



Research Paper

Diurnal changes in differential sensitivity and temporal resolution in morning-type and evening-type individuals with normal hearing

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Received 24 January 2017; received in revised form 14 October 2017; accepted 25 October 2017
Available online 14 June 2018

KEYWORDS

Differential sensitivity;
Temporal processing;
Morningness;
Eveningness;
Diurnal changes

Abstract The present study attempts to determine diurnal changes by testing the differential sensitivity and temporal resolution in morning-type, evening-type, and intermediate-type individuals with normal hearing. Thirty participants with normal hearing were divided into morning-type, evening-type, and intermediate-type using “Morningness–Eveningness Questionnaire”. The tests of differential sensitivity and temporal resolution were administered to all the participants in the morning and evening, respectively. The differences in the test results between different timing across all the three groups were analyzed. The results of the study showed that there was a significant diurnal effect on psychoacoustic tests as morning-type individuals performed better when tested in morning and evening-type performed better when they were tested in evening. However, there was no diurnal effect found in intermediate group. The lack of inhibitory control and poor cognitive load in off peak time could have lead to poor scores. Thus, the variable of diurnal effects should be considered in further studies on psychoacoustic tests, especially in young adults. Furthermore, studies could be performed to explore diurnal effects on objective audiological tests in a larger group of population in the future.

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Peer review under responsibility of Chinese Medical Association.



Introduction

Diurnal type is defined by chrono-psychologists as the time of the day when an individual is most active.¹ An individual who is 'morning type' (M-type) is more active earlier in the day, while an 'evening type' individuals (E-type) prefer lateral time of the day. There are indications that M-types can be differed from E-types based on the values they record on certain psychological and physiological variables during morning and evening hours, respectively. One of the self-assessed questionnaires used to determine whether the individual is a morning or evening type is "Morningness–Eveningness Questionnaire" developed by Horne and Ostberg.² This questionnaire helps to classify individuals into "definite morning", "moderate morning", "intermediate", "moderate evening", and "definite evening", based on the scores obtained. Previous studies have suggested that individuals who are M-type perform tasks better in the morning than in the evening, whereas it is vice versa for E-types individuals.² In addition, with respect to self-rated alertness, individuals who are M-type are reported to attain higher values than E-types in the morning, while E-types attain higher values in the evening.^{3–5} Previous studies have reported that subjective alertness shows a significant difference between diurnal types, with M-type individuals peaking in the late morning and E-type individuals in the late afternoon.^{6–8} However, there are few studies that attempted to study the diurnal variations in behavioral and electrophysiological tests in the field of audiology.

There are several studies reported previously that have attempted to assess diurnal changes in N1-P2 and P300 responses in individuals who are M-type and E-type.^{9,10} Huang et al¹⁰ reported that P300 amplitude was higher and latency shorter in the morning for M-type individuals and in the evening for E-type individuals. Huang et al⁹ also reported that cognitive function of the individuals varies according to the diurnal changes. Recently, Veneman et al¹¹ also attempted to determine the effect of measurement time of the day on speech recognition in noises. They reported that younger adults performed significantly better on the speech-in-noise tasks and claimed that significantly less mental demand is required when they were tested at their peak (evening) than off-peak (morning) time of the day. Even though few reports of diurnal effects on behavioral and electrophysiological tests of audiology is published, there is rarely any no study performed to determine the diurnal effects on psychoacoustic measures such as differential sensitivity and temporal resolution. In addition, intermediate group has not been considered as a control group for interpreting the results in previous work.

The psychoacoustic tests, such as differential limen for intensity (DLI), differential limen for frequency (DLF), duration discrimination (DD) tasks, and gap detection test (GDT) are used extensively in audiological research.^{12,13} But, the diurnal effects on these psychoacoustic measures haven't been studied in detail, which would provide a valuable insight whether results vary from M-type to E-type individuals on these tests. This is essential for appropriate interpretation of test results and control the variable, if necessary. Thus, our study attempts to determine diurnal

effects on the tests of differential sensitivity and temporal resolution in morning-type, evening-type, and intermediate-type individuals with normal hearing.

