

Event-related potential in facial affect recognition: Potential clinical utility in patients with traumatic brain injury

Henry L. Lew, MD, PhD;^{1–2*} John H. Poole, PhD;² Jerry Y. P. Chiang, MD;³ Eun Ha Lee, MD;¹
Elaine S. Date, MD;¹ Deborah Warden, MD⁴

¹Physical Medicine and Rehabilitation Service, Department of Veterans Affairs Palo Alto Health Care System, Palo Alto, CA, ^{1–2}Defense and Veterans Brain Injury Center, Palo Alto, CA; ³Stanford University School of Medicine, Stanford, CA;

⁴Defense and Veterans Brain Injury Center, Walter Reed Medical Center, Washington, DC

Abstract—Traumatic brain injury (TBI) frequently leads to deficits in social behavior. Prior research suggests that such deficits may result from impaired perception of basic social cues. However, these social-emotional deficits have not been studied electrophysiologically. We measured the P300 event-related potential (ERP), which has been shown to be a sensitive index of cognitive efficiency, in 13 patients with a history of moderate to severe TBI and in 13 healthy controls. The P300 response was measured during detection of 30 pictures of angry faces (rare target) randomly distributed among 120 neutral faces (frequent nontarget). Compared to control subjects, the TBI group's P300 responses were significantly delayed in latency ($p = 0.002$) and lower in amplitude ($p = 0.003$). TBI patients also showed slower reaction times and reduced accuracy when manually signaling their detection of angry faces. Coefficients of variation (CVs) for the facial P300 response compared favorably to those of many standard clinical assays, suggesting potential clinical utility. For this study, we demonstrated the feasibility of studying TBI patients' P300 responses during the recognition of facial affect. Compared to controls, TBI patients showed significantly impaired electrophysiological and behavioral responses while attempting to detect affective facial cues. Additional studies are required for clinicians to determine whether this measure is related to patients' psychosocial function in the community.

Key words: affect recognition, brain injury, cognition, electroencephalograph, emotional processing, event-related potential, social perception.

INTRODUCTION

Impairments in emotional and social behavior are a frequent consequence of traumatic brain injury (TBI), including emotional disinhibition, reduced social activity, and a breakdown in relationships [1–2]. Cognitive studies in this area have focused on behavioral measures in assessing patients' capacity to recognize facial and vocal expressions of basic emotions such as anger or happiness. Studies have found affect recognition is frequently impaired in TBI patients [3–4], and these patients have greater difficulty recognizing negative than positive affect [5]. At least one study suggested the severity of these deficits may account for differences in TBI patients' social functioning [2].

Abbreviations: CV = coefficient of variation, EEG = electroencephalograph, ERP = event-related potential, SD = standard deviation, TBI = traumatic brain injury, VA = Department of Veterans Affairs.

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*Address all correspondence to Henry L. Lew, MD, PhD; VA Palo Alto Health Care System, PM&R Service, MS-B117, 3801 Miranda Avenue, Palo Alto, CA 94304; 650-493-5000, ext. 65368; fax: 650-849-0129; email: henry.lew@med.va.gov
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We used cognitive event-related potentials (ERPs) to analyze the temporal processing of facial affect in healthy individuals [6–7]. The recognition of facial affect is undoubtedly a complex, multifaceted task, and several early and late ERP components have been found to be related to different aspects of this process. A “face-related” N2 component (150–200 ms) is thought to reflect mainly nonemotional aspects of face perception, while a later P300 component (250–550 ms) is more strongly related to the detection of facial emotions [6–8]. In addition, several studies in healthy individuals have found that the amplitude of the P300 typically shows a more robust response to negative facial emotions (e.g., anger, fear) than positive facial emotions [9–10]. This may reflect a general characteristic of the P300 in which the amplitude of the response is proportional to the meaning and emotional salience of stimuli [11].

Prior studies in TBI patients have demonstrated ERP abnormalities that are closely related to patients’ neuropsychological status [12] and functional outcome [13]. To our knowledge, however, no study has examined TBI patients’ ERP responses to affect recognition tasks. In a prior study, we found that TBI patients have significantly lower-amplitude and longer-latency P300 responses to simple visual stimuli [14]. The present study extends this line of research by comparing the P300 response of TBI patients and healthy controls during facial affect recognition. In view of the stronger P300 response reported for negative emotions, as well as the reportedly greater impairment of TBI patients in recognizing negative emotions behaviorally, we focused the present study on the detection of angry faces. We asked subjects to identify relatively infrequent angry faces among many faces with a neutral expression. To assess possible contributions from generalized psychomotor slowing, we also analyzed the relationship of subjects’ P300 latencies to the speed of their manual responses to the same facial stimuli.

