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RESEARCH ARTICLE

Effect of sinusoidally amplitude modulated broadband noise stimuli on stream segregation in individuals with sensorineural hearing loss

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Abstract

Background and Aim: Auditory stream segregation is a phenomenon that splits sounds into different streams. The temporal cues that contribute for stream segregation have been previously studied in normal hearing people. In people with sensorineural hearing loss (SNHL), the cues for temporal envelope coding is not usually affected, while the temporal fine structure cues are affected. These two temporal cues depend on the amplitude modulation frequency. The present study aimed to evaluate the effect of sinusoidal amplitude modulated (SAM) broadband noises on stream segregation in individuals with SNHL.

Methods: Thirty normal hearing subjects and 30 subjects with mild to moderate bilateral SNHL participated in the study. Two experiments were performed; in the first experiment, the AB sequence of broadband SAM stimuli was presented, while in the second experiment, only B sequence was presented. A low (16 Hz) and a high (256 kHz) standard modulation frequency were used in these experiments. The subjects were asked to find the irregularities in the rhythmic sequence.

Results: Both the study groups could identify the irregularities similarly in both the experiments. The minimum cumulative delay was slightly higher in the SNHL group.

Conclusion: It is suggested that the temporal cues provided by the broadband SAM noises for low and high standard modulation frequencies were not used for stream segregation by either normal hearing subjects or those with SNHL.

Keywords: Stream segregation; sinusoidal amplitude modulation; sensorineural hearing loss

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Introduction

Auditory stream segregation is a psychoacoustic phenomenon that splits sounds into different perceptual auditory streams [1]. The perceptual auditory streams are formed by grouping or segregating the possible sound sources [1]. The cues responsible for this phenomenon have been widely studied and documented [1-3]. Sequential stream segregation or grouping is a feature where successive sounds are categorized as dissimilar sounds, while similar sounds are grouped together. This categorization of successive

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sounds is done by comparing the acoustic properties of the successive sounds in a time scale [4,5]. The major cue for sequential stream segregation or grouping is the frequency difference between the successive sounds [2-6]. Temporal variations (such as rate or envelope) are also known to cause sequential stream segregation. Even some difference in the amplitude modulation of broadband noise between the successive sounds can result in stream segregation among people with normal hearing [7,8].

The natural sounds have both spectral and temporal variations. Sinusoidally amplitude modulated (SAM) signal is a sound that can provide temporal or spectro-temporal cues based on its parameters [9]. The auditory stream segregation is observed by SAM signal tone parameters, varying in normal hearing people. Changes in carrier frequency, modulation depth, and modulation frequency can provide cues for stream segregation [9]. The broadband SAM signal can also produce stream segregation in normal hearing people. Researchers have predicted that the modulation frequency of the SAM signal alone can be enough for stream perception in individuals with normal hearing [8]. Perception of SAM signal in case of exposing to tonal and broadband carrier stimuli depends on two different cues, which is either spectral or temporal. The spectrum of SAM signal consists of a carrier frequency and two sidebands [10]. The sideband spectral distance from the carrier frequency depends on the modulation frequency. As the modulation frequency increases, the sideband may fall within another auditory filter and heard as a separate tone [10]. Hence, in case of exposing to tonal stimulus, both temporal and spectral cues have a role in perception of modulation depending on the modulation frequency; while in case of exposure to broadband stimulus as the carrier stimulus, the modulated frequency sidebands may fall within the auditory filters of the carrier stimuli and, then, is masked. Thus, only temporal cues play a major role in detecting the modulation when broadband SAM signal is used [10].

There are two types of information provided by temporal modulation detection in individuals with normal hearing; low modulation frequency detection provides information for envelope coding, while high frequency modulation detection gives information about the temporal fine structure [8]. The stream segregation using broadband noise has been studied with a standard modulation frequency of 100 Hz; thus, it evaluates the temporal fine structure only [8]. The modulation frequencies were varied between 200 Hz to 800 Hz in the alternate SAM stimuli in the sequence. The stream segregation is perceived when the broadband SAM stimuli have modulation frequencies with 1−2 octaves higher than the standard modulation frequency. The percentage of stream perception increases with the increase in modulation frequency up to 3 octaves compared to the standard modulation frequency [8]. However, the stream segregation with low modulation frequencies responsible for envelope coding has not yet studied. It can be interesting to see that the identification of stream perception is influenced by different modulation rates. The stream segregation with broadband SAM signal is measured using subjective listening task paradigm. In this task, the subjects are asked to classify their subjective perception on stream segregation when they hear a single or two streams [8]. One of the disadvantages of this method is that it may have individual biases [11]. In objective listening task paradigm, the subjects are given temporal gap discrimination task. The threshold differences in identifying the temporal gaps between two sequences are used to estimate the amount of stream segregation [11]. Roberts et al. [12] used such method to study the stream perception where the minimum delay between the two consecutive stimuli in a sequence was varied up to 32 ms. It can be interesting to compare the results obtained from the objective and subjective listening task paradigms.

