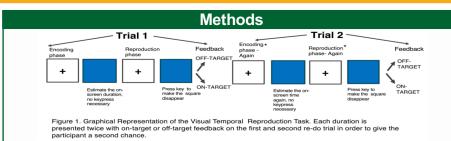# The Effect of Feedback and Reinforcement Learning on Time Perception

Farah Bader, MPH, Mohammad Alquraishi, and Martin Wiener, PhD
Department of Psychology, Krasnow Institute, George Mason University

Introduction

- Recognizing errors in timing and correcting them is essential for metacognition, performance monitoring, and adaptive behavior (Ullsperger et. al, 2014; Fleming & Dolan, 2012)
- Behavioral evidence suggests that humans can detect the magnitude and direction of errors in timing with confidence (Akdogan & Balci, 2017)
- M/EEG studies also demonstrate that humans can successfully self-evaluate timing errors and that the duration is reflected in oscillatory activity (Kononowicz et. al, 2018)
- Learning time and learning from timing errors occurs rapidly. In fact, it can be achieved in one trial due to the swift updating of temporal representations (Simen et. al, 2011)
- Feedback can facilitate learning and improve performance on timing tasks (Aiken,1965; Mitani& Kashino, 2018; Ryan et. al, 2002), particularly if previous trial feedback is applied to the next trial of the same duration (Ryan et. al, 2016)
- Our aim is to understand how targeted feedback and reinforcement learning impact timing behavior
- We will also explore the neuroanatomical correlates and the physiological mediators of learning time and detecting timing errors

Methods

Figure 1. Graphical Representation of the Visual Temporal Reproduction Task. Each duration is presented twice with on-target or off-target feedback on the first and second re-do trial in order to give the participant a second chance.

Study 1 (Behavior only):
- 17 neurotypical, right-handed participants
- Age range of 18-30 years and mean age= 20.92 years, 5 males, 12 females

Task Parameters:
- Randomized durations presented include 1.5, 2.1, 3, 4.2, & 6 sec
- 6 blocks and 10 complete trials per block (2 exposures per trial)
- Re-do trials allow for a second chance to apply feedback from the previous trial to the next trial of the same duration (Ryan et. al, 2016)
- Adaptive on- or off-target feedback starts with initial window of 30%. With subsequent trials, 1% increase in the window with on-target and 1% decrease with off-target responses

Study 2 (Single Subject Simultaneous fMRI-EEG):

Imaging
- EPI-weighted T2 images (6 BOLD sequences) acquired in interleaved sequence from a healthy 21 year old male in 3T Phillips scanner

Electrophysiology:
- Simultaneous fMRI-EEG Recording performed using the passive 64-channel electrode MR-compatible Brain Products EEG cap
- MR-compatible amplifiers connected via fiber optic cable to recording computer
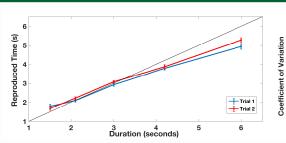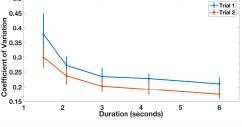
Results

Figure 2. Timing Accuracy by Trial Type. Participants' reproduced time showed a significant main effect of duration (p<0.001), trial (p=0.03), and trial x duration interaction (p<0.034) with less uncertainty in time estimation observed in the second trial and closer estimations to the target durations represented by the identity line. Data expressed in reproduced time ±SEM.

Figure 3. Changes in Precision by Trial type. Participants had significantly lower CV in the second trial (p=0.007). There was also a main effect of duration (p=0.002). Data expressed in CV±SEM.

Figure 4. Individual reproduced time slope changes by trial type. The slope of the second trial was significantly higher than the first trial t(16)=-2.692,p=0.016 and above the identity line. Data expressed as a scatter plot with x and y coordinates corresponding to the first and second trial slopes, respectively of each individual subject.

Figure 5. EEG set-up of 64-channel MR-compatible cap prior to positioning participant inside of the scanner. Later, when in the bore, the subject will be positioned in a large head immobilization device and MR-compatible amplifiers will be connected by ribbon cables to the cap.
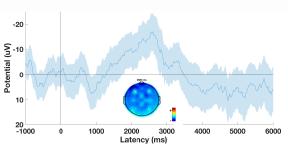

Figure 6. Single Subject Contingent Negative Variation (CNV) from Onset of Reproduction phase. This event related potential was generated from the following fronto-central electrodes: F1, Fz, F2,FC1, FCz, FC2,C1,Cz, and C2 (1000-3000 ms). Data includes both the first and second reproduction onset times (trials 1 and 2) and is expressed in μV ±SEM.
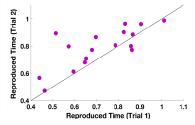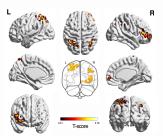

Figure 7. Single Subject EEG-informed fMRI Peak activations. High BOLD activation displayed in the right middle frontal gyrus, right triangular part of the inferior frontal gyrus, right angular gyrus, and the left superior parietal lobe. CNV amplitudes from reproduction onset times in both trials were parametrized and convolved with hemodynamic response function. Voxelwise correction of p<0.01 and cluster threshold of p<0.05, FWE corrected.

Conclusions

- Participants exhibited central tendency with over-reproduction of shorter intervals and under-reproduction of longer intervals
- When offered a second chance to reproduce a given duration, participants were less error-prone and had more accurate temporal estimates, nearer to the target durations
- Subjects were more precise in their second reproduction estimates and showed less bias and more certainty in their estimates
- Behavioral findings demonstrate that subjects were able to learn interval durations by leveraging the on- and off-target feedback to improve time perception in the second round of the task, demonstrating the metacognitive ability to adapt without receiving directional feedback

- The observance of the CNV during the reproduction onset implies the presence of attentional, anticipatory, accumulator, and timing-related processes
- The CNV is linked to BOLD activation in regions devoted to time perception such as the inferior frontal gyrus
- Continuing work on this study will examine ERP responses and the neuroanatomical regions linked to on- and off-target feedback and reward/reinforcement learning directly
- Future work on this study will explore ERPs (Pe) related to making confidence judgements about interval durations
- Further work on this study will analyze oscillatory activity related to temporal preparation, error correction, or self-deduction of temporal errors

Contact:
Farah Bader
George Mason University
Email: fbader2@masonlive.gmu.edu

Martin Wiener
George Mason University
Email: mwiener@gmu.edu

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