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Early neurorehabilitation in a patient with severe traumatic brain injury to the frontal lobes

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: It seems to be generally believed that early neurostimulation after severe TBI is useless or even harmful, and neuropsychological intervention should not be initiated until the patient is medically stable. On the other hand, the unstimulated brain can incur irreversible damage. The purpose of the present study is to assess the impact of early neuropsychological rehabilitation on a patient with an extremely severe TBI.

Case Report: The patient, a 32-year old male, suffered a massive cranio-facial injury with significant loss of tissue in the right frontal lobes after being struck by a tram. Beginning two weeks after injury, after pharmacological coma, he was attended on a daily basis by a neuropsychologist and a neurolinguist, with the active assistance of his family, when he was still in critical condition and essentially without logical contact. By the time he returned to Scotland 4 weeks later, he was sitting up, writing complete, sensible and grammatical sentences, and making rapid progress every day despite the development of hydrocephalus. Over the course of neurorehabilitation, most of MF's cognitive dysfunctions resolved. Six months later, however, hydrocephalus was increasing and the patient was showing severe frontal syndrome. A personalized version of Community Based Rehabilitation was applied. After two weeks of intensive treatment considerable improvement was achieved and frontal syndrome was reduced.

Conclusions: The present case suggests that the prevailing views regarding the inadvisability of early neurorehabilitation in the acute phase after TBI should be reconsidered.

key words: **neurostimulation • frontal syndrome • executive dysfunction • Community-Based Rehabilitation**

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Background

The topic of early neuropsychological stimulation after a severe traumatic brain injury (TBI) has stirred considerable controversy in contemporary medical and neuropsychological literature [1,2]. The first priority in such cases is of course to save the patient's life [3]. The clinical status of such a patient is highly unstable [4], so that the prognosis remains uncertain for several months after the initial injury [5], due to a number of diverse factors, of which the most important are:
– hydrocephalus;
– late developing hematomas;
– inflammation.

The first two authors of the present study have elsewhere pointed out [6] that a pharmacological coma, deliberately induced in order to spare the central nervous system (CNS) for the duration of post-traumatic and post-surgical shock, masks the actual clinical status of the patient, which cannot be determined until sedation is discontinued. Those authors who have discussed the dilemmas this situation poses [7,8] have asked a number of pertinent questions, of which the most important are the following:
– Is any purpose served by neuropsychological intervention during a pharmacological coma? Why stimulate a brain that we have intentionally put to sleep?
– If not immediately, when is the right time to begin rehabilitation after TBI?

The purpose of the present study is to assess the impact of early neuropsychological rehabilitation in the case of a patient who had suffered an extremely severe TBI. The prognosis was not favorable immediately post-injury, but the outcome of neurosurgical treatment was good, and neuropsychological intervention began almost immediately after the patient had been aroused from pharmacological coma. Secondly, we tried to answer the question as to whether the early neuropsychological intervention led to a better outcome than would have been achieved without any such efforts.

Case Report

The patient (initials MF) is a 32-year-old resident of Edinburgh, UK. In August of 2005, he organized for a friend of his a "bachelor's weekend" in Cracow. Late in the evening of 12 August 2005, while crossing a street in downtown Cracow, he was struck by a tram that he had failed to notice (perhaps because he was accustomed to left-sided traffic and looked the wrong way before crossing). He was transported in critical condition to the Neurotraumatology Department at the Jagiellonian University Hospital, which fortunately was not far from the scene of the accident. In the emergency room he was found to have a massive cranio-facial trauma on the right side (with 28 distinct fractures) and a triple compound fracture of the right femur. The wounds were cleaned, debrided and bandaged. The prognosis was extremely poor (Figure 1A,B).

One week after the accident, the decision was made to perform a neurosurgical operation to rebuild the facial aspect of the skull. The patient came through the operation very well, but remained in a pharmacological coma for two weeks (Figure 2).

Diagnosis and Neurorehabilitation

The first neuropsychological and neurolinguistic consultation took place on 1 September 2005. At that point his condition was described as follows:
– eyes open;
– sporadic, uncertain reactions (hand squeezing) on verbal command with a delay of ca. 10 seconds;
– lack of any verbalization (at least partly due to tracheostomy);
– loss of appetite (explicable in terms of avulsion of the olfactory nerves);
– epileptic seizures, controlled with Depakine;
– spastic clenching of the jaws.

The decision was then made to commence intensive neurostimulation, according to the principles of the comprehensive program of neuropsychological rehabilitation developed by the first author of the present study [9–11]. Initially we applied selected elements of this program, consisting in unrelenting efforts to evoke a reaction, using all available sensory channels. This included the following:

– Auditory stimulation: telling the patient about the day-to-day affairs of members of his family; bedside conversation about the weather, sports, British politics (avoiding extremes in vocal timbre, i.e neither too quiet and subdued nor too loud and cheerful); playing of the patient's favorite music over headphones.

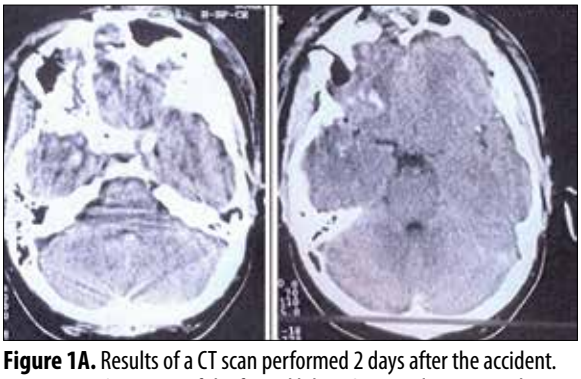

Figure 1A. Results of a CT scan performed 2 days after the accident. Contusion of the frontal lobes. Scattered intracranial air pockets.