The auditory stream segregation has been reported to be affected in individuals with cochlear hearing loss [5,13]. Due to poor frequency resolution, the auditory stream segregation was found to be affected even when the frequency separation between the successive tones was large in these individuals [5,13]. However, there

Table 1. Distribution of gender, and mean and standard deviation of age, pure tone average, and speech identification scores of participants in the normal hearing group (group I) and sensorineural hearing loss group (group II)

Details	Group I	Group II
Gender		
Male	15	19
Female	15	11
Mean (SD) age (yr)	27.4 (3.47)	34.6 (4.65)
Mean (SD) PTA (dB)		
Right	12.58 (2.26)	36.59 (7.24)
Left	10.62 (3.09)	37.46 (6.81)
Mean (SD) SIS (%)		
Right	97.46 (2.25)	92.68 (6.95)
Left	98.14 (1.92)	90.18 (7.03)

PTA; pure tone average, SIS; speech identification score

is no significant difference between people with normal hearing and cochlear hearing loss when the temporal features alone were changed between the successive tones [14]. Few studies have also shown that there is no conclusive result on stream segregation in people with cochlear hearing loss [5,15,16]. There are some evidences that the ability of discriminating changes in the SAM signal is also affected in people with cochlear hearing loss [17]. Difference in the ability of identifying changes in modulation depth has also been reported between individuals with normal hearing and cochlear hearing loss. Koopman [17] speculated that the discrimination performance in people with cochlear hearing loss may be influenced by stream segregation. There are also some reports that temporal modulation transfer function (TMTF) for tonal stimuli is not much affected in people with cochlear hearing loss [18]. Several studies have also found that the TMTF for broadband noises, which helps with envelope coding, is very similar between people with normal hearing and cochlear hearing loss indicating that temporal resolution is not affected in people with cochlear hearing loss [19]. However, perception of high modulation rate responsible for the perception of temporal fine structure cues are affected in individuals with sensorineural hearing loss (SNHL) in the absence of spectral information [20].

There is a need to study the stream perception in people with SNHL as this phenomenon can be responsible for perception of speech in adverse listening conditions. Understanding of the cues involved in stream segregation is also important. To our knowledge, this is the first study that evaluates the stream segregation of broadband SAM signals in people with SNHL. It is an attempt to know whether the modulation rate in SAM tone with broadband stimuli can produce stream segregation in people with normal hearing and SNHL. The results can help understand the perception of SAM tone and stream perception using SAM tone with same or two different processes, since modulation depth perception using broadband noises totally depends on temporal processing. In this regard, the aim of this study is to evaluate the effect of temporal cues in broadband SAM stimuli on stream segregation in individuals with normal hearing and SNHL using objective listening task paradigm.

Methods

Subjects

The study involves standard group comparison research design. Hence, the study was conducted on 30 individuals with normal hearing (Group I) and 30 individuals with SNHL (Group II). The information of their age, gender, pure tone average (PTA), and speech identification scores (SIS) are presented in Table 1. Normal hearing subjects reported no otological complaints. Their pure tone thresholds for the clinical audiometric test were within normal limits. The SNHL subjects had either mild or moderate degree of bilateral SNHL with flat audiometric configuration. Their speech identification scores were in proportion to the degree of their hearing loss. Both groups of participants had type A and A_s tympanograms. Normal hearing subjects had normal acoustic reflex thresholds, while SNHL subjects had elevated or absent acoustic reflexes. Transient evoked otoacoustic emissions (TEOAEs) were present in normal hearing subjects and absent in SNHL subjects. Prior to the study, ethical approval was obtained from the Bio-behavioural Research Ethics Committee (Code: WOF-0348/2014-15). Informed consent was obtained from the all participants according to the guidelines of the ethics committee.

Generation of stimuli

The SAM stimuli required for testing were generated using AUX Viewer version 1.0 [21]. To do so, the sampling frequency was kept at 44.1 kHz with a 10-ms cosine ramp and modulation depth of 100%. The SAM stimuli as broadband noise carrier stimuli with standard modulation frequencies (f_{mod}) of 16 Hz and 256 Hz were generated by multiplying a white noise by a DC-shifted sine wave. The low f_{mod} was selected to see the envelope coding and the high f_{mod} was for the temporal fine structure. These SAM stimuli were considered as standard SAM stimuli. For the target sequence, the SAM stimuli with f_{mod} of 1, 2, 3 and 4 octaves higher than the f_{mod} of standard stimuli were generated. These variations in the target f_{mod} were according to the results of previous studies [8]. The overall duration of each SAM stimuli was maintained at 60 ms to align the sequence of SAM stimuli, Adobe Audition v. 3.0 software was used.