METHODS

Participants

This protocol was approved by the Department of Veterans Affairs’ (VA) local institutional review board, and all subjects provided signed informed consent. From the brain injury rehabilitation unit of a university-affiliated VA medical center, we recruited patients who had a his-

tory of moderate to severe TBI (initial Glasgow Coma Score = 3–12) with good recovery (current Glasgow Coma Scale = 15 and Glasgow Outcome Scale = 5). Healthy control subjects were recruited from the patients’ friends and family and from hospital volunteers and staff. All subjects were fully oriented, able to follow instructions, and had visual acuity within normal limits and bilateral upper-limb strength of 5/5 on neurological screening. We excluded subjects taking sedatives, anticholinergic agents, dopamine agonist, or antagonists within the prior 72 h, so we could avoid the potential influence of these agents on the morphology of the electroencephalograph (EEG) waveforms [15–16].

Instrumentation

The Neuroscan (El Paso, Texas) STIM system and version 4.2 software were utilized for stimulus generation, data acquisition, and analysis of ERP waveforms and reaction times. We employed gold-cup electrodes, placed on the scalp at Fpz, Fz, Cz, and Pz (International 10–20 System), with the ground electrode over the sternum, and one reference electrode at each mastoid. Electrode impedance was kept at less than 5 k Ω . A bandpass filter was used, with low and high frequencies set between 0.15 Hz and 30.0 Hz. Four facial stimuli from Ekman’s series were used [17], consisting of 150 pictures of a man and a woman (equally represented), each showing either an angry or a neutral facial expression. We used 30 (20%) angry faces as rare/target stimuli, which randomly appeared among the remaining 120 (80%) neutral faces (nontarget, frequent stimuli). The faces measured 5.55 \times 7.75 in. and appeared on the monitor for 1.0 s each at an interstimulus interval of 2.11 s, with a luminance of 0.15 foot-candles at a viewing distance of 2 ft.

Procedures

We tested all subjects between 3 and 5 p.m. to reduce variability related to diurnal effects [18]. Subjects were instructed to focus on the monitor and press a response button as quickly as possible whenever the target stimuli appeared. EEG waveforms and manual responses (reaction time and accuracy) were recorded simultaneously during the process. The entire procedure, including electrode application, instructions to subject, and completion of the experiment, required approximately 30 min per subject.

Data Analysis

EEG responses to nontarget and target stimuli were separately time-locked, sorted, and averaged. Since the expected P300 responses are largest at Pz [18], we analyzed the averaged ERP waveform at the Pz electrode for each subject. Amplitudes and latencies of the P300 waveforms were determined and entered into a database for further analyses. We measured the amplitude from the prestimulus baseline to peak, and the latency from stimulus onset to peak. P300 amplitude and latency were normally distributed within both subject groups, as well as within the total sample (Kolmogorov-Smirnov $Z < 1$; $p > 0.5$), allowing the use of parametric statistics (t -tests and Pearson correlations). We defined statistical significance as two-tailed $p < 0.05$.

To provide initial estimates of the clinical utility of the P300, in terms of the interindividual variability within normal samples [18], we calculated coefficients of variation (CVs) ($CV = \text{between-subject standard deviation} \div \text{the group mean}$) for the P300 amplitude and latency. Lower CV values are generally considered an important prerequisite for clinical measures, without which it can be difficult to attain suitable levels of sensitivity and specificity. We performed statistical analyses with the Statistical Package for Social Sciences (SPSS) 10.1.

RESULTS

We recruited 13 TBI patients and 13 control subjects, and each group completed the procedure. TBI patients' initial Glasgow Coma Scores ranged from 3 to 12; three patients had alcohol-related injuries. The TBI group consisted entirely of males (military veteran sample), while the control group consisted of seven males and six females (nonveterans).

