People with traumatic brain injury (TBI) often experience persistent cognitive deficits. Teaching approaches that leverage feedback are of great importance, as they may have an impact on learning outcomes, treatment effects, and ultimately, reintegration into society. Studies investigating feedback processing and learning have used a range of behavioral measures, such as reaction times (RTs) and self-assessed confidence levels. However, these measures may not be completely satisfactory as they are highly dependent on individual experience and may not fully capture the complexity of learning processes. In this study, we used event-related potentials (ERPs) associated with feedback processing, along with behavioral measures, to examine learning across two different treatment conditions. ERPs are electrical brain activity recorded using electrodes placed on the scalp. They have been shown to provide valuable information about the functional significance of different cognitive processes.

**METHODS**

### Participants

<table>
<thead>
<tr>
<th>Participants</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean age (SD)</td>
<td>46.3 (11.7)</td>
<td>38.8 (15.4)</td>
</tr>
<tr>
<td>mean yrs of education (SD)</td>
<td>10.4 (2.4)</td>
<td>17.1 (1.3)</td>
</tr>
<tr>
<td>% male</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>2 mild, 1 moderate, 6 severe</td>
<td>No history of TBI, neurological disease, significant psychiatric history or substance abuse</td>
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### Task

Participants completed a two-choice paired associate word learning task. The goal of the task was to learn the word names of 60 novel objects. In the Errorless condition (30 items), the learner was first presented with the Correct Association slide, showing an object and its name. In the Errorful condition (30 items), the learner was first presented with the Stimulus slide, showing an object and two possible name choices.

### ERP Data Collection and Analysis

An EGI system with a 32-electrode net was used to collect EEG data. EEG was continuously recorded at a sampling rate of 1000 Hz and 0-1.2 Hz bandpass. ERPs were time-locked to the presentation of feedback. Grand-averaged waveforms were generated for each participant, and for each of the two conditions, the FRN and the FCP. In addition, a temporal principal component analysis was performed to separate overlapping ERP components into different temporal factors.

### Results

**Behavioral Data**

- Overall, people with TBI performed worse than control participants on the behavioral learning outcomes measures, with lower accuracy and slower RTs.
- There was no overall difference in confidence between conditions.

**Do people with TBI benefit from Errorless as compared to Errorful learning, relative to control participants?**

- No interaction effect between Group and Learning Condition for either of the behavioral learning outcomes measures.

**Do the FRN and FCP, two ERP components associated with learning, differ in people with TBI compared to controls?**

- Yes, there were differences between controls and people with TBI in both components.

**ERPs**

- The two learning conditions were controlled so that the learner was exposed to the correct word-object association equally in both conditions, just in a different order.

**DISCUSSION**

ERP measures pointed to differences between Errorful and Errorless learning between controls and people with TBI. Comparing the people with TBI to controls, there were:

1. **ERP differences in feedback processing in the Errorful condition:**
   - **FRN:** Overall smaller negativity in people with TBI in comparison to controls. No difference between positive and negative feedback processing in people with TBI, while the larger negativity associated with negative feedback was elicited in controls.
   - **FCP:** No difference between positive and negative feedback processing in people with TBI, while there was a larger positivity associated with negative feedback in people with TBI compared to controls.

2. **No ERP differences in positive feedback processing in the Errorless condition.**

There was an alignment of the electrophysiological data with the confidence ratings: Unlike controls, people with TBI failed to show ERP differences in response to positive versus negative feedback in the Errorful condition, but ERPs did not differ from controls in the Errorless condition. This indicates that feedback processing and subsequent learning were primarily disrupted in the Errorful condition. Consistent with this, people with TBI did not show confidence “boost” the controls did in the Errorful condition relative to the Errorless condition. It is noteworthy that behavioral learning outcomes measures did not differ across the two learning conditions in people with TBI. TBI supports the importance of using electrophysiological measures to capture processing differences that are not detectable with behavioral outcomes measures.

**References**


Miltner, W. H. J., & Mangels, J. A. (2003). Event-related potentials (ERPs) associated with feedback processing, along with behavioral measures, to examine learning across two different conditions. ERPs make it possible to evaluate learning during the process of learning and allow for multidimensional, graded measures rather than just binary outcomes measures. We consider two learning-related ERPs components.

The Feedback Related Negativity (FRN) is shown to occur when the learner is reliant on feedback to determine if a response was correct or incorrect. The FRN is elicited in response to negative feedback.

The Frontal-Central Positivity (FCP) is thought to function as the `fronto-central' cognitive plan. The FCP is elicited when the learner is not reliant on feedback to determine if a response was correct or incorrect.

**Errorful Learning** is defined as learning with feedback processing, while **Errorless Learning** is defined as learning without feedback processing.