The Effect of Noise and Hearing Impairment on the Processing of Simultaneous Sentences

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Abstract

In everyday situations, communication involving multiple simultaneous talkers is the most difficult for normal hearing as well as individuals with hearing impairment. Such communication situations involve selectively attending to one of several talkers or simultaneously attending to more than one talker. The present study aimed at assessing the effects of noise and hearing impairment on selective and divided auditory attention tasks. Normal hearing a well as individuals with moderate and moderately sere sensori-neural hearing loss carried out selective and divided attention tasks to two separate sentences in quiet as well as conditions wherein the addition of speech shaped noise degraded the sentences O0 dB and -6 dB SNRs). The results revealed that as the degree of hearing loss increased, the performance on both the selective and divided attention tasks, in all the conditions worsened. With the addition of noise, performance on selective and divided attention tasks decline. In the divided attention task, performance on the message reported second was poorer in all the conditions and more affected by noise level than performance on the message reported first. When compared to listeners with normal hearing, listeners with hearing loss showed a larger deficit in recall of the second message than the first. Hearing impairment, as well as the addition of noise affected individuals ability to selectively attend too. Tasks involving the processing of simultaneous messages may be useful for assessing hearing handicap and the benefits of rehabilitation in realistic listening scenarios.

Key words: *Selective attention, divided attention, processing of simultaneous sentences*

Introduction

One of the most challenging situations that humans face on a day to day basis involves acoustic environments comprising of multiple talkers in addition to the background noise that is inherent to most situations, be it in the form of the distant humming of the fan or the music being played in the background. The difficulty in processing information in such a complex acoustic environment is what has been termed the cocktail party problem (Cherry, 1953). The cocktail party phenomenon can be viewed from many perspectives. The task is intuitive and simple from a normal hearing listener's point of view. From physiological or psychological perspective, evidence that have been put together to explain this effect is vast and potentially complex due to the many interactions between the signal, the auditory system, and further on, the central nervous system. Acoustically, the problem has been compared to that encountered in attempting to separate, under noise conditions, a single talker's speech from a spectrogram containing speech signals from multiple speakers. This would prove to be a challenge to even an expert in the field of acoustics or linguistics (Bregman, 1990).

A variety of cues are utilized by listeners to perform the segregation task in a cocktail party task. The cues may be related to the speech utterance itself, such as rhythmic and temporal cues (offsets, onsets, and prosodic cues) or based on the features of the competing speech signals. This also includes factors like the voice characteristics of the individual talkers (speaking style, vocal tract length, F0). The listener's inherent knowledge about the context of the ongoing conversation as well as the constraints offered by the particular language also play a role. Apart from the use of monaural cues, the ability to utilize the binaural difference cues could enhance the ability to selectively attend as well as segregate the competing voices into different perceptual streams.

This ability of the human auditory system to segregate sounds issued from different acoustical sources in different perceptual streams is referred to as *Auditory Scene Analysis (ASA)* (Bregman, 1990). Scene analysis utilizes the perceptual differences between sounds in order to carry out the segregation task and the perceptual difference perceived is a major factor in determining the success of segregation. Perceptual differences have been found to be reduced in situations where in the sounds themselves are degraded or in situations where the reception of the sounds by the ear is degraded, like in hearing impaired listeners.

In order to gain insight into the mechanism involved in ASA, Bregman (1990) suggested assessing the

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processes that are aimed at segregating simultaneous acoustic events. To examine the processing of multiple speech stimuli, two different types of experimental approaches have predominantly been used. One is the *Monaural cocktail party task* (Gallun, Mason & Kidd, 2007), in which researchers have generally presented multiple speech stimuli to the *same* ear and have reported on the factors that lead to *errors* in processing only one of two presented stimuli (Brungart, Simpson, Ericson, & Scott, 2001). It has been reported in literature that two kinds of masking mainly contribute to interference that is perceived by the listener in such a task (Kidd, Mason, Rohtla & Deliwala, 1998; Freyman, Balakrishnan & Helfer, 2001; Freyman, Helfer, McCall, & Clifton, 1999) '***Energetic masking'*** which occurs when there is an overlap in temporal and spectral characteristics of the competing signal in such a manner that the individual is unable to detect some of the acoustic information contained in the target speech. '***Informational Masking'*** is seen to occur when the target and the competing speech signals are similar therefore leaving the listener unable to segregate the acoustically detectable elements (important for stream segregation) of the target speech from that of the masking speech.

The second type of experimental approach used is the *dual-ear experiment* (Gallun et al., 2007) in which the presentation of one speech utterance is to one ear and the other ear is provided with a separate stimuli. The effects of energetic masking in such a situation are negligible in the dual ear listening configuration as each ear receives an independent speech signal. The effects of informational masking too are reported to be reduced as the differences in the spatial locations of the sources can be utilized in order to segregate the speech signals (Freyman et al., 2001). In such a task, when presented with two dichotically competing yet simultaneous speech utterances, the response mode can either be to ignore one and report the other (*selective attention*), where the subject is asked to ignore any distracting inputs that might occur concurrent to the stimuli of interest and to focus attention on a single source of information and (Broadbent, 1958; Cherry, 1953). The other response mode involves reporting both (*divided attention*), where the subject is expected to allocate necessary resources to focus of attention across two or more sources and to respond to by processing information from any one or more than one of them at the same time (Howard-Jones & Rosen, 1993; Moray, 1959; Spieth, Curtis, & Webster, 1954; Treisman, 1964; Yost, Dye, & Sheft, 1996).

