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NEUROBEHAVIORAL GRAND ROUNDS

Neuropsychological outcome following near-drowning in ice water: Two adult case studies

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Abstract

Two men, 56 and 33 years old, (case 1 and case 2) were examined neuropsychologically after successful resuscitation from circulatory arrest following extreme accidental hypothermia and near drowning. After submersion in ice water for at least 20 minutes they received CPR for 45 to 60 minutes. Body-core temperature at start of CPB was 24°C and 22°C, respectively. A neuropsychological examination was performed within two months after the accident and 1 year later. An additional follow-up interview was made 3 years after the accidents. Both had severe problems with memory, visuospatial performance, executive function, and verbal fluency. The follow-up demonstrated improvement in the visuospatial test in both and in the verbal learning, recall, and logical reasoning tests in case 2. Both still had problems with executive function, and case 2 also in verbal fluency. Case 1 also had problems with flexibility, planning and abstract ability. Despite the protective effects of hypothermia and gradual improvement of symptoms over time, some of the deficits were permanent. A thorough neuropsychological examination of patients suffered from anoxia is advisable, because gross neurological examination and MRI scans may not always reveal underlying brain dysfunction. (*JINS*, 2008, *14*, 660–666.)

Keywords: Accidental hypothermia, Anoxic brain damage, Cognitive, Case study, Sequelae, Magnetic Resonance Imaging.

INTRODUCTION

Hypothermia dramatically increases brain tissue tolerance to ischemia and anoxia (Erecinska et al., 2003; Han et al., 2003), thus making possible cardiac and thoracic surgery during circulatory arrest. The upper limit for recovery from anoxia in normothermic conditions is considered to be 5–7 minutes whereas 12–14 minutes of anoxia almost inevitably leads to brain death (Abramson et al., 1985). Hypothermia under controlled circumstances reduces cerebral metabolic rate and oxygen demand, protecting the brain from anoxia for more than 40 minutes (Wypij et al., 2003). Consequently, accidental hypothermia can be protective in cases of near drowning in cold or ice water. An accidental immersion into cold water affects both CNS and the cardiovascular system (Mallet, 2002). A heart that gradually slows down to profound bradycardia because of hypothermia may still maintain some cerebral circulation. However, several factors may influence the outcome in ice water-submersion accidents (Orlowski, 1988). The accident scenario, which resembles conditions of therapeutic hypothermia, may be beneficial for the outcome. For example, falling into ice water where rapid cooling occurs before the drowning or circulatory arrest may be protective.

Despite a great number of adult case reports documenting good outcomes, most of them do not include an objective neuropsychological examination of the survivors of near drowning (Bierens et al., 2002), which is necessary in order to assess post anoxic higher cortical functions such as memory or executive functions.

This paper presents a study of neuropsychological outcomes in two cases of accidental hypothermia, in order to

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assess short term and long-term neuropsychological effects of near-drowning in ice water.

CASE REPORTS

Case 1

A 56-year-old man, experienced anoxia as a result of nearly drowning in ice water when ice skating on his own in December 2002. Nine months before the accident he had suffered a minor myocardial infarction and a subsequent cardiac bypass surgery. There were no records or complaints of any cognitive deficits after the cardiac surgery. He was in good physical shape at the time of the accident. The patient graduated from high school (12 years of schooling) with average marks and completed then a course for paramedics and firemen. He worked as a fireman and had adult children.