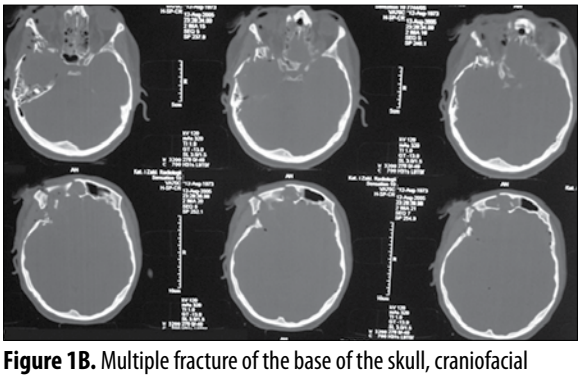

Figure 1B. Multiple fracture of the base of the skull, craniofacial trauma.

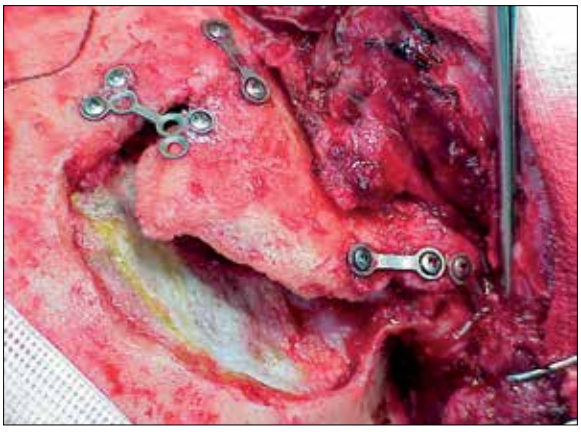

Figure 2. Intraoperative photo: bone fragments stabilized by mini-plates; underneath, dura mater covered with tachosil.

- Tactile stimulation: stroking the skin with a feather; massage with various brushes and devices; writing the names of his closest persons on his forearm with the finger (the family "wrote" endearments in this way); massage of the jaw with ice to release spasticity; "sweep tapping."
- Taste stimulation: searching for flavors that would evoke a reaction (e.g. putting a small piece of chocolate on the patient's tongue, or a few drops of his favorite wine).
- Olfactory stimulation: various fragrances were used (primarily fragrant oils, such as lemon or vanilla), despite the avulsion of the olfactory nerves.
- Visual stimulation: Stimulation with a special blue pen-light; at a later phase, when the patient spontaneously opened his eyes, stimulation with a special white pen-light and various objects (mobiles, hears, bells), waving a colored ball in front of his eyes, from left to right and back again, in order to initiate visual tracking.
- Multi-sensory stimulation: presentation of the patient's favorite objects with naming; in successive weeks, attempts to stimulate the patient to manipulate these objects.

During therapy sessions, breaks were made when the patient fell asleep. It should be emphasized at this point that brief periods of sleep (10–15 minutes) constituted a safety valve of sorts, preventing the patient's brain from excessive stress. As soon as the patient awoke, neurostimulation was renewed.

First week

In early neurorehabilitation sessions minimal reactions were noted (initially squeezing the hand once to signal "yes"; we were unable to induce him to squeeze twice to signal "no" for the first several days). There was some spontaneous effort to repeat movements of the healthy leg that had been performed several times passively. MF tried several times to pull his feeding tube out, and refused to eat; swallowing was impeded by paralysis of the muscles of the larynx. While his teeth were being brushed he opened his mouth when requested (the family reported that he had always been particularly meticulous about oral hygiene). He displayed a distinctly aversive reaction to the music that was being played for him through headphones. Blue light stimulation of the healthy left eye produced a weak reaction: initially only dilation, later blinking and avoidance. During this period MF correctly answered "yes" and "no" with hand squeezes when particular letters were traced with a finger on the skin of his forearm and he was then asked if that was the letter "A". The first few times this exercise was tried, it was observed that in fact he was answering "Yes," i.e. one squeeze, to every question. A few days later, however, he was correctly answering "No" when the letter was different. When he was shown a photograph of his 18-month-old daughter, he grasped it with his fingers and placed it on his lips as though to kiss it. During this period the severely damaged right leg was operated; MF came through this surgery very well.

Second week

MF began to react correctly to verbal commands much more often. The reaction time became much shorter (ca. 1 minute). When a pencil was placed in his hand, MF reacted to a verbal request by drawing a line, a circle, and a man (Figure 3).

During this time he began to read short commands printed in block capitals on a sheet of paper, and fulfilled most of them. For example, he read the command "Please close your eyes" from the MMSE, and closed his eyes. On the 13th day of neurorehabilitation he began to exhibit spontaneous volitional movements of his limbs (both upper limbs and the healthy lower limb), including certain hand gestures which his family recognized as being characteristic for him. MF reacted well to a visit by friends from England. It was during this visit that he grasped a cricket ball they had brought him, giving it the proper grip for bowling. That same day he waved goodbye to his wife and to the therapists. The next day respiratory therapy was commenced, and the first attempts were made to sit him up with the help of a physiotherapist. He first sat up for two minutes, then 3 minutes, then 5 minutes, with half-hour breaks between sessions.

