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RESEARCH ARTICLE

Characteristics of Cognitive Function in Patients After Traumatic Brain Injury Assessed by Visual and Auditory Event–Related Potentials

ABSTRACT

Doi R, Morita K, Shigemori M, Tokutomi T, Maeda H: Characteristics of cognitive function in patients after traumatic brain injury assessed by visual and auditory event–related potentials. Am J Phys Med Rehabil 2007;86:641–649.

Objective: Using auditory and visual stimuli including facial affective stimuli, we analyzed the P300 components of event-related potentials (ERPs) in patients after traumatic brain injury (TBI) to assess their cognitive characteristics.

Design: Twenty TBI patients and 32 age-matched control subjects were recruited. Using conventional oddball paradigms, visual ERPs were recorded using images of crying and smiling babies as visual stimuli. Auditory ERPs were obtained using 2-kHz tones as stimuli without affective stimuli. The peak amplitude and latency for P300, and the latency for N200, were recorded.

Results: In visual ERPs, the P300 amplitudes were significantly smaller in patients than in controls for the crying baby, but the amplitudes were similar between groups for the smiling baby. Controls showed smaller P300 amplitudes for the smiling baby than for the crying baby, but patients showed no difference. In patients, the P300 latency for both smiling and crying babies was longer than in the controls. Patients' auditory ERPs showed smaller P300 amplitudes but similar P300 latencies compared with controls. The N200 latency in patients was significantly longer than in controls only for the crying baby.

Conclusions: Visual ERPs are a potentially useful marker for evaluating cognitive dysfunction in patients after TBI.

Key Words: Traumatic Brain Injury, Event-Related Potentials, Visual and Auditory Stimuli, Facial Affect

Event-related potentials (ERPs) have been investigated as a biological marker of information processing by the human central nervous system.[1–5] As pointed out by Polich,[3,4] adherence to standard paradigms, such as the oddball paradigm, is necessary for meaningful comparisons between studies, because differences in stimulus presentation alter ERP components. ERP amplitudes vary widely, depending on the complexity of the task and the arousal and emotional states of subjects.[3,4] Many studies of emotional influences have been reported, and the significant effects of viewing facial expressions on ERPs are known.[6–9]

Measurement of the amplitudes of ERPs in patients after brain injury has been suggested as a useful complementary analysis to neuropsychological assessment.[10,11] Several ERP studies in patients with cognitive dysfunction after brain injury have been reported, but some characteristics remain unknown. Muller et al.[12] report that patients who had sustained traumatic brain injury (TBI) showed a significantly longer latency for the auditory P300 than did healthy subjects. A visual oddball paradigm showed a smaller P300 amplitude and prolonged P300 latency in patients after TBI.[10,13,14] These authors suggest that the abnormalities reflect cognitive impairment in the patients. Sangal et al.[15] report that head injury patients with mild cognitive complaints but no abnormal neurological findings or psychiatric disorders had prolonged P300 latencies in response to visual but not auditory stimuli. Furthermore, Werner and Vanderzant[16] also report a normal auditory P300 in most patients with mild closed-head injury.

On the other hand, P300 of such patients showed both a longer latency and reduced amplitude in visual and auditory oddball paradigms.[10,13,14] The results indicate that processing of visual and auditory stimuli, including perception and discrimination of stimulus features, and evaluation and categorization of stimuli, might be impaired after TBI. Clarification of the significance of ERP-modality differences such as visual *vs.* auditory stimuli may be important for the accurate evaluation of patients after TBI.

Some patients with TBI have been shown to manifest a significant deficit in the ability to correctly identify emotions associated with facial expressions.[17] Such patients show a distinctive emotional inappropriateness, to which an impaired ability to identify facial expressions might contribute. Up to now, few studies have compared the effects of facial affective recognition on ERPs between controls and patients with TBI. These patterns of facial expression effects might shed light on the mechanism of cognitive impairment in TBI.

We have reported previously that neutral stimuli caused ERPs similar to those caused by negative facial affective stimuli such as anger or crying.[8] The present study was conducted to characterize cognitive dysfunction in patients after TBI, according to ERPs obtained with neutral auditory or affective visual stimuli, particularly concerning the effects of facial expressions on ERPs in patients compared with control subjects.

SUBJECTS AND METHODS

Subjects

The subjects included 20 patients who had sustained TBI (35.1 ± 11.8; 14 men and 6 women), who ranged in age from 20 to 55 yrs (mean, 33.3 ± 11.8), and 32 healthy volunteers (16 men and 16 women), who ranged in age from 20 to 54 yrs (mean, 33.5 ± 9.5). No significant age differences were noted between these groups. All subjects were right-handed and had no historical evidence of psychiatric illness. All patients were free from focal neurological or physical deficits such as motorpalsies and speech disturbance (Table 1). No subjects had any history of alcoholism or drug abuse. No patients or control subjects had visual disabilities, and all subjects could recognize the images presented on photographs used for visual ERP analysis. Written informed consent was obtained from all subjects before the study.

