Hemispheric differences in parietal contributions to auditory beat perception

Shannon Proksch*[1], Jessica Ross[2], and Ramesh Balasubramaniam[1]

*Corresponding Author: sproksch@ucmerced.edu

[1]Cognitive & Information Sciences, University of California, Merced, Merced, USA

[2]Berenson-Allen Center for Noninvasive Brain Stimulation, Harvard Medical School, Boston, USA

ABSTRACT

Previous work with transcranial magnetic stimulation (TMS) down-regulated activity, using the continuous theta burst (cTBS) protocol, in the dorsal auditory stream and demonstrated a causal relationship between this motor cortical network and musical beat perception (Ross et al., 2018). Specifically, cTBS of the left posterior parietal cortex (PPC) interfered with accurate detection of shifts of beat-phase, but not absolute interval timing discrimination or changes in musical tempo. **The data presented here are part of an ongoing study examining whether the right PPC, which is implicated in many aspects of spatial cognition and pitch transformation, is also causally involved in beat-based musical timing perception, and if there are differences between left and right hemisphere PPC involvement in beat-based timing perception.** We compared the effects of downregulating the left versus right PPC in 18 participants to discover hemispheric differences in beat-based musical timing perception. **Three aspects of timing perception are investigated: 1) discrete interval timing discrimination, as well as two facets of relative beat-based musical timing—detection of alterations to 2) tempo (sped up/slowed down) and 3) shifts in phase (forward/back).** Participants were tested pre- and post- stimulation using a psychoacoustic test of sub-second interval discrimination and the Adaptive Beat Alignment Test (A-BAT). Preliminary data suggest a role for the left PPC in detecting shifts in beat phase and interval discrimination, but not in tempo detection. The data also suggest a possible effect of the right PPC in interval discrimination, but not in detection of phase or tempo alterations. We discuss these trends in the context of hemispheric and functional differences across the parietal lobes and the Action Simulation for Auditory Prediction (ASAP) hypothesis.

BACKGROUND & HYPOTHESES

With increasing evidence for the involvement of the motor system in perception and cognition—including in music, speech, and language processing—it is important to determine whether motor activity plays a causal role in perception or if it is merely an epiphenomenal result of associative learning. **Transcranial Magnetic Stimulation (TMS) provides a method of investigating the causal role of motor activity** by temporarily down-regulating or up-regulating neural activity of a target network and observing subsequent behavioral or perceptual effects. **The ASAP Hypothesis suggests that periodic dorsal auditory stream activity allows for auditory prediction in beat-based musical timing perception** (Patel & Iverson, 2014). This is supported by causal TMS research, demonstrating links between specific types of beat processing and regions of the dorsal auditory stream. Earlier work showed that medial cerebellum may be involved in absolute interval timing, but not beat-based timing (Grube, Lee et al., 2010; Grube, Cooper et al., 2010), and Ross et al. (2018) showed that left PPC may be involved in one aspect of beat-based timing, phase shift detection, but not tempo detection or discrete interval discrimination. **The current study predicts that down-regulating activity in left PPC will interfere with the ability to detect changes in beat phase, but not tempo or interval timing, and asks whether there are hemispheric difference between left and right PPC in beat-based timing.** It has been suggested that time is represented in spatial terms (Bonato et al., 2012), and lesions in right PPC impair temporal processing of narrative events (Bonato et al., 2016). fMRI work suggests that mental reversal of musical stimuli in the auditory-temporal domain, like mental rotation in the visual-spatial domain, recruits right PPC (Zatorre et al., 2010). Thus, we hypothesize right PPC involvement in beat-processing, motivated by it's role in temporal processing, auditory imagery, and it's critical location in the dorsal stream between auditory and motor planning regions.

