mirror reflection and favorite things compared to the other stimuli).

According to the classification used in Russia [6, 19], the higher level, positive minimally conscious state (MCS+) or akinetic mutism with speech recognition can be characterized by one of the following behaviors: execution of simple commands, gestural/verbal yes/no responding, and any targeted behavior (movements and emotional response to external stimuli).

Some significant behavior types can develop at this stage earlier than execution of instructions or the yes/no response:

- exploration of one’s own body parts and face of a person who stands/sits nearby;
- exploration of things without a possibility of using them properly;
- the use of nonverbal communication;
- mimetic responses, gesture imitation;
- execution of reward instructions.

Thus, the behavioral patterns typical of a patient should be determined when performing neuropsychological evaluation.

The descriptive scales or neuroimaging (functional magnetic resonance tomography [20]) data are not sufficient to elaborate the rehabilitation approaches and develop recovery programs; hence, we mainly focus on neurobehavioral monitoring to evaluate the minimal changes in patient’s behavior.

We have analyzed 14 clinical cases and determined the following processes that should be presented in neuropsychological evaluation at early recovery:

1. **Communicability:**
   - no communication attempts are made;
   - inadequate characteristics of the contact (negativism, contact discrimination, etc.);
   - nonverbal communication
   - verbal communication with insufficient initiative;
   - adequate verbal communication.
2. **Neurodynamic parameters of mental activity:**
   - activity (awakening) state (independent: either spontaneous or stimulated);
   - attraction of nonexecutive attention to the environment and the retention duration;
   - attraction of executive attention to a stimulus and duration of attention to a stimulus or a task;
   - duration of response latency when executing an instruction.

It is noteworthy that monitoring the neurodynamic parameters of mental activity reveals differences in patient’s activity parameters throughout a day, as well as his/her variable accessibility for various rehabilitations. No dynamics or worsening of the monitored neurodynamic parameters between examinations can be a result
of a low rehabilitation potential, insufficient rehabilitation program, or a sign of developing complications after a severe traumatic brain injury (e.g., posttraumatic hydrocephalus).

3. Integrity of the analyzing functions and the recovery of perception (visual, auditory, and tactile):
   — generalized non-differentiated reaction;
   — stimulated emotional mimic reactions;
   — distinct localization (visual, tactile, auditory or noxious) depending on stimulus modality.

4. Executive level of movements and actions:
   — nonexecutive orientation responses (i.e., any orientation response regardless of the modality of its manifestation);
   — targeted spontaneous responses free of directed external stimulation;
   — targeted movements and actions in response to an instruction.

5. Instruction execution:
   — execution of mimic instructions;
   — execution of reward instructions and instructions supported by other modalities;
   — execution of instructions according to verbal (sometimes written) instruction.

Thus, at minimally conscious state, a functional diagnosis can be specified by neuropsychological assessment of patient’s behavior with respect to the executive action component. The structural-topical diagnosis may reflect the features of the recovery of different brain structures: the vertically organized ones (subcortical-cortical organization), interhemispheric interaction, and the horizontally organized ones (cortical-cortical interaction). It should be understood that these generalization forms are aimed at solving various clinical problems, (e.g., functional diagnosis attesting to function disorders and the dynamics of individual rehabilitation) and allow one to refine the rehabilitation objectives at early stages.

The main problem associated with the minimally conscious state (MCS⁻) within early neuropsychological rehabilitation is preparing a platform for executive action. A thorough analysis of disordered functions helps a patient to develop his or her own way of recovery. For example, object tracking ensured by the visual function is not the only qualitative criterion of patient’s emergence from a vegetative state. The inability to maintain gaze fixation and object tracking under simultaneous emergence of other behavioral responses often correlates both with primary disorders of the analyzing system and severe disturbances of visual object perception. In such cases, development of an executive component, including the possibility to execute instructions, can be fulfilled through the auditory function (see Table). In contrast to the previous stage (of examination?) of stimulation from different modalities applied to a patient [9], it is reasonable to isolate the dominant modality and stimulus for further formation (facilitation) of the executive component.

The objectives of neuropsychological rehabilitation vary in accordance with the recovery stage [17].

As consciousness is recovered, beginning from the minimally conscious state (MCS⁺), early neuropsychological diagnostics becomes available, which is adapted with allowance for patient’s age and his/her functionalities (primary injuries of the analyzing systems and motion disorders of various genesis). The diagnostics makes it possible to assess the injuries of higher mental functions and the dynamics of their recovery.