Electroencephalographic Recording

Each subject sat in a sound-attenuated, electrically shielded room and was asked to relax with their eyes open. Subjects were requested to try not to blink during the test. ERPs were recorded from

TABLE 1 Characteristics of patients (n = 20)

Age, yrs (range)	35.1 ± 11.8 (20–55)
Male:female (n)	14:6
Time to event-related potential from injury, mos	25.68 ± 8.87
Mechanism	
Traffic	13
Fall	4
Other	3
Intracranial diagnosis*	
Diffuse brain injury	16
Evacuated mass lesion	4
Post-resuscitation GCS	
Mean	11.85 ± 2.80
13–15	12
9–12	6
≦8	2
GOS	
Good recovery	18
Moderate disability	2

* TCDB computed tomography classification for intracranial diagnosis.

GCS, Glasgow coma scale; GOS, Glasgow outcome scale (6 mos after injury).

Ag/AgCl electrodes at Fz, Cz, Pz, Oz, T3, and T4 positions, as designated by the international 10–20 system, with reference electrodes at the mastoids. A forehead electrode served as the ground. The electroencephalographic signal was amplified and processed with filters that passed a band from 0.5 to 50 Hz and was then recorded conventionally (NeurofaxΣ, Nihon-Kohden; Tokyo, Japan) for examination of the continuous electroencephalographic.[18–19] The impedance was maintained below 5 KΩ. An averaged waveform was obtained from 20 artifact-free epochs associated with individual target stimuli for each type of tone or image during one block of stimulus presentation, as proposed by Polich.[3] One block was presented to each subject as the first session. Vertical electrooculogram was recorded from electrodes positioned above the left eye. Trials exceeding 50 μV in amplitude were automatically excluded from the averaging process. The sampling rate was 256 Hz. The P300 latency was estimated from the peak amplitude beginning at stimulus initiation.[20] Sampling was initiated 100 msecs before stimulus onset and continued for 1 sec. The averaged value before the stimulus was used as the baseline value.[18–20]

In auditory ERPs, tone frequencies of target stimuli were 2000 Hz (probability of presentation, 20%), and those of no target stimuli were 1000 Hz (probability, 80%) without affective stimuli. All subjects were asked to maintain their gaze within a circle on a 1.5-m square panel, positioned 1 m away at eye level. Both stimulus types were presented at an appropriate intensity (sound presentation at 70 dB). Tone duration was 100 msecs, with a 10-msec rise time. Tones were presented in a random sequence at a mean rate of 1700 msecs. The P300 latency was estimated from the latency of the largest positive peak occurring between 250 and 500 msecs. The P300 amplitude was calculated from the baseline to the peak of positive waveforms appearing between 250 and 500 msecs.[19,20] The N200 latency was determined as the latency of the largest negative peak between 150 and 250 msecs.

In visual ERPs, the probability of presentation of target stimuli was 20% (photographs of smiling or crying), and the probability was 80% for no target stimuli (baby neither smiling nor crying: neutrality). Stimulus duration was 250 msecs. Images were presented in random sequence at a mean rate of 1700 msecs. All subjects were asked to look at the baby's face on a television monitor positioned 0.5 m away. Two blocks (smiling and crying) presented to each subject in a balanced manner constituted one session. The P300 latency was determined as the latency of the largest positive peak between 300 and 600 msecs.[8,20] The P300 amplitude was calculated from the baseline to the peak of the largest positive waveform between 300 and 600 msecs.

The N200 latency was determined as the latency of the largest negative peak between 200 and 300 msecs.

Protocol for Recording ERPs and Evaluating Facial Expression

ERP recording sessions took place from 2:00 to 4:00 p.m. Auditory ERPs were recorded first, in about 30 mins. Then, visual ERPs were obtained in about 1 hr. For visual ERPs, sessions included the presentation of two photographs (smiling or crying) during double-task performance to maintain attention and arousal (counting and pressing a button on seeing target stimuli).[8,19] After completing a session, subjects were asked to look closely at each of the two target stimuli presented (smiling or crying) to evaluate the affect associated with the facial expression. All healthy controls and patients responded as expected with respect to expression in the two photographs: smiling was associated with pleasure, whereas crying was associated with sadness.