The accident happened when he fell through the ice and could not get out of the water. It is not known for how long he was struggling in the ice water. The rescue team was notified by a person passing by and arrived at the site of the accident in 15 minutes. They found the patient unconscious, submerged under water but still visible under the surface. When he was pulled out of the water he had no pulse, no respiration and his pupils were maximally dilated and not reactive to light. Cardiopulmonary resuscitation (CPR) was started immediately as he was transported to the hospital in an ambulance helicopter. ECG taken in the emergency room showed a ventricular fibrillation. He did not react to pain stimuli (Glasgow Coma Scale 3) and was immediately directed to Thoracic Surgery Department for re-warming using Cardio-Pulmonary Bypass machine (CPB). The initial blood gas analysis revealed an extreme acidosis and hypoxia (pH 6.78, pO2 3.6 kPa, pCO2 14 kPa, BE −21.8). At the start of the CPB the patient had 24°C body-core temperature. Upon reaching 27°C, he spontaneously converted to sinus rhythm. During re-warming, which took 3 hours; his pupils contracted and started to react to light. He also began to cough and react to pain stimuli. His hemodynamics was stable when coming off CPB at 36°C rectal temperature and he was then admitted to the Intensive Care Unit (ICU). He was cooperative directly after re-warming and could be extubated. The clinical interview revealed an anterograde amnesia, which lasted for about 24 hours. He stayed at the ICU for 2 days, and was then moved to the medical ward. He developed pneumonia, with infiltrate in the right lung, and received antibiotics. Laboratory examinations revealed a massive release of cardiac enzymes (S-CKMB 53 μg/L, S-TnT 4.0 μg/L, S-amylase 8.2 μcat/L, S-LD 26 μcat/L, and S-myoglobine 5600 μg/L), which returned to normal in a few days. There were no clinical signs of cardiac, renal, or hepatic failure. The echocardiographic examination showed a good left ventricle (LV) function with ejection fraction (EF) at 60%. The neurological examination revealed paraesthesias in his hands and feet, but was otherwise normal. He was discharged from the hospital 4 days after the accident.

Case 2

A 33-year-old man, experienced anoxia as a result of nearly drowning in ice water when driving on the ice in January 2003. Prior to the accident he had enjoyed good health with no previous neurological deficits and he was in good physical shape. He graduated from high school with marks slightly above average. After school he had worked as a motor mechanic for two years and then started a business of his own. He was single and had no children.

The accident happened when he was driving a motor vehicle with two friends across a lake covered with ice. The ice broke unexpectedly and the vehicle landed in the water. The rescue team was activated by someone who heard screams from the site of accident, and arrived in about 40 minutes. They found the driver unconscious, floating in the water with his face down. The bodies of his two friends were found after several hours by rescue-divers. At the initial examination, the patient had no pulse, was not reactive to pain stimuli (GCS 3) and had maximal dilated pupils with no reaction to light. The rescuers started CPR immediately. ECG was taken during transport to the hospital and showed ventricular fibrillation, alternating with asystolia. Attempts to defibrillate gave no result. When arriving at the emergency room his body core temperature was 22°C. The patient went to surgery for establishing the CPB, which began after about 60 minutes of continuous CPR. He was re-warmed to 36°C in three hours. At 36°C he still had a ventricular fibrillation, and was converted to sinus rhythm by defibrillation. He was hemodynamically unstable, when coming off CPB, and needed an inotrope support with norepinephrine and antiarhythmic treatment using amiodarone. He arrived to the ICU intubated, still at GCS 3, with pupils normal sized and reacting to light. One hour later he started to move his extremities and opened his eyes, however he still was not cooperative and had no respiratory drive. The next day, he started to breathe spontaneously and responded to verbal commands. He was then extubated, and commenced a program for rehabilitation. The clinical interview revealed an obvious anterograde amnesia, which lasted for 24 hours. The X-ray examination showed pneumonic infiltrate bilaterally, and he received antibiotics. Laboratory results revealed a massive enzyme release (S-CKMB 87 μg/L, S-TnT 14 μ g/L, S- myoglobine 7800 μ g/L), which returned to normal after a few days. Echocardiography showed a good LV function with no hypokinetic areas. The release of cardiac enzymes was iatrogenic due to resuscitation attempts. He was moved to the medical ward 2 days later, and discharged from the hospital 7 days after the accident. MRI of the brain was performed 2 months after the accident but showed no signs of anoxic damage. Less than 3 months after the accident he started to work part time.

METHOD

The tests used in the neuropsychological examinations were chosen in order to assess higher cortical functions such as memory, executive, visuospatial and visuoperceptual functions, which are subserved by brain areas particularly sensitive to the anoxia. The self-rated questionnaires were chosen to assess subjective awareness of cognitive problems and symptoms of posttraumatic stress (Horowitz et al., 1979). All standardized tests and questionnaires used in the neuropsychological examinations are presented in Table 1.

