How Does Feedback Processing Affect Learning in People with Traumatic Brain Injury?

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Introduction

Many people with traumatic brain injury (TBI) struggle with learning and memory after their injury. Errorless learning, a technique in which errors are minimized during the learning process, can be effective in this population. However, this type of learning is not appropriate for all situations and is not as flexible as being able to learn from feedback. This study explores the efficacy of three different learning conditions in people with TBI and neurotypical control participants: (1) Errorless learning, (2) Errorful learning, based on feedback, and (3) Strategy, in which participants were taught a simple cognitive strategy designed to emphasize positive feedback in an errorful learning environment. EEG was recorded in order to examine event-related potentials (ERPs) associated with feedback processing, specifically the feedback-related negativity (FRN) and the fronto-central positivity (FCP).

Research Questions:

1) How do the 3 learning conditions affect learning outcomes in neurotypical controls and people with TBI?
2) How does strategy use affect ERPs associated with feedback processing during learning in neurotypical controls?

Methods

Participants

- 27 control participants and 9 participants with TBI
- Fluent English Speakers
- No current substance abuse or use of psychiatric medication
- Controls had no history of TBI, neurological disorders, or significant psychiatric history

Table 1: Profiles of Participants with TBI

Participant	Severity	Time post-injury (yrs)	Gender	Age
1	Severe	12	M	39
2	Mild-Moderate	4	F	28
3	Moderate	2	M	49
4	Severe	2	M	27
5	Moderate	1	M	20
6	Mild	18	F	49
7	Mild-Moderate	5	F	21
8	Severe	5	M	48
9	Severe	2	M	37

Overall Experimental Structure

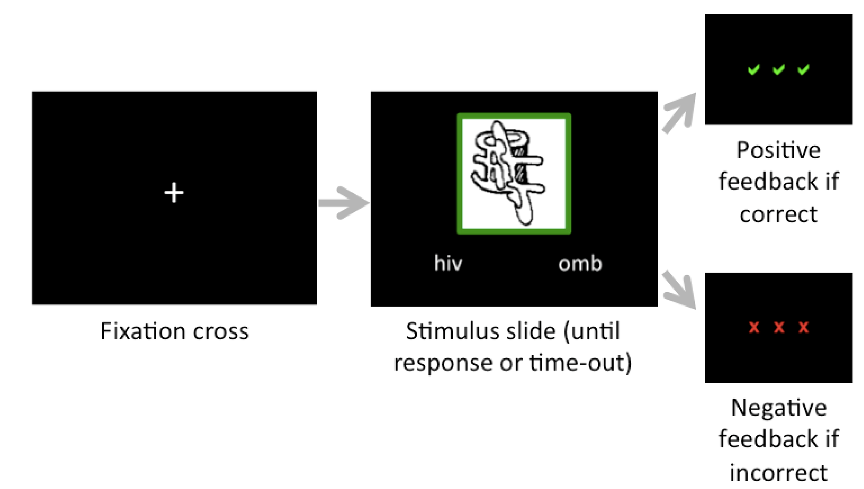
Three learning tasks were presented on 3 separate days: Errorful, Errorless, and Strategy. The order of the first 2 tasks was counter-balanced across participants. The Strategy task was always presented last.

Day 1	Day 2 24-48 Hours	Day 3 7-10 Days
1. Learning Task (Errorful or Errorless); Immediate Test after each block 2. Short Delay Test after all blocks are complete 3. 1 hour interval 4. Long Delay Test	1. Learning Task (Errorful or Errorless); Immediate Test after each block 2. Short Delay Test after all blocks are complete 3. 1 hour interval 4. Long Delay Test	1. Learning Task (Strategy); Immediate Test after each block 2. Short Delay Test after all blocks are complete 3. 1 hour interval 4. Long Delay Test