A follow-up CT scan made at this time showed that hydrocephalus was developing (Figure 4).

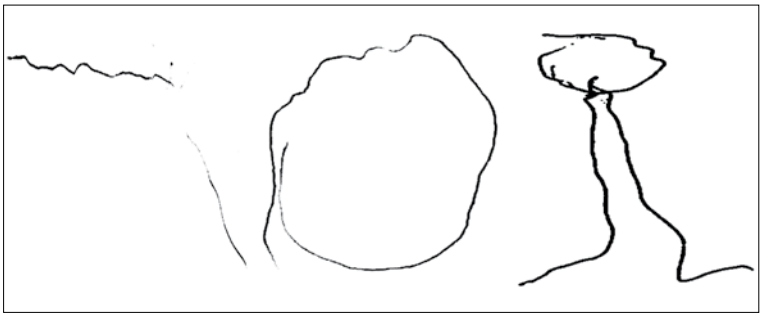

Figure 3. MF's drawings of a line, a circle, and a man.

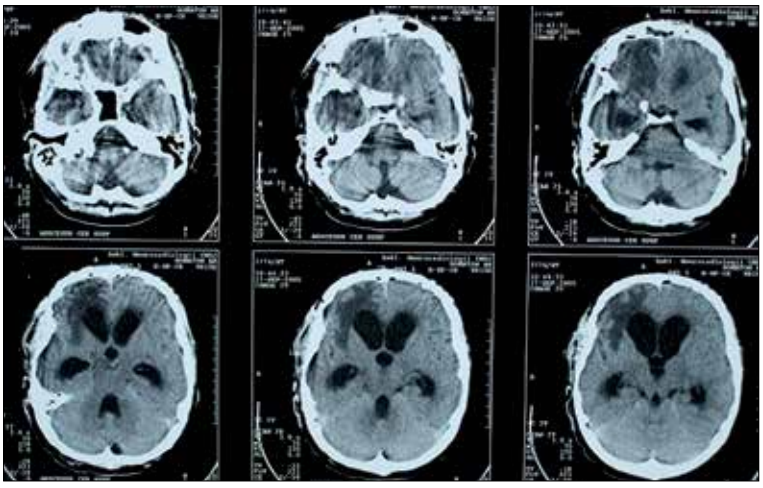

Figure 4. Results from a CT scan of MF's brain, one month after the accident. Dilatation of the lateral ventricles, signs of encephalomalacia of the right frontal lobe.

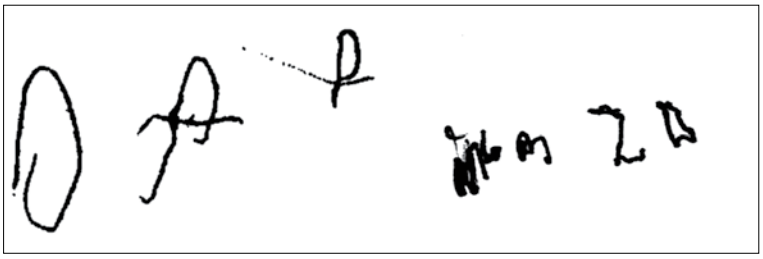

Figure 5. MF's first attempts to write words: "Dad" on the left and his wife's first name (illegible) on the right.

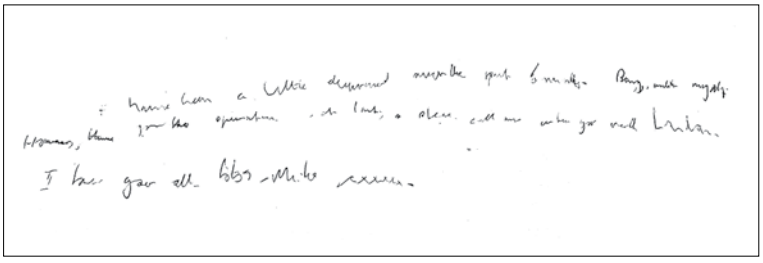

Figure 6. MF's first attempt to write an extended message (see text).

Third week

On the 15th day of neurorehabilitation MF maintained eye contact with the healthy left eye for the first time. He reacted correctly to simple verbal commands, such as giving a handshake to say "Hello." There was still no verbalization of any kind, however, or any attempt to initiate communication. He still did not initiate any independent action at all, nor did he signalize physiological needs. When the physiotherapists was bringing him to a sitting posture he showed signs of trying to sit up himself.

Fourth week

MF was transferred from intensive care to a normal double room. By this time he was showing signs of recognizing family members and the primary members of the therapeutic team, pointing to each as the name was mentioned. He actively assisted while being turned in the bed, and seemed to enjoy sitting in a wheelchair and looking out the window.

On the day before his planned air transport home to Scotland (6 weeks after the accident), MF made his first spontaneous attempt to communicate. Just after breakfast, he took a pen and pad of paper that were lying on his bedside table and began to write single words: first "Dad," then another expression that may have been a pet name for his wife (Figure 5).

On the evening of that same day, he wrote a longer text, which read:

"I have been a little depressed over the last six months. Being not myself. However, thanks for the operation. At last, please call me when you visit London. I love you all lots. Mike xxxxx."

As can be seen, the text shows a considerable disorientation in time; he seems to be aware that he has been ill, but does not know what has actually happened or how long he has been out of touch. The reference to London shows a time break; he and his wife had in fact lived there for several years, but had moved to Edinburgh (MF's home) a few years before the accident. It is not clear whether MF is addressing his family or his therapists (Figure 6).