Within the control group, gender was unrelated to P300 amplitude, P300 latency, reaction time, or accuracy on the manual task (all p values > 0.10 by t -test). The TBI group was marginally younger than the control group (26 ± 9 vs. 32 ± 7 years, $p = 0.07$ by t -test). Age correlated significantly with P300 latency ($r = -0.59$, $p = 0.03$) and marginally with reaction time ($r = 0.48$, $p = 0.10$) in the TBI group; no age effects were apparent in the control group. To rule out possible age artifacts, we controlled for age in the following analyses.

The **Figure** shows the grand-average ERP waveforms of the control and TBI groups. The **Table** provides each

group's mean P300 amplitude and latency data, as well as their reaction times and accuracy on the manual task. As the **Figure** and **Table** show, the P300 wave of the TBI group had smaller amplitude (11.3 vs. 19.1 μV , $t = 3.27$, $p = 0.003$) and longer latency (486 vs. 416 ms, $t = 3.58$, $p = 0.002$) than that of the control group. In terms of individual subjects, 7 of the 13 TBI patients had mean P300s that were lower in amplitude than the tenth percentile of controls (versus one control subject in this range). Similarly, for mean latency, 9 of the 13 TBI patients attained their peak P300 more slowly than the tenth percentile of controls (versus one control subject). On the manual task, the TBI group had longer reaction times (653 vs. 443 ms, $t = 3.70$, $p = 0.002$) and slightly lower accuracy than controls (95% vs. 99%, $t = 2.30$, $p = 0.04$). Slower subjects were generally less accurate on the manual task ($r = -0.65$, $p < 0.001$), indicating these group differences were not due to a simple speed-accuracy trade-off. When the aforementioned series of analyses were repeated controlling for age, the results were unchanged.

To assess possible contributions from generalized psychomotor slowing, we also compared subjects' P300 latencies to their reaction times on the manual task. Horizontal bars representing the reaction time of both groups to target faces are shown below each ERP waveform in the **Figure**. In the control group, subjects' average reaction time did not differ significantly from their P300 latency (443 vs. 416 ms, $t = 1.13$, $p = 0.3$). In contrast, the TBI group's average reaction time lagged 167 ms behind their P300 responses (653 vs. 486 ms, $t = 2.63$, $p = 0.02$). P300 latency was not significantly correlated with reaction time ($r = 0.27$, $p = 0.2$). We estimated the normal variability of the P300 response in the control group, with the CV. For P300 amplitude, the CV equaled 32 percent. For P300 latency, the CV equaled 7 percent.

DISCUSSION

In this study, we were the first to demonstrate that subjects with moderate to severe TBI have altered cognitive ERPs in response to emotionally charged human faces. These responses were significantly delayed and lower in amplitude than those of healthy control subjects. This replicates and extends the finding of prior studies in healthy subjects [6–10] that classical P300 waveforms can be generated in response to the relatively complex stimulus of a human face expressing emotions. The findings are also

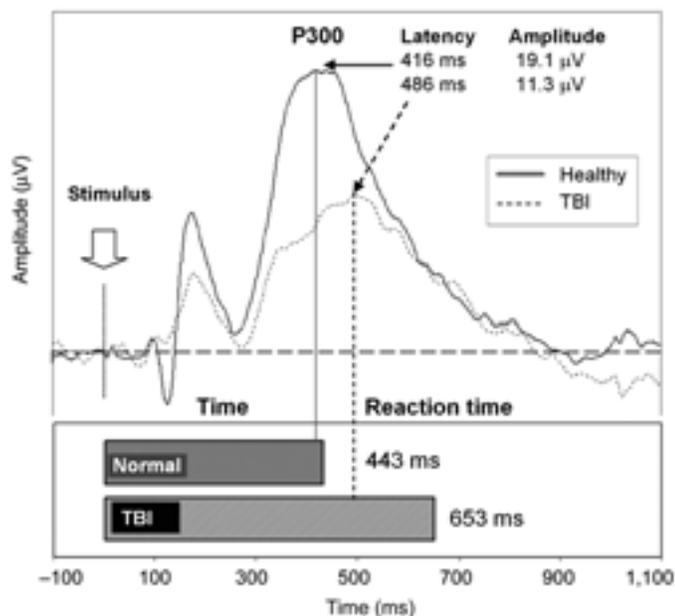


Figure. Grand-average event-related potential (ERP) waveforms and reaction times. TBI = traumatic brain injury.

consistent with a number of prior reports [12–14] showing that subjects with TBI have delayed, lower amplitude P300 responses compared to healthy controls.