METHOD

Participants (N=18, 10F/8M, ages 18-23) were University of California, Merced undergraduate students. All participants were dominantly right-handed and screened for atypical hearing and contraindications for TMS. Six participants were identified as musicians, defined as 3+ years of musical training/experience (one with 6 years, one with 4 years, and four with 3 years musical experience). **Participants were tested in three timing perception tasks, one that determines a threshold for absolute interval timing discrimination, and two that determine thresholds for relative beat-based timing perception with musical stimuli (detecting changes in tempo or phase shifts), both pre- and post-TMS.** TMS was applied using a continuous theta burst stimulation (cTBS) protocol (Huang et al., 2005) to down-regulate cortical activity at target locations. cTBS was administered in a 40-sec train of three pulses at 50Hz, repeated at 200ms intervals, for a total of 600 pulses at 80% of the participant's active motor threshold (AMT). AMT was determined as the lowest stimulator intensity sufficient to produce a visible twitch in 5 out of 10 trials in the first dorsal interosseous (FDI) muscle with single pulse to a left primary motor cortex hotspot. **cTBS was applied to down-regulate activity in two target locations—left and right posterior parietal cortex (PPC)—and in a sham condition over left motor cortex with the coil facing away from the head.** Participants received all three conditions across three separate days in a randomized order. All participants completed all three timing tasks in a randomized order pre- and post-stimulation at each session.