In crowded listening environments, selective attention enables information to be extracted from a talker of interest. However, in many cases, it is desirable to retrieve information from a talker who is outside the immediate focus of attention (e.g., when two people talk at once). Although some early studies showed that listeners with normal hearing perform poorly when asked to recall messages from unattended talkers (Cherry 1953), subsequent studies indicate that listeners are able to process unattended speech to some extent (Moray 1959; Conway, Cowan & Bunting 2001; Rivenez, Darwin & Guillaume, 2006) and can perform remarkably well at following two talkers when instructed to do so in advance (Best et al., 2006; Gallun, Mason & Kidd, 2007; Ihlefeld & Shinn-Cunningham, 2008).

Normal hearing listeners are able to direct top-down attention to select desired auditory objects from out of a sound mixture. As peripheral objects are the basic units of attention, proper object formation is important for being able to selectively attend. To select a desired object, listeners must know the feature that identifies that object and enables them to focus and maintain attention on the desired object. The ability to switch attention at will is important in many social settings. Listeners often miss bits of an unattended message as a result of masking from competing sources as well as lapses in object formation, object selection and attention switching. However, they are able to cope with incomplete messages by filling in the missing bits from glimpses they do hear and by replaying the message from memory. Te speed of each processing stage is important, as listeners must be able to keep up with the flow of information to interact with others in a social setting.

Multiple factors conspire to interfere with the ability of hearing impaired listeners to communicate when they are many talkers. The spectrotemporal structure of sound determines how objects form. However, spectrotemporal detail is not encoded robustly in such listeners. This degraded peripheral representation is likely to impair and slow down object formation in them. Impaired object formation is likely to degrade the ability to filter out unwanted sources, which will in turn interfere with the ability to understand the source that is the desired focus of attention. Features that enable object selection are also less distinct, making it difficult for them to select the desired source from a mixture. As the process of selective attention are slower in hearing impaired listeners, they are likely to miss more f a desired message as they try to focus and switch attention in social scenes. As more of the message is missed, additional processing is required to perceptually fill in and replay the missing message to understand it. The overall effect is that hearing impaired listeners have much greater processing demands and at best normal processing capabilities.

When demand exceeds capacity, the result can be a failure to keep up with the flow of information.

Despite many years of research on the topic of processing of simultaneous sentences, the effects of degradation of the input as well as hearing loss in young adults have not been well studied. Considering the subjective reports of individuals with hearing impairment regarding the difficulties they face in speech perception in the presence of noise, there is a need to report on the performance of such individuals in order to set the stage for further research to address the issue as well as to generate data on the difficulties faced by individuals in a realistic situation. Studies that have probed into this have mainly focused on divided listening skills in hearing impaired population consisting mainly of older listeners (Strouse, Wilson, & Brush, 2000; Singh, Pichora-Fuller & Schneider, 2008; Humes, Lee & Coughlin, 2006) wherein factoring out the contributions of age and hearing loss as well as cognitive status to the results(Best, Gallun, Kidd & Shinn-Cunningham, 2010). There is thus a dearth of literature regarding the processing of simultaneous stimuli in the hearing impaired population. The aim of the present study was to investigate the processing of simultaneous sentences. In particular, to determine the effect of hearing loss on the processing of simultaneous sentences as well as to determine the combined effect of noise and hearing loss as well and finally, to compare these performances with that of normal hearing individuals.

Method

Participants

Data was collected from a total of number of 37 participants. The participants were assigned to one of the two groups, the control group or the clinical group.

Control group: Fifteen participants were recruited as a part of the control group and were between the age range of 15 to 55 years (mean=32 years). All the individuals had bilateral normal hearing sensitivity with the pure tone average being less than 15 dBHL for octave frequencies from 250 to 8000 Hz. The participants had ‘A’ type Tympanograms, indicative of normal middle ear status. All the individuals were native speakers of Kannada language. They did not present with any complaints of psychological, cognitive or neurological problems.

Clinical group: Individuals with postlingually acquired sensori-neural hearing loss served as participants in this group. A total number of 22 participants between the age range of 20 and 55 years were recruited. The clinical group was sub grouped into Group A and Group B. All the individuals comprising the clinical group were native speakers of Kannada language. The participants had ‘A’ type tympanograms indicative of normal middle ear status. They did not have any complaints of psychological, cognitive or neurological problems.

Clinical Group A consisted of a total of 12 Participants. The participants of this group had an age range of 20 to 55 years (mean=37 years, SD=4.13). All the participants were diagnosed to have bilateral, symmetric moderate sensorineural hearing loss (mean PTA=46.6 dB), flat audiometric configuration with 5 dB rise or fall per octave (Lloyd & Kaplan, 1978).

Clinical Group B consisted of a total of 10 Participants. The participants of this group had an age range of 20 to 55 years (mean=39 years, SD=6.54). All the participants were diagnosed to have bilateral, symmetric moderately severe sensori-neural hearing loss (mean PTA=63.3) flat audiometric configuration with, 5dB rise or fall per octave (Lloyd & Kaplan, 1978).