Procedure

To study the stream segregation, two experiments were conducted. The procedure was adapted from the objective listening task paradigm used by Roberts et al. for stream segregation [12]. Two-alternative forced choice (2-AFC) method was used to conduct the experiments. Each block consisted of a reference sequence and a target sequence. The target sequence had a cumulative delay. The participants were asked to identify the target sequence in each block. The step size for each reversal of the cumulative delay was changed by a factor of 1.189 [12]. The shortest cumulative delay that could be identified as the irregular one was considered as minimum cumulative delay (d). It was calculated by finding the delay corresponding to the correct point of 70.7% on the psychometric function [22]. The order of two experiments was randomized between the participants in both study groups.

Experiment I

In the first experiment, a reference sequence of SAM stimuli and a target sequence were presented. The reference and target sequences consisted of 12 pairs of A and B SAM stimuli. The A stimuli in the reference AB sequence had broadband SAM with f_{mod} of 16 Hz or 256 Hz. The B stimuli in this sequence had f_{mod} of 1, 2, 3 or 4 octaves higher than the standard f_{mod} of A stimuli. The gap between the two A and B stimuli in the reference AB sequence was constant at 40 ms. In the target AB sequence, the gap between the two stimuli in the sequence was kept constant at 40 ms for the first six pairs. From the 7th pair onward, the gap between them was increased by a factor of ΔT. The gap was increased further by $2\Delta T$, $3\Delta T$, and $4\Delta T$ for the successive four pairs. The gap between the last two pairs was equal to $4\Delta T$. As the gaps between the A and B stimuli were progressively increased, the silence period between the AB pairs were adjusted accordingly to keep the overall duration of the sequence at 2400 ms. The $4\Delta T$ denoted the cumulative delay; for the initial target AB sequence, the cumulative delay was 32 ms. Fig. 1 shows a sample of reference and target sequences presented in experiment I.

The increasing gaps in the target sequence induce irregularities that can be perceived by participants. There were two standard f_{mod} and four variants (octaves) of target modulation frequencies for each f_{mod}. The sequence was presented in MATLAB v. R2014a using a Sony VAIO personal computer (SVE14125 model). The output was routed through a calibrated audiometer (Piano, Inventis Co., Italy). A HDA 200 headphone was used for conducting the experiments. The sequences were presented diotically to the participants and the volume was set to their most comfortable level. The participants were asked to identify whether the first or second

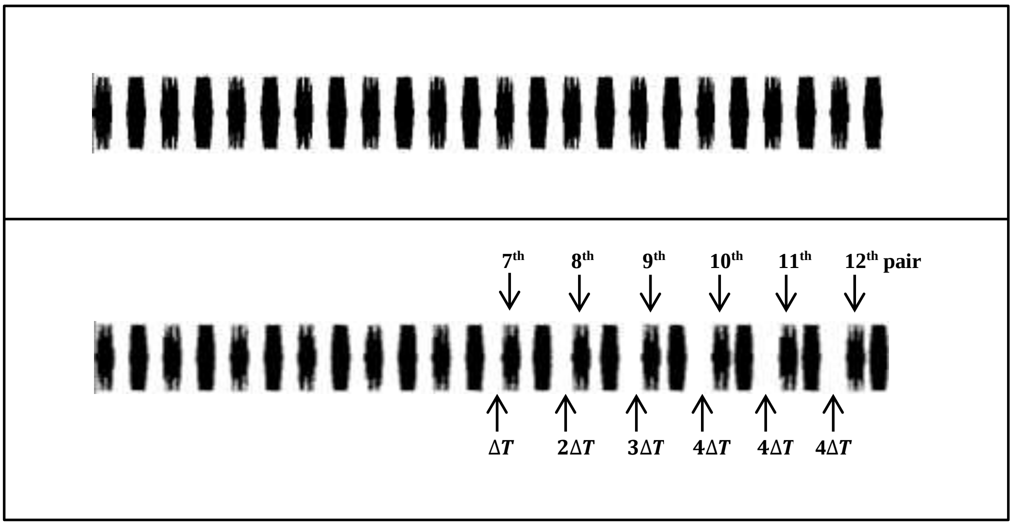

Fig. 1. A sample of AB reference sequence and a target AB sequence presented in test I. The upper panel represents the reference sequence of A (modulated by 16 Hz) and B (modulated by 256 Hz) stimuli with equal intervals. The lower panel represents the target sequence of A and B stimuli with silence durations delayed by 8 ms at 7th pair (ΔT), 16 ms at 8th pair ($2\Delta T$), 24 ms at 9th pair ($3\Delta T$), and 32 ms at 10th, 11th, and 12th pairs ($4\Delta T$).

presented sequence had irregularity. The d1 values were measured for all 8 target sequences presented in a randomized order.