Despite the establishment of some kind of logical contact, MF was unable to complete any neuropsychological tests

and seemed to be increasingly annoyed at being in the hospital. He was particularly angered by his catheter and had to be watched constantly to keep him from pulling it out. On the day before his departure the catheter was removed.

Family involvement

MF's family and friends were ready and eager to cooperate in his therapy. His wife, parents, and parents-in-law all flew to Cracow immediately after the accident, and with some rotation they all remained with him throughout his stay there; other close friends and family members came for 2–3 days at a time. The family was provided with printed materials covering:
- TBI and its sequelae, with particular attention to the frontal lobes and executive functions;
- certain stimulatory techniques that could be applied by a person without specialized training;
- a journal for recording all observations, especially during periods when the family was present but no therapists were in the room.

Rehabilitation in Edinburgh

After his return to Edinburgh by a specially chartered airplane, MF was admitted to a hospital, and then transferred to a rehabilitation center, where he remained until June 2006. We remained in contact with the family by e-mail in order to provide emotional support, advice, etc. The family, especially MF's wife, confided that they had almost no communication with the doctors now handling MF's case. The only advice they received was that MF should be placed in a nursing home, since he would require constant care and would never be able to resume a normal life. By April of 2006 MF had emerged from post-traumatic amnesia, though he remained highly disoriented in time and place for at least two more months. His wife reported that he did not seem to know who he was, and assumed several fictitious identities. There were many indications of frontal syndrome: impulsiveness, aggressiveness, hyperorality, utilization syndrome, and difficulty in making even simple decisions, e.g. when given a choice of dishes for a meal. When he finally left the rehabilitation center and returned home, these problems made ordinary family life (with two small children, the youngest born while MF was still in post-traumatic amnesia) very difficult. We then asked the family to fill out the Frontal Behavioral Inventory by e-mail. The results confirmed a severe frontal syndrome.

Renewed rehabilitation in Poland

MF's family, especially his wife, expressed frustration at the lack of interest in MF shown by the local health service, which seemed to regard him as a hopeless case, suitable only for institutional care. Accordingly, it was arranged that MF and his wife would return to Poland for rehabilitation. They arrived on 3 October 2006 and left on 24 October, spending the first two weeks of that time with the rehabilitation team in a mountain resort in the south of Poland.

MF insisted that his only real problem was an almost complete lack of energy. In neuropsychological and neurolinguistic examinations, we found disturbances of selectivity of attention and memory (especially working memory), dyspragmatic disturbances, hyperorality and other features of frontal syndrome, and executive dysfunction.

Community-based rehabilitation

Community Based Rehabilitation was applied [9,12,13] with additional elements developed especially for MF. The program was applied by the therapists during the stay in the mountains, with instructions on how to continue working at home.

A strategic plan was first developed for MF's rehabilitation, using concepts and methods that were familiar to MF from his business experience. A considerable part of the therapy was environmental, and consisted of practical exercises in actual social situations (cafes, restaurants, cookouts, etc.). Each day MF went on a walk with one of therapists, with the walks becoming longer and more arduous each day. At the beginning of the two-week therapy he began to complain of fatigue and refused to continue after walking only a few hundred meters; during the next week, however, he was able to make a fairly arduous climb up to a ruined castle.

Art therapy was also applied. MF initially protested that he had no artistic talent, but he enjoyed making humorous drawings and inventing elaborate stories to explain them. Later, he was joined by another severe TBI patient, and discussion with her seemed to give him some insight into his own problems, though he continued to insist that his only problem was fatigue.

Threats

A CT scan made during this second visit in Poland (Figure 7) showed that hydrocephalus was increasing. However, the National Health Service in Edinburgh refused to install a shunt to reveal the intracranial pressure, which would be standard procedure in Poland.

In addition, MF has urological problems caused by the fact that he was kept on a catheter for six months after he returned to Edinburgh (the processing of weaning him from the catheter was just beginning when he left Poland, but the attending physicians in Edinburgh felt that he needed continued catheterization).

MF still has a serious cranial defect on the right side, resulting in disfigurement and complicating the recovery of vision. MF is unwilling to consider reconstructive surgery, which is the cause of considerable tension in the family.

Generally speaking, MF is very resistant to advice of any kind, and will not revise or reconsider a decision once he has made up his mind.

RESULTS

Cognitive functions

Over the course of neurorehabilitation, MF's verbal and non-verbal IQ increased significantly (cf. Table 1). Most of his cognitive dysfunctions also resolved, including immediate and delayed logical and visual recall on the WMS-III (cf. Table 1). His results for maintaining attention on the WMS-III also improved (34/40 points).