FIGURE 1

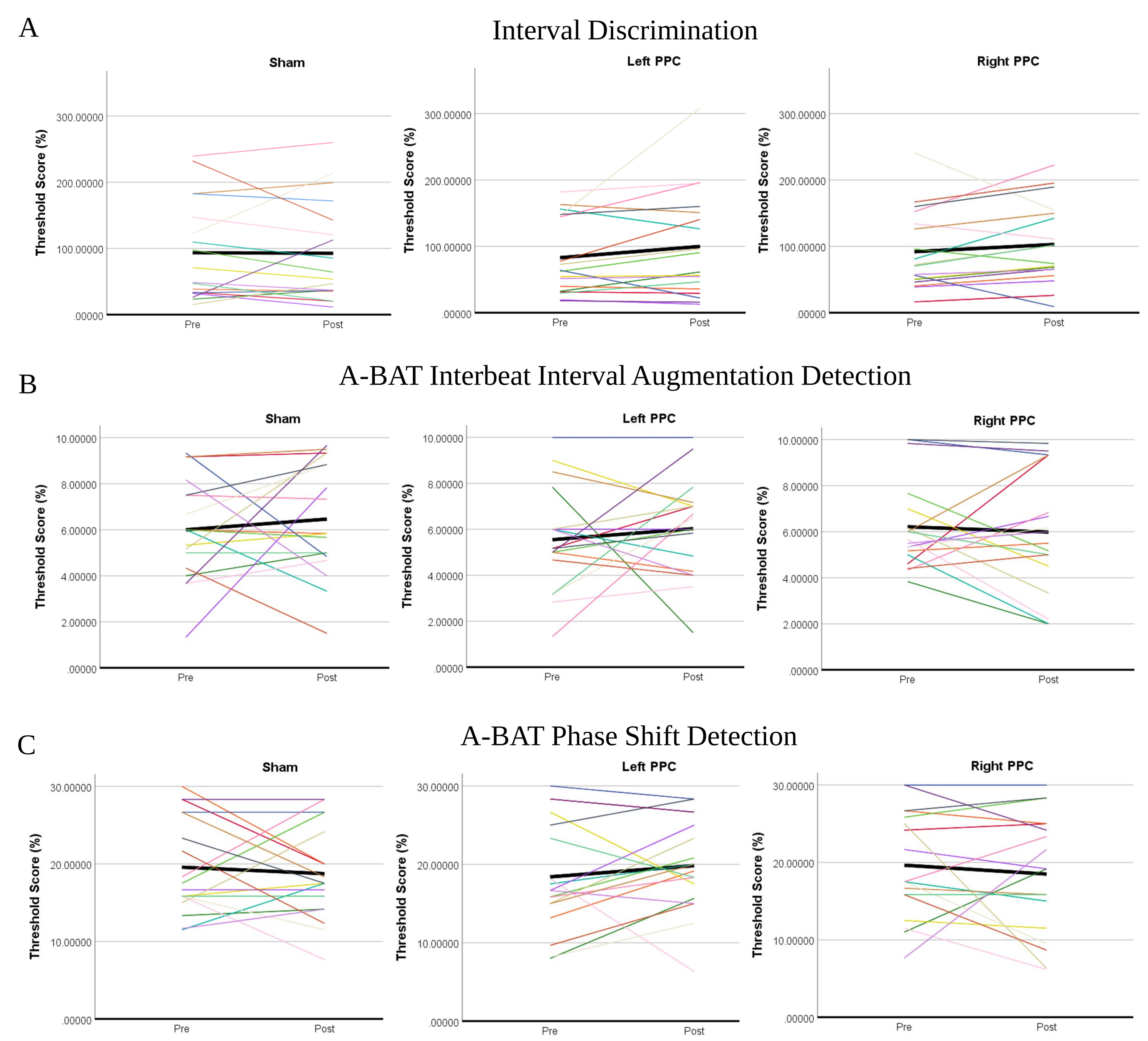
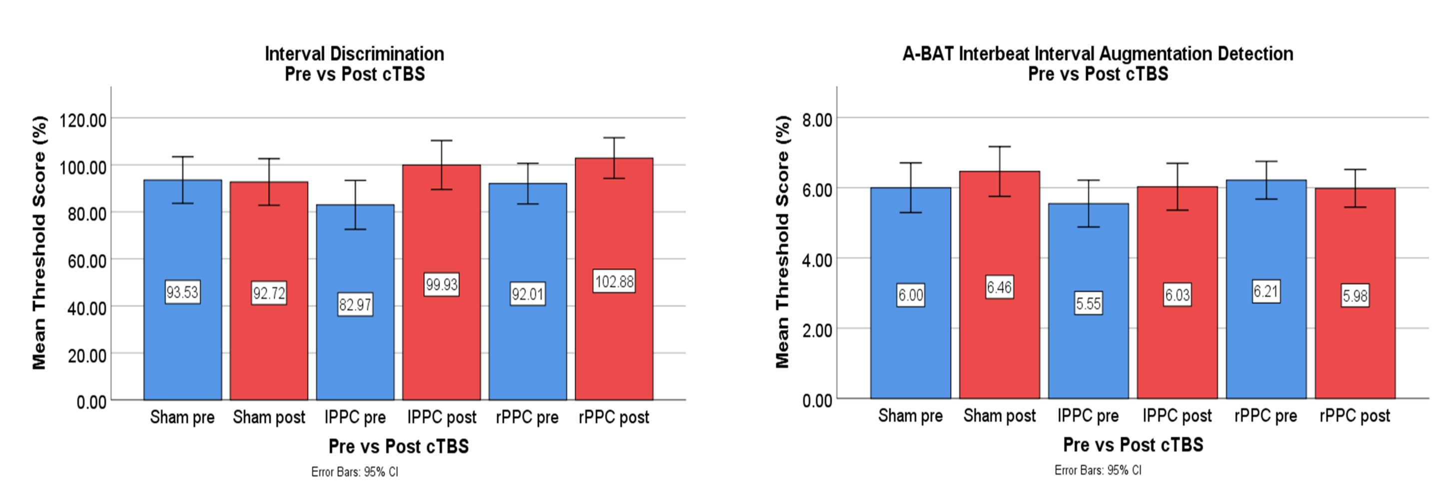


Figure 1. Pre- and post-cTBS thresholds for three timing perception tasks in two stimulation conditions and one sham stimulation condition (mean thresholds in black, individual thresholds in color). (A) Single-interval duration discrimination. (B) IBI deviation detection with musical stimuli (A-BAT IBI). (C) Phase shift detection with musical stimuli (A-BAT Phase).

