DOI 10.1007/s11062-018-9707-5
Neurophysiology, Vol. 49, No. 6, December, 2017

Effects of Aging and Background Babble Noise on Speech Perception Processing: An fMRI Study

H. A. Manan,[1,2,3] A. N. Yusoff,[1] E. A. Franz,[4] and S. Z.-M. S. Mukari[5]

Received March 20, 2016

Speech perception processing in a noisy environment is subjected to age-related decline. We used functional magnetic resonance imaging (fMRI) to examine cortical activation associated with such processing across four groups of participants with age ranges of 23–29, 30–37, 41–47 and 50–65 years old. All participants performed a forward repeat task in quiet environment (SQ) and in the presence of multi-talker babble noise (SN; 5-dB signal-to-noise ratio, SNR). Behavioral test results demonstrated a decrease in the performance accuracy associated with increasing age for both SQ and SN. However, a significant difference in the performance accuracy between these conditions could only be seen among the elderly (60–65 years old) subjects. The fMRI results across the four age groups showed a nearly similar pattern of brain activation in the auditory, speech, and attention areas during SQ and SN. Comparisons between SQ and SN demonstrated significantly lower brain activation in the left precentral gyrus, left postcentral gyrus, left Heschly's gyrus, and right middle temporal gyrus under the latter condition. Other activated brain areas showed no significant differences in brain activation between SQ and SN. The decreases in cortical activation in the activated regions positively correlated with the decrease in the behavioral performance across age groups. These findings are discussed based on a dedifferentiation hypothesis that states that increased brain activation among older participants, as compared to young participants, is due to the age-related deficits in neural communication.

Keywords: speech perception, fMRI, aging, background babble noise, speech stimuli, dedifferentiation.

INTRODUCTION

A noisy background is distracting; the presence of noise affects both ability to concentrate and communicate and, therefore, may impose deleterious effects on cognitive processing [1]. Previous studies indicated that speech processing diminished in the presence of background noise [2, 3]. It is, therefore, not surprising that older adults experience increased difficulties in understanding speech in a noisy background, as compared to younger adults [4]. Throughout a normal human development, changes in the brain structure and functions take place to tolerate interference from background noise. These age-related changes in neural activation and mechanisms in the brain areas dedicated to auditory, memory, and speech processing have been reported in many previous studies [1–3, 5]. In addition, the effects of noisy background on the aging brain have also been reported [1, 3]. What are lacking in the previous works are the neural mechanisms of such processing across age groups; the respective studies would provide additional information with regards to changes in the brain underlying the process of normal aging.

As was mentioned earlier, noise may impose deleterious effects on various cognitive processing, and the respective shifts are greater in older adults. Recent evidence showed that the increasingly compromised speech understanding under noisy condition in older adults was due not only to auditory changes, but also to alterations in other cognitive areas, such as attention and memory [6, 7]. Previous studies reported age-related changes in cognition, which were not uniform across all

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[1] School of Diagnostic and Applied Health Sciences, Faculty of Health Sciences, Universiti Kebangsaan, Kuala Lumpur, Malaysia.
[2] Center of Neuroscience Services and Research (P3Neuro), Universiti Sains Malaysia, Kubang Kerian, Malaysia.
[3] Makmal Pemprosesan Imej Kefungsian, Department of Radiology, Pusat Perubatan Universiti Kebangsaan Malaysia, Jalan Yaacob Latif, Bandar Tun Razak, 56000 Cheras, Kuala Lumpur.
[4] Department of Psychology and fMRI, University of Otago, Dunedin, New Zealand.
[5] School of Rehabilitation Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia.
Correspondence should be addressed to A. N. Yusoff
(e-mail: nazlimtrw@ukm.edu.my).

cognitive domains and across all older individuals. Furthermore, attention- and memory-related structures were the most affected processing areas. Perception also showed a significant age-related decline attributable mainly to declining sensory capability. A deficit at early processing stages could affect cognitive functions in the latter processing stream. Higher-level cognitive functions, such as language processing and decision making, may also be affected by age. These tasks naturally rely on more basic cognitive functions and will generally show deficits to the extent that those fundamental processes are impaired. Moreover, complex cognitive tasks may also depend on a set of executive functions, which manage and coordinate various components of the task realization. Considerable evidence points to impairment of the executive function as a key contributor to age-related declines in a range of the cognitive tasks [8, 9]. Previous researchers also agreed that, as neural areas in the brain are tightly interconnected with each other, a deficit in one area might result in deterioration of the entire process [10]. For example, changes in cognition may be attributed to changes in sensory processing (i.e., deficits in vision and hearing), which, in turn may contribute to alterations in speech, attention, and memory [11]. Previous studies have also shown that older adults exhibit dissimilar patterns (i.e., underactivation or overactivation) of brain activation, compared to younger adults, during the execution of various tasks, including tasks involving auditory, memory, attention, and speech processing [12–15].

