Electrophysiological Evidence for Learning Differences in Traumatic Brain Injury

MGH Institute of Health Professions
A graduate school founded by Massachusetts General Hospital

Lauryn Zipse and Yael Arbel

MGH Institute of Health Professions, School of Health and Rehabiliatation Sciences, Boston, MA

INTRODUCTION

People with traumatic brain injury (TBI) often experience persistent cognitive deficits. Teaching compensatory strategies is an important component of treatment, but people with TBI also frequently exhibit impaired self-monitoring of their performance. This negatively impacts their ability to implement strategies and generalize them to real-world situations. Concerns about treatment effects have led to an interest in learning in TBI.

In this study, we use event-related potentials (ERPs) associated with feedback processing, along with behavioral measures of learning outcomes, to examine learning across two different conditions that vary in the extent to which feedback processing and self-monitoring are needed.

We address the following research questions:

1. Do people with TBI benefit from Errorless as compared to Errorful learning, relative to control participants?
2. Do people with TBI feel more confident about material they have learned in an Errorless as compared to an Errorful condition, relative to control participants?
3. Do the Feedback Related Negativity (FRN) and Fronto-Central Positivity (FCP), two ERP components associated with learning, differ in people with TBI compared to controls?

BACKGROUND

Errorless vs. Errorful Learning Conditions

In this study, we compare two learning conditions:

1. ***Errorless Learning****:* learner is prevented from making errors during the learning process
2. ***Errorful Learning****:* a more traditional trial-and-error approach; requires the learner to make use of positive and negative feedback

Event-Related Potentials (ERPs)

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 ERP components:

The ***Feedback Related Negativity*** (FRN; Miltner et al., 1997)

- A negativity with a latency of 200-300 ms following the presentation of feedback
- Localized to the dorsal anterior cingulate cortex
- Occurs when the learner is reliant on feedback to determine if a response was correct
- Higher amplitudes (i.e., more negative) in response to negative feedback

The ***Fronto-Central Positivity*** (FCP; Butterfield & Mangels, 2003)

- A positivity with a latency of 300-400 ms following the presentation of feedback
- Associated with the processing of feedback
- Functional significance is not yet well understood
- Higher amplitudes (i.e., more positive) in response to negative feedback

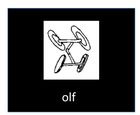
METHODS

Participants

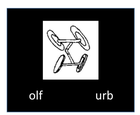
	9 people with TBI	10 controls
mean age (SD)	46.3 (11.7)	33.8 (15.4)
mean yrs of education (SD)	16.4 (2.4)	17.1 (1.3)
% male	0.7	0.4
	2 mild, 1 moderate, 6 severe	No history of TBI, neurological disease, significant psychiatric history or substance abuse

Task

Participants completed a two-choice paired associate word learning task. The goal of the task was to learn the nonword 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.

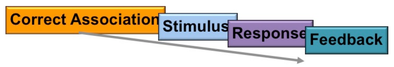


Correct Association slide

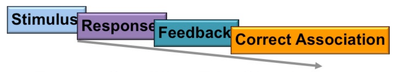


Stimulus slide

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.



Errorless Condition Trial Structure



Errorful Condition Trial Structure

Following presentation of the *Stimulus* slide, visual feedback was provided to indicate whether the learner's response was correct (✔✔✔) or incorrect (✖✖✖).

Procedure

In each learning condition, the 30 items were presented in 3 sets of 10 items during a learning phase. Learning was tested at 3 different time points, Immediate, Same Day, and Next Day.

Learning and Immediate Testing		Same Day Testing	Next Day Testing
• Each condition presented separately • 30 items presented in each condition, in 3 sets of 10		• Each condition tested separately directly after Learning and Immediate Testing were completed for all sets of that condition • Each item tested twice • No feedback	• Both conditions intermixed (60 items) • Each item tested once • No feedback
Blocks 1-3 Learning Phase	**Block 4 Immediate Testing**		
• Each set repeated across 3 learning blocks • Feedback after every response • EEG recorded, time-locked to feedback presentation	• Each item in the set tested twice • No feedback • Binary Confidence of Learning ratings provided twice for each item		

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 0.1-30 Hz bandpass. ERPs were time-locked to the presentation of feedback.

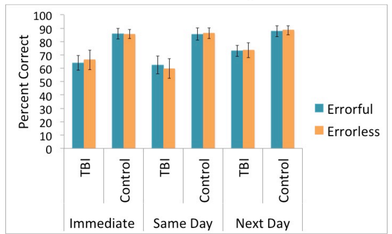
Grand-averaged waveforms were generated for each group and each condition, for each of the two components of interest, the FRN and the FCP. In addition, a temporal principal component analysis (PCA) was performed to separate overlapping ERP components into different temporal factors (Spencer, Dien, & Donchin, 2001). Factor scores for the FRN and the FCP were computed by group for each condition and electrode of interest.