Experiment II

In the second experiment, we only used the B stimuli in the AB sequence presented in experiment I. The reference sequence and a target sequence of B stimuli were presented. Since there were only B SAM stimuli, 24 B stimuli were presented instead of 12 pairs of AB stimuli that were used in experiment I, which were arranged in a sequence. The reference sequence had 24 stimuli with constant gap of 40 ms between each stimulus. In the target sequence, the first 13 stimuli had a constant gap. From the 14th stimuli onward, a gap of ΔT was induced like the way performed in experiment I. Similarly, a gap was introduced progressively at 16th, 18th and, 20th stimuli by a factor of $2\Delta T$, $3\Delta T$, and $4\Delta T$, respectively. The gap between 22nd and 24th stimuli was equal to $4\Delta T$. The participants were asked to identify the irregular or arrhythmic sequence based on the 2-AFC method, similar to experiment I. The $4\Delta T$ denoted the cumulative delay; for the initial target B sequence, the cumulative delay was 32 ms. Since the B sequence alone could not generate two streams, no stream segregation was possible; therefore, the d2 values were considered as reference. The d2 value was measured for all 8 target sequences presented in a randomized order. Fig. 2 shows a sample of reference and target sequences presented in experiment II. The d1 values obtained from the experiment I were subtracted from the d2 values obtained from the experiment II, and the result was considered as the final difference (D). The D values may indicate the level of stream perception.

Data analysis

The d1, d2 and D values were subjected to statistical analysis in SPSS v.20 software. Shapiro-Wilk test of normality was conducted and the results showed that the data were not normally distributed ($p < 0.01$). Hence, non-parametric tests were performed to examine the differences in d1, d2 and D values between study groups and between target modulation frequencies. Friedman test was used to evaluate the difference in d1, d2 and D values within groups for both low and high standard f_{mod}. To

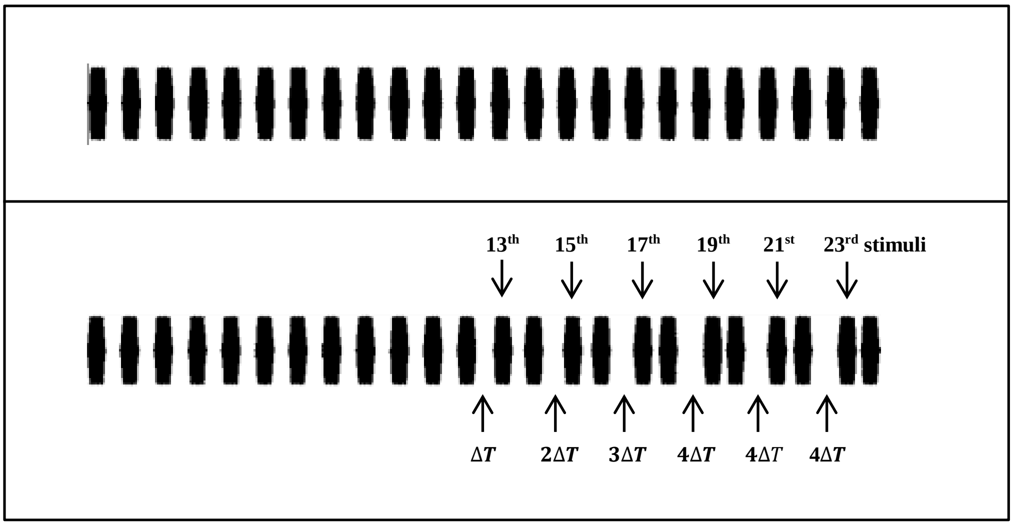

Fig. 2. An example of B SAM reference sequence and a target B SAM sequence that was presented in experiment II. The upper panel represents B SAM stimuli sequence with equal interval between the two broadband SAM in the sequence modulated by 256 Hz. SAM; sinusoidal amplitude modulated.

examine the difference between groups for each target f_{mod}, Mann-Whitney U test was conducted.