We also found that TBI subjects differ from control subjects in the relationship between their P300 and behavioral responses to target faces. Control subjects' manual response occurred near the peak of their P300 responses. In contrast, TBI subjects' manual responses typically occurred significantly after their peak P300. A number of possible explanations exist for the difference. One possibility is control subjects achieved accurate decisions regarding facial stimuli earlier than TBI patients and therefore initiated their behavioral response earlier.

Furthermore, TBI patients may have a variety of psychomotor deficits that can interfere with manual responses. Undoubtedly, some causes of slower motor response may reside in functional domains unrelated to the cognitive P300 response. We found that mean reaction time and P300 latency were uncorrelated with one another, in agreement with other studies that also found no necessary relation between these measures [14,19–20]. This finding is important because it shows that reaction time and P300 latency are not redundant measures of a single parameter, such as processing speed.

Finally, to provide initial estimates of the potential clinical utility of the P300 response to facial stimuli, we calculated interindividual CV in the normal sample. Relatively low normative values of the CV are required if a test is to have practical potential for differentiating normal from impaired performance [18]. Measures with low CV values have narrower “normal limits” than those with larger CVs. This is an important prerequisite for clinical measures, because low CV measures are more likely to have suitable sensitivity and specificity for detecting dysfunction. In the present study, we obtained CVs of 7 percent for P300 latency and 32 percent for P300 amplitude. A previous study [21] reported this aspect of the P300 response to simple nonfacial visual and auditory stimuli in 120 normal subjects and obtained CVs of 11 percent for latency and 41 to 48 percent for amplitude. These values are comparable to or better than those reported for many standard clinical measures, which typically range from 6 to 45 percent, including electroretinograms of retinal sensitivity [22], a common screening test for cognitive decline [23], and widely used blood assays for lipids, glucose, and thyrotropin [18]. Of course, our results from a limited number of normals may not represent the population at large and should be replicated with a larger sample. Nonetheless, these findings suggest that the P300

Table. Mean P300 ERP and behavioral responses to target stimuli.

Data	Healthy Group (Mean ± SD)	TBI Group (Mean ± SD)	Group Difference <i>t</i> -Test (<i>p</i>)
Electrophysiological			
P300 Latency (ms)	416 ± 30	486 ± 64	0.002
P300 Amplitude (µV)	19.1 ± 6.1	11.3 ± 6.1	0.003
Behavioral			
Reaction Time (ms)	443 ± 64	653 ± 204	0.002
Accuracy	99%	95%	0.04
ERP = event-related potential	SD = standard deviation	TBI = traumatic brain injury	

response to emotionally charged faces promises to be a biomedical assay for cognitive dysfunction.

This study should not be overinterpreted. Although the target stimuli were angry faces, we cannot conclude that differences between the TBI and control subjects' ERP waveforms reflect differences in emotional processing *per se*. The present findings may simply reflect generalized impairment in our capacity to detect relatively infrequent target stimuli among distractors. To address this question, future studies should compare patients' P300 responses to emotional stimuli with measures of their cognitive skills and behaviors. We are currently conducting studies comparing subjects' P300 responses to facial emotions with neuropsychological measures of their emotion perception and other cognitive abilities, as well as to behavioral measures of their interpersonal skills and problems.

CONCLUSION

We feel the main value of this preliminary study demonstrates the feasibility of the P300 response to probe emotional processing in people with TBI. Specifically, we found that both control and TBI subjects produce classic P300 responses to the detection of angry faces. Normal subjects' ERP waveforms following these stimuli had CVs that compare favorably to those of P300 responses to non-facial visual stimuli as well as many standard clinical tests. TBI subjects showed impaired P300 responses to these stimuli, both in terms of latency and amplitude. These findings could not be explained by generalized psychomotor slowing, as measured by manual reaction time, suggesting that the P300 reflects aspects of cognition that may not be easily measured by patients' motor reactions. Taken together, we suggest that P300 response may provide a probe into patients' altered capacity to process facial cues. Thus, we are currently preparing another study to determine whether patients' P300 responses to the detection of facial affect have a meaningful relationship to their emotional processing and social functioning in the community.

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