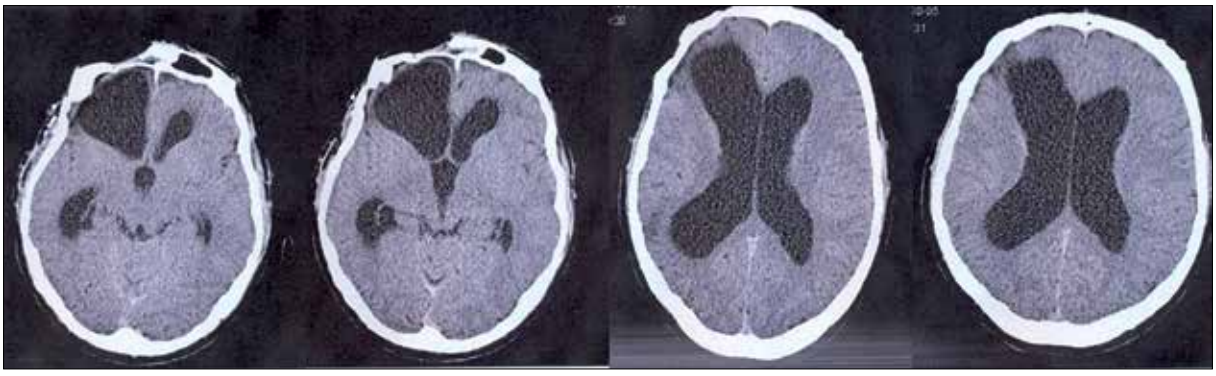

Figure 7. Images from a follow-up CT scan, performed one year later. Dilatation of the ventricles and extension of the right frontal cornu, caused by encephalomalacia of the right frontal lobe.

Table 1. Improvement in MF's cognitive scores over the course of neurorehabilitation.

Parameter	Scale	Exam. 1	Exam. 2	Exam. 3
	WAIS-R			
I.Q. – Full	100	61.5	80.5	94.5
I.Q. – Verbal	100	65.5	86.5	99.5
I.Q. – Nonverbal	100	57.5	74.5	89.5
	WMS – III			
Immediate logical memory	24	5	13	20
Delayed logical memory	24	3	7	18
Immediate visual recall	41	9	21	37
Delayed visual recall	41	4	17	26
Number of confabulations	40	13.7	3.1	0.0
Number of perseverations	40	21.7	7.2	1.2
	MMSE			
Total number of points	30	15.6	21.5	27.9

Table 2. Results obtained by MF in the Clinical Test of Executive Functions – Revised, in terms of qualitative task performance criteria.

Criterion	Examination			
	1	**2**	**3**	**4**
Independence	1.2	1.6	3.0	3.9
Performance time	1.1	1.5	2.3	3.4
Effectivenness	1.2	1.4	2.4	3.7
Priming	1.3	1.6	1.7	3.8

On Wilson's Behavioural Memory Test MF's results also improved in each examination: from 107.5 in the first examination, to 138 in the second and 149 in the third (157 points maximum). By the end of the two-week neurotherapy session, MF was also performing the Wisconsin Card Sorting Test at or above age-corrected norms.

Executive dysfunction

MF's executive functions were measured using the Clinical Test of Executive Functions-Revised [14] (Tables 2, 3).

Table 3. Results obtained by MF in the Clinical Test of Executive Functions – Revised, in terms of the time needed to perform the particular tasks.

Task	Examination			
	1	2	3	4
Making a sandwich	15.5	10.3	7.0	5.3
Pouring ¼ liter of water	14.5	10.0	7.3	4.5
Buying a newsppaer	15.3	11.3	7.3	4.3
Writing a short letter	15.5	9.3	5.0	4.0
Addressing an envelope	14.8	8.8	4.3	4.0
Making a telephone call	14.8	5.5	4.5	4.0
Finding a key	14.5	8.5	4.0	4.0

Characteristics of frontal syndrome

In order to evaluate the qualitative disturbances occurring in MF's behavior, we used the Frontal Behavioral Inventory [15]. This questionnaire consists of 24 questions that can be answered by a layman who has regular contact with the patient (usually a close family member), and has proven to be a sensitive and specific measure of frontal syndrome [16,17]. Each of the questions simply asks whether or not a particular behavior has been occurring or has changed since the injury, with four possible answers:
– No, never (0 points);
– Yes, but only occasionally or slightly (1 point);
– Yes, rather often (2 points);
– Very much so, all the time.

If the person answering the questions is uncertain or does not understand the question, the person administering the inventory can amplify or clarify. The questionnaire itself labels each question with the name of the symptom that the behavior presumably exemplifies, but in our own experience with this test we have found that the labels often confuse the examinee. For example, the first question on the questionnaire reads as follows:

Apathy: Has she/he lost interest in friends or daily activities?

If we read the question exactly as written, the examinee often focuses on the word "apathy," which they may or may not understand, whereas the simple question "Has she/he lost interest in friends or daily activities?" elicits a more concrete answer, which is what the interpretation of the Inventory really requires.

For purposes of analysis the 24 questions can be grouped into four categories:
– impaired social conduct (social inappropriateness, impulsivity, poor judgement and inappropriate jocularity);
– impaired personal conduct (perseverations and obsessive/compulsive behavior, inflexibility, and concreteness);
– mood disorders (irritability, aggression, restlessness);
– control disorders (hyperorality, hypersexuality, utilization syndrome).

In the present study, the authors asked MF's wife to complete the questionnaire 3 times: once 3 months after the accident (exam I), again one year after the accident (exam II), and again immediately after completion of the Community-Based Rehabilitation program (exam III).

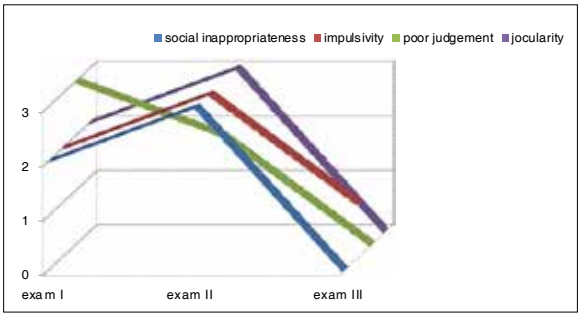

Figure 8. MF's results on the Frontal Behavioral Inventory in the category "Impaired social conduct" over three examinations (see text).