Results

The mean and the standard deviation (SD) of d1, d2, and D values obtained from both study groups are shown in Figures 3, 4 and 5, respectively. As it can be seen, the d1 values for target modulation frequencies were higher in SNHL group than in the normal hearing group for both low and high standard f_{mod}. To examine the difference in d1 values between target modulation frequencies compared to the two standard f_{mod}, Friedman test was performed. The results showed no significant difference in d1 values between target modulation frequencies in either normal hearing group for 16 Hz ($\chi^2(3) = 3.47$, $p = 0.32$) and 256 Hz ($\chi^2(3) = 3.19$, $p = 0.36$) standard f_{mod}, or SNHL group for 16 Hz ($\chi^2(3) = 1.42$, $p = 0.69$) and 256 Hz ($\chi^2(3) = 1.34$, $p = 0.71$) standard f_{mod}. To examine the difference in d1 values between the normal hearing and SNHL groups for each target f_{mod}, Mann-Whitney U test was performed. The results showed a significant difference between groups for each target f_{mod} with reference to 16 Hz and 256 Hz standard f_{mod} (Table 2 and Fig. 3).

In the Fig. 4, it can be noted that the d2 values for the target modulation frequencies were higher in the SNHL group than in the normal hearing group for both low and high standard f_{mod}. Friedman test results showed no significant difference in d2 values between target modulation frequencies in either normal hearing group for 16 Hz ($\chi^2(3) = 3.32$, $p = 0.34$) and 256 Hz ($\chi^2(3) = 1.89$, $p = 0.59$) standard f_{mod} or SNHL group for 16 Hz ($\chi^2(3) = 3.82$, $p = 0.28$) and 256 Hz ($\chi^2(3) = 1.24$, $p = 0.74$) standard f_{mod}. Mann-Whitney U test results showed significant difference between the two study groups for each target f_{mod} (Table 2 and Fig. 4).

Friedman test results showed no significant difference in D values between target modulation frequencies in either normal hearing group for 16 Hz ($\chi^2(3) = 1.99$, $p = 0.57$) and 256 Hz ($\chi^2(3) = 1.25$, $p = 0.74$) standard f_{mod} or SNHL group for 16 Hz ($\chi^2(3) = 2.48$, $p = 0.48$) and 256 Hz ($\chi^2(3) = 2.19$, $p = 0.53$) standard f_{mod}. Mann-Whitney U test results reported no significant differences between the two groups for each target f_{mod} (Fig. 5).

Discussion

The study was conducted to investigate the

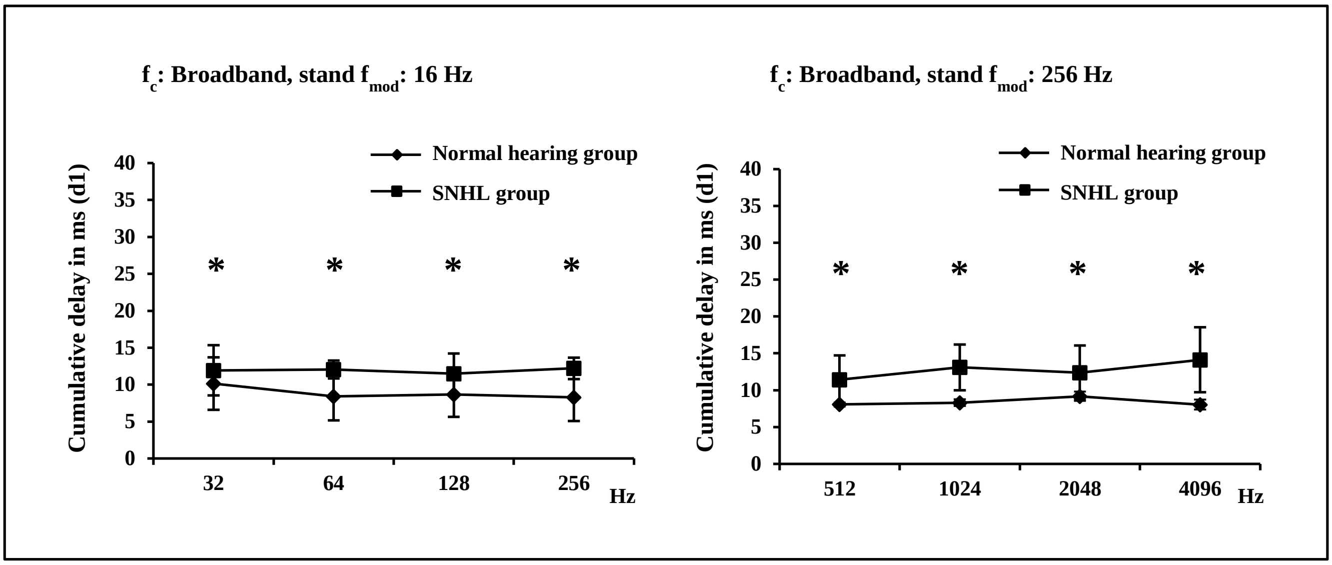

Fig. 3. The mean and standard deviation of the d1 values for normal hearing group (group I) and sensorineural hearing loss group (group II). The * indicates the significant difference of d1 values between the groups.