Most tests are routinely used internationally. Some tests are mostly known in Scandinavia: story M9 comprised in the Luria Neuropsychological Investigation (Christensen & Stegmann, 1984) consists of five sentences making up a short story. The task is to retell the story after it has been read to the subject. The CD-learning and retention test (Claeson et al., 1971) is a standardized test comprising 10 words which initially are to be learned and recalled within a maximum of 10 repetitions made by the test leader. After 30 minutes the subject is asked to recall all ten words. During this time interval other tests are administered so as to prevent rehearsal of the list. The SRB:2 (the Figure Classification Test) assesses inductive logical reasoning (Dureman et al., 1971). The task is to identify one figure among five that is not constructed according to a principle shared by the other four (max score =30). The Swedish standardized S-a word fluency test (Dureman et al., 1971) requires the subject to write as many words as possible beginning with an "S" and ending with an "a" during three minutes. All obtained test scores were judged against reference values of non-brain injured peers (i.e., matched for sex, age and number of schooling years). The neuropsychological examinations were administered twice for each patient, the first within 2 months after the accident and the second occurred about $1\frac{1}{2}$ year after the accident. A follow-up interview was made 3 years after the accident where the self-rated questionnaires used previously were readministered.

Table 1. The neuropsychological tests and questionnaires

Memory and Attention
Auditory short-term- and working memory: Digit span; WAIS-R (Wechsler, 1981; Lezak et al., 2004)
Auditory verbal memory, recall of story: Story M 9; Lurias neuropsych. invest. (Christensen & Stegmann, 1984)
Auditory verbal learning, 10-word list: C-D learning test, (Claeson et al., 1971)
Verbal memory, recall of 10-word list after 30 minutes: C-D learning test
Visual memory, recall of complex figure after 30 minutes: RCFT (Lezak et al., 2004)
Visual memory, recall of 9 symbols after 3 minutes: Digit symbols; WAIS-R
Visuospatial, visuoperceptual, and visuomotor ability
Visuospatial ability and speed: Block design; WAIS-R
Visuospatial/graphomotor ability: RCFT
Visuospatial/graphomotor speed: RCFT
Speed, attention, and accuracy: Digit symbols; WAIS-R
Speed, attention, and accuracy: Trail Making Test; TMT A (Reitan, 1956; Lezak et al., 2004)
Speed, flexibility, divided attention, and accuracy in a visual task: Trail Making Test; TMT B
Executive and abstract ability
Logical reasoning in a visual task: SRB:2; D-S-battery (Dureman et al., 1971)
Word fluency/number of words in 3 minutes: FAS (Lezak et al., 2004)
Word fluency/number of words in 3 minutes: S-a; D-S-battery
Verbal abstract ability: Similarities; WAIS-R
Cognitive flexibility and reasoning in a visual categorizing task: WCST (Lezak et al., 2004)
Accuracy and speed in a visual planning task: Zoo Map Test; BADS (Alderman et al., 1996)
Current subjective cognitive problems in daily life
Cognitive Failures Questionnaire; CFQ (Broadbent et al., 1982)
Current subjective distress for any specific traumatic event
Impact of Event Scale; IES:15 (Horowitz et al., 1979)

MRI scans were obtained using GE 1,5 Tesla camera. T1 and T2 weighted spin-echo and FLAIR sequences. Thin slices (3 mm) were used to study the hippocampal area.

All data included in this manuscript was obtained in compliance with regulations of our institutions and with the Helsinki Declaration.

RESULTS

Case 1

The patient's wife accompanied him and stayed for a short interview before the testing procedure. She reported that the patient recognized her immediately when he regained consciousness but still behaved inadequately, e.g. he constantly repeated everything that was said to him. The patient's last memory before the blackout was falling into the water and trying to get up on the ice. During the examination the patient was cooperative, talkative, and quite eager so he had to be stopped several times since he started before test instructions were given. He denied having any posttraumatic stress symptoms but admitted he felt like crying when the accident was mentioned.