Instrumentation

A calibrated two channel diagnostic audiometer, Madsen Orbiter 922 with TDH 39 headphones encased in MX 41AR ear cushion was used to obtain air-conduction thresholds and perform speech Audiometry. Bone conduction testing was done using Radio ear B-71 BC vibrator. A Calibrated Grason Stadler Inc, model-Tympstar middle ear analyzer (Version 2.0) was used to assess the middle ear status and rule out middle ear pathology. Computer Software’s used during the course of the study for the preparation of the speech stimuli were Adobe audition (Version 3) which was used to record the stimuli as well as to carry out consequent editing of the recorded material. Scaling and normalization of the sentences was done using this software to ensure that the onset and termination of the sentence pairs were approximately the same and that the intensity of all the sounds was brought to same level. Matrix Laboratory (MATLAB v.6) was used to prepare an algorithm to embed the noise at different SNRs.

Stimuli

Speech materials from the Competing Sentence Test–Kannada (Hemalatha, 1982) which consisted of 25 sentence pairs were utilized in the study. The sentences were of similar length and contained approximately equal number of words and syllables. Both the sentences of the pair contained a common theme. Naturally produced sentence by a female native

Kannada speaker with normal vocal tract effort was used for the preparation of the stimuli. The test items were spoken naturally; peak intensities of the sentences were monitored to avoid distortion. The sentences were recorded using a digital recorder with a 16 bit processor at 44 kHz sampling frequency with a high fidelity microphone placed at a distance of 10 m from the speaker. The list was edited using adobe audition (Version 3). All the sentences were normalized to ensure that intensity was at the same level. The recorded sentences were prepared as dichotic stimuli by inserting the sentences into two separate tracks which were routed to the left and the right channels. The stimuli were scaled to ensure that the onset and offset of each of the sentence pair was similar. The pairs of stimuli were concatenated with an inter stimulus interval of 10 seconds.

For test blocks wherein noise was added, MATLAB algorithms were incorporated to embed the prepared sentences in speech shaped noise at two SNRs (0, -6 dB) as recommended by Best, Gallun, Mason, Kidd & Shinn-Cunningham (2010). Speech-shaped noise was created by filtering randomly generated broadband noises with the average frequency spectrum of the set of sentences used in the experiment. For all the dichotic stimuli, the noise was independent in the two ears but equal in level. A 1000 Hz calibration tone with the RMS value, the same as the vocalic amplitudes of the syllables in the sentences, was incorporated at the onset as a reference calibration signal. The prepared test material was recorded onto an audio CD. The recorded dichotic material was played to the participants by routing the CD output through the calibrated Madsen audiometer with TDH-39 supraural earphones.

Procedure

The following procedure was adopted to carry out the study. Otoscopic evaluation of all subjects was done to rule out any outer ear and/or tympanic membrane pathologies. Pure tone audiometric thresholds were obtained for both air-conduction (at octave frequencies of 250 Hz-8000 Hz) and bone-conduction (at octave frequencies of 250 Hz-4000 Hz) using modified Hughson - Westlake procedure (Carhart & Jerger, 1959) as recommended by ANSI S3.21 1978 (R 1997). Speech eudiometry was done to obtain the speech recognition thresholds and speech identification scores. Immittance evaluations were carried out to ensure normal middle ear functioning. Tympanometry was carried-out using a 226 Hz probe tone with a pump rate of 50 dapa/unit time.

All the tasks of the experiment were carried out in two listening conditions, *Quiet condition* and *noise condition*, where in, for the latter, all the stimuli were presented at two SNRs of spectrally shaped speech noise 0 dB SNR and -6 dB SNR. The order of presentation of the 3 tasks in the two experimental conditions varied from subject to subject, randomized through a ‘lottery without replacement’/ ‘simple random sampling’ method (Kalton, 1983).

Familiarization of test stimulus: The individuals were initially ***familiarized*** with the test material. The test material, consisting of a total of 50 sentences was presented auditorily at comfortable and at a clearly audible level to all the subjects before the onset of the testing. Prior to the familiarization, the clients were informed that the sentences presented to them would be the test stimuli for the following tests and were instructed to attend to the input provided.

Presentation Level: For the normal hearing subjects, levels were set by measuring the quiet speech recognition threshold and presenting the speech stimuli at a fixed level above this threshold (35 dBSL). For the hearing impaired subjects, presentation level was set by measuring the quiet speech recognition threshold and presenting the speech stimuli at a fixed level above this threshold (35 dBSL) , in subjects who found this level uncomfortable, the level was set at that determined to correspond to the most comfortable level

Tasks

Control Trials: Wherein only one message was presented to one ear and the subjects were to report the presented stimulus verbatim.

Selective attention task (Single-task trials): The stimuli were presented dichotically and the listeners were to report verbally the sentence heard in the target ear. Before the presentation of the stimuli, the subject was made aware of which ear was the target ear by means of a visual representation of the same. Presentation of the stimuli to the target ear was randomized such that each ear was the target ear 50% of the time. The subjects were instructed to repeat the sentence heard in the target ear verbatim and ignore the sentence in the non target ear.

Divided attention task (Dual task trials): Dichotic stimuli were presented and the listeners were to report verbally the message from the target ear followed by the message from the non target ear. Ahead of the presentation of the stimuli, the subject was made aware of which ear was the target ear by means of a visual representation of the same. The stimuli were randomized and presented in such a manner as to ensure that each ear was the target ear 50% of the time. The subjects were instructed to repeat both the sentences, first the sentence heard in the target ear followed by the sentence heard in the non target ear.

Scoring

Control Trials: Total numbers of sentences presented were 5; each assigned a score of 20% for a verbatim response.

Selective attention trials: Total number of sentences presented was 10; each assigned a score of 10% for a correct response, the maximum possible score being 100%.

