Benefits of Targeted Memory Reactivation in Perceptual Learning of Non-native Tones are Associated with Slow-oscillation Phase and Delta-theta Power
Xiaocong Chen1, Jiayi Lu1, Zhen Qin2, Xiaqing Hu3, Caicai Zhang1
1The Hong Kong Polytechnic University, 2The Hong Kong University of Science and Technology, 3The University of Hong Kong
xiaocong.chen@polyu.edu.hk, jiayi-rachel.lu@polyu.edu.hk, hmzqin@ust.hk, xiaqinghu@hku.hk, caicai.zhang@polyu.edu.hk

Perceptual learning of non-native speech sounds involves the formation of new phonological categories in long-term memory, which is supported by memory consolidation processes [1]. Recent studies indicate that sleep could facilitate memory consolidation during the perceptual learning of non-native speech sound categories [2][3]. Intriguingly, a new technique, known as targeted memory reactivation (TMR), has been reported to boost the reactivation of newly learned information during sleep by presenting external sensory cues associated with prior learned information during sleep [4]. However, the neural oscillatory activities induced by TMR in relation to the behavioral performance of memory consolidation are not well understood. Besides, TMR has been successfully applied to vocabulary learning [5] and grammar learning [6], but the application of this new technique in the perceptual learning of non-native speech sounds remains unexplored. To address these issues, the current study employed TMR in the perceptual learning of Cantonese level tones by native Mandarin speakers and examined the TMR benefits and the associated underlying neural activities.

Sixty-two native Mandarin speakers who were naïve to Cantonese were recruited to complete the perceptual learning of three Cantonese level tones. The experiment consisted of three sessions: (a) pre-TMR training and assessment session, where participants received training on the three Cantonese level tones and were assessed by a forced-choice identification task (identifying the correct tonal category among the three level tones upon hearing a tonal syllable); (b) a 90-min nap session with TMR, where half of the learned auditory tonal syllables (i.e., cues) were played to the participants during the slow-wave sleep (SWS) stage while their sleep EEG signals were recorded (the cued and uncued syllables were counterbalanced across the participants); (c) post-TMR assessment session, where participants’ learning of the Cantonese level tones were re-assessed using the same forced-choice identification task as in the pre-TMR training session.

Although our focus is the individual differences in the brain oscillatory patterns as they contribute to the TMR benefits, we first analyzed the learning effect and behavioral changes related to TMR cues. By comparing the accuracy of the initial and final block of the pre-TMR training task, we observed significant accuracy improvement after tonal training, confirming the occurrence of perceptual learning. Intriguingly, the logistic mixed-effect regression analysis for the pre- and post-TMR identification tasks revealed no significant difference in the consolidation effects between the TMR-cued and uncued tonal syllables, indicating TMR benefits were not confined to specific cued items in tonal learning (see Fig 1). There was only a significant main effect of testing session, with worse performance in the post-TMR identification task than the pre-TMR identification task, indicating memory decay after sleep. The lack of cued syllable effects can be explained by the nature of the training task, which requires participants to categorize tonal categories in an abstract manner irrespective of syllables, consistent with the formation of abstract tonal representations.

Importantly, we compared the sleep EEG data between participants with higher TMR and those with lower TMR benefits. The phase analysis showed that the phase angles at the onset of the auditory cues for the higher benefit group exhibited a significant non-uniform distribution in the parietal electrodes, which was not observed for participants with lower TMR benefits. Specifically, the trial-level cue onsets from the parietal electrodes among the higher benefit group were preferentially coupled to the slow oscillatory up-states (see Fig 2). In addition, the time-frequency analysis revealed higher post-cue delta-band (1-4 Hz) and theta-band (4-8 Hz) power for the higher benefit group than the lower benefit group (see Fig 3). These suggest that the degree of TMR benefits may be associated with the relative coupling between the cue onset and the SO up-state, and the increase in the post-cue delta-theta power, consistent with recent findings [7][8]. These findings shed some new light on the neural oscillatory mechanism of memory reactivation and consolidation during sleep in speech sound learning, and also demonstrate some potential value of TMR for assisting in the perceptual learning of non-native speech sounds by second language learners.
Figure 1: Accuracy of the pretest and posttest for cued and uncued syllables.

Figure 2: Phase angle distributions of the cue onset in PZ for high- and low-TMR-benefit groups

Figure 3: Average time-frequency power of nine electrodes for high- and low-TMR-benefit groups

References