The first neuropsychological examination was performed 4 days after the accident. As seen in Table 2, his results on the memory tests were all below average relative to the norm for his age group (−2 SD) He also had impairments in visuospatial, visuoperceptual and visuomotor performance. He had some difficulties in the word fluency tests, mainly because of frequent perseverations and he was unable to do the executive planning test where he broke the rules on several occasions.

The follow-up examination was performed about 1 year after the accident and demonstrated that all the memory functions had not changed from the first examination as shown in Table 2. He had improved his visuospatial performance from −2 SD to almost normal level for his age group. He had also improved on word fluency (writing) and visuomotor speed. This time he was also tested for visual mem-

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Table 2. Test results from neuropsychological examinations after near drowning accidents

Tests of neuropsychological functions:	First examination four days after accident (Case 1)	Follow-up examination 1.5 years after accident (Case 1)	First examination 2 months after accident (Case 2)	Follow-up examination 1.5 years after accident (Case 2)
Memory and attention				
Luria Story M 9 (recall)	unable	unable	unable	able
C-D learning test (learning)	T = 29	T = 29	T = 29	T = 53
C-D learning test (recall)	T = 36	T = 41	T = 27	T = 44
RCFT (recall)	—	T = 42	—	T = 37
Digit Symbols (recall)	3/9	4/9	5/9	—
Digit span	3 WP	3 WP	10 WP	9 WP
max. no of forward digits	4/9	4/9	7/9	7/9
max. no of backwards digits	3/8	4/8	4/8	4/8
Visuospatial, visuoperceptual and visuomotor ability				
Block design	3 WP	8 WP	5 WP	9 WP
RCFT (copy accuracy)	—	T = 38	—	T = 51
RCFT (copy time)	—	65 Perc.	—	10 Perc.
Digit Symbols	10 WP	12 WP	6 WP	7 WP
TMT A	T = 55	T = 48	T = 41	T = 39
TMT B	T = 20	T = 20	T = 20	T = 20
Executive and abstract ability				
SRB:2	T = 56	T = 56	T = 36	T = 48
FAS	8 Perc.	—	22 Perc.	11 Perc.
S-a	Sta. 4	Sta. 6	Sta. 1	—
Similarities	—	6 WP	—	—
WCST	—	—	T = 56	—
Zoo Map Test	unable	—	able	—

Test performance is compared to controls from the same age group and educational level.
10 WP (weighted points) is the mean (M) on a 19 degree scale, 7 WP is 1 standard deviation (SD) below the mean and 4 WP is 2 SD below the mean for the age group. Other standardized tests are in T-scores (M = 50), stanines (M = 5) or in Percentiles (M = 50).

ory and abstract ability where his results were more than 1 SD below average. In addition, he showed no improvement in visuomotor ability as shown in TMT B, and was still impaired on verbal fluency.

A qualitative evaluation of his performance in the copy-task indicated that he had executive difficulties demonstrated as problems in planning, cognitive accuracy and evaluation. Executive difficulties were also seen in one of the visual scanning tests as difficulties with cognitive flexibility and several perseverative errors. He was still quite eager and started some of the tests before instructions were given. He had not returned to work after the accident and was now on early retirement. Subjectively, he experienced memory problems, word finding difficulties, restlessness and mood alterations. His score on the CFQ, a self inventory of subjective cognitive problems in daily life (the higher the score the more subjective cognitive problems), was relatively low (28/100) which is in contrast to his low performance on many of the objective measurements.

A brief follow-up interview was made 3 years after the accident. An MRI of the brain was also administered and showed no signs of anoxic damage (Fig. 1).

He was asked to fill in the self-rating questionnaires (CFQ and IES). This time he reported that his memory had probably become a little worse according to his wife. He tried to compensate for this by using a calendar, shopping lists, and taking notes. His CFQ-score was almost the same as 2 years ago (33 *vs*. 28/100) indicating some subjective cognitive difficulties in daily life. He still experienced restlessness and mood alterations. He was more vulnerable to stress. Physically he was in very good shape and was more active and felt more energetic than 2 years previously. His score on the Impact of Event Scale (IES) was very low (7/75) indicating no signs of post traumatic stress. He was enjoying social life with his family as well as hunting, fishing, and taking long walks on his own. He did not think of the accident very often.