Impaired social conduct

As can be seen in Figure 8, MF showed severe disturbances in this category in the first examination. The second examination showed deterioration in every aspect except for "poor judgement" (which went down from 3 to 2), but in the third examination the scores had fallen to zero in every category except impulsivity.

Impaired personal conduct

MF did not exhibit significant perseverations at any time. His wife reported mild symptoms of obsessive/compulsive behavior and inflexibility in the first examination, which had markedly worsened by the time of the second examination (though evaluation is complicated by the family's observation that a tendency to "fussiness" and "stubbornness" had always been part of MF's character). Inflexibility was noted at the level of "1" in the third examination, a judgment with which the authors would concur: in therapy MF was occasionally difficult to manage precisely when he felt that there had been a departure from what he had expected. Concreteness, on the other hand, was rated very high on the first examination, but steadily declined to zero in the final examination (Figure 9).

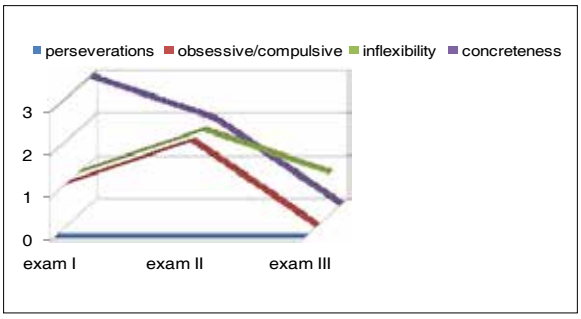

Figure 9. MF's results on the Frontal Behavioral Inventory in the category "Impaired personal conduct" over three examinations (see text).

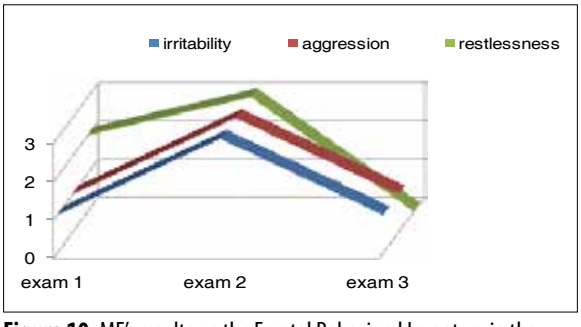

Figure 10. MF's results on the Frontal Behavioral Inventory in the category "Mood disorders" over three examinations (see text).

Mood disorders

The pattern of change in this category is rather similar to the results in the category "impaired social conduct": that is, moderate symptoms in the first examination, much worse symptoms in the second examination, and significant improvement in the third (Figure 10).

Control disorders

In this category, again, MF went from mild to moderate symptoms of hyperorality and utilization behavior in the first examination, to severe symptoms in the second, dropping to zero in the third. Hypersexuality, on the other hand, did not occur; in fact, MF's lack of libido emerged in therapy during Community-Based Rehabilitation as a serious problem (Figure 11).

Discussion

It is tempting to look only at the improvement in MF's test results and proclaim this case a great success – which indeed it is, given the severity of his injuries. There are several reasons, however, to temper this optimism. Some serious problems remain, and there are reasons to wonder if they can actually be solved.

Due to the changes in his brain, it would be advisable for MF to have a shunt installed, but the health care system in the United Kingdom would not allow such an operation. The family would like to have the operation done in Poland, but MF adamantly refuses any form of surgery. The same problem arises in respect to the reconstruction of his skull (his face is seriously disfigured on the right side), and the urological problems. Every discussion about the possibility of treating these problems surgically meets with a categorical refusal even to discuss the options.

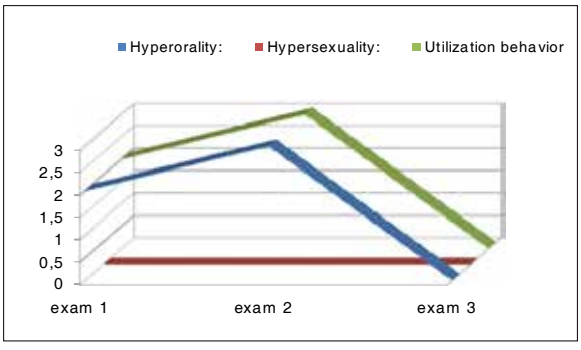

Figure 11. MF's results on the Frontal Behavioral Inventory in the category "Control disorders" over three examinations (see text).

Although MF often seems to be in a good humor, his vegetative symptoms and emotional lability suggest depression, which is common after severe TBI [18,19]. Here again, however, efforts even to address the problem, let alone solve it, are stymied at the outset by the patient's resistance.

It should be stated at this point, however, that MF's attitude is not entirely uncharacteristic of him. To judge from the relations of family and friends, even before the accident MF was strong-willed, reluctant to listen to advice, and inclined to make rapid decisions from which he subsequently would not withdraw. As often occurs, brain damage in this case exacerbated character traits that were already present in some form, and did not add something entirely new to his personality. In his present state of consciousness, however, his ability to temper his reactions to make them more adequate to the situation is compromised by his emotional lability and lack of insight.