effect of temporal cues responsible for stream segregation in normal hearing and SNHL people. There was no significant difference in the d1 values between target modulation frequencies with reference to 16 Hz and 256 Hz standard modulation frequencies in the normal hearing group. These results suggest that the participants in this group were able to detect the changes in gap between A and B stimuli in the AB sequence. When a separable rhythmic perception of the A and B stimuli in the AB sequence is perceived, two streams of the A and B sequence are formed. This causes the individual to have difficulty in detecting the arrhythmic AB sequence [12]. However, the good performance in detecting the irregularities indicate that they can detect the changes in cumulative delay in the AB sequence as there was no formation of two separate streams of the A and B stimuli [12]. The present study showed that the cues responsible for envelope coding were not useful for stream segregation in individuals with normal hearing. Even with an increase in the modulation rate up to 4 octaves with reference to the standard low modulation frequency, no stream segregation was noticed. Hence, it can be suggested that the temporal cues for envelope coding have no contribution in stream segregation in individuals with normal hearing. However, further studies are required to confirm this finding using very low modulation frequencies. The results reported no significant difference in the d1 values for higher target modulation frequencies, which is against the results of Grimault et al. [8]. In their study, the temporal fine structure cues in the broadband stimuli alone were found to cause stream segregation. When the temporal modulation frequency was increased by one octave compared to the standard modulation frequency, the stream segregation was perceived in individuals with normal hearing. They concluded that the temporal fine structure cues in the broadband stimuli, in the absence of any spectral or other temporal cues, resulted in stream segregation in normal hearing subjects [8]. Our study, however, showed that the temporal fine structure cues had no contribution in stream segregation in individuals with normal hearing. This discrepancy can be due to the difference in the method used to study the stream segregation. Grimault et al. [8] used a subjective listening task, while we used an objective listening task. In subjective listening tasks, there is a subjective inclination in setting

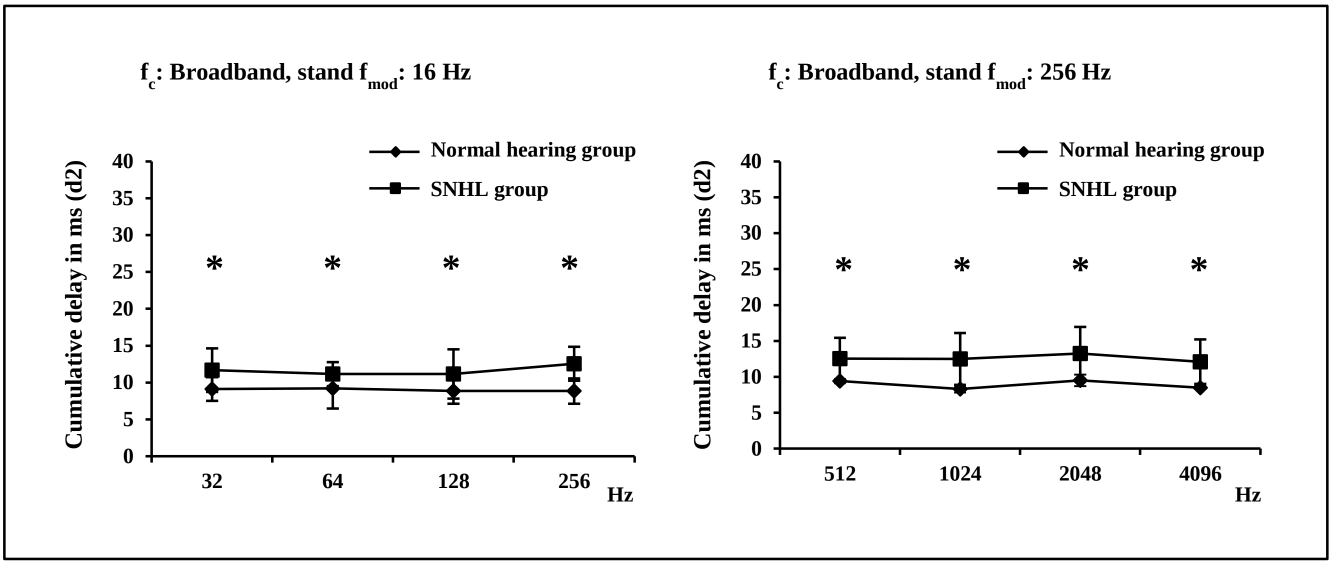

Fig. 4. The mean and standard deviation of the d2 values for normal hearing group (group I) and sensorineural hearing loss group (group II). The * indicates the significant difference of d2 values between the groups.

a lower criterion for responding two streams [11]. Thus, the objective listening task paradigm used in our study suggests that the normal hearing subjects may not use the temporal fine structure cues in the broadband carrier stimuli for stream segregation.