Based on previous evidence in cognitive aging studies, we put forward two major hypotheses. The first hypothesis is about dedifferentiation; it suggests that some intensification in brain activation in older participants (as compared to young ones) is due to the deficits in neurotransmission, which causes a decrease in the signal-to-noise ratio (SNR) and loss of neural specialization [7, 8, 16]. The dedifferentiation hypothesis is contrasted by the second hypothesis known as compensation, which predicts that age-related increases in brain activation, as well as the recruitment of additional areas, compensate for various neural and behavioral deficits [6, 7, 12, 13, 15].

In this study, we aimed to investigate whether the underactivation and overactivation in neural networks during speech perception processing in the elderly are caused by dedifferentiation or compensation. To achieve this, an fMRI technique was applied to four groups of subjects with different age ranges, in order to capture brain responses at different ages during the performance of a speech perception task in the quiet environment and under the action of background noise (5-dB SNR). If the dedifferentiation hypothesis can be generalized to other sensory domains, we would see a decrease in brain activation in such a way that cognitive processing is accompanied by decreases in the behavioral performance across age groups. Conversely, if the compensation hypothesis is in action, we would see a decrease in brain activation in some brain areas, which will be accompanied by increases of activation in other brain areas, and the behavioral performance will remain comparable across all age groups.

METHODS

Participants. Fifty-two right-handed [17] adult Malay male participants, with an age ranges from 20 to 65 years, were divided into four groups (Table 1). Data obtained from group 1 have been mentioned in our previous communication [18]. All participants had normal hearing and were free from tinnitus and neurological diseases. The oldest participants (50 years old and above) were subjected to Mini Mental Status Examination (MMSE) [19]. All participants scored normal in such examination (between 28 and 30).

Audiometry. Prior to the fMRI scans, answers to a standard questionnaire and an online audiometric measures (Rochester Hearing and Speech Center, http://myhearingtest.net/) were obtained from participants.The hearing thresholds for all participants were within the normal limits in the frequency range relevant for speech perception (250-8000 Hz) [20].

Experimental Stimuli.The stimuli consisted of a series of natural speech words produced by a Malay male adult and were digitally recorded (Sony Digital Voice Editor), stored, and edited using Adobe Audition 2.0 software. The average intensity of the stimuli was approximately 55 dB SPL. For the noisy condition, the same stimuli were used with babble noise (+5 dB above the background). Babble noise is the sound of multi-talkers (*n* = 7) reading different texts; these sounds were digitally recorded, stored, and edited using the previously mentioned software. The intensity of the stimuli was fixed. The loudness of the stimuli was adjusted and matched to all conditions so that all participants could hear the stimuli clearly and comfortably. The order of the delivery of the stimuli (with and without babble noise) was counterbalanced. More details of experimental stimulation can be found in our previous reports [21–23].

Experimental Paradigm. A total of four experimental conditions were used, as shown in Fig. 1 A; (i) listening and responding to speech stimuli in the quiet environment (SQ), (ii) listening and responding to speech stimuli in the noisy environment (SN), (iii) listening to babble noise (N), and (iv) listening under quiet condition (Q; not shown). Both the SQ and SN conditions consisted of five consecutive 0.6-sec-long stimuli separated by 0.5-sec-long silence intervals, making up a total stimulus duration of 5 sec per stimulus train. Figure 1B, C illustrates the delivery of the speech

Table 1. Demographic and Performance Data Obtained from the Participants of Different Age Groups

Age groups	Group 1 (youngest)	Group 2	Group 3	Group 4 (oldest)
N	14	14	10	14
Age range	23 – 29	30 – 37	41 – 47	50 – 65
Mean age	27 ± 2.2	33 ± 2.2	45 ± 2.3	59 ± 2.7
Years of education	14.80 ± 0.79	15.40 ± 1.50	13.90± 3.16	13.00 ± 2.46
Behavioral performance during SQ	17.50 ± 2.27	17.70 ± 2.36	14.20 ± 2.90	15.07 ± 3.51
Behavioral performance during SN	17.28 ± 2.92	18.36 ± 2.02	14.50 ± 2.91	12.71 ± 3.98

Footnotes. SQ and SN are quiet and noisy (5-dB SNR) conditions; means ± s.d. are shown.