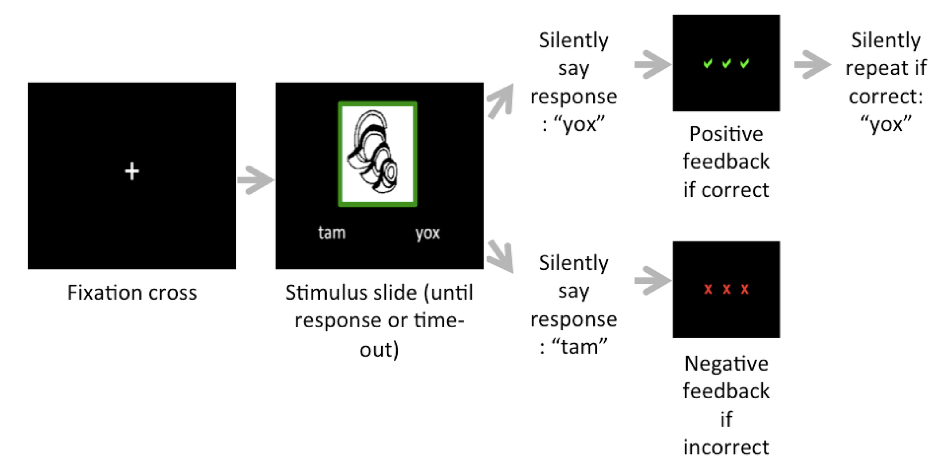
Learning Task Structure

- For each learning task (Errorful, Errorless, Strategy), the participants attempted to learn the non-word names of 27 novel objects. Different non-word names and objects were used for each task.
- The 27 objects for each task were presented in 3 blocks of 9. Within each block, all 9 items were presented 5 times each.
- Immediate testing then took place. At the end of all 3 blocks, all 27 items had been presented, and the Short Delay test was conducted.

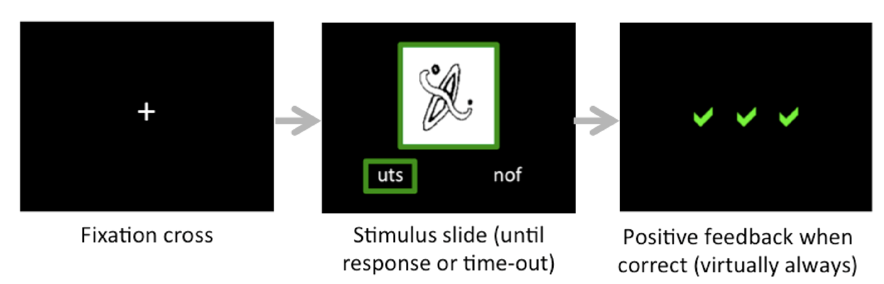
Errorful Learning Trial Structure



Strategy Learning Trial Structure



Errorless Learning Trial Structure



Analysis

EEG Data

Online: EEG was continuously recorded at a sampling rate of 1000 Hz using a 32-electrode sensor net (GES 400, Electrical Geodesics, Inc.). Impedances were maintained below 50kΩ. EEG data were time-locked to feedback presentation.

Offline: A BP filter of 0.1-40 Hz and 1000 ms epoch segmentation were applied. <15% of epochs were manually rejected for artifacts. Data were re-referenced to the average and baseline corrected to the 200 ms prior to feedback presentation. Independent Components Analysis (ICA) was applied using Matlab. Components representing blinks, drift, or noise were rejected. Data from electrode 28 was split into 6 subsets by learning round and feedback type (Pos 1, Neg 1, Pos 2-3, Neg 2-3, Pos 4-5, Neg 4-5). Principal Component Analysis (PCA) was applied to create individual factor scores for FRN and FCP components.

