Research Article

Is It Possible to Use the Speech-Evoked Auditory Brainstem Response Test During Sleep as It Is Used During Wakefulness?

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Highlights

- The speech-evoked auditory brainstem response can be recorded during sleep
- It seems that sleep can affect some parameters of speech-ABR in comparison to awake

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ABSTRACT

Background and Aim: It is important to know how much are the auditory electrophysiological tests affected by sleep and wakefulness to be employed in different situations. This problem is more important for the speech-evoked Auditory Brainstem Response (speech-ABR) test that is affected by higher-level processing. This study aimed to compare the results of the speech-ABR test between wakefulness and sleep states.

Methods: Sixteen young male adults (aged 20–28 years) with normal hearing participated in this study. The speech-ABR to the /da/ syllable was recorded during wakefulness and sleep. Electroencephalography (EEG) and behavioral tests (eyes position, body movements, etc.) were monitored during the test time to confirm the sleep state.

Results: The speech-ABR test parameters showed significant changes during sleep compared to wakefulness (latencies of waves V and A were longer and the amplitudes of waves V and A, the slope of V-A complex, and the spectral magnitude of F1 were lower). However, the spectral magnitude of higher frequencies was not significantly different. In addition, no significant statistical difference was observed in speech-ABR parameters between right and left ears.

Conclusion: Although the speech-ABR originates from brainstem centers, unlike conventional click-evoked ABR, it is affected by sleep as it is affected by the higher-level auditory processing functions. Although, further studies are needed. However, our study opens the way for many applied auditory studies about the possibility to use speech-ABR for auditory processing assessments in sleep state of different population groups, such as neonates.

Keywords: Auditory brainstem response; speech acoustics; sleep; electroencephalography

Introduction

In recent years, due to the importance of the use of speech stimuli in auditory assessments, most researchers use speech-based auditory tests [1, 2]. These tests are divided into two general categories: behavioral and electrophysiological, which examine different levels of the auditory system, from the cochlear to the cortex [3].

The speech-evoked Auditory Brainstem Response (speech-ABR) test is one of the important electro-physiological tests that has been widely used in recent years. It evaluates the auditory processing of speech stimuli in the subcortical levels [1, 2]. Speech-ABR consists of two main transients (waves V, A, C, and O) and sustained (waves D, E, and F) portions. Waves V and A represent the responses to the speech onset; wave C represents the transition from consonant to vowel; the region between wave D and F shows the Frequency-Following Response (FFR); and wave O represents the response to the speech offset [1, 2]. Speech-ABR, like the click-evoked ABR, seems to originate from the brainstem [4]. However, speech-ABR indicates higher-level cognitive-auditory processing [4, 5] and are affected by higher auditory skills [6] and disorders [7-9]. Therefore, the speech-ABR can be helpful as an objective test for auditory processing in newborns and children.

Electrophysiological tests, including speech-ABR tests, are challenging to perform in wakefulness state due to muscle artifacts in newborns and hard-to-test patients. Conventional click-evoked ABRs are not affected by sleep [10]; therefore, they are suitable for use when subjects are asleep or sedated [1, 4, 10]. However, speech-ABR is more sensitive to higher-level auditory processing than click-evoked ABR [9], causing it to have better performance in wakefulness state to eliminate unconsciousness effects [1, 4]. This limitation makes speech-ABR less suitable for young children or hard-to-test groups.

Wakefulness is a conscious state where individuals can monitor, interact, and respond to their surroundings consciously [11]. Sleep, on the other hand, is a natural, involuntary, recurring [12], cyclical [13, 14], and physiological state [13] with reduced mobility, decreased alertness [12], and reduced response to sensory stimuli [14]. The American Academy of Sleep Medicine (AASM) has proposed new criteria for classifying sleep stages, including wakefulness (stage W), Non-Rapid Eye Movement (NREM) sleep (N1, N2, and N3), and Rapid Eye Movement (REM) sleep (stage R) [13]. N1 and N2 are known as light sleep, N3 as deep sleep, and REM as paradoxical or dreaming sleep [15]. These stages typically start from stage N1 and end at stage R, repeating cyclically for 4–5 times during adult night sleep [16]. Stage R usually occurs 80–100 minutes after the start of sleep [13].