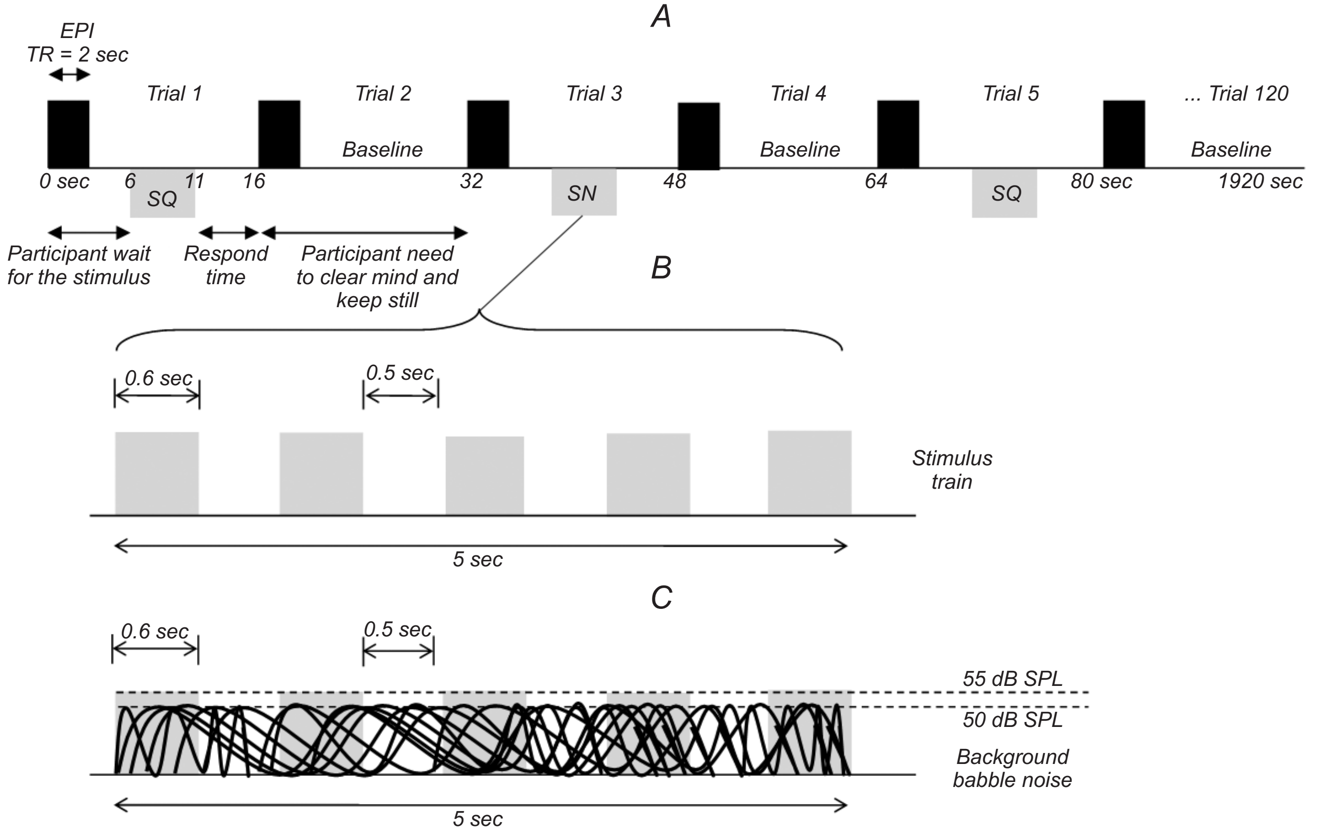


Fig. 1. Experimental paradigm. A) Illustration of the sparse fMRI paradigm. B) Stimulus train consisting of a sequence of five unrelated familiar words (randomly selected verbs and nouns) for listening and responding to speech in the quiet (SQ) and background babble noise (SN) environments. C) Pattern of the noise used in the tests.

stimuli in the presence of background babble noise. Speech stimuli consisted of 30 two- or three-syllable unrelated familiar Malay words (verbs and nouns). These words were randomized to produce each of the 20 SQ and SN trial sets. During a trial, the stimuli were presented at the 6th second and lasted approximately 5 sec, as shown in Fig. 1A. During the speech perception task, participants were given 5 sec to repeat forward all the five words presented. Each trial lasted 16 sec, and there were 120 trials in total.