Statistical Analysis

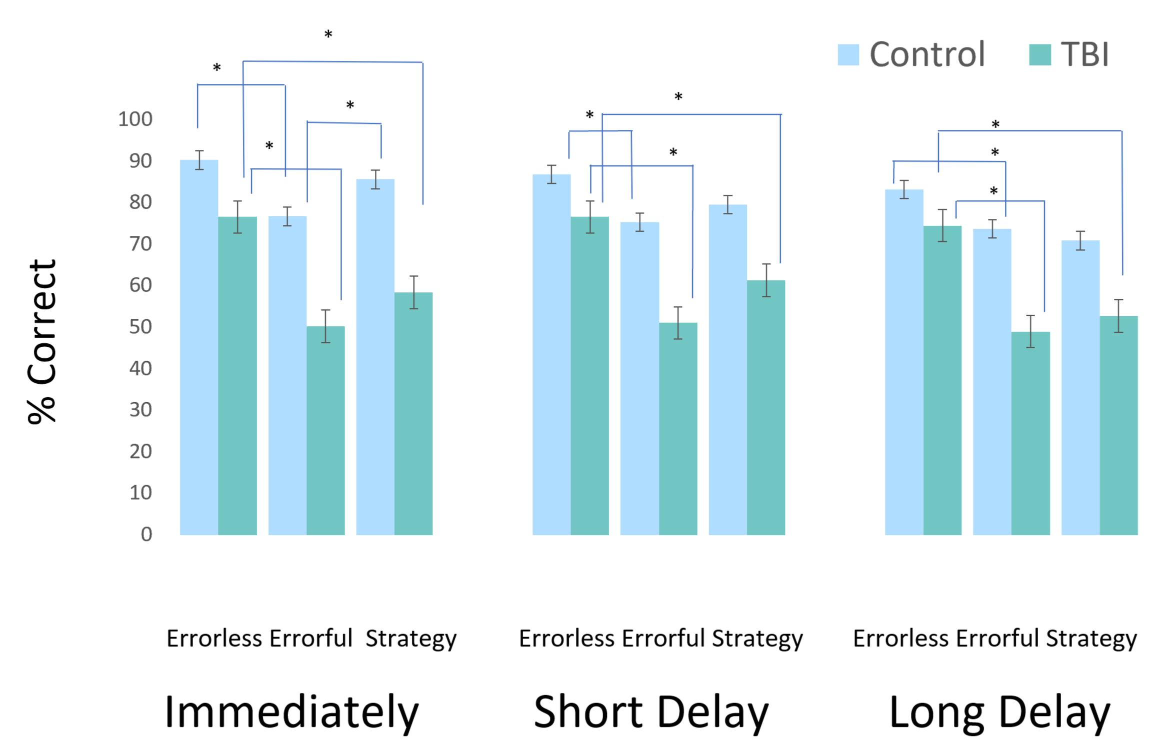
To evaluate learning outcomes, 2x3 ANOVAs (group x learning condition) were run for each testing time point. For each group, t-tests were used to compare the learning conditions at each time point. Alpha was set at .05 with Bonferroni corrections applied to the set of comparisons at each time point for each group.

EEG data was statistically analyzed for the control group to characterize electrophysiological responses in neurotypical individuals. 2x3 ANOVAs (feedback type x round) were used to analyze FRN and FCP factor scores separately for the Errorful and Strategy learning conditions.

Results

Research Question 1

There was a main effect of group at all time points, with controls showing better learning outcomes than people with TBI. For both groups, errorless learning generally resulted in the best performance on average, followed by Strategy, and then Errorful. On-average differences are shown at right, with significant contrasts highlighted. Items were presented 4x each, so chance performance is 25%.