Previous studies have examined the effects of sleep and wakefulness on electrophysiological auditory responses to investigate the possibility of using them in sleeping state [10, 17, 18]. Studies show that Auditory Steady-State Responses (ASSRs) can be recorded during sleep, but the results vary depending on the stimulation rate. The 80-Hz ASSR remains unaffected during sleep, but the conventional 40-Hz ASSR is reduced [17]. In the Auditory Middle-Latency Responses (AMLRs), which originated from the supra-brainstem regions [3], the amplitudes decrease, and the latencies increase during NREM sleep [10], while in Auditory Late-Latency Responses (ALLRs), which originate from the cortical levels and the thalamocortical region [3], the latencies increase and the amplitudes change individually and differently during sleep [18]. Additionally, the function of auditory regions in the temporal lobe decreases during NREM sleep [19]. As a result, the effects of wakefulness on electrophysiological auditory responses increase from the cochlear to the auditory cortex, with higher-level responses affected by wakefulness [19]. Regarding speech-ABR, which mostly originate from the rostral parts of the auditory brainstem, one study used the speech-ABR during sleep [20], but there was no comparison in speech-ABR parameters between wakefulness and sleep conditions. In addition, there is no consensus among researchers on the state of arousal for recording speech-ABR in sleep [4]. This suggests the need for further investigation of the difference in speech-ABR parameters between wakefulness and sleep conditions. Given the proven ability of the speech-ABR test to demonstrate higher-level processing of auditory skills and deficits, contrary to the click-evoked ABR test that is not affected by sleep, it seems that speech-ABR can be affected by the state of consciousness. In this regard, this study aimed to investigate the effects of wakefulness and sleep (regardless of the sleep stages) on speech-ABR test parameters.

Methods

Participants

In this cross-sectional study, 18 Persian-speaking men voluntarily participated. Regarding gender differences between men and women in the speech-ABR [21], and according to the available population, only male subjects were tested in this study. Of 18 participants, two were excluded due to poor speech-ABR morphology. The age of participants was in the range of 20–28 years (mean: 23.81±2.1 years). This age range is one of the normative ranges (age 18–28 years) for speech-ABR test in the auditory evoked potential device (Bio-logic Navigator Pro, Bio-Logic Systems Corp, Mundelein, IL, USA). All participants had normal middle ear function (tympanometry type An and existence of acoustic reflexes at frequencies of 500–4000 Hz using AT235-Tympanometer, Interacoustics, Denmark), bilateral normal hearing (hearing thresholds<20 dB HL at frequencies of 250–8000 Hz using AC40-audiometer, Interacoustics, Denmark), normal click-evoked ABR (normal latency and morphology of wave V using the Bio-logic Navigator-Pro), and were good sleepers based on self-report. None of them had special musical skills and any history of neurological, sleep, or auditory disorders, and they were not using ongoing medications. The subjects were asked not to sleep the night before the study or sleep only for 2–4 hours and avoid caffeine consumption 24 hours before the study. After explaining the study objectives and methods to them, and obtaining a written informed consent from them, they entered to this study.

Stimuli and electrophysiological recording

For speech-ABR test, the used stimulus was the syllable /da/ that was synthesized with 5 speech sound formants (fundamental frequency (F0): 103–125, F1: 220–720, F2: 1700–1240, F3: 2580–2500, F4: 3600, F5: 4500 Hz). The speech-ABR test consisted of 7 waves including V, A, C, D, E, F, and O that occur 6–50 ms after the presentation of the speech stimulus. Three electrodes were used using conventional pattern (reference electrode on the ipsilateral mastoid, active electrode on the Fz, and ground electrode on the contralateral mastoid). The impedance of the electrodes was below 3 kΩ. The stimuli were presented with an intensity of 80 dB SPL at a rate of 10.9/s for 40 ms at a time window of 85.33 ms with an artifact rejection of ±23.8 mV with band-pass filtering from 100 to 2000 Hz and alternating polarity through an earphone (ER-3, Etymotic Research, Elk Grove Village, IL, USA). Two blocks of 3000 trials were collected and combined with the Bio-logic Navigator Pro System; therefore, 6000 sweeps without artifacts obtained.

Physiological recording

Electroencephalography (EEG) was continuously recorded by an amplifier (ANT-Neuro, Enschede, Netherlands), and data were uploaded to ASA-Lab software v.4.10.1 (ANT-Neuro b.v., Netherlands) for monitoring. The conventional gel-based cap (Wave guard Original, ANT-Neuro b.v., Enschede, Netherlands) was used. Impedance of electrodes was below 10 kΩ. Responses were filtered from 0.1 to 100 Hz at a rate of 250 Hz.