Instructions to the Participants. Prior to fMRI scans, a detail explanation about the speech perception task was given to the participant. It was emphasized that the participant must focus with an otherwise clear mind throughout the procedure and to keep still. During the scan, participants lay comfortably in a supine position in the MRI scanner. An adjustable head holder restricted head movements.Auditory stimuli were presented binaurally through earphones. In addition, individual participant's score (number of correct answers) were recorded manually by the experimenter in the console room.

fMRI Scans. Details of fMRI data acquisition and analysis can be found in our previous publications [18, 24, 25] but are also given here in brief. Participants were positioned in a 1.5-Tesla magnetic resonance imaging (MRI) system (Siemens Magneton Avanto, Siemens, Germany) equipped with functional imaging options and echoplanar imaging capabilities. A radiofrequency (RF) head coil was used for signal transmission and reception. Prior to the functional imaging scans, structural T1-weighted images were acquired using a multiplanar reconstruction (MPR) spin-echo pulse sequence with the following parameters: Repetition time (TR) = 1240 msec, field of view (FOV) = = 250 × 250 mm, flip angle = 90 deg, matrix size = = 128 × 128, and slice thickness 1.0 mm. Functional images were then acquired using a gradient echo-echo planar imaging (GRE-EPI) pulse sequence. Each whole brain acquisition consisted of 21 axial slices covering all brain regions including the cerebellum. The following parameters were used for the functional scans: TR = 2000 msec, echo time (TE) = 50 msec, (FOV) = 192 × 192 mm, flip angle (α) = 90 deg, matrix size = 128 × 128, and slice thickness 5 mm with 1.25 mm gaps. A sparse temporal sampling was used to avoid the interference of scanner sound onto the stimulus [26].

Data Analysis. Each participant's behavioral performance was scored as how many times the series of words were correctly repeated. Repeated-measure analyses of variance (ANOVA, SPSS 20.0) were then implemented on all participants' data using age group as a between-subjects factor, to evaluate the effect of age-related differences on the performance accuracy. The data were further analyzed using the Tukey *post-hoc* test to obtain pairs of groups that showed age-related differences. Linear regression was used to evaluate the performance accuracy vs. age across four groups of the participants. Finally, correlation analysis was applied to the data to evaluate the relationship between the performance accuracy of four age groups and levels of brain activation and to evaluate the relationship between sensory and cognitive areas (each brain area was evaluated separately).

The sparse fMRI data were analyzed using MATLAB 7.4 – R2008a (Mathworks Inc., USA) and Statistical Parametric Mapping (SPM8) (Functional Imaging Laboratory, Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College of London, Great Britain; http://www.fil.ion.ucl.ac.uk/spm). The first two image volumes of every EPI-recording session were discarded to account for the approach to steady state of the MR signal. Prior to image analysis, each participant's raw data were motion-corrected and normalized. The magnitude of absolute motion did not exceed 3 mm for any participant [27–30]. The data of two participants were discarded from data analysis due to excessive motion. Data were further analyzed using a 12-parameter non-linear normalization onto the MNI-reference state as implemented in SPM8 and with smoothing (FWHM = 6 mm). The fMRI data were analyzed according to the general linear model (GLM). With regard to different conditions, four regressors were included in the design, SQ, SN, N, and Q. The regressors were convolved using the hemodynamic response function, as provided in SPM8. Statistical analysis was performed using a mixed-effects model; fixed-effects analysis (FFX) was used for single-participant analysis and random-effects analysis (RFX) was applied for group analysis. For the latter, contrast images were computed for each participant. The one-sample *t*-test was later performed. For FFX analysis, the statistical significance was set at $P < 0.05$ and corrected for multiple comparisons from a whole-brain analysis. For RFX analysis, the statistical significance was set at $P < 0.001$, and uncorrected for multiple comparisons with a minimum cluster size of 20 voxels and t-values greater than 3.5. RFX analysis is based on regions-of-interest using automatic anatomical templates from the toolbox of the Wake Forest University (WFU) pickatlas [31].