There was no significant difference in the d1 values between target modulation frequencies with reference to 16 Hz and 256 Hz standard modulation frequencies in the SNHL group. The identification of irregularities in the AB sequence in this group was similar to that in the normal hearing group. There was no formation of two separate A and B stimuli streams in this group, like the normal hearing group. The TMTF of the broadband stimuli responsible for envelope coding in the SNHL group was found to be similar to that of normal hearing group at supra-thresholds reported in other studies [19]. The absence of stream formation indicates that the intact temporal envelope coding cues in the broadband stimuli have no effect on stream segregation in the SNHL group, like the normal hearing group. However, a study suggests that temporal fine structure cues are impaired in individuals with SNHL [20]. There was no difference in the d1 values for higher target modulation frequencies in subjects with SNHL. This suggests that the temporal modulation detection ability has no effect on stream segregation and is similar to the result observed in the normal hearing group. There was a significant difference in the d1 values of broadband SAM signal in all target modulation frequencies between the two study groups. This is because, although there was no formation of two A and B stimuli streams in the AB sequence, the d1 values were higher in the SNHL group than the in the normal hearing group. This indicates that the individuals with SNHL require a little longer minimum cumulative delay to detect the changes in gap between A and B stimuli in the AB sequence. Many studies have indicated that the temporal resolution such as gap detection is not generally affected in SNHL people [23]. However, some studies have reported that the gap detection is affected in SNHL people at the most comfortable listening level [24]. Since, the experiment in our study was conducted at the most comfortable level, it can be one of the reasons for reporting higher d1 values in the SNHL group. There was no significant difference in the d2 values between target modulation frequencies with reference to both low

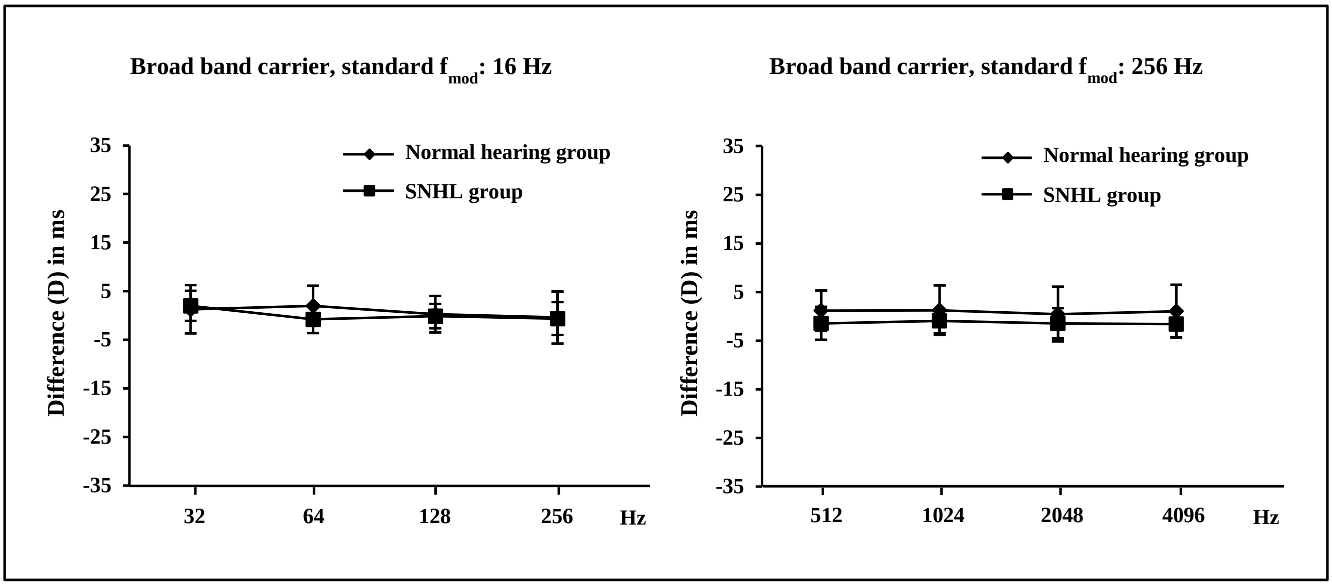

Fig. 5. The mean and standard deviation of the D values for normal hearing group (group I) and sensorineural hearing loss group (group II).