Procedure

After assessing the inclusion criteria in preliminary tests (started at around 10 AM and lasted for about one hour), the speech-ABR test was performed in the right ear and then in the left ear in wakefulness state, while the participants sat in a comfortable chair with their eyes open in a quiet room (started at around 11 AM and lasted less than one hour). After this stage, the lights in the room were turned off and people lay down on a bed and were asked to sleep. After 1–1.5 hours, the speech-ABR test was recorded in the right ear and then in the left ear in sleeping state (started at around 1 PM and lasted less than one hour). During the study, participants were monitored using EEG and behavioral-physiological tests to confirm that people are asleep to record speech-ABR in two states of wakefulness and sleep. As a result, sleep stages were not identified separately. However, all participants reported experiencing light sleep [17], and according to the visual analysis of EEG data (for no artifacts [22] and monitoring of eye movements and body movements), behavioral-physiological observations (Closed eyes, recumbent position, relaxation of body and face [13, 23], slow body movements or lack of movement, regular and deep respirations [23], lack of interaction with the environment or reduced response [13, 23], and snoring) and the total time of evaluations (less than 1 hour), the speech-ABR results seemed to be collected during NREM sleep. Therefore, a distinction between wakefulness and sleep states was concluded, which was in line with the study design.

Statistical analysis

Descriptive statistics included mean and standard deviation of amplitudes and latencies of waves V and A, slope of V-A complex, and spectral magnitudes of F1 and Higher Frequencies (HF). The Shapiro-Wilk test was used to check the normality of data distribution. In case of normality, paired t-test would be used; otherwise, non-parametric Wilcoxon test would be used to compare the speech-ABR test parameters between wakefulness and sleep states, and between right and left ears. The statistical analyses were performed in SPSS v.16.

Results

Speech-ABR test results were recorded in the right and left ears with acceptable morphology and reproducibility for 16 subjects in wakefulness and sleep states. Figure 1 shows the speech-ABR morphology of one participant in both ears and two states, as an example. Comparison of the speech-ABR test results between the two states showed that the latencies of waves V and A were significantly longer and the amplitudes of waves V and A, the slope of V-A complex, and the spectral magnitude of F1 were significantly lower in the sleep state. However, there was no significant difference in spectral magnitude of HF between wakefulness and sleep states (Table 1).

The comparison of the speech-ABR test results between right and left ears, showed no significant differences (Table 2).

Discussion

The present study aims to assess the possibility of using speech-ABR test during sleep, which can have beneficial outcome for evaluating auditory processing in hard-to-test people. According to the results, there was no difference between the right and left ears in the parameters of speech-ABR test. Previous studies have also reported no significant differences; therefore, it seems that there is no any directional superiority in processing the auditory brainstem response to speech stimuli [4]. In addition, the comparison of wave V latency between wakefulness and sleep states in the right ear showed a significant difference. This may be due to