Although it is an undisputed fact that recent years have brought tremendous advances in our knowledge of how the brain works, there is a great deal that remains unknown, including problems of considerable theoretical and practical importance. We seem to have nearly mastered those cognitive functions that can be evaluated and analyzed objectively and quantitatively, such as memory or visual perception. Yet there are other brain functions, no less essential, that are much harder to conceive, and thus to examine, in these categories. Among these is consciousness, which from a strictly empirical point of view may seem to be a mere abstraction, a thing of interest to philosophers and poets, but not to scientists. Yet it would be hard to make the case that we understand the human mind if we cannot account for the phenomenon of consciousness. It is possible, of course, to bracket the problem, taking refuge in a sort of mysticism, echoing Hamlet: "There are more things in heaven and earth, Horatio, / Than are dreamt of in your philosophy" (*Hamlet* I.5.919–920). It is equally possible, and rather more common in this day and age, to attempt to reduce what we do not fully comprehend to more manageable elements, or mechanisms, as though assuming that consciousness is

nothing more or less than the sum of all the other cognitive functions. Such an approach makes for easier research, to be sure, but it leaves the essence of the matter untouched.

There are many reasons why the problem of consciousness has proven so difficult to grasp that many researchers seem to prefer to give the whole problem a wide berth. One of these reasons is surely the tendency of modern science to compartmentalization: that is, to break down a complex problem into a series of smaller issues, each of which can be investigated independently. Mental functions are first broken down into two main categories, cognitive and emotional, and then each of these is further analyzed into discrete functions that can be parameterized and then measured using specialized tests. The assumption here is that cognitive functions, associated primarily with the neocortex, and emotional functions, associated with subcortical structures (especially the limbic system) constitute separate domains for theoretical purposes. To be sure, we have long been aware of the inhibitory role of the frontal lobes, and in fact it would be possible to discuss the case of MF as described here strictly in terms of "frontal syndrome," apparently resulting from the loss or disorganization of these inhibitory functions [20–22].

It is also becoming more and more apparent that many cognitive functions, including memory, have both cortical and subcortical components, which can be distinguished from each other. Yet it is precisely the process of distinguishing that creates the conceptual problem, because we know very little about how these "distinct" systems cooperate in the process of storing and recalling information in memory. This layering of memory systems is what distinguishes human memory from computer memory: a computer will "remember" all the data it receives within given parameters of processing, while the human brain best remembers information that bears an emotional load of some kind, quickly forgetting whatever is "boring," i.e. devoid of any such load.

An essential relationship between consciousness and memory was the foundation of Freudian psychoanalysis [23], and despite many current doubts about the Oedipus complex and psychoanalysis in general, the link between a remembered past and present symptoms remains a basic tenet of many psychotherapeutic techniques [24,25]. Serious disturbances of consciousness are often concomitant with disordered consciousness, though it may be difficult to establish whether the former are causes or effects of the latter. But if the starting point for an understanding of consciousness is the subjective feeling of being oneself, the Freudian "ego" that speaks of itself in the first person singular [26], then it is difficult to imagine that such an ego could function in the absence of information about its own past. How can I know who I am if I do not know who I was? [10,27]. It is even possible to define consciousness as the experience of being oneself – which constitutes yet another essential difference between human and computer memory [28]. A computer can "think," if by "thinking" we mean processing information, but it cannot experience itself as a thinking entity; it passively receives and copies all the information that it is asked to copy and is capable of copying, and then processes it, again, within the limits of what it can do and has been told to do. Such tasks the computer can perform even faster and more accurately than the human brain, but it cannot be said to be aware of what it is doing. It remembers information, but does not remember the process of remembering, and it cannot choose to do anything other than what it is instructed to do, whether by the user, or the programmer, or the computer virus resident in its memory. Meta-memory, defined as "remembering that one has remembered," is no part of how a computer operates. Disturbances of meta-memory are also very characteristic for damage to the frontal lobes [29,30].

Another fundamental difference between human and electronic memory is the role of emotion. The hippocampus, part of the limbic system, plays an essential role in determining what is remembered and what is not, which is a major part of the neuronal foundation for the link between the emotional loading of information and the ease with which we remember it and recall it later. Research on the electrophysiology of the brain has shown that information acquired during the day is rehearsed simultaneously in the hippocampus and the cortex, despite the absence of direct neuronal connections between the areas involved, and this rehearsal during sleep is essential to the process of remembering [31–33].

All this seems to indicate clearly that the various memory systems in the brain are of varying significance for consciousness. Although it might appear that autobiographical memory would play the largest role, the case of MF illustrates how important working memory is in this context. It is working memory, in fact, that binds the "atoms" of momentary feeling into "molecules" of experience, and without experience identity and the feeling of being oneself can hardly be thought to exist. This can be seen in the ordinary course of dementia of the Alzheimer's type: the preservation of extensive amounts of autobiographical information from the past cannot preserve the sense of self, when the patient can no longer complete a sentence, because before he finishes it, he does not remember what he has already said, or meant to say. But this is by no means the only problem. A person's life makes sense when at least some of what is happening at a given moment fits into a certain logical structure, such as a chain of cause and effect. Without some such structures, the mind is disoriented, and life is experienced as a random series of unconnected events. Such a state of consciousness, familiar to clinicians who work with various forms of dementia, is equally common (though less often diagnosed) in patients recovering from a severe TBI. The end stage of dementia is a clinical status that would fit perfectly the definition of akinetic mutism, which is the first stage of arousal from coma. In dementia, this end stage is preceded by a profound apathy; in coma patients, akinetic mutism is followed a phase of apathy and psychomotor retardation. In dementia patients, the loss of logical contact with the outside world is preceded by a state of confusion and severe disorientation, which is, again, precisely what we see in severe TBI patients after they begin to be more than sporadically responsive to external stimuli.