Statistical Analysis

ERP data were examined using two-way analysis of variance (ANOVA; groups $\times$ electrodes: Fz, Cz, and Pz) in auditory ERPs for the main group effects, and for each emotion (crying or smiling) in visual ERPs for the main group effects. In visual ERPs, three-way ANOVA (groups $\times$ face types $\times$ electrodes) was also done. G–G epsilon was used to measure the extent to which the correlation of the observations violated the validity of the P values. The uncorrected differences were used in reporting the ANOVA outcomes.

Next, if an interaction was obtained, one-way ANOVA was performed (between controls and patients) to assess the main group effect for each electrode site including Oz, T3, and T4. Tukey–Kramer analysis, carried out post hoc, was used to test for significant differences. A probability of $<5\%$ was considered significant. Pearson's correlation coefficient was used to identify significant relationships between the duration of illness or symptom scores and measures of ERPs. A level of $P < 0.05$ was accepted as significant. Values are presented in the text as means $\pm$ standard deviation.

RESULTS

Auditory ERPs

P300 Peak Amplitude

Significant main effects for groups were seen using two-way ANOVA ($F_{2191} = 20.20$, $P < 0.0001$; Fig. 1B, upper panel) The peak amplitude was larger for controls than that for patients ($P <$

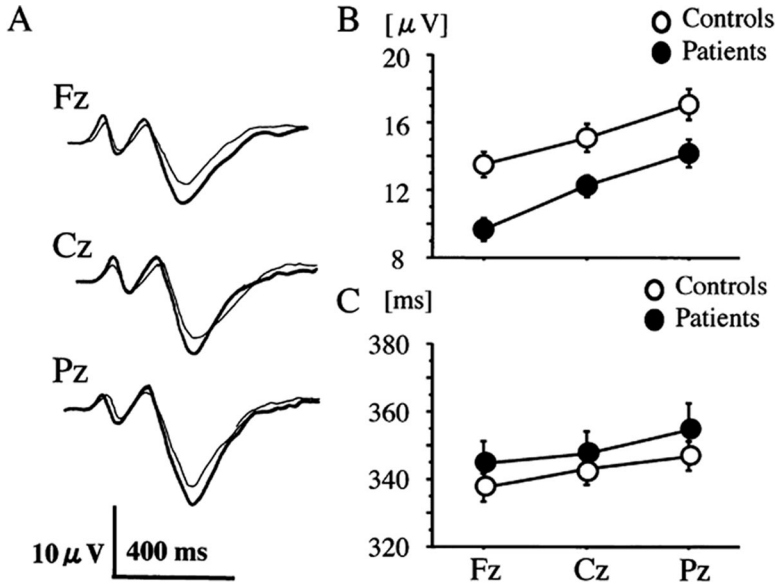

FIGURE 1 *Grand-averaged waveforms (*A*) and mean amplitudes (*B, upper panel*) and latency (*B, lower panel*) for the auditory P300. ○, controls; ●, patients.* Bars *indicate the standard error (SE).*

0.0001). There was no interaction between groups and recording sites. The peak amplitude for controls was larger than for patients at Fz ($F = 11.8$, $P < 0.01$), Cz ($F = 5.93$, $P < 0.05$), and Pz ($F = 4.35$, $P < 0.05$). The peak amplitude for controls was significantly larger than for patients at T3 ($F = 11.26$, $P < 0.01$) and T4 ($F = 6.08$, $P < 0.05$).

P300 Latency

Significant main effects for groups were not seen using two-way ANOVA (Fig. 1B, lower panel) . There was no interaction between groups and recording sites. The latency for controls was similar to that for patients. No significant difference for latency was observed between controls and patients at Oz, T3, and T4 recording sites.

N200 Peak Amplitude

Significant main effects for group were not seen using two-way ANOVA. There was no interaction between groups and recording sites. The peak amplitude for controls was similar to that for patients in all recording sites.

N200 Latency

Significant main effects for group were not seen using two-way ANOVA. There was no interaction between groups and recording sites. The latency for controls was similar to that for patients in all recording sites.

Reaction Time

Controls (374.3 ± 94.3 msecs) had significantly shorter reaction times than patients (542.7 ± 175.3; $F_{1191} = 33.03$, $P < 0.0001$). There was no significant correlation between the reaction time and P300 and N200 amplitude and latency, respectively.

Accuracy of Counting and Tone Assessment

Both counting and button-pressing accuracy exceeded 90% for all subjects. No significant difference was evident between controls and patients.