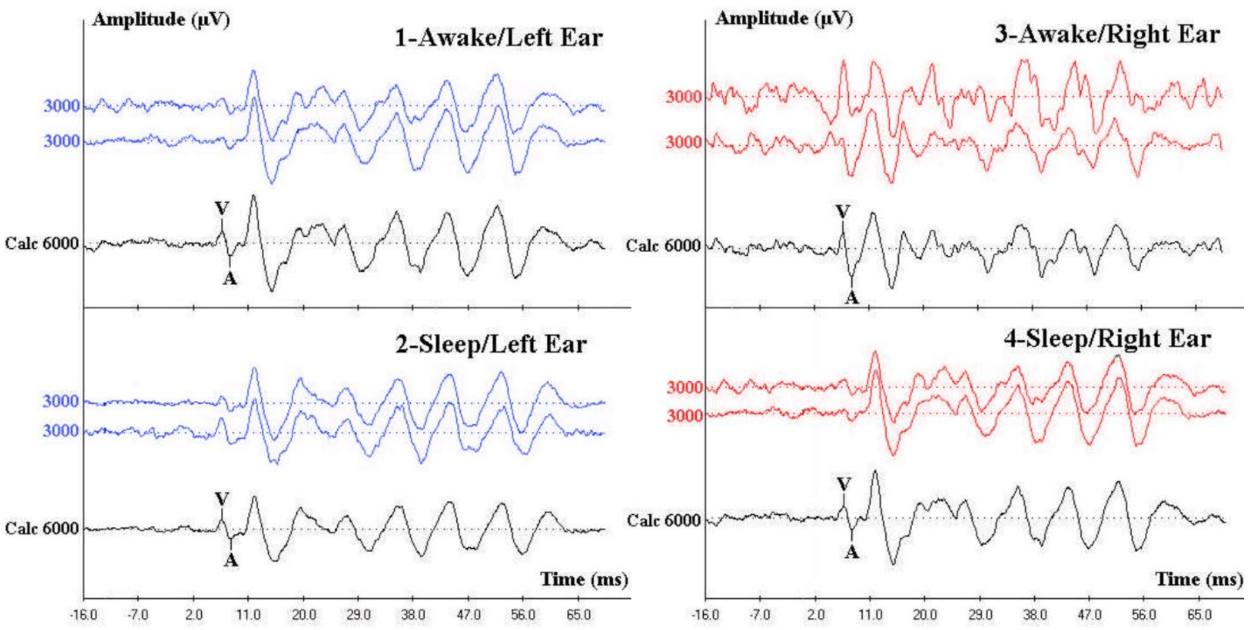

Figure 1. Example of speech-evoked auditory brainstem response morphology in the left (1, 2) and right (3, 4) ears of a participant in the awake (1, 3) and sleep (2, 4) states. In each stage, 2 recordings were performed (3000 sweeps collected), then combined offline (obtained 6000 sweeps)

the small number of samples. Nevertheless, our results showed that the latencies of the speech-ABR onset waves were significantly longer and the amplitudes were significantly lower in sleeping state. However, a study examined the click-evoked ABRs showed that the click-evoked ABR test parameters were sleep-resistant [10]. Therefore, it seems that the effect of wakefulness on the parameters of speech-ABR and click-evoked ABR tests is different. Since speech stimuli are more complex than click stimuli, it is possible that these two stimuli are processed differently [1]. In addition, it seems that higher-level processing disorders have different effects on these responses, and unlike click-evoked ABR, the speech-ABR onset is affected by learning problems [9]. Moreover, in people with auditory processing disorder and specific language impairment [7], stuttering [8], and learning disability [9], it has been reported that the speech-ABR onset was delayed. Difference in speech-ABR test parameters have also been reported in people with obstructive sleep apnea [24]. On the other hand, a study showed that the latencies of the speech-ABR onset were shorter in musicians than in the control group [6]. Furthermore, the origin of the speech-ABR seems to be slightly different than the click-evoked ABR [25]. The latency of V and Vn waves of click-evoked ABR originate from the lateral lemniscus at the inferior colliculus [26]; however, the speech-ABR onset (V and A waves) originate from the inferior colliculus [2]. Thus, unlike conventional click-evoked ABR, it seems that the speech-ABR onset is more affected by higher-level processing through the efferent system [5], which indicates a wakefulness state.

The study on the V-A complex showed a lower slope during sleep. In a previous study, it was observed that defects in the higher-level processing, such as stuttering, reduced the slope of the V-A complex [8]. Other study reported that the slope of V-A complex in patients with specific auditory skills (e.g. musicians) was significantly larger than in the control group [6]. Therefore, given the effects of these factors on the V-A complex, it seems that sleep as a high-level function affects this complex

Table 1. Comparison of the speech-evoked auditory brainstem response parameters between wakefulness and sleep states in right and left ears (n=16)

	Parameters	Wakefulness (mean±SD)	Sleep (mean±SD)	p*
Right ear	V latency (ms)	6.79±0.35	6.90±0.41	0.055
	V amplitude (μV)	0.13±0.05	0.10±0.04	**0.020**
	A latency (ms)	7.87±0.32	8.04±0.35	**0.001**
	A amplitude (μV)	0.13±0.05	0.11±0.04	**0.036**
	V-A slope (μV/ms)	0.25±0.07	0.21±0.06	**0.004**
	F1 spectral magnitude (μV)	1.26±0.48	1.05±0.40	**0.010**
	HF spectral magnitude (μV)	0.51±0.14	0.51±0.16	0.932
Left ear	V latency (ms)	6.67±0.35	6.96±0.35	**0.014**
	V amplitude (μV)	0.13±0.05	0.09±0.03	**0.019**
	A latency (ms)	7.77±0.28	8.06±0.30	**<0.001**
	A amplitude (μV)	0.14±0.05	0.11±0.04	**0.033**
	V-A slope (μV/ms)	0.24±0.08	0.19±0.06	**0.023**
	F1 spectral magnitude (μV)	1.21±0.33	0.94±0.32	**0.002**
	HF spectral magnitude (μV)	0.48±0.11	0.48±0.11	0.917