Materials and methods

Participants

Forty five normal hearing adults (23 males and 22 females) between the age of 18–25 years (mean age: 21.4, $SD = 2.45$) participated in the study. None of the participants had any otological history of ear infection, noise exposure, or drug ototoxicity. They had normal hearing sensitivity that they have less than 15 dB HL decrease in air conduction and bone conduction thresholds. They also had normal middle ear functioning according to the immittance evaluation. On the basis of "Morningness–Eveningness Questionnaire",² the participants were sub-divided into three categories (moderately morning-type, intermediate type, and moderately evening-type) with 15 participants in each using purposive sampling. Participants who belong to definitely morning type and definitely evening type were few. Hence, these two groups were not included in our study. The age range of participants in moderately morning-type was 18–22 years old (Mean age = 20 years, $SD = 2.59$) with 8 males and 7 females. Similarly, the age range was 18–25 years old in the intermediate category (Mean age = 22.5 years, $SD = 2.04$) with 7 males and 8 female. In addition, for moderately evening-type category, the age range between 18 and 23 years old (Mean age = 21.8 years, $SD = 3.06$) with 8 males and 7 females.

Procedure

The air conduction (AC) and bone conduction (BC) thresholds were estimated using Modified Hughson and Westlake procedure.¹⁴ AC thresholds were obtained for pure tones from 250 Hz to 8 kHz and BC thresholds from 250 Hz to 4 kHz in octave frequencies. Speech identification scores were obtained by phonemically balanced words developed for adults in Kannada by Yathiraj and Vijayalakshmi.¹⁵ Immittance evaluation using tympanometry and acoustic reflex threshold testing was done with 226-Hz probe tone and acoustic reflexes for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz (ipsilateral and contralateral) using a calibrated middle ear analyzer (GSI Tymptstar V 2.0). All the participants had normal tympanogram with reflexes present in both ears.

"Morningness–Eveningness Questionnaire" developed by Horne and Ostberg² was administered on all the participants in the study. The questionnaire consisted of 19 questions pertaining to habitual bed and waking times, preferred times of physical and mental performance, together with subjective fatigue after rising and before going to bed. Based on this questionnaire, participants can be divided into five groups according to their scores: definitely morning type (70–86), moderately morning type (59–69), neither/intermediate type (42–58), moderately evening-type (31–41), and definitely evening type (16–30). Based on this classification, participants who were moderately morning-type, intermediate-type, and

moderately evening-type were further recruited for our study. The differential sensitivity and temporal processing tasks were administered on all the participants at morning between 8:00 a.m to 9:00 a.m and evening from 6.30 p.m to 7.30 p.m. This time was chosen based on the previous questionnaire results wherein, the moderately morning-type individuals were most active during the time between 8:00 a.m to 10:00 a.m and moderately evening-type were most active during the time between 5:00 p.m to 10:00 p.m. As the time range of 8:00 a.m to 10:00 a.m and 5:00 p.m to 10:00 p.m are large, 8:00 a.m to 9:00 a.m in the morning and from 6:30 p.m to 7:30 p.m in the evening were chosen due to subject availability and was the most comfortable time for the participants in the undergo tests. The order of the presentation in the tests and order of times for testing was randomized across the participants.

Differential sensitivity tests like differential limen for intensity (DLI), differential limen for frequency (DLF), duration discrimination (DD) tasks, and gap detection test (GDT) were considered for the study. DLI was obtained from 1-kHz and 250-ms pure tones. The participant had to identify the loudest tone. The onset and offset of the tones were gated with two 10-ms raised cosine ramps. DLF was obtained by a 250-ms long pure tone. The highest pitch tone had to be discriminated among a number of choices. The onset and offset of tones were gated on and off with two 10-ms raised cosine ramps. DD was administered using white noise. The participant had to identify the longest noise. The noise had raised cosine onset and offset gates of 10-ms. GDT, which is a test of temporal resolution, was administered using a band of 750-ms Gaussian noise with a gap in its temporal center. The duration of gap is varied according to the listener performance. The noise has 0.5-ms cosine ramps at the beginning and end of the gap.

These tests were measured using “mlp” tool box which implements a maximum likelihood procedure in MATLAB.¹⁶ The maximum likelihood procedure uses a large number of candidate psychometric functions, and after each trial, calculates the probability (or likelihood) of obtained the listener's response to all of the stimuli that have been presented given each psychometric function. The psychometric function that yield the highest probability is used to determine the stimulus to be presented on the next trial. Within about 12 trials, the maximum likelihood procedure usually converges on a reasonably stable estimate of the most likely psychometric function, which then can be used to estimate threshold.^{17,18} Stimuli were produced at 44,100 Hz sampling rate. A two-interval alternate forced choice method using a “maximum likelihood procedure” was used to track an 80% correct response criterion. In all of the psychoacoustical tests, stimuli were presented binaurally at an intensity of 80 dB SPL. Stimuli were presented via a laptop computer connected to calibrated HDA-200 earphones. All the tests were carried out in a quiet room using the test standard test settings provided in the “mlp” MATLAB toolbox.¹⁶ The differences in performance across three groups when participants were tested in morning and evening was compared using appropriate statistical analyses.