Error was defined as:

a. Any instances where portions of the two sentences are interchanged resulting in a new sentence.
b. Instances of syntactic confusion.
c. Omission or substitution of any crucial words which would alter the meaning of the given sentence.

Total number of sentences presented was 10; each assigned a score of 10% for a correct response, the maximum possible score being 100%

Divided attention trials: Total number of sentences presented was 10; each assigned a score of 10% for a correct response, the maximum possible score being 100% for the target stimuli and 100% for the non target stimuli. Three types of response were scored.

a. Both the sentences are correct (Both M1 and M2).
b. Only one member of the stimulus pair is correct (Single Correct) (M_1 or M_2).
c. Neither member of the stimulus pair is correctly reported (Double error).

Here, the sentences were scored correct even if the words were changed, provided the meaning of the sentence remained the same.

The third task (Divided attention) was scored separately for both the target and the non target responses and was therefore considered as two tasks i.e. divided attention M1 (response to target stimuli), Divided attention M2 (response to secondary stimuli) for ease of statistical analysis. Henceforth, the tasks would therefore refer to control tasks, selective attention tasks, divided attention M1 and divided attention M2. The third noise condition -6 dB SNR was not included in the data set for statistical analysis since individuals with moderate and moderately severe hearing loss were unable to perform the 4 tasks. The data of processing of simultaneous sentences collected for the three groups, under the four tasks in the two conditions were analyzed using Statistical Package for the Social Sciences (SPSS for windows, Version 16).

Results and Discussion

Comparison of mean and standard deviation across groups for the tasks and conditions

Table 1 provides data of the mean and standard deviation values (SD) for the three subject groups across the tasks and conditions. The results indicate that the best performance was noticed in the control task in quiet condition and then in 0 dB SNR for all three groups. Among the simultaneous stimulation condition, the mean scores obtained in the selective attention tasks were higher than those obtained in the divided attention tasks.

For the control task in noise, similar performances were seen in the normal hearing group and in the moderate hearing loss group, with the mean reducing to 92% in the moderately severe hearing loss group. In the selective attention task, where there was a semantically similar sentence presented to the ear opposite to the target, scores in three listener groups reduced indicating that the message in the unattended ear interfered with performance. In the divided attention task, performance for M1 was consistently poorer than selective attention task performance and performance for M2 was on an average worse than the performance for M1. The mean scores across the groups were seen to be better in the quiet condition over the noise condition. The results also indicated that with increasing degree of hearing loss, decrease in the processing of the stimuli was present.

A similar trend in results was reported by Best, Gallun, Mason, Kidd, Shinn-Cunningham (2010). They conducted a study on normal hearing and individuals with moderate-moderately severe hearing loss wherein the mean values obtained for the control task was better than for the single task (selective attention) trials, which was better than for the dual task trials (divided attention), M2 responses being poorer than M1. Poorer performance in noise condition (0 dB SNR) over quiet condition was also reported by the authors. The reductions in performances obtained in the study across tasks as well as between the normal and hearing impaired subjects were of a lesser magnitude than that obtained in the current study. The differences in the magnitude of reduction in performance may be

Table 1: Mean and standard deviation of the percentage correct scores (max=100%) obtained by the three groups for the tasks in quiet and noise conditions

Groups → Tasks and condition↓	Normal hearing group (N=15)		Moderate hearing loss Group(N=12)		Moderately severe hearing loss group(N=10)	
	Mean	SD	Mean	SD	Mean	SD
Control task in quiet	100	0.00	100	0.00	100	0.00
Control task in 0dB SNR	100	0.00	98.33	5.77	92.00	10.32
Selective attention in quiet	94	7.36	79.17	6.68	69.00	11.00
Selective attention in 0 dB SNR	85.33	5.16	66.67	9.84	56.00	5.16
Divided attention - M1 in quiet	88	7.74	75.00	10.00	59.00	11.00
Divided attention - M1 in 0dB SNR	75.33	6.39	55.83	11.64	43.00	9.48
Divided attention- M2 in quiet	79.33	7.03	57.50	9.65	45.00	8.49
Divided attention- M2 in 0dB	67.33	4.07	43.33	13.02	18.00	11.35

attributed to methodological differences. The stimuli used in the study by the authors were speech materials taken from the Coordinate Response Measure (CRM) corpus (Bolia, Nelson, Ericson & Simpson, 2000), which consisted of sentences of the form ‘Ready <call sign>, go to <colour> <number> now.’ Therefore, the task was of the form of identification of keywords in the sentence. Apart from differences in material used and the scoring method adopted, the response modality in the current study was verbal response of the stimulus perceived, and in the study by Best et al., (2010), it involved clicking with the computer mouse on a graphical user interface, which reduced the memory loading of the task.

Comparison of group performances across tasks and conditions

In order to assess if there existed any interaction among the three subject groups, four tasks and the two conditions, Mixed ANOVA was carried out. Mixed ANOVA revealed that there was significant difference in the main effect of tasks [F(3,102)=497.913, p<0.001] and conditions [F(1, 34)=230.098, p<0.001]. Test of between subjects effects also revealed that there was significant differences between the groups [F(2, 34)=93.36, p<0.001] as well. Further, the interactions between task × group [F(6,102)=28.88, p<0.001], condition × group [F(2, 34)=7.777, p<0.05], task × condition [F(3,102)=20.787, p<0.001] were also found to be significant. Mixed ANOVA failed to show any interaction in task × condition × group [F(6,102)=2.034, p>0.05].