F1; first formant, HF; higher frequencies

* p; (p<0.05) are bolded

Table 2. Comparison of the speech-evoked auditory brainstem response parameters between right and left ears during wakefulness and sleep states (n=16)

Parameters	Wakefulness (p*)	Sleep (p*)
V latency (ms)	0.247	0.393
V amplitude (µV)	0.941	0.518
A latency (ms)	0.072	0.716
A amplitude (µV)	0.817	0.318
V-A slope (µV/ms)	0.552	0.257
F1 spectral magnitude (µV)	0.897	0.363
HF spectral magnitude (µV)	0.341	0.286

F1; first formant, HF; higher frequencies

and reduces its slope and probably eliminates some processes.

We also assessed the spectral magnitudes of F1 (180–755 Hz) and HF (756–1130 Hz), which are important components of the FFR part of speech-ABR [21]. The findings showed that the spectral magnitude of F1 decreased significantly during sleep, but there was no significant difference in the spectral magnitude of HF between the two states of wakefulness and sleep. Different mechanisms are involved in the production of speech onset responses and FFR [27], indicating that they are processed in different auditory regions [25]. In addition to subcortical regions such as the cochlear nuclei [28], the inferior colliculus [28, 29], and the medial geniculate body [28], cortical regions such as the auditory cortex [28, 29] are involved in the FFR generation. Since the FFR recorded during sleep in the present study, the participation of subcortical regions in generating these responses may be greater [29]. However, higher-level processing performance can affect the FFR. A study reported that, in higher-level processing defects such as stuttering, the spectral magnitude of F1 was significantly lower, but no significant difference was observed for the HF spectral magnitude [8]. On the contrary, a study found that the spectral magnitude of F1 was higher in people with special auditory skills (musicians) than in those without any musical skill [6]. At the cortical level, the phase-locking of neurons seems to be limited at speech frequencies (up to 150–200 Hz) [29]. HF is likely to be coded through the brainstem phase-locking capacity [30]. In this regard, the spectral magnitude of HF was not significantly different between wakefulness and sleep states. It seems that, in addition occurrence in the brainstem [29], the phase-locking at F1 occurs at the cortical level; therefore, the spectral magnitude of F1 is affected by higher-level processing and sleep. Considering the use of wide frequency spectrum in the current study to determine the spectral magnitudes of F1 (180–755 Hz), further studies with detailed frequency analyses are required for a more accurate conclusion.

Overall, it can be said that, although speech-ABR test has the potential to be used as an objective tool for auditory processing screening in sleeping children or hard-to-test people, changes in its parameters in wakefulness or sleep states should be considered by therapists or physicians.

Considering the limitations of this study, further studies with larger sample sizes, female participants, different age groups, control group, assessments of wakefulness and sleep in two different sessions, and at different stages of sleep, are recommended.

Conclusion

The speech-evoked auditory brainstem response test results are not different between the right and left ears. Although speech-ABR, like conventional click-evoked ABR, can be recorded during sleep with acceptable morphology and reproducibility, but it is partially affected by sleep and wakefulness (similar to auditory steady-state response and auditory middle-latency response). This confirms that the speech-ABRs are affected by cortical centers, efferent pathways, and higher-level processing skills and disorders. Therefore, wakefulness state seems to be the ideal condition for administering the speech-ABR test.

Ethical Considerations

Compliance with ethical guidelines

Current study was approved by the Ethics Committee of University of Social Welfare and Rehabilitation Sciences (Ethical Number: IR.USWR.REC.1398.172).

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Authors' contributions

AK: Acquisition of data, drafting the manuscript, and interpretation of the results; MS: Supervision, study design, interpretation of the results, and critical revision of the manuscript; EB: Statistical analysis; MJ: Supervision, study concept and design, acquisition of data, interpretation of the results, and critical revision of the manuscript.

Conflict of interest

There is no conflict of interests regarding the publication of this paper.

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