Visual ERPs

P300 Peak Amplitude

Significant main effects for group were seen using three-way ANOVA ($F_{2382} = 9.46$, $P < 0.01$; Figs. 2 and 3). The peak amplitude for controls was larger than that for patients. The peak amplitude for the crying stimulus was larger than that for the smiling stimulus. A significant interaction was observed between groups and face type ($P < 0.01$). Significant main effects for group were seen using two-way ANOVA for the crying stimulus ($F_{2191} = 16.39$, $P < 0.0001$) and for the smiling stimulus ($F_{2191} = 0.04$, $P = 0.831$). The peak amplitude for the crying baby was larger for controls than for patients. There was no interaction between groups and recording sites. The peak amplitude for patients was significantly smaller than for controls at Fz ($F = 5.29$, $P < 0.05$), Cz ($F = 4.09$, $P < 0.05$), and Pz ($F = 7.69$, $P < 0.01$), only using the crying stimulus. While viewing the crying baby, the P300 amplitudes for healthy controls were not significantly different from those of patients. The peak amplitude for controls was significantly larger than for patients at Oz ($F = 6.22$, $P < 0.05$) and T3 ($F = 12.60$, $P < 0.001$). In healthy controls, the amplitude while viewing the crying baby was signifi-

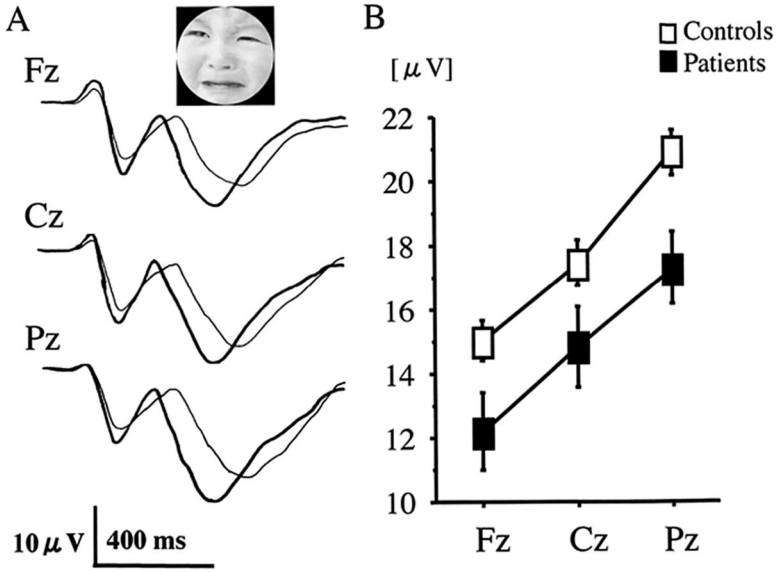

FIGURE 2 *Grand-averaged waveforms (*A*) and mean amplitude of visual P300 (*B*) when viewing the crying baby. ○, controls; ●, patients. Significant difference was observed between patients and controls.* Bars *indicate the standard error (SE).*

cantly larger than while viewing the smiling baby ($F_{1269} = 48.53$, $P < 0.0001$). Significant differences were obtained from all recording sites (Fz: $F = 10.25$, $P < 0.001$; Cz: $F = 17.22$, $P < 0.0001$; Pz: $F = 22.03$, $P < 0.0001$). However, in patients, the amplitude while viewing the crying baby was similar to that observed while viewing the smiling baby.

P300 Latency

Significant main effects for group were seen using three-way ANOVA ($F_{2382} = 104.6$, $P < 0.0001$; Fig. 4). The latency for controls was shorter than that for patients. Significant main effects for group were seen using two-way ANOVA for the crying stimulus ($F_{2191} = 86.68$, $P < 0.0001$) and for the smiling stimulus ($F_{2191} = 30.03$, $P < 0.0001$). The latency when viewing the crying baby was shorter for controls than for patients. There was no interaction between groups and recording sites. The latency for patients was significantly longer than for controls at Fz ($F = 27.95$, $P < 0.0001$), Cz ($F = 31.81$, $P < 0.0001$), and Pz ($F = 27.58$, $P < 0.0001$) for the crying stimulus and at