Bonferroni’s Pair-wise comparison was carried out between the tasks as Mixed ANOVA showed significant main effect of tasks. The analysis of the data set revealed significant differences between the four tasks. Duncan’s post hoc analysis of the main effect between the groups also revealed significant differences between the groups (α defined at 0.05). There was a significant reduction in scores as the degree of hearing loss increased. The results obtained in this study regarding the main effects and the interactions are in agreement with the results obtained by Best et al., (2010) who also reported of a significant main effect of task and SNR. Furthermore, they also reported that all task conditions -control task, single task (selective attention) trials, dual task trials (divided attention), were significantly different from one another for both normal hearing as well as for hearing loss group.

Since Mixed ANOVA revealed significant interaction effects, the data was also subjected to MANOVA and subsequently Duncan’s post hoc analysis to see the influence of the groups across the tasks and conditions. The results of MANOVA revealed significant difference in the task and condition performance across groups. Duncan’s post hoc analysis was then carried out to see the influence of groups in each of the taskand condition. The results obtained are discussed below.

Comparison between groups in control task at 0 dB SNR condition

Duncan’s post hoc analysis revealed that there was no significant difference between the normal hearing and moderate hearing loss group for the control task at 0dB SNR, but the performance of the moderately severe hearing loss group was significantly different from the normal hearing and moderate loss groups. The high scores exhibited by normal hearing individuals are in agreement with reports of similar performances by several authors (Gallun et al., 2007; Drullman & Bronkhorst, 2000; Brungart & Simpson, 2002; Best et al., 2010). This can be attributed to the stimuli utilized in the present study. Sentences are the easiest signal to understand as they provide the listener with acoustic information, semantic and contextual cues and linguistic content, i.e. greater redundancy (Miller, Heise & Lichten, 1951). Due to speech redundancy, normal-hearing individuals can understand the signal even though it may be highly degraded (Wilson & Strouse, 1999). The absence of a significant difference in the performance by individuals with moderate loss may be attributed to the inherent redundancy offered by the stimuli as well as to the additional redundancy that the familiarization process afforded them. In addition to it, according to Wilson & Strouse (1999), some hearing-impaired individuals have understanding ability equal to a normal hearing person while others understand very little regardless of presentation level. Humes (1996) showed that the degree of sensorineural hearing loss is the primary variable for speech understanding in noise, greater the degree of loss, poorer the performance. This could account for the relative poorer performance by individuals with moderately severe hearing loss for speech perception in noise (Dubno, Dirks, Morgan, 1984; Duquesnoy, 1983; Plomp, 1986; Plomp & Mimpen, 1979).

Comparison between groups in selective attention task in quiet and 0 dB SNR conditions

The post-hoc analysis carried out for the data set revealed significant differences in the performance of the control group and the hearing impaired groups, as well as significant differences between the two hearing impaired groups. Performance exhibited by individuals with moderate hearing loss was poorer than that by the control group consisting of normal hearing individuals and the poorest performance was by the moderately severe hearing impaired group. The addition of noise further degraded the performance of the three groups, although the trend in performance between the groups remained the same.

Previous experiments have shown that, listeners are able to attend to the signal in the target ear without any measurable interference from masking sounds to the unattended ear (Cherry 1953; Drullman & Bronkhorst, 2000; Kidd, Mason & Rohtla, 1995). These reports are in disagreement with the results obtained in the current study. In the present study, it was found that the presence of the speech signal in the contralateral ear made it significantly difficult for the listeners to extract information from the talker in the target ear. Such a pattern of performance was found in earlier experiments by Brungart and Simpson (2001, 2002) that examined within-ear and across-ear interference using the CRM stimuli. Similar results have also been reported by Gallun et al., (2007), Moray (1959), Wood & Cowan (1995), Treisman (1960) in normal hearing individuals for different kinds of speech stimuli and by Best et al., (2010) in normal hearing as well as individuals with moderate-moderately severe hearing loss. Such reductions in performance can be attributed to informational 'across-ear' interference. This occurs from a masking talker in the ear opposite the target talker for selective attention in quiet condition. For the task in noise condition, reduction in performance could be from possible interactions between the informational and energetic 'within-ear' interference that occurs from a masking stimulus in the same ear as the target speech (Brungart & Simpson, 2002; Gallun et al., 2007).

It has been reported in literature that impaired listeners have reduced temporal and spectral acuity in comparison to normal hearing listeners (Leek & Summers, 2001, Deeks & Carlyon, 2004, Bernstein & Oxenham, 2006, Carlyon, Long, Deeks & McKay, 2007). Speech intelligibility for them would be degraded even in quiet if the features that convey speech meaning are degraded due to reduced audibility as well as a diminished spectrotemporal resolution. Hearing impaired listeners also suffer from effective increases in the amount of energetic masking that is due to the reduced spectral selectivity of their peripheral auditory filters and the amount of masking increases as the degree of loss increases. Altogether, these factors cause less of a target source to be audible to a hearing impaired listener compared to a normal hearing listener in the same acoustic setting (Shinn-Cunningham & Best, 2008).

Normal-hearing listeners can direct top-down attention to select desired auditory objects from out of a sound mixture as well as are able to enhance it and suppress competing maskers (Shinn-Cunningham & Best 2008). This could explain the relatively smaller reductions in performance seen in them in the current study over the control task. In hearing impaired individuals, failures in selective attention that cause such a drastic reduction in performance can result from failures in separating the target from the other sources i.e. failures in object formation and directing attention to the correct object in the scene i.e. failures in object selection.