Case 2

The patient was referred to a rehabilitation unit about one month after the accident. Three months later the patient required aid of rehabilitation psychologist, because of sleeping problems, nightmares, depressed mood, and frequent

Fig. 1. Brain MRI, saggital view through the left hippocampal area (case 1). 1,5 Tesla magnetic coil, 3 mm slice. The image shows no signs of hippocampal atrophy or signal abnormalities within the basal ganglia, which are characteristic changes associated with anoxic brain injury.

recalling of the accident. Crises intervention with the psychologist was started a few weeks later. The antidepressants (SSRI) were offered to the patient, but he refused. Five months after the accident he was working full time. He met with the psychologist for 10 sessions and could end the crises intervention one year after the accident.

The first neuropsychological examination was performed two months after the accident. He scored 2 SD below average on the verbal learning and recall tests as shown in Table 2. He also had difficulties with visuospatial performance and scored at 1 SD below average compared to his age group. He also had problems with visual scanning when cognitive flexibility and divided attention were required and performed at 2 SD below average. In other tests of visual scanning and visuomotor speed, which are less demanding cognitively, he performed at about 1 SD below average. He had some problems with the word-fluency tests performing at 1 to 2 SD below average. The result on the logical reasoning test was 1 SD below average, because he was only able to answer half of the questions within the time limit. Psychologically he appeared quite affected by the death of his two friends and his score on IES, (30/75) indicated some risk of post traumatic stress disorder (PTSD). He had noticed that he was more irritated, emotional, short tempered, and vulnerable to stress than before. Also he had subjective complaints about, memory, mood alterations, and sleeping problems. His score on CFQ was 36/100 indicating some subjective cognitive difficulties in daily life.

The follow-up examination was performed about 1 year after the accident and showed that his verbal memory functions had improved considerably. Thus, as presented in Table 2, his verbal learning score had improved 2 SD and was now at an average level in comparison to his age group and his verbal recall had also improved to an average level. His performance in visual memory was more than 1 SD below average. He had difficulties in visual scanning, which requires cognitive flexibility and divided attention. He had improved his visuospatial performance more than 1 SD and was performing just a little slower than average. His performance on the logical reasoning test had improved 2 SD back to the normal range. A slight improvement in visuomotor speed was also seen but there was no improvement in word fluency, where his performance was even lower than at the first testing and far below average.

The qualitative evaluation of the test results showed that he had problems with visuospatial performance. He had difficulties with complex patterns and was very slow on the copy task. He also experienced himself being slower in cognitive demanding activities where he had to put in much more effort than before the accident. His score on the CFQ, (57/100) was considerably higher than at the first examination, even though his verbal memory functions had improved. His own explanation was that he was more aware of his memory problems this time and more vulnerable to stress. He had improved emotionally and reported no posttraumatic stress symptoms as evidenced from his lower IES score (16 *vs*. 30/75). He had been working full time in his firm for more than a year and had resumed most of his physical activities.

A brief follow-up interview was made 3 years after the accident. He was also asked to fill in the self rating questionnaires (CFQ and IES). His memory problems were more or less the same as at the follow-up examination two years ago and he still had to use a lot of compensatory strategies, like a planning calendar, taking memory notes and using his mobile phone as a reminder. He also reported that he was slower and more vulnerable to stress than before the accident. In order to function at work he had to spend more time on planning and preparing himself. His score on the CFQ was almost the same as two years ago (61 *vs*. 57/100) indicating that he still experienced a high degree of cognitive problems in his daily life. The IES score was exactly the same (16/75), which implies that he had no post traumatic stress symptoms. Occasionally he had sleeping problems, which he never had had before. He was now working more than 40 hours a week but felt he could manage although he had to put in much more time and effort than before the accident. He was in good shape physically and enjoyed the social life with his friends and girlfriend.