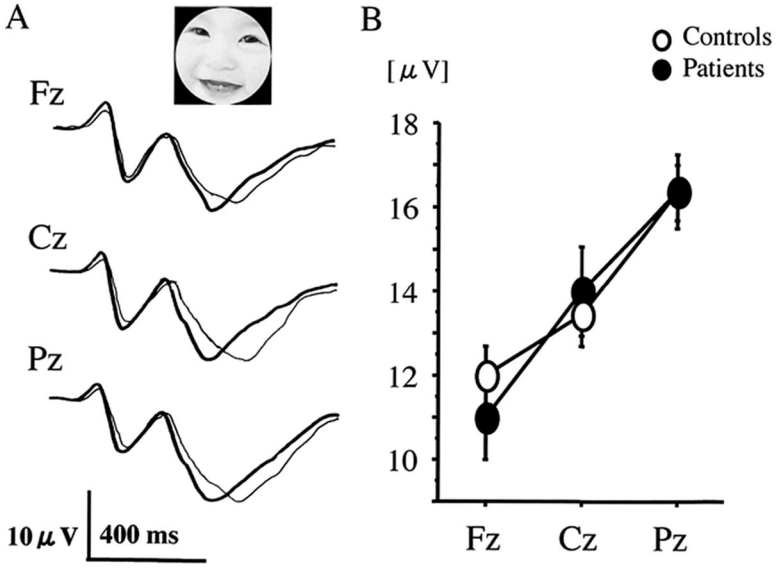

FIGURE 3 *Grand-averaged waveforms (*A*) and mean amplitude of visual P300 (*B*) when viewing the smiling baby. ○, controls; ●, patients. No significant differences were observed between patients and controls.* Bars *indicate the standard error (SE).*

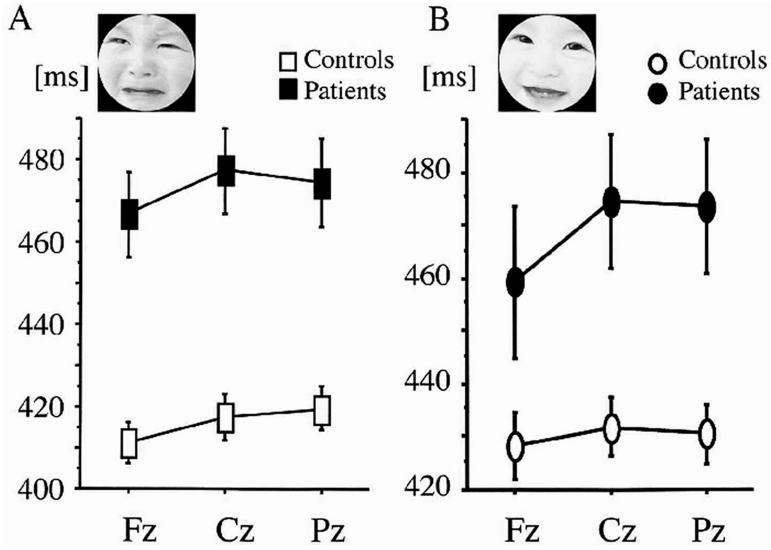

FIGURE 4 *Mean latency of visual P300 when viewing the crying baby* (A) *and when viewing the smiling baby* (B). □ *and* ○, *controls;* □ *and* ●, *patients.* Bars *indicate the standard error (SE).*

Fz ($F = 5.88, P < 0.01$), Cz ($F = 13{,}01, P < 0.001$), and Pz ($F = 13.26, P < 0.001$) for the smiling stimulus. The peak amplitude for controls was significantly larger than for patients at Oz ($F = 17.33, P < 0.0001$), T3 ($F = 14.90, P < 0.0001$), and T4 ($F = 12.75, P < 0.0001$) for the crying stimulus. The peak amplitude for controls was significantly larger than for patients at Oz ($F = 14.6, P < 0.001$), T3 ($F = 8.7, P < 0.01$), and T4 ($F = 10.19, P < 0.001$) for the smiling stimulus. In healthy controls, there were main group effects ($F_{1269} = 9.78, P < 0.01$), and the latency while viewing the crying baby was significantly shorter than while viewing the smiling baby. The latency was significantly shorter for the crying baby than for the smiling baby at Fz ($F = 4.49, P < 0.05$) and Cz ($F = 4.45, P < 0.05$). However, in patients, the latency while viewing the crying baby was similar to that observed while viewing the smiling baby.

N200 Peak Amplitude

Significant main effects for group were not seen using three-way ANOVA for visual stimuli. Significant main effects for group were not seen using two-way ANOVA for both stimuli. There was no interaction between groups and recording sites. The amplitude of patients was similar to that of controls at all recording sites.

In healthy controls, a significant main effect for the N200 amplitude was observed ($F_{1269} = 7.86, P < 0.01$). The amplitude while viewing the crying baby was significantly smaller than while viewing the smiling baby. However, in patients, the amplitude for the crying baby was similar to that for the smiling baby.

