Learning and Feedback Timing: Comparing Immediate and Delayed Feedback in Healthy Adults

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INTRODUCTION

Feedback about an individual's action can occur immediately or with a delay, and processing of feedback that varies in its delivery time has been proposed to engage differential neural mechanisms. The present study offers an electrophysiological examination to compare the effects of timing on the neural mechanisms responsible for feedback processing. Previous studies indicate that individuals with different diagnoses benefit from adjustments to feedback timing. Because feedback is an essential part of clinical intervention, a greater understanding of feedback processing may provide useful insight for improving service delivery.

BACKGROUND

The **mesencephalic dopamine system**, which includes the striatum and anterior cingulate cortex (ACC), may be most efficient when feedback is **immediate** (Dobryakova & Tricomi, 2013).

•In an fMRI study, healthy adults showed increased activation of the striatum when learning with immediate feedback (Foerde & Shohamy, 2011).

•Individuals with Parkinson's disease, in which the striatum is degraded, showed impaired learning with immediate but not delayed feedback (Foerde & Shohamy, 2011).

The **hippocampal system** is recruited when feedback is **delayed** (Foerde, Race, Verfaellie, & Shohamy, 2013; Peterburs, Kobza, & Bellebaum, 2016).

•The same fMRI study showed an increase in hippocampal activation in healthy adults when feedback was delayed (Foerde & Shohamy, 2011).

•Adults with damage affecting the hippocampus exhibited impaired learning with delayed but not immediate feedback (Foerde et al., 2013).

Complementary to the high spatial resolution that fMRI offers, electroencephalography (EEG) provides high temporal resolution through the examination of event-related potentials (ERPs).

•The **feedback-related negativity (FRN)** has a fronto-central scalp distribution and a maximal peak about 250-300 milliseconds after the presentation of feedback and is generated by the **anterior cingulate cortex** (Holroyed & Coles, 2002; Miltner, Braun, & Coles, 1997).

•The **N170 and vertex positivity potential (VPP)** are recorded by the right occipito-temporal and central electrodes, respectively, between 140-200 ms after stimulus presentation and have been used to study **hippocampal activation** (Epstein, Harris, Stanley, & Kanwisher, 1999, Maguire, Frith, Burgess, Donnet, & O'Keefe,

METHODS

Participants

- Twenty-five healthy adults (19 females, 6 males) between the ages of 20 and 34 (M = 25.72, SD = 3.49). Analysis performed for sixteen participants (12 female, 4 male) ages 20 to 32 years (*M* = 25.4, *SD* = 3.1).
- English as primary language.
- No history of learning or neurological disorders.

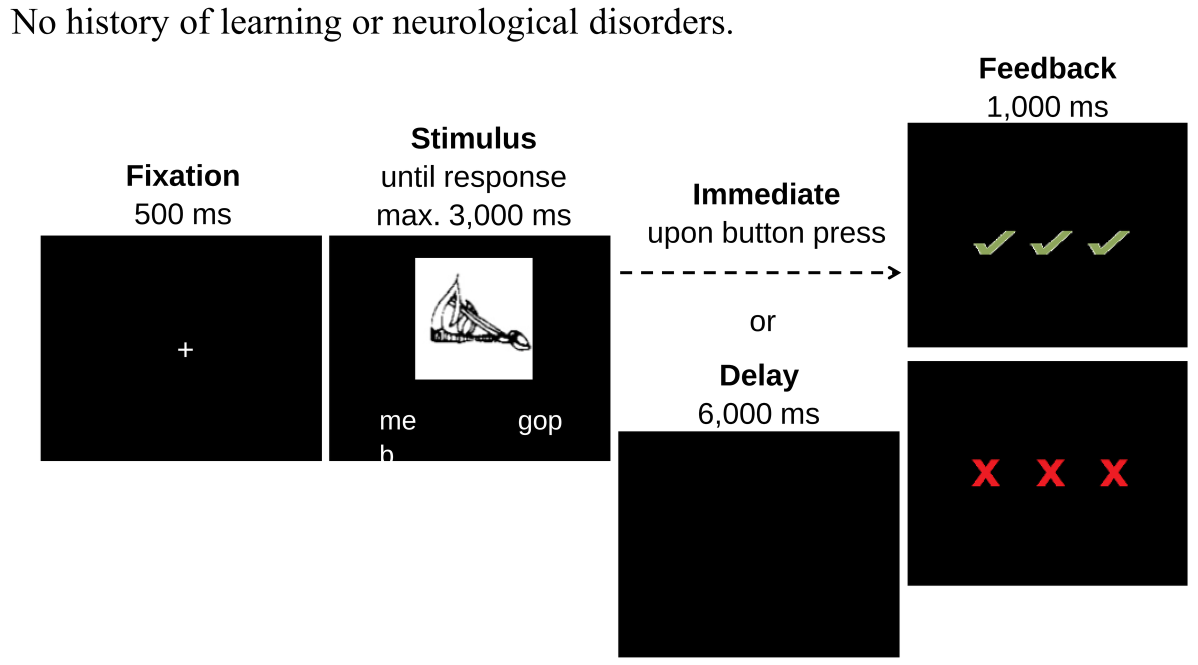

Figure 1. Sequence and time course of stimulus presentation followed by feedback in the immediate and delayed condition.