Statistical analyses

Shapiro Wilks Test of normality showed that the data was not normally distributed and hence non-parametric tests were done for analysis. Wilcoxon signed rank test was used to compare the scores obtained when tested in morning and evening for all three groups separately.

Ethical considerations

In the present study, all the testing procedures done were using non-invasive technique adhering to conditions of ethical approval committee of the institute and complied with the Declaration of Helsinki. All the test procedures were explained to the participants before testing and informed consent has been taken from the participants for participating in the study.

Results

Our results showed that performance on differential sensitivity and temporal resolution was poorer for moderately morning-type individuals when they were tested in evening versus morning. Similarly the scores were worse for moderately evening-type individuals when they were tested in morning compared to evening. However, the results obtained during morning and evening were similar for intermediate group. The mean and standard deviation of DLI and DLF obtained for all three groups in two diurnal conditions are shown in Figs. 1 and 2, respectively. The mean and standard deviation of DD and GDT obtained for all three groups in two diurnal conditions are shown in Figs. 3 and 4, respectively.

Wilcoxon signed rank tests were performed if there was any statistical significant difference in scores between morning and evening across the three groups. The results of the study showed that scores for DLI, DLF, DD, and GDT were significantly better ($P < 0.05$) for moderately morning type individuals when they were tested morning. In addition, the scores were also significantly better ($P < 0.05$) for

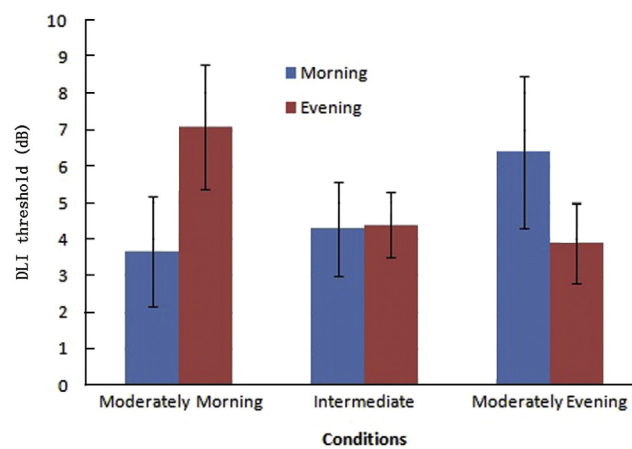


Fig. 1 Mean and SD of DLI scores during morning and evening for all the three groups.

moderately evening type individuals when they were tested evening. However, there was no significant difference ($P > 0.05$) no matter the participants of intermediate group were tested in morning or evening. Kruskal Wallis H test was administered to determine if there was a significant difference in scores among the three groups. The results of the Kruskal Wallis H test showed that the scores for DLI, DLF, DD, and GDT were significantly different ($P < 0.01$) across the groups. Besides, Mann–Whitney U test was administered to compare between the groups for all psychoacoustic tests. The results showed that the scores were significantly different ($P < 0.05$) between all the three groups considered in the study.

Discussion

Our results showed that there was a significant diurnal effect in psychoacoustic tests that were used in the study. The scores were better for morning-type individuals when they were tested in morning, while evening-type individuals scored better when they were tested in evening. In addition, it was also found the intermediate group showed no significant differences across diurnal testing conditions. In other words, differential sensitivity and temporal resolution were better in the morning than evening for morning-types, while it was better in the evening for evening-types. The results of the study are in consensus with previous studies that reported participants performed typically best at specific point in the day and it corresponds to individual's circadian arousal level indifferent cognitive tasks (Kerkhof, 1985; Kerkhof et al, 1980; Natale & Cicogna, 1996; Schmidt, Collette, Cajochen, & Peigneux, 2007).^{6,7,19,20} As a result, morning-types were often feeling their best in the morning and tend to be engaged in activities such as going to work or exercising in the morning when possible. In contrast, evening-type adults typically were reported to feel sharpest in the later time and tend to engage in daily activities in the evening.

Previous studies have also shown that speech perception in noise scores also varies across the time of testing for

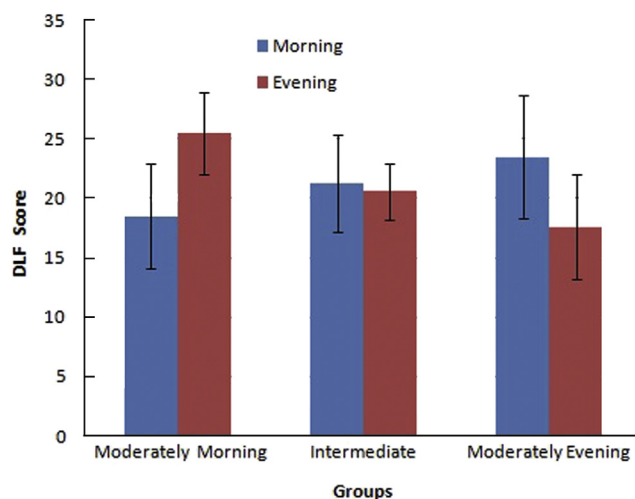


Fig. 2 Mean and SD of DLF scores during morning and evening for all the three groups.