Dealing with failures of object formation, it has been found that hearing impaired individuals are also likely to have difficulty properly grouping sound sources. The spectro-temporal cues that convey speech meaning are also the basis of short-term grouping (Bregman, 1990; Darwin & Carlyon, 1995). Therefore, a less-robust representation of spectro-temporal content as seen in impaired listeners may cause problems with object formation. For example, the onsets, offsets, modulation, and harmonic structures which are important for forming objects over short time scales in a multitalker environment are less perceptually distinct for individuals with hearing loss than normal-hearing counterparts (Leek & Summers, 2001; Buss, Hall, & Mason, & Walsh, 2002; Moore, Glasberg, & Hopkins, 2006; Bernstein & Oxenham, 2006). Broader than normal frequency selectivity in impaired listeners also results in fewer independent frequency channels to represent the auditory scene, making it harder to perceptually segregate the component sources (Gaudrain, Grimault, Healy, & Bera, 2007).In addition, they also appear to have difficulty encoding the spectrotemporal fine structure in sounds which are critical for robust pitch perception, for speech intelligibility in noise, and for the ability to make use of target object information in moments during which the interfering source is relatively quiet i.e. 'listening in dips' (Pichora-Fuller, Schneider, MacDonald, Brown & Pass, 2007). Discussing in terms of object formation, fine structure may also enable a listener to segregate target energy from masker energy and therefore form a coherent object from the discontinuous target glimpses.

If there is failure to properly form auditory objects, they will have difficulty selectively attending to a target. When objects form properly, biased competition between objects works to suppress the objects outside the focus of attention. When objects fail to form properly, the competing sources will not be suppressed effectively, and therefore will cause greater perceptual interference (Desimone & Duncan, 1995; Shinn-Cunningham & Best, 2008).

Comparison between groups in divided attention task in quiet and 0 dB SNR conditions

Divided attention M1

The results of the Duncan's post hoc analysis of the performance between groups for the divided attention task in quiet and in noise reveal that the mean scores for divided attention M1 were significantly reduced for the two groups of individuals with hearing impairment. This decrease in performance in the two groups is significantly different from the performance by the control group and the performance for the M1 task is significantly different between the two groups of hearing impaired subjects, for quiet as well as for noise.

Divided attention M2

The results obtained for the post hoc test indicate that the performance of the control group for the divided attention M2 task, in quiet and in noise is significantly different from the scores obtained by the moderate and moderately severe hearing impaired groups. In addition, the performances of the two groups in quiet and in noise are significantly different from each other.

In the divided attention task, performance was poorer for each message than for the one message reported in the selective attention task. For M1, the difference was comparatively smaller. Similar results were reported by Best et al., (2010) which they attributed to an increase in confusion errors (having to report both messages increased the chances of subjects interchanging the words) and an increase in random errors (a consequence of processing load). For M2, they reported that the deficit relative to the single task was far greater because of a much larger occurrence of random errors (Best et al., 2010). Poorer performance in M2 over selective attention task, as well as M1 was also seen in the present study.

Broadbent (1954) proposed that simultaneous inputs to the auditory system are to some extent processed serially. In his study, he presented two sequences of digits simultaneously to the two ears and reported that, although listeners could recall all digits, the responses were always made to one ear followed by the other. Therefore, Broadbent (1958) postulated that simultaneous sensory inputs are stored temporarily via immediate auditory memory which is then processed by a limited capacity mechanism serially (Lachter, Forster, & Ruthruff, 2004). A consequence of such a scheme is that the secondary message in the pair is to be stored while the primary message is processed. Apart from this, with the dual-response design, the responses themselves have to be made sequentially, be it in any response mode. It is possible that the poorer performance on M2 is related to the fact that it must be retained in memory longer than M1 during the response interval (Sperling, 1960). Authors have commented on the fact that information degrades while being held in the sensory buffer and may be replaced by subsequent sensory stimuli (Vogel & Luck, 2002). The results of the present study, showing large reduction in performance for the message reported second (M2), can be attributed to its degradation as it is retained in the memory due to processing of the first message as well as due to the sequential mode of response. Similar conclusions have also been reported in other studies (Ihelfeld & Shinn-Cunningham, 2008; Best et al., 2010).

Gallun, Mason & Kidd (2007) also reported that the performance in the divided listening task was poorer than in the selective listening task as expected, although there was a substantial reduction in the selective listening condition due to the presence of distracting speech stimulus. However, it was reported that for the divided listening task, the costs (Difference between divided attention and selective attention) in performance calculated were much greater when the listener task was to monitor both ears for speech identification than when the listener only had to identify speech in one ear and detect the presence of speech in the opposite ear. The authors speculated that the costs of dividing attention are correlated to the extent to which the two tasks require the same or different pools of processing resources. When two identification tasks were required, the observer was utilizing the same pool of resources. This is in agreement with the postulates of the multiple resource models (Navon & Gopher, 1979).