N200 Latency

Significant main effects for group were seen using three-way ANOVA for the visual stimulus ($F_{1382} = 9.20, P < 0.01$). The latency was significantly longer for patients than for controls. Significant main effects for group were seen using two-way ANOVA for only the crying stimulus ($F_{1269} = 15.36, P < 0.0001$). The latency was significantly longer for patients than for controls. There was no interaction between groups and recording sites. The latency of patients was significantly longer than that of controls at Fz ($F = 6.18, P < 0.05$), Cz ($F = 4.54, P < 0.05$), and Pz ($F = 4.98, P < 0.05$). The latency for controls was significantly shorter than for patients at T3 ($F = 4.90, P < 0.05$) and T4 ($F = 6.88, P < 0.01$) for the crying stimulus.

There was no significant difference in the N200 latency between the two stimuli, both in controls and in patients.

Reaction Time

The reaction time for controls was 472.2 ± 88.2 msecs for the crying baby and 485.1 ± 98.2 msecs for the smiling baby. The reaction time for patients was 603.8 ± 178.5 msecs for the crying baby and 578.5 ± 123.6 msecs for the smiling baby. Significant main effects for group were seen using two-way ANOVA ($F_{1166} = 34.61, P < 0.001$). The reaction time was significantly longer for patients than for controls ($P < 0.0001$) for both stimuli. There was a significant correlation between the reaction time and P300 latency ($r = 0.402, P < 0.01$) in controls and patients ($r = 0.514, P < 0.01$) only for the smiling baby.

Accuracy of Counting and Tone Assessment

Both counting and button-pressing accuracy exceeded 90% for all subjects. A significant difference was not evident between controls and patients.

Relationship Between Glasgow Coma Scale or Duration from TBI, and P300 Measures

No significant relationship was observed between Glasgow coma scale (level of consciousness disturbance when hospitalized) and the duration from the TBI and P300 or N200 measures (amplitude and latency, respectively).

DISCUSSION

The present findings clearly show prolongation of the visual P300 latency in patients after TBI, whereas the auditory P300 latency was not prolonged compared with age-matched control subjects. The present findings also show that the P300 amplitude in patients after TBI is affected by exposure to emotionally charged images and differed from the P300 amplitude in controls.

TBI patients have been reported to show deficiencies in cognitive function, reflected by P300 and reaction time.[11,15,21–23] In the early stages of ERP research in patients with TBI, only auditory ERPs were evaluated for correspondence to patient characteristics.[21,22,24] As ERP evaluation continued to develop, Lew et al.[14] reported that TBI patients had significantly longer P300 latencies in response to both auditory or visual stimuli, and they concluded that TBI patients demonstrated impaired performance both electrophysiologically and behaviorally.

Duncan et al.[25] report that auditory P300 latency was prolonged but that visual P300 latency was not, suggesting that the processing of auditory stimuli may be impaired after head trauma, whereas visual sensory processing may be spared. The same report notes that auditory P300 abnormalities correlated strongly with the duration of unconsciousness, concluding that the processing of auditory stimuli, including perception and discrimination of stimulus features and evaluation and categorization of stimuli, may be impaired after head trauma.[26,27]

In disagreement with respect to modality, Werner and Vanderzant[16] report a normal amplitude and latency of auditory P300 in most patients with mild closed-head injury, with P300 abnormalities being apparent only for visual stimuli.

Considering all reports, the P300 latency seems to be a better index for evaluating patients after TBI than the P300 amplitude. In the present study, auditory P300 latency for patients was not prolonged beyond that seen in healthy controls, but visual P300 latency was prolonged significantly. Morita et al.[8] report that P300 latency when viewing a neutral face was similar to that when viewing smiling, angry, and crying faces at Fz, Pz, and Cz. This indicates that P300 latency caused by auditory modality without emotionally laden stimuli was essentially similar to P300 latency with facial affective stimuli. However, ERPs using visual modality without emotionally laden stimuli are needed. Our present TBI subjects were outpatients who were studied during the recovery period (over 10 mos after brain injury: 25.68 $\pm$ 8.87 mos) and who lacked neurological deficits, consistent with mild TBI.

One should note that auditory ERPs have been reported to be prolonged in severe TBI[16–23] and in the short term.[10,13,14,20,24–26] Although the auditory system is more likely to be injured by TBI rather than the visual system, visual sensory processing may be more complex and involve a higher order of function. Therefore, the speed of allocation of attention resources, reflected by visual P300 latency,[3,4] may be more likely to be affected than auditory latency in mild-TBI patients.

Polich[3,4] suggests that the P300 amplitude might be a good indicator for determining the effect of attention resource diversion and allocation time (evaluation time) in both healthy subjects and patients with cognitive disorders. In the present study, the P300 amplitude for visual stimuli in controls was larger than in patients when viewing the crying baby, but no difference was apparent when viewing the smiling baby.