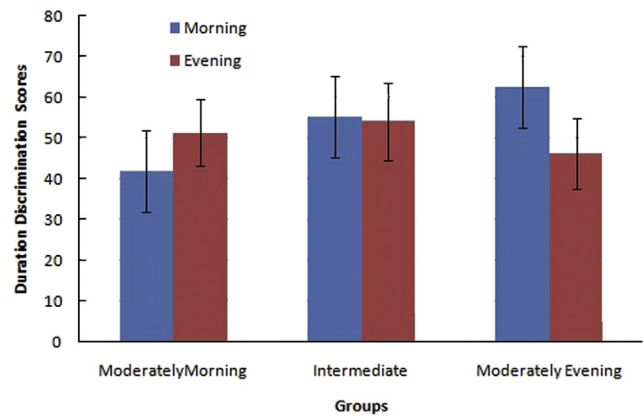


Fig. 3 Mean and SD of DD scores during morning and evening for all the three groups.

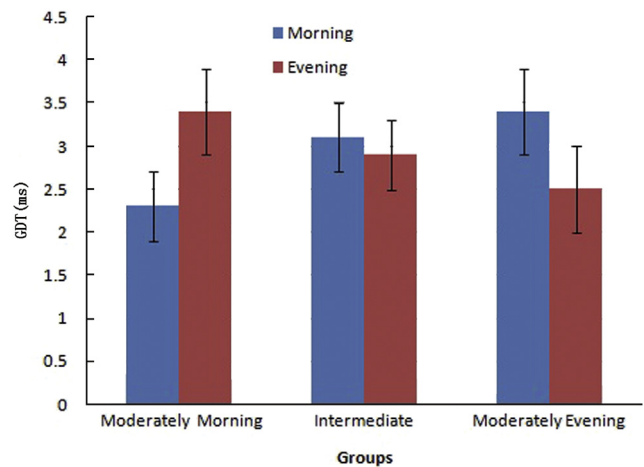


Fig. 4 Mean and SD of GDT scores during morning and evening for all the three groups.

morning-type and evening-type individuals.¹¹ Inhibitory control or the ability to suppress irrelevant information from consciousness may play a major role in psychoacoustic test measures. Our results demonstrated strong effects from the preference of the time of day. Most of the previous studies on visual modality show time-of-day affect the inhibition control.^{21,22} The result our study shows that it can also be generalized to auditory system, which may be less susceptible to distractions and more efficient in suppressing information that is no longer relevant to the peak level of circadian arousal.^{22–25}

The inhibition is thought to play a role in cognitive processes, such as selective attention, working memory, and speech comprehension.²⁴ Thus, a change in inhibitory control (and therefore, the ability to ignore distracting stimuli) associated with the time of testing during the day may alters the psychoacoustic measures that used in the study. As inhibition has been shown to be less efficient at off-peak hours of day, differential sensitivity and temporal resolution may be poorer at off-peak times of day as well. In addition, no significant diurnal differences on the tests used in the study among intermediate group suggest they lack peak time of arousal. Thus, the present study suggests

that diurnal changes affect psychoacoustic test measures and should be controlled in future research studies especially for younger adults.

Limitations of the study

The study should be conducted on a larger sample size including individuals of definitely morning type and definitely evening type for better generalization of the results. The study was carried out on younger adults, thus, the diurnal effect on older adults should be verified. The diurnal effects on morning type and evening type individuals should also be studied in more objective audio-logical tests.

Conclusions

The present study attempted to determine diurnal effects on tests of differential sensitivity and temporal resolution in morning-type, evening-type, and intermediate-type individuals with normal hearing. The results of the study showed that there was a significant diurnal effect on psychoacoustic tests with morning-type individuals performing better in the morning and evening-type performed better in the evening. There was no diurnal effect seen for individuals in intermediate group. The lack of inhibitory control, and poor cognitive performance during the off-peak hours could account for the poor scores. Thus, the variable of morning-type or evening-type individuals should be controlled in further studies on psychoacoustic tests in younger adults.

Conflict of interest statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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