FIGURE 2



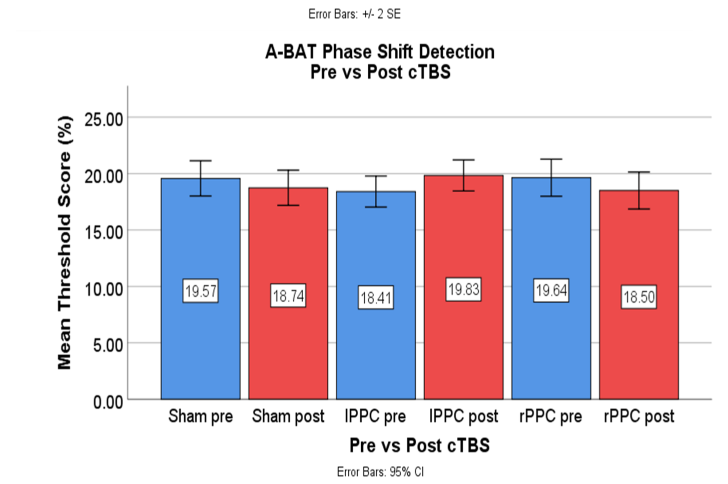


Figure 2. Pre- and post-cTBS mean threshold scores for three timing tasks in two stimulation conditions and one sham stimulation condition. Error bars represent 95% confidence intervals. Trends are observed in left PPC for an increase in detection threshold pre- to post-stimulation for phase shift detection with musical stimuli. Trends are observed in left and right PPC for an increase in single interval duration discrimination.

TIMING TASKS

- **Absolute timing perception: A) Single interval discrimination**. Participants were presented with a series of single interval discrimination trials which consisted of two groups of two beeps. Participants indicated by key press whether the interval of silence between the two beeps in each group were the same or different. This test used an adaptive procedure, as in Grube et al (2010).
- **Relative, beat-based timing perception with musical stimuli: B) A-BAT Interbeat interval augmentation detection, C) A-BAT Phase shift detection.** Participants were given the A-BAT (Ross et al., 2018), an adaptive version of the Beat Alignment Test developed by Iverson & Patel (2008). In each subtest, participants hear a musical excerpt overlaid with a metronome beep that is either on-beat or off-beat. In the A-BAT IBI subtest the off-beat metronome beep corresponded to a manipulation of tempo (faster or slower). In the A-BAT Phase subtest, the off-beat metronome corresponds to a phase asynchrony, or manipulation of phase late or early. In both tests, participants indicate by key press whether the metronome is on- or off- beat in each trial.

PRELIMINARY RESULTS

These preliminary data show no statistically significant effects. The data exhibit a slight trend toward an increase pre- to post-stimulation in phase shift detection thresholds with cTBS to left PPC ($t(17) = -1.037$, $p = .314$. There is a subsample of participants who become less sensitive to phase shifts after cTBS to left PPC. Both of these results are consistent with previous research (Ross et al., 2018). The data also trend towards an increase in single interval duration discrimination threshold with cTBS to right PPC ($t(17) = -1.257$, $p=.226$), as well as to left PPC ($t(17) = -1.631$, $p=.121$), contrary to previous indication that left PPC is not involved in absolute interval timing (Ross et al., 2018). Substantial individual differences are common in perceptual tasks and in response to the cTBS protocol (see Figure 1), and require large samples to accurately rule out outliers and to determine real statistical effects. As data collection continues (target sample of N=35 as per power analysis), real cTBS induced changes will become significant.

DISCUSSION POINTS FOR COMPARING MUSIC AND LANGUAGE

The current trajectory of motor theories of both music and language cognition are emblematic of the pragmatic turn toward action-oriented views in cognitive science (see Engel, Friston, & Kragic, 2015). The involvement of the motor system in perception and cognition extends farther than simple mirror-neuron simulation of other's actions, and it is increasingly shown that perception involves activity in distributed motor planning pathways. **TMS provides a non-invasive means for studying the causal role of the motor system in both music and language perception/cognition.** One explanation for motor involvement in perceptual processing is that motor neural activity provides a stable predictive model for other sensory modalities. In musical beat-perception, the motor system provides a predictive model of the periodic motor action that would be required to generate the current periodic auditory stimuli, facilitating auditory timing perception (Patel & Iverson, 2014). In speech processing, the motor system provides a predictive model of the articulatory motor action required to generate the current acoustic speech signal, facilitating speech perception (Mottonen, & Watkins, 2011). **Causal TMS experiments continue to expand the boundaries of action-oriented cognitive science, enhancing our understanding of the predictive & embodied nature of cognition.**

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