Assuming that the magnitude of the P300 amplitude reflects the emotional impact of the observed facial expression, attention resources devoted to evoking the visual P300 seem to be diverted by exposure to external stimuli. Psychologically, sadness stimuli and anger stimuli have been reported to divert more attention resources than pleasure.[7] Thus, patients recovering from TBI may show particular impairment of attention resource allocation when exposed to negative stimuli. Recently, Lew et al.[17] have suggested that patients' ability to recognize facial affective stimuli was impaired after brain damage. This disability may disturb interpersonal relationships, because it interferes with the interpretation of cues that require specific responses according to social conventions. TBI patients have shown significantly impaired electrophysiological and behavioral functions while attempting to detect affective facial cues.

One explanation is that the attention level may increase while viewing a crying baby but decrease while viewing a smiling face, because subjects are expected to be more attentive to anger or sadness than pleasure, as reported previously.[7] In contrast to the crying and angry faces, the smiling face is a

positive stimulus[6] that caused less alteration of visual P300 characteristics than did the pictures with negative emotional content.

These properties resulted in a significant difference in the visually induced P300 amplitude. When TBI patients viewed the smiling baby, their P300 amplitude was not reduced from that in control subjects, whereas the patients' P300 latency was significantly prolonged compared with controls. In other words, bigger changes in P300 abnormalities were observed by the negative stimulus rather than the positive stimulus.

Further study is needed to clarify the emotional effects on the auditory ERPs using an affective stimulus.

N200 latency prolongation in patients has been reported previously.[23,25] In the present study, the N200 latency was prolonged only for the crying baby. These results indicate that the N200 latency under negative affective stimuli may be useful, and task discrimination may be more difficult in patients than in controls.

The push-button reaction time was significantly prolonged, both in the auditory and the visual tasks. A significant correlation between the reaction time and P300 latency was observed in the visual task, both in the controls and the patients. These results indicate that the reaction time may also be a useful marker for evaluating patients.

There was no significant correlation between Glasgow coma scale or the duration from TBI, and the p300 or the n200 measures.

Further study is needed to assess patients during the acute and subacute phases, and among severe-TBI patients.

Finally, the present results indicate that the stimulus-recognition process, reflected by P300 characteristics, is particularly impaired when stimuli involve negative emotion (crying baby). Thus, TBI may impair more complex facial recognition. Therefore, improvement of a patient's social skills might benefit from an increased focus on rehabilitation training in emotion perception.

Our present technique, in terms of the emotionally charged visual ERPs, seems useful for evaluating subtle problems with facial affective perception and expression. Hereafter, results have to be compared serially across some period to evaluate progress in recovery from TBI.[26,27] Additional studies could determine how meaningful this assessment method is for patients' psychosocial functioning in the community.