DISCUSSION

This paper provides data on neuropsychological outcome in two adult patients after accidental hypothermia and circulatory arrest. The majority of previous outcome studies of near drowning focus primarily on gross neurological status of the victim (Bierens et al., 2002; Suominen et al., 2002). However, patients with seemingly complete neurologic recovery can still suffer from profound long term cognitive deficits, as shown in a pediatric study by Hughes (Hughes et al., 2002). Unfortunately, there is limited data on neuropsychological outcome in adults after near drowning in ice water (Huckabee et al., 1996), but since the plasticity of brain declines with age (Bergado & Almaguer, 2002), one can assume even more profound deficits following the anoxic brain injury in adults.

Other anoxic conditions as cardiac arrest and carbon monoxide poisoning are relatively well studied (Wilson et al., 2003; Hopkins & Haaland, 2004; Green & Howes, 2005), demonstrating common memory, executive, visuospatial, and visuoperceptual difficulties. Interestingly, the patterns of cognitive deficits vary between the cases (Wilson et al., 2003).

In the present study both cases had severe problems with memory, visuospatial performance, executive function, and verbal fluency. The follow-up demonstrated improvement in the visuospatial test in both cases; and in the verbal learning, recall, and logical reasoning tests in Case 2. Both still had problems with divided attention, executive function, and verbal fluency. Case 1 had problems with flexibility, planning, and abstract ability. Case 2 also had considerable difficulties in the word fluency test. Taken together, the neuropsychological deficits in both cases were essentially similar in character but more subtle in Case 2, who developed a variety of compensatory strategies. It is likely that Case 2 showed more improvement over time because of his younger age and more active life style.

The observed difficulties in immediate and/or working memory in both our cases corroborates well with what could be expected in post anoxic patients, because the most vulnerable cortical areas are prefrontal cortex and posterior association cortex, along with subcortical structures as globus pallidus, striatum, and hippocampus in the limbic system (Lishman, 1987). The ischemic damage of hippocampal area is associated with anterograde amnesia and/or deficits in new learning abilities in both humans and animals (Zola-Morgan & Squire, 1986). Working memory is central for attention and concentration, and is associated with prefrontal cortical areas. Damage to these areas could probably result in working memory deficits, combined with other signs of executive problems such as dysfunction in organization and planning (Barkley et al., 1992; Manes et al., 2002).

Undertaking this study, we aimed to find possible differences in patterns of neuropsychological deficits between normothermic *versus* hypothermic anoxia cases. This would allow us to draw conclusions regarding which of brain structures benefit most from hypothermic protection. However, the two anoxic cases in the present study showed similar impairments in memory, attention and executive functions as did anoxic patients without hypothermia (Hopkins et al., 1995; Manns et al., 2003).

Both cases in the present study were examined with MRI (Fig. 1). Neither of them showed any signs of anoxic damage, but MRI is not always sensitive enough to reveal the minor neurologic damage. In the longitudinal study by Hughes (Hughes et al., 2002), MRI did not provide marked evidence of structural changes, whereas neuropsychological examinations repeatedly identified areas of significant functional deficits. Possibly, the anoxic damage could be seen on MRI performed sooner after the accident or using a MR-camera with stronger magnetic field (3 Tesla).

This study, presenting thorough neuropsychological examination of two adult patients with accidental hypothermia and prolonged cardiac arrest, is rather unique. However, there are limitations: comparison to the previous studies of anoxia is difficult, because of variations in patients' age, sex, and education. We evaluated the results using normative data, not controls. Furthermore, the differences in time of evaluation relative to anoxic episode may influence the data. We acknowledge that scientific rigor in terms of controlled conditions is lacking in the present study. However, these authentic and unique cases may serve as a source of ideas and hypotheses about cognitive performance in patients who have suffered from anoxia with or without hypothermia.

We conclude that:

1. Hypothermia may preserve life.
2. Accidental hypothermia may provide some degree of neural protection, but more studies that compare anoxic patients or animals with and without hypothermia are needed.
3. A thorough neuropsychological examination of patients suffered from anoxia is advisable since gross neurological examination and MRI scans may not always reveal underlying brain dysfunction.

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