RESULTS

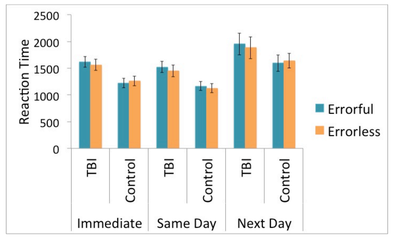
Behavioral Data

- Overall, people with TBI performed worse than controls on the behavioral learning outcomes measures, with lower accuracy and slower RTs.
- There was no clear overall benefit of one learning condition relative to another.

Do people with TBI benefit from Errorless as compared to Errorful learning, relative to control participants? No, as there was no interaction effect between Group and Learning Condition for either of the behavioral learning outcomes measures.

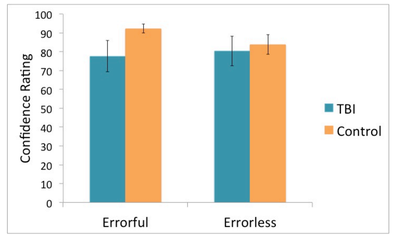


Significant main effect of Group at all three time points (Immediate: $F(1,17)=8.95$, $p=.008$; Same Day: $F(1,17)=9.61$, $p=.007$; Next Day: $F(1,17)=5.66$, $p=.03$), with a higher percent correct for Controls compared to TBI. No main effect of condition at any time point. No interaction effect at any time point.



Main effect of Group at Immediate ($F(1,17)=6.59$, $p=.02$) and Same Day ($F(1,17)=5.83$, $p=.03$), with faster RTs for Controls. No main effect of Group at Next Day. Main effect of Condition at Same Day ($F(1,17)=6.23$, $p=.02$) with faster RTs for Errorless compared to Errorful. No main effect of Condition at Immediate or Next Day. No interaction effect at any time point.

Do people with TBI feel more confident about material they have learned in an Errorless as compared to an Errorful condition, relative to control participants? Yes, control participants were marginally more confident about their learning in the Errorful condition compared to the Errorless condition, but people with TBI did not show this difference.

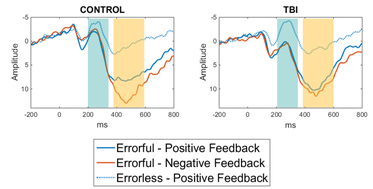


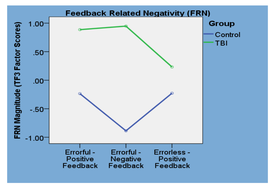
At the Immediate time point, binary Confidence of Learning ratings were provided 2x for each item. Items were scored as 1 if they were rated "confident" both times, 0.5 if rated "confident" once, and 0 if rated "not confident" both times. An overall % score was computed for each participant.

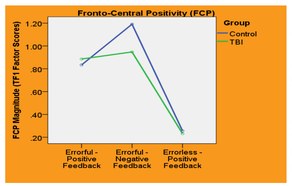
2x2 mixed model ANOVA (Group x Learning Condition). Effect of Group approached significance ($F(1,17) = 1.03$, $p = .057$), with the Control group feeling more confident overall than the group with TBI. Interaction effect approached significance ($F(1, 17) = 4.40$, $p = .051$). For controls, the difference in Confidence between the two learning conditions approached significance ($t(9) = 1.94$, $p = 0.09$), with greater confidence reported in the Errorful condition. For people with TBI, the difference in Confidence between conditions was not significant.

Electrophysiological Data

Do the FRN and FCP, two ERP components associated with learning, differ in people with TBI compared to controls? Yes, there are differences between controls and people with TBI in both components.







FRN: 2 x 3 mixed model ANOVA (Group x Condition). Main effect of Group ($F(2,32)=9.37$, $p=.007$) and interaction effect ($F(2,32)=4.28$, $p=.03$. No main effect of Condition.

FCP: 2 x 3 mixed model ANOVA (Group x Condition). Main effect of Condition ($F(2,32)=4.42$, $p=.03$). No main effect of Group and no interaction effect.

DISCUSSION

ERP measures pointed to differences between Errorless and Errorful 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 the larger positivity associated with negative feedback was elicited in 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 vs. 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 the 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. This supports the importance of using electrophysiological measures to capture processing differences that are not detectable with behavioral outcomes measures.

References

Miltner, W. H. R., Braun, C. H., & Coles, M. G. H. (1997). Event-related brain potentials following incorrect feedback in a time-estimation task: evidence for a "generic" neural system for error detection. *Journal of Cognitive Neuroscience, 9*(6), 788-798.

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