Neuropsychological diagnostics during the first six months after a severe brain traumatic injury allowed the authors to determine the following deficiencies in 51 children [5, 15]:

1. disorders of neurodynamic parameters of mental activity;
2. modality non-specific memory disorders;
3. disorders of regulatory functions, programming and control of activity (executive functions).

The following mechanisms of the impairment of executive functions were found:

1) pathologic impact of the emerged stereotypes causing problems in switching from one program element to another and from one program to another;
2) inability to inhibit direct responses to a situation causing impulsive behavior;
3) loss of initiative as a basic component of the motivation—needs sphere manifested as severe aspontaneity [14].

The objectives of neuropsychological rehabilitation at the stage of clear consciousness are obvious and have been sufficiently described. They are directly related to the detected mechanisms of the impairment of control functions. The following rehabilitation objectives are common for children with severe brain traumatic injury:

<table>
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<tr>
<th>The main objectives of neuropsychological rehabilitation at early recovery stages in children with severe brain traumatic injury</th>
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<tbody>
<tr>
<td><strong>Substages of the minimally conscious state (MCS)</strong></td>
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<tr>
<td><strong>Levels of patient’s executive activity in neuropsychological contact</strong></td>
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<tr>
<td><strong>Primary objectives of early neuropsychological rehabilitation</strong></td>
</tr>
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</table>
— to reduce the intensity of non-specific neuropsychological symptoms (apart from and pathological passiveness of mental processes);
— to increase self-control over the course of both physiological and cognitive processes;
— to organize proper patient—environment interaction.

It is worth mentioning that a longitudinal study including 13 5—17-year-old children in post-traumatic period (first six months and two years after an injury) showed a statistically significant recovery dynamics only for such components of the executive control of activity as pathological passiveness of mental processes [15]. Disorders in other processes of the control functions were either preserved or the dynamics of their regression was insignificant at repeated examination of the children two years later.

Thus, we determined the key role of an executive factor and executive control over psychological processes in early period of children’s rehabilitation after a severe brain traumatic injury, using our own data of continuous follow-up and stimuli. Further intensive clinical observations are needed to verify the concept, to specify the structure of neurobehavioral assessment, and to develop certain techniques for early neuropsychological rehabilitation.

REFERENCES


Commentary

The article deals with the urgent topic of neuropsychology: recovery of consciousness in children with severe traumatic brain injury and formation of executive mental activity. Occurrence of executive activity is the crucial moment in life of an unconscious patient. This is a point of considerable expansion of the entire range of active stimuli that can be used both for accurate diagnosis of cognitive functions and for further rehabilitation and judgments on outcome prognosis.

The greatest part of the work is the review of the theories concerning executive functioning. The author demonstrates good knowledge of classical Russian publications in neuropsychology and the current scales of consciousness assessment. Detailed lists of behaviors in patients with different states of consciousness are a significant advantage of the article. Observations of patients’ behavior and responses to various stimuli will allow one to detect the emergence of even the minimal executiveness of mental activity. Such lists of behavioral patterns during mental recovery can be refined and used to develop grading scales. Such a detailed stepwise description of patients’ behavior is indicative of the author’s deep clinical knowledge.

However, the article contains some controversial issues and unfortunate mistakes. First: “neuropsychological assessment” as applied to unconscious patients (in particular, in vegetative status) can be argued over, since specialized tests cannot be performed in patients in this state, while it is not only a neuropsychologist who monitors the patient but a resuscitationist, a neurologist, a psychiatrist, etc. as well. The author mentioned in the end of the article that as consciousness recovers, beginning from the minimally conscious state + (mut-
ism with speech recognition, according to T.A. Dobrokhotova and O.S. Zaitsev’s classification, when execution of simplest tasks can be performed, early neuropsychological diagnosis becomes feasible. Until that, neither neuropsychological assessment nor diagnosis can be performed. Second, the article title says “...in children”. Nevertheless, all the described clinical assessments of behavior recovery are universal both for children and adults. It would be interesting to know the details of revealing consciousness formation in children, if they are available. Third, the article is actually a theoretical review. The longitudinal study comprising 14 children is briefly mentioned in the end of the article (although referring to the author’s own previous article). However, the main positive dynamics in these children was the regression of passiveness of their mental processes. But this statement should be proved by at least specifying the nature and location of injuries, which strongly determine the observed neuropsychological syndromes. Finally, the article cites the papers by O.M. Grindel; however, we cannot find her name under the mentioned numbers in the References section. Meanwhile, O.M. Grindel et al. reported the electroencephalographic data on later recovery of interhemispheric relations in the frontal areas compared to the other brain areas during consciousness recovery several years earlier than the cited paper by J. Leon-Carrion et al. (2012).

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