Procedure

- Visual feedback-based paired-associate learning task with EEG.
- Participants learned non-word names (Rastle, Harrington, & Coltheart, 2002) of 56 novel objects (Kroll & Potter, 1984)
- Four sets of 14 objects: immediate feedback provided in two of the sets and delayed feedback in the other two.
- Each set included five training blocks and a sixth testing block.
- Participants pressed a key on a keyboard to indicate which of the two non-words was the correct name of the novel object (see Figure 1).
- Instructed to guess the correct object name when the options were presented for the first time and use feedback thereafter.
- In the first block, half of the responses resulted in positive feedback and half in negative feedback, creating an equal baseline for all participants. Mapping between objects and names remained constant, leading to valid feedback across all blocks.

RESULTS

Behavioral Data

- Task performance increased across rounds regardless of feedback timing, indicating comparable learning in both experimental conditions.

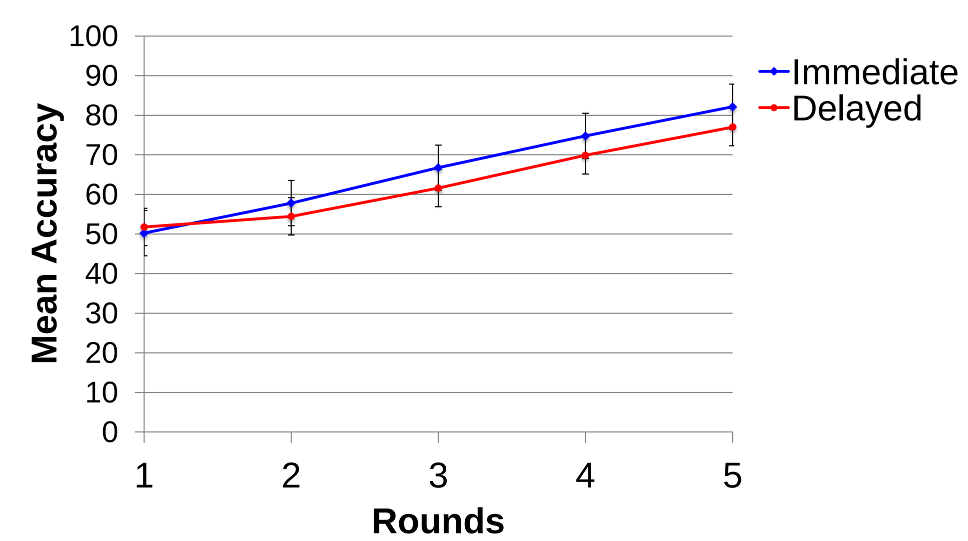

Figure 2. Comparison of mean accuracy across rounds for between the experimental conditions.

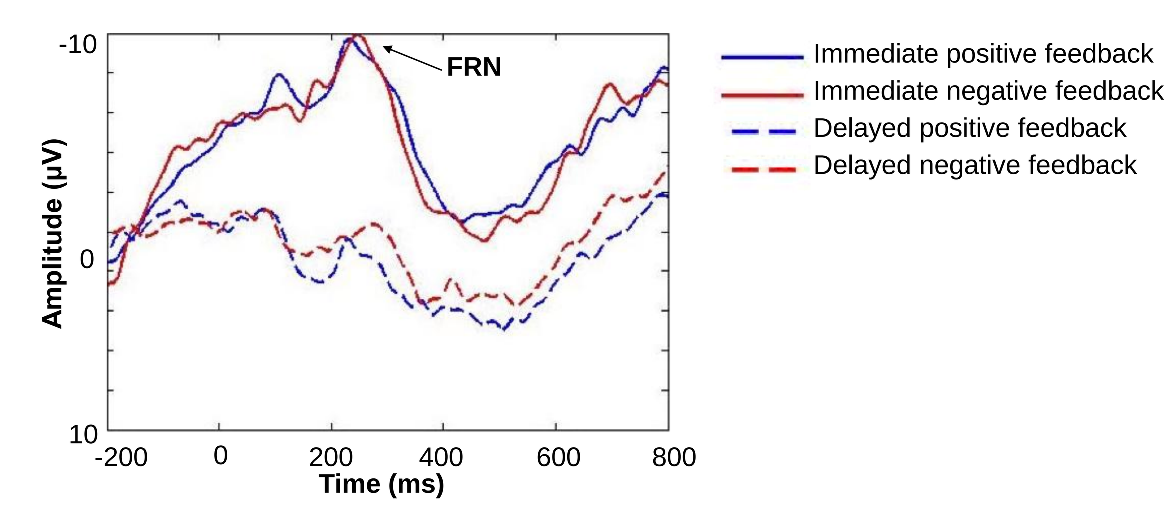

Figure 3. Activity recorded 200 ms before and 800 ms after feedback presentation by electrode FCz.