In both normal hearing and hearing loss groups, in the current study it was found that addition of the noise affected the performance for M1 in the divided attention task in nearly the same way that it affected performance in the selective listening task. Also, the ability to report M2 decreased more dramatically with addition of noise which was attributed by Best et al., (2010) to an increase in random errors in the study they conducted. These results support the conclusion that the processing of simultaneous messages interacts with the quality of the inputs (Best et al., 2010). In the model described earlier in which simultaneous inputs are processed serially, the inputs that are processed second are held in the form of raw sensory representations that are volatile and have been found to degrade with time (Broadbent, 1957; Brown, 1958; Durlach & Braida, 1969). This could explain why performance in M2 is particularly sensitive to the integrity of the acoustic input. A degraded input like with the addition of noise would degrade even further in this store and would not be useful by the time it was fully processed. Various authors claim of a trade-off between SNR and the time interval during which period a sensory trace must be maintained. Best et al., (2010) in their study noted that that the effect of noise on M2 was almost exclusively due to an increase in the random errors noted and that confusion errors were quite constant as a function of the various SNRs they utilized. This therefore supports the idea that sensory degradation and maybe not an increased confusion between the streams could probably be responsible for the dramatic effect of noise on the recall of M2.

An alternative explanation to this result is that the increased difficulty of processing M1 in trials with noise effectively drained a limited pool of processing resources, leaving fewer resources for processing of M2 to occur. This rationale was used previously to explain the effect of noise on the reduced ability of individuals to store part of a single-attended message for later recall (Rabbitt, 1968; Pichora-Fuller, Schneider & Daneman, 1995).

Comparison of performance between the tasks.

Normal hearing Subjects group

To assess the performance of normal hearing individuals across the tasks in quiet and noise conditions, repeated measure ANOVA was carried out for the conditions separately. The results revealed significant difference across the tasks [$F(3, 42)=27.22$, $p<0.001$] in quiet as well as in noise condition [$F(3, 42)=150.45$, $p<0.001$]. Bonferroni's post hoc analysis was performed to see the difference between tasks in quiet and noise conditions separately. The results of the pairwise comparison indicated significant difference across all the tasks in quiet and noise condition separately ($\alpha=0.05$). Hence, paired t test was administered between the tasks in noise and quiet condition. The results have been tabulated in Table 2. Paired t test revealed significant differences between the three pairs of task i.e. selective attention, divided attention – M1 and M2 in the quiet vs. noise conditions.

Moderate hearing loss group

Two separate repeated measures of ANOVA tests were carried out for this group across the tasks, one analysis for performance in quiet and the other for the performance in noise. Results revealed that there was significant differences between the tasks in quiet [$F(3, 33)=94.686$, $p<0.001$] as well as between the tasks in noise [$F(3, 33)$ 85.457, $p<0.001$]. To determine which tasks were different from each other, Bonferroni's pairwise comparison test was carried out. The analysis revealed that the trend in moderate hearing loss group across the two conditions (quiet and noise) were the same, with there being significant differences between all the tasks in the two conditions except the selective attention and divided attention M1 task. Paired t test was then carried out to assess if there was a significant

Table 2: t values and level of significance for comparison between tasks in quiet and noise conditions in normal hearing group

Tasks and conditions		t	df	p
Pair 2	selective attention quiet - selective attention 0 dB SNR	4.516	14	0.000
Pair 3	divided attention M1 in quiet - divided attention M1 0 dB SNR	6.141	14	0.000
Pair 4	divided attention M2 quiet - divided attention M2 in 0 dB SNR	6.874	14	0.000

Table 3: t values and level of significance for comparison between tasks in quiet and noise conditions in moderate hearing loss group

	Tasks and conditions	t	df	p
Pair 1	control task, quiet - control task, 0 dB SNR	1.000	11	0.339
Pair 2	selective attention quiet - selective attention 0 dB SNR	5.000	11	0.000
Pair 3	divided attention M1 in quiet - divided attention M1 0 dB SNR	5.702	11	0.000
Pair 4	divided attention M2 quiet - divided attention M2 in 0 dB SNR	3.957	11	0.002

Table 4: t values and level of significance for comparison between tasks in quiet and noise conditions in moderately severe hearing loss group

	Tasks and conditions	t	df	P
Pair 1	control task, quiet - control task, 0 dB SNR	2.449	9	0.037
Pair 2	selective attention quiet - selective attention 0 dB SNR	4.333	9	0.002
Pair 3	divided attention M1 in quiet - divided attention M1 0 dB SNR	4.311	9	0.002
Pair 4	divided attention M2 quiet - divided attention M2 in 0 dB SNR	9.000	9	0.000

difference between tasks across the two conditions. The results as shown in Table 3 indicated that there was significant difference between 3 tasks in the quiet and noise condition, with the scores in the 0 dB SNR condition being poorer than in quiet for the selective and divided-M1 and M2 tasks. The control task in noise and quiet did not show a significant difference.

Moderately severe hearing loss group

To assess if the performance for the tasks in this group were different, repeated measure ANOVA was carried out separately for the quiet and noise conditions. The analysis revealed significant differences between the tasks [F(3, 42)=27.22, p<0.001] in quiet as well as in noise [F(3, 27)=146.923, p<0.001]. To determine the tasks which differed in scores from each other, Bonferroni's pairwise comparison was carried out for the quiet and noise conditions separately. The analysis revealed that there was a significant difference between all the 4 tasks in noise as well as in quiet conditions. Sampled t test was then carried out and the results are revealed in Table 4.