Research Question 2

Statistical Analysis of FRN and FCP Factor Scores

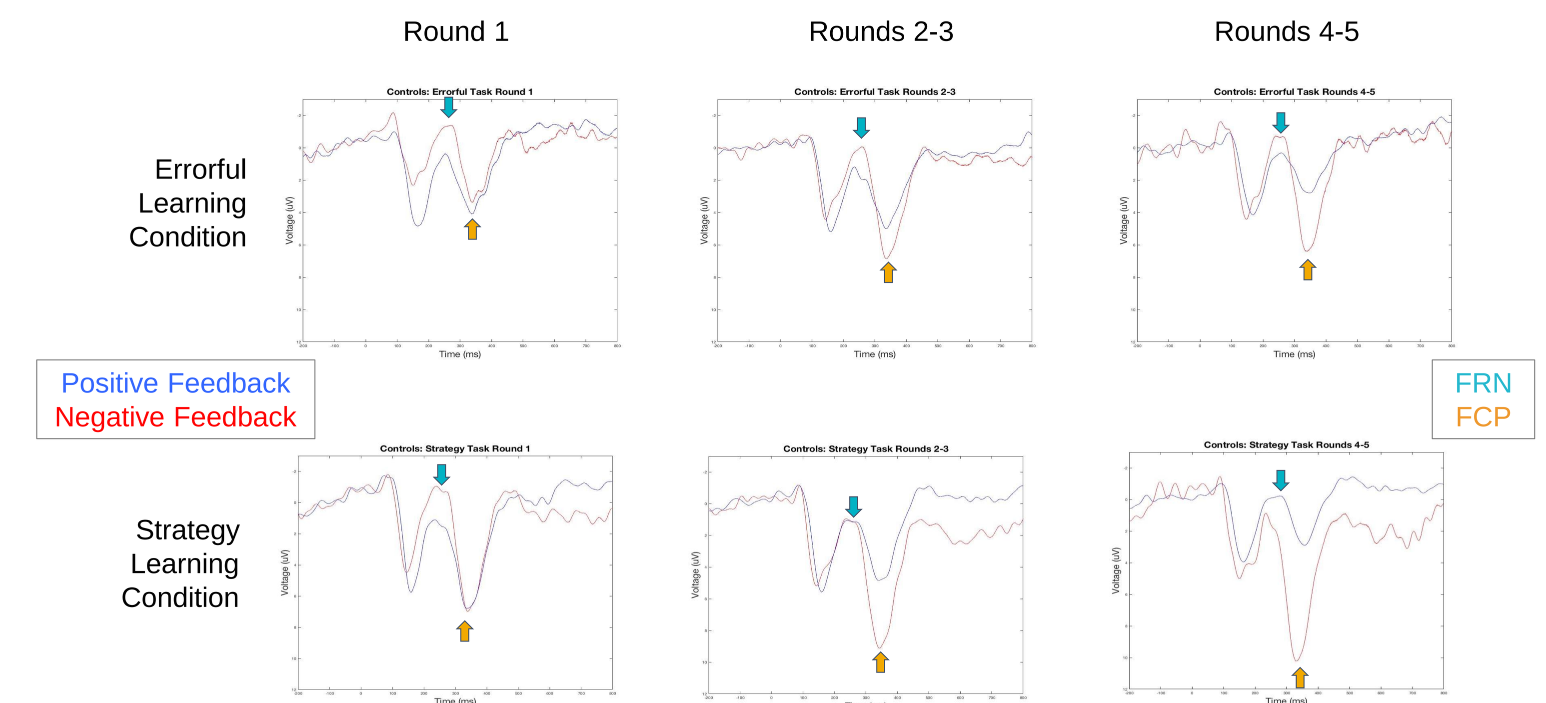
Analysis of FRN Factor Scores for Controls: significant main effect of feedback type in the Errorful condition, with larger amplitudes to negative compared to positive feedback. This was not observed in the Strategy condition, where there were no significant effects.

Analysis of FCP Factor Scores for Controls: significant main effects of feedback type and learning round, and a significant feedback type x learning round interaction, with FCP amplitude in response to negative feedback increasing throughout the learning process. There were no significant effects in the Strategy condition.

Control Grand-averaged ERP Data

Averaged waveforms reflect the larger FRN response to negative feedback revealed in statistical analysis of the Errorful condition. This increased overall FRN response to negative vs. positive feedback is not seen in the Strategy condition, and in fact the response to positive feedback is greater in the later learning rounds.

In the Errorful condition, the increasing FCP response to negative feedback over time is apparent, as revealed in the statistical analysis. A similar increased FCP response to negative feedback over time appears in the Strategy condition, but this did not attain significance, likely due to greater inter-individual variability in this learning condition.



Discussion

For both the control and TBI groups, Errorless learning resulted in the best learning outcomes. The Strategy condition, in which learners were taught a strategy to focus on positive vs. negative feedback, resulted in marginally better learning outcomes compared to the Errorful condition.

In the Errorful condition, there were significant effects of feedback type on ERP responses related to feedback processing. The expected finding of larger FRNs to negative feedback was observed, as well as larger FCPs to negative feedback that increased in amplitude during the learning process. In contrast, these ERP effects were not statistically significant in the Strategy condition, and the FRN was larger on average to positive vs. negative feedback in later rounds of learning, This suggests that the strategy resulted in increased processing of positive feedback. The large FCPs to negative feedback in later learning rounds in the Strategy condition did not attain statistical significance, likely due to within-group variance. This response may reflect a tendency towards heightened attention when suppressing a response, as part of using the strategy.

Taken together, the results support the idea that applying the strategy encouraged a focus on positive feedback, making the errorful learning environment in the Strategy condition more errorless in nature. These effects were not very strong with minimal strategy training and a small number of learning rounds. However, the findings are suggestive that a strategy training approach may be applied to make an errorful learning environment more errorless. This may be applicable when treating patients with memory impairment who benefit from errorless learning.