In other words (and at the risk of some simplification), the sequence of stages that in dementia leads from confusion to apathy to unconsciousness and finally to death occurs also in these severe TBI patients, but in a reverse order, as the patient emerges from a deep unconsciousness to an apallic syndrome to apathy and sluggishness, and then to confusion and disorientation, before full consciousness

is recovered, given, of course, that this process can be arrested at any stage.

A new way of understanding the nature of this sequence of mental states is provided by microgenetic theory [28,34–39]. According to this theory, every mental state arises as a result of microgeny, which unfolds in a fraction of a second along the developmental course (a particular sequences of phases) that has been established, first by phylogeny, over millions of years, and then by ontogeny, over the lifetime. There are two "quantum leaps" in microgeny (corresponding to equivalent "leaps" in evolution and development): from the midbrain to the forebrain (i.e. from mesencephalon to prosencephalon), and then within the forebrain, from the subcortical nuclei (thalamus, limbic system, basal ganglia) to the neocortex. In behavioral terms, this is a transition from drive, instinct, and conditioned reflex, through affect and mood (i.e. approach and avoidance mechanisms, Freud's "pleasure principle"), to conscious perception and cognition.

In the case of a comatose patient, such as MF at the beginning of treatment, microgeny is complete at the level of the brainstem. The basic physiological functions regulated by the brainstem keep the patient alive, but there is no awareness. Exteroception is essentially "switched off," and introception is working only at a very basic level: there is essentially no discourse between body and conscious mind. This is precisely the rationale for inducing a pharmacological coma: to allow all the energy resources available to the central nervous system to be focused on the life processes of the brainstem. Contact with the world "out there" is only a distraction at this point, but the means used to keep these "distractions" at bay can make it very difficult (sometimes impossible) to reconnect world, body, and mind. Indeed, the loss of cortical tissue and synapses caused first by the injury itself, then by the means used to repair the injury, and finally by the prolonged inactivity of the cortex, can mean that there is much less room, even physically, for mental life to unfold.

The core of what is now sometimes called "the emotional brain" [40] is the limbic system, and the theory would expect this part of the brain to "awaken" from coma first. In the early phases of neurorehabilitation, when MF was still reacting to stimuli only very sporadically and uncertainly, his hand was placed on the abdomen of his wife, who was then in the fifth month of pregnancy with their second child. When the fetus moved under his hand, he visibly stiffened, and then tears appeared in the unbandaged left eye. His first attempts to communicate were directed towards his wife, parents, and in-laws (with whom he had been very close), and the contents of the first sentences he wrote were highly emotional (Figure 6). Still, little sense could be made of what he wrote, and he clearly had no real understanding of where he was or what had happened to him. Even four or five months later, when he was able to converse normally and seemed to realize that he was in the hospital because of a head injury, he slipped in and out of a world of fantasy (e.g. he claimed to be a Spitfire pilot who had been shot down). He remembered later that he had gone to Cracow in August, and now has some recollection of the dinner that preceded his accident, but the accident itself and everything that happened in Cracow and Edinburgh until the spring of the next year has been wiped out of his memory. In neurological terms, the hippocampus was simply not doing its job. Even his earliest preserved recollections from the Edinburgh rehabilitation center have, he reports, something of the misty, unreal quality of a remembered dream. Since in the dreaming state the limbic system is highly active with only limited restraint from the neocortex, this "dream-like" quality can be understood. Only when the working memory system was able to use the mediation of the hippocampus to store the contents of momentary consciousness in some kind of a logical context did MF's mental life begin once more to make sense for him. It was only then that MF could become once again the subject of his own conscious life, and not merely the object of the ministrations of doctors and nurses, or a center of affect unable to change the environmental conditions that are producing the affects.

It would be premature and presumptuous to say at this point that MF has been "cured." The lingering symptoms of frontal syndrome, which he himself does not see, make family life difficult. Nevertheless, the basic levels of microgeny are now functioning normally, from midbrain to forebrain.

Conclusions

In the case described here, early neuropsychological intervention was applied in a patient with a severe injury to the frontal lobes, and played a significant role in his recovery of complete consciousness. There were no undesirable side-effects of early neurostimulation, which began as soon as the coma-inducing drugs were discontinued. This result (which in our practice is not an isolated one) suggests that the prevailing view among clinicians, that these patients should be allowed to sleep through the first months after injury, should be re-examined.

Furthermore, the decision that a patient after a severe TBI is not a candidate for rehabilitation may be a self-fulfilling prophecy. If it becomes an untested axiom that a patient who has been in coma for more than a few days cannot be restored to health, then it stands to reason that no therapy will be provided other than palliative measures. In such a case it is hardly surprising that a follow-up after a year or so finds the patient still dysfunctional and dependent, which serves as "evidence" that the original decision not to invest rehabilitation resources in this patient was a sound one. The claim, of course, is that the opposite assertion – that neuropsychological rehabilitation of severe TBI patients is effective – has never been proven. Though a single case study hardly suffices to prove efficacy, still, the results reported here, at the very least, tempt us to modify a famous quotation about Christianity [41]: "Early neuropsychological rehabilitation has not been tried and found wanting; it has been found difficult and left untried."

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