Electrophysiological Data

FRN

•Larger FRN amplitudes associated with immediate feedback than delayed feedback.

•FRN amplitudes in later rounds were larger than the initial round.

•FRN amplitude was larger with immediate negative feedback than immediate positive feedback, but FRN elicited by delayed negative and positive feedback did not differ.

N170

•Delayed feedback was associated with larger N170 amplitudes than immediate feedback.

•The N170 amplitude was not sensitive to the progression of task related learning or to feedback valence.

VPP

•VPP amplitudes larger for delayed positive feedback than delayed negative feedback.

•No significant differences in the immediate feedback condition between positive and negative feedback.

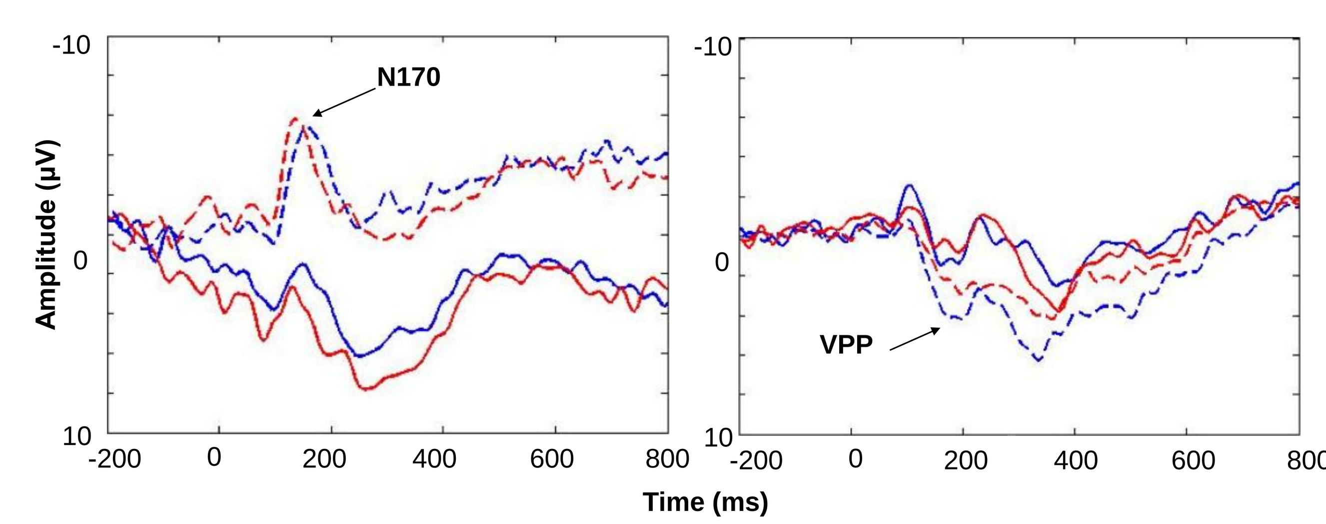

Figure 4. Activity recorded 200 ms before and 800 ms after feedback presentation by electrode P8 (left) and Cz (right).

DISCUSSION

Our findings indicated greater activation of the mesencephalic dopamine system with immediate feedback and recruitment of the hippocampal system when feedback was delayed. These results have implications for clinicians working with individuals who have impairments involving these feedback systems.

Because feedback is an essential aspect of intervention, it may be necessary to evaluate and adjust feedback timing when working with certain individuals, especially if they have disorders affecting their striatum or hippocampus. Individuals with damage to the striatum may benefit more from learning with immediate than delayed feedback, whereas individuals with hippocampal damage may show improved learning when feedback is delayed.

FUTURE RESEARCH

While our participants had no history of learning or neurological disorders, future research with individuals who have impairments affecting the striatum or hippocampus would provide valuable insight to further study the effects of feedback timing on learning.

Furthermore, our findings using the N170 and VPP provided preliminary evidence that supports the use of these ERP components to study the hippocampus in the context of learning. While our study used visual feedback, future research should explore the effects of auditory feedback on this system because the hippocampal feedback processing system may be specific to the visual modality.

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