Auditory stimulation of EEG slow waves (SW) during non-rapid eye movement (NREM) sleep has shown to improve cognitive function when it is delivered at the up-phase of SW. SW enhancement is particularly desirable in subjects with low-amplitude SW such as older adults or patients suffering from neurodegeneration such as Parkinson disease (PD). However, existing algorithms to estimate the up-phase suffer from a poor phase accuracy at low EEG amplitudes and when SW frequencies are not constant. We introduce two novel algorithms for real-time EEG phase estimation on autonomous wearable devices. The algorithms were based on a phase-locked loop (PLL) and, for the first time, a phase vocoder (PV). We compared these phase tracking algorithms with a simple amplitude threshold approach. The optimized algorithms were benchmarked for phase accuracy, the capacity to estimate phase at SW amplitudes between 20 and 60 V, and SW frequencies above 1 Hz on 324 recordings from healthy older adults and PD patients. Furthermore, the algorithms were implemented on a wearable device and the computational efficiency and the performance was evaluated on simulated sleep EEG, as well as prospectively during a recording with a PD patient. All three algorithms delivered more than 70% of the stimulation triggers during the SW up-phase. The PV showed the highest capacity on targeting low-amplitude SW and SW with frequencies above 1 Hz. The testing on real-time hardware revealed that both PV and PLL have marginal impact on microcontroller load, while the efficiency of the PV was 4% lower than the PLL. Active auditory stimulation did not influence the phase tracking. This work demonstrated that phase-accurate auditory stimulation can be delivered during home-based sleep interventions with a wearable device also in populations with low-amplitude SW [1].

In the operating room, auditory stimulation with broad-band clicks is preferred. Each clicks should be generated by a single 100-µs monophasic square wave pulse. Conformable earplugs connected to a transducer are generally used for stimulation. If compressible tubing is used to connect the earplugs to the transducer, care should be taken to avoid obstruction of the tubing system that would lead to failure of sound transmission. In-ear speakers are an acceptable alternative. Earplugs connected to a transducer or in-ear speakers should be protected from blood and fluids by waterproof adhesive tapes. Prior to placement of earplugs, otoscopic visualization of the external auditory canal is useful to confirm patency. Excessive cerumen that could interfere with the auditory stimulation should be cleared prior to the monitoring. Clicks should be delivered monaurally, i.e., one ear at a time. Although the ear ipsilateral to the site of surgical intervention may be continuously stimulated and monitored, the contralateral ear should also be stimulated at regular intervals to check for developing asymmetry, latency, and amplitude differences. When stimulating the ears sequentially, the nonstimulated ear should be masked with a white noise at 60 dB pe SPL or 30-35 dB HL to eliminate “crossover” responses, i.e., bone-conducted responses originating in the nonstimulated ear. Modern NIOM equipment has the ability to deliver interleaved stimulation. This effectively allows simultaneous averaging of left and right ear stimulation. However, interleaved stimulation does not allow contralateral masking. This is not a significant problem intraoperatively, as lack of masking will not prevent recognition of auditory pathway compromise.{Legatt, 2008 #44}

[1]
Ferster ML, Da Poian G, Menachery K, Schreiner S, Lustenberger C, Maric A, Huber R, Baumann C, Karlen W. Benchmarking real-time algorithms for in-phase auditory stimulation of low amplitude slow waves with wearable EEG devices during sleep. IEEE Trans Biomed Eng. 2022 Mar 8;PP. doi: 10.1109/TBME.2022.3157468. Epub ahead of print. PMID: 35259094.