REFERENCES

1. Donchin E, Coles MGH: Is the P300 component a manifestation of context updating? *Behav Brain Sci* 1988;11: 357–86
2. Hillyard SA, Kutas M: Electrophysiology of cognitive processing. *Annu Rev Psychol* 1983;34:33–61
3. Polich J: P300 in clinical applications: meaning, method, and measurement. *Am J EEG Technol* 1991;31:201–31
4. Polich J: Clinical application of the P300 event-related brain potential, *Phys Med Rehabil Clin N Am* 2004;15: 133–61
5. Prichard WS: Cognitive event-related potential correlates of schizophrenia. *Psychol Bull* 1986;100:43–66
6. Johnston VS, Miller DR, Burleson MH: Multiple P3s to emotional stimuli and their theoretical significance. *Psychophysiology* 1986;23:684–94
7. Lang SF, Nelson CA, Collins PF: Event-related potentials to emotional and neutral stimuli. *J Clin Exp Neuropsychol* 1990;12:946–58
8. Morita Y, Morita K, Yamamoto M, et al: Effects of facial affect recognition on the auditory P300 in healthy subjects. *Neurosci Res* 2001;41:89–95
9. Yee CM, Miller GA: Affective valence and information processing. *Electroencephalogr Clin Neurophysiol Suppl* 1987; 40:300–7
10. Campbell K, Houle S, Lorrain D, et al: Event-related potentials as an index of cognitive functioning in head-injured outpatients. *Electroencephalogr Clin Neurophysiol* 1986; 38:486–8
11. Mazzini L: Clinical application of event-related potentials in brain injury. *Phys Med Rehabil Clin N Am* 2004;15:163–75
12. Muller SV, von Schweder AJ, Frank B, Dengler R, Munte TF, Johannes S: The effects of proprioceptive stimulation on cognitive processes in patients after traumatic brain injury. *Arch Phys Med Rehabil* 2002;83:115–21
13. Kane NM, Curry SH, Rowlands CA, et al: Event-related potentials—neurophysiological tools for predicting emergence and early outcome from traumatic coma. *Intensive Care Med* 1996;22:39–46
14. Lew HL, Lee EH, Pan SS, et al: Electrophysiologic abnormalities of auditory and visual information processing in patients with traumatic brain injury. *Am J Phys Med Rehabil* 2004;83:428–33
15. Sangal RB, Sangal JM: Closed head injury patients with mild cognitive complaints without neurological or psychiatric findings have abnormal visual p300 latencies. *Biol Psychiatry* 1996;15:305–7
16. Werner RA, Vanderzant CW: Multimodality evoked potential testing in acute mild closed head injury. *Arch Phys Med Rehabil* 1991;72:31–3
17. Lew HL, Poole JH, Chiang JYP, et al: Event-related potential in facial affect recognition: potential clinical utility in patients with traumatic brain injury. *J Rehabil Res Dev* 2005; 42:29–34
18. Maeda H, Morita K, Kawamura N, et al: Amplitude and area of the auditory P300 recorded with eyes open reflect remission of schizophrenia. *Biol Psychiatry* 1996;39:743–6
19. Yamamoto M, Morita K, Tomita Y, Tsuji K, Kawamura K, Maeda H: Effect of facial affect stimuli on auditory and visual P300 in healthy subjects. *Kurume Med J* 2000;47: 285–90
20. Picton TW, Bentin S, Berg P: Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology* 2000;37: 127–52
21. Deacon D, Campbell KB: Effects of performance feedback on P300 and reaction time in closed head-injured outpatients. *Electroencephalogr Clin Neurophysiol* 1991;78: 133–41
22. Cremona-Meteyard SL, Geffen GM: Event-related potential indices of visual attention following moderate to severe closed head injury. *Brain Inj* 1994;8:541–58
23. Duncan CC, Kosmidis MH, Mirsky AF: Closed head injury-related information processing deficits: an event-related potential analysis. *Int J Psychophysiol* 2005;58:133–57
24. Papanicolaou AC, Levin HS, Eisenberg HM, et al: Evoked

potential correlates of posttraumatic amnesia after closed head injury. *Neurosurgery* 1984;14:676–8

25. Duncan CC, Kosmidis MH, Mirsky AF: Event-related potentials assessment of information processing after closed head injury. *Psychophysiology* 2003;40:45–59
26. Keren O, Ben-Dror S, Stern MJ, Goldberg G, Groswasser Z: Event-related potentials as index of cognitive function during recovery from severe closed head injury. *J Head Traum Rehabil* 1998;13:15–30
27. Mazzini L, Zaccala M, Gareri F, et al: Long latency auditory-evoked potentials in severe traumatic brain injury. *Arch Phys Med Rehabil* 2001;82:57–65

BOOK REVIEW

The Mutilated Hand

by Norman Weinzweig, MD and Jeffrey Weinzweig, MD. 618 pages. Published 2005 by Elsevier, Inc., Philadelphia. $262.00. ISBN: 156053446X.

The Mutilated Hand is a comprehensive textbook covering essentially all aspects of the management of mutilating injuries of the arm and hand. The book is designed to be a definitive resource and reference textbook for hand surgeons, surgical residents, plastic surgery fellows, and orthopedic hand-surgery fellows. Rehabilitation professionals including PM&R physicians, hand therapists, prosthetists, and orthotists will also find this textbook to be a valuable resource.

The text is detailed and comprehensive in nature. It is organized into 12 sections and 42 chapters. The editors have selected well-known and respected individuals to author chapters for the text. Most chapters have two or three contributors. Overall, the text is very well written, readable, and well organized. The textbook begins with a historical perspective and an overview and classification of mutilating injuries. Subsequent chapters provide in-depth descriptions and management strategies for various arm- and hand-mutilating injuries. The text ends with sections on postoperative management and limb allotransplantation. Although each chapter can stand alone, the text overall flows well from chapter to chapter, and the editors seem to have minimized redundancy.

Outstanding features of this text include the introductory sections to each chapter, the marvelous color photographs, and the summary tables. The color photographs are included in each chapter and help to illustrate the devastating nature of mutilating injuries to the arm and hand. The case studies included in many of the chapters are also enlightening. The chapters on psychological aspects, rehabilitation management, pain management, and prosthetics are particularly well suited for rehabilitation professionals.

Overall, this text is rated as excellent. The text seems unique in its comprehensive coverage of mutilating injuries to the arm and hand. Although primarily designed for surgeons, the text will also be a very good reference book for PM&R physicians, therapists, prosthetists, and orthotists who deal with mutilating injuries of the arm and hand.

Rating: ★★★★

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