and high standard modulation frequencies in the normal hearing group. The subjects could identify the irregularities in the B sequence within the target modulation frequencies with reference to both standard modulation frequencies. This can be due to the formation of a single stream, since only the B sequence was presented. Therefore, the results suggest that when the B sequence is presented, there is no possibility of the formation of two streams. In this regard, it is easy for the participants to detect the changes in the gap between two adjacent SAM stimuli [12]. These results were consistent to the results obtained for d1 values under experiment I. No significant difference in the d2 values was found between target modulation frequencies in the SNHL group, like the normal hearing group. This indicates that the d2 values were comparable between target modulation frequencies with respect to both low and high standard modulation frequencies. Because of the single stream perception, the SNHL group could identify the irregularities in the B sequence like the normal hearing group. These results are similar to the results of d1 in the SNHL group. There was a significant difference in the d2 values of the broadband SAM in all target modulation frequencies between the two study groups. This difference may be due to the larger d2 values in the SNHL group compared to the normal hearing group. The slightly larger d2 values indicate that the detection of minimum cumulative delay in the broadband SAM stimuli sequence is affected in individuals with SNHL. This suggest that the temporal resolution is affected in SNHL people when they listen in the most comfortable loudness level [24], which was also indicated after testing d1 values.

Finally, we found no significant difference in the D values for SAM broadband stimuli in any target f_{mod} within the study groups. These results suggest that the d1 and d2 values obtained from the experiment I and experiment II were similar in both the groups. The d1 and d2 values represent the temporal resolution in identifying iregularity by two groups. There was no significant difference in the D values between the normal hearing and SNHL subjects for broadband SAM stimuli for any target f_{mod}. These results were different from the results of d1 and d2 values obtained between the two groups. The higher d1 and d2 values may be because of the fact that, as mentioned above, they are slightly affected in the SNHL group, not because of any stream

Table 2. The Mann-Whitney U, p and r values for target f_{mod} between normal hearing group (group I) and sensorineural hearing loss group (group II)

	Experiment I			Experiment II		
Target f_{mod} in Hz	**U**	**p**	**r**	**U**	**p**	**r**
32	228.50	< 0.001	−0.45	271.00	0.005	−0.36
64	129.00	< 0.001	−0.67	276.50	0.006	−0.35
128	125.00	< 0.001	−0.67	215.50	< 0.001	−0.48
256	70.00	< 0.001	−0.79	146.50	< 0.001	−0.61
512	63.00	< 0.001	−0.81	200.50	< 0.001	−0.51
1024	17.50	< 0.001	−0.89	227.50	< 0.001	−0.45
2048	43.50	< 0.001	−0.83	165.00	< 0.001	−0.57
4096	34.50	< 0.001	−0.86	247.00	0.002	−0.40

perception. Regarding no difference in the D values in the normal hearing group, it can be said that the normal hearing people do not use temporal modulation cues in the broadband stimuli for stream segregation. Therefore, it can be stated that the temporal modulation cues in the broadband carrier stimuli may not be a primary cue for stream segregation in normal hearing individuals. This may be because the spectral cues in tonal SAM are very useful in forming two streams in these individuals [9]. Hence, the spectral cues can be a predominant cue for stream segregation and thus, the temporal cues would not have contributed for stream segregation in the normal hearing group. The D values were not significantly different in the SNHL group. This indicates that they do not use the temporal modulation cues for stream formation either. However, this result should be interpreted with caution since the frequency selectivity is affected in individuals with the SNHL and thus the spectral cues may not be a primary cue for stream segregation in them [5,13]. Most studies have shown that the temporal processing at supra-threshold levels is almost intact in individuals with SNHL, but in our study the temporal cues had no effect on stream segregation in them. There is a possibility that the SNHL group may have started to shift to use temporal cues for stream segregation which was not detected in our experiments. It may be premature to conclude that both the groups may be using other similar cues rather than temporal cues for stream segregation. Thus, more studies are recommended to evaluate the effect of temporal cues on stream segregation in SNHL people to validate these findings. The other possibility that cannot be neglected is that the perception of broadband SAM signals and stream perception are two different process and may not be interrelated to each other. However, there is a need for further studies to come into a conclusion.

Conclusion

Temporal modulation frequency cues in the broadband sinusoidal amplitude modulated signal are not used for stream segregation in normal hearing and sensorineural hearing loss (SNHL) people. This indicates that the temporal cues provided by low and high modulation frequencies in the broadband stimuli have no effect on stream segregation in neither normal hearing group nor SNHL group. The minimum cumulative delay is slightly higher in people with SNHL than in normal hearing people. This may be due to the fact that the temporal gap detection is slightly affected at the most comfortable listening levels in people with SNHL.

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Conflict of interest

We declare that there is no conflict of interest to be disclosed.

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