Discussion for the comparison between tasks

A similar trend was seen across the three groups for the comparison of performances between the tasks. In all the groups, the performance was found to reduce as the tasks performance demanded the need for larger attentional and processing resources. The mean scores obtained across the groups for the selective attention tasks were significantly poorer than those obtained in the control task (Brungart & Simpson 2002). As previously described, this could be attributed to the informational masking effect due to the presence of a similar message, by the same talker in the nontarget ear. This would result in interference in the processing of the target sentence and therefore a reduction in performance in normal hearing as well as hearing impaired groups (Brungart & Simpson, 2002). In the group with hearing impairments, this effect is further exacerbated by the reduced temporal and spectral acuity compared to normal-hearing listeners (Leek & Summers, 2001; Deeks & Carlyon, 2004; Bernstein & Oxenham, 2006). Due to reduced audibility and diminished spectro-temporal resolution, the features that convey speech meaning are degraded; therefore speech intelligibility will be degraded even in quiet when compared to normal hearing individuals in the same situation (Shinn-Cunningham & Best, 2008). Hearing impaired listeners also have difficulty properly grouping sound sources as well as with object formation due to the reduced ability to process spectro-temporal content. Also, robust location, pitch, and harmonic cues may not be available to them; further impairing their ability to properly separate the mixture into streams (Bregman, 1990). This in turn would result in difficulty selectively attending to a target. In addition, loss of spectro-temporal detail in the periphery may affect perception of higher-order features that distinguish target from masker (Desimone & Duncan, 1995).

In the divided attention task, there was a further reduction in performance over the selective attention task in all the groups which is in agreement with several studies (Ihelfeld & Shinn-Cunningham, 2008; Best et al., 2010). These authors have stated various explanations for such a finding. One such explanation for the same is based on the limited availability in processing resources available. The processing of M1 drains a limited pool of resources, therefore leaving limited or no resources for the processing of M2 depending on the task (Rabbitt ,1968; Pichora-Fuller, Schneider & Daneman, 1995). Another explanation concerns the degradation M2 undergoes as it is stored in a memory buffer while M1 is process as well as while M1 was being reported (Broadbent, 1957; Brown, 1958; Durlach & Braida, 1969; Cowan, Saults, Elliott & Moreno, 2002; Vogel & Luck, 2002). The further degradation in response in hearing impaired listeners is also explained in terms of an 'effort hypothesis.' According to this hypothesis, hearing loss makes the immediate speech task more demanding, leaving fewer processing resources for storing the to-be-recalled items. This hypothesis is also supported by studies that have used a secondary task that is non-auditory and thus does not depend directly on the quality of the auditory stimuli (Rakerd, Seitz, & Whearty, 1996). For the task explored in this study, namely the immediate recall of simultaneous messages, it is possible that hearing loss may also have a direct effect on the processing of M2 by degrading its spectrotemporal representation in the auditory system. In other words, hearing loss may compromise a listener's ability to process simultaneous messages in a similar way to added noise, by degrading the sensory trace that is used for the processing of a source outside the primary focus of attention (Shinn-Cunningham & Best, 2008).

Discussion for the effect of condition

Across the groups, performance was found to degrade with the addition of noise for the selective attention as well as for the divided attention task-M1 as well as M2. For the tasks, poorer performance could be explained based on the shared-resource model of attention (Hirst & Kalmar, 1987) where speech segregation ability was constrained by a limited pool of shared attentional resources, and the listeners were to choose to allocate attentional resources either to within-ear speech segregation or to across-ear speech segregation. In the presence of noise, selective as well as divided attention tasks would require within-ear segregation to reduce the effects of energetic masking as well as across ear segregation to deal with further informational masking as well as formation of a stream for the divided attention tasks (Gallun et al., 2007). In addition to this, the divided attention task M2 is particularly sensitive to the integrity of the acoustic input. This could be because a degraded input will degrade even further as it is stored as a raw representational form in a buffer until the serial processing of the simultaneous inputs is carried out and therefore may not even be useful by the time it is fully processed (Best et al., 2010). The inability to perform at poorer SNRs like -6dB by the hearing impaired groups can be attributed to the above mentioned reasons as well as the perceptual deficits exhibited by them in the form of reduced frequency and temporal resolution, inability to listen in gaps as well as poor spectrotemporal fine structure resolution that further degrades their performance (Moore, 1997).

Conclusions

These two experiments provide insight into how normal as well as hearing impaired listeners process simultaneous messages in an auditory speech display. Performance for not only divide attention tasks, but also the relatively less complex selective attention tasks are affected by the addition of noise as well as the presence of hearing impairment.

Implications of the study

It provides a basic understanding of the performance, as well resources necessary to process stimuli in the presence of multiple stimuli in both normal's as well as hearing impaired individuals. Improved performance of individuals in quiet could suggest that environmental modifications, behavioural changes, or technology involved in improving the SNR should be effective in reducing the challenges face by hearing impaired individuals in complex environments. The results indicating towards the secondary talker being more affected could be used to assess the benefit of bilateral amplification. Listening tasks involving extraction of information from simultaneous sources could provide additional benefits regarding the bilateral benefits.

Limitations of the study

The number of stimuli used per task was only ten. Therefore, the mean scores may overestimate the actual difficulties faced by the listeners. Results were reported for performance only at 0dB SNR as the tasks proved to be too difficult for the hearing impaired subjects at -6 dB SNR. Testing could have been carried out at other SNRs as well (+3,-3 dB SNR) to assess if improvements in performance occurred with positive SNRs. The mode of response required sequential verbal output which could have brought into play the effects of memory. The scoring was carried out on a strict criterion which required correct response of the entire stimuli. Scoring based on the number of words or phonemes repeated would have provided a more sensitive estimate.

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