ANOVA were then used on all participants' data using an age group as the between-subjects factor, to evaluate age-related differences within all activated areas obtained from both tasks. The data were further analyzed using the Tukey *post-hoc* test, to evaluate which groups show age-related differences. Linear regression was used to evaluate the activated areas vs. age across four groups of the participants. Finally, a paired t-test was applied to the data, to evaluate the differences between brain activation at SQ and SN tasks. Each brain area was analyzed separately.

RESULTS

Behavioral Data. These data for SQ and SN conditions across four age groups are presented in Table 1. For SQ, there was a significant main effect of age on the behavioral scores:F (3, 48) = 4.786, $P = 0.005$. Further analysis using linear regression also revealed a significant effect ($P = 0.005$, $b = –0.388$, F (1, 50) = –2.977, $R^2 = 0.151$). A similar result was also obtained for SN, with a significant main effect of age on the behavioral scores: F (3, 48) = 8.735, $P = 0.001$. The Tukey *post hoc* test further revealed significant differences between group 1 and group 4 ($P = 0.003$) and between group 2 and group 4 ($P = 0.001$). Linear regression analysis also revealed a significant effect ($P = 0.001$, $b = –0.522$, F (1, 50) = = –4.330, $R^2 = 0.272$). These results allowed us to conclude that there is a decrease in the performance accuracy with increasing age for both SQ and SN.

A paired t-test was applied to examine the difference in the performance accuracy between SQ and SN and revealed a significant difference between tasks only in group 4 ($t = 0.001$). This result demonstrates that participants of this group (the oldest one) scored significantly better during SQ, as compared to the respective values during SN. Other groups showed only statistically insignificant differences between the two conditions

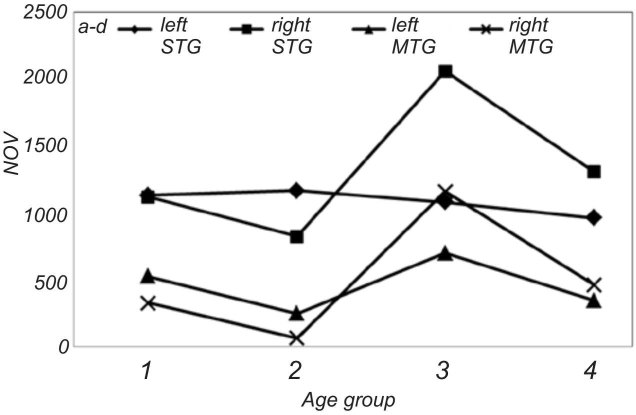
fMRI. N condition, the STG and MTG were activated bilaterally and showed a significant main effect of age: F (3, 48) = 170039.73, $P < 0.001$ for the left STG, F (3, 48) = 4552662.92, $P < 0.001$ for the right STG, F (3, 48) = 430899, $P < 0.001$ for the left MTG, and F (3, 48) = 2421807.35, $P < 0.001$ for the right MTG. These results indicated that there were changes in the brain activation pattern for both left and right STGs and MTGs across age groups. However, these changes were not uniform. This brain activation pattern is tabulated in Table 2 and Fig. 2. The number of activated voxels (NOV) in the left STG decreased slightly with age. However, for the bilateral MTGs and right STGs, NOV showed some fluctuations but peaked for group-3 participants.

Results obtained from group analysis of the fMRI data indicated that, SQ and SN conditions, areas including the STG, MTG, precentral gyrus (PCG), inferior frontal gyrus (IFG), middle frontal gyrus (MFG), cerebellum, thalamus, postcentral gyrus (post-CG), and HG were activated. For both SQ and SN situations, the ANOVA test revealed that there was a significant main effect of brain activity in all areas across age groups.The NOV and P-values are tabulated in Table 3 for SQ and Table 4 for SN, while plots of the brain activation pattern are depicted in Figs. 3 and 4 for the above conditions, respectively. All areas showed nearly similar brain activation patterns in the left and right hemispheres. The NOV

Table 2. Numerical Data Obtained from Group Analysis Across Four Groups of Participants During Listening to Babble Noise (N)

Anatomical areas	Hemisphere	Group 1			Group 2			Group 3			Group 4		
		P value	Coordinates (x, y, z, mm)	NOV	P value	Coordinates (x, y, z, mm)	NOV	P value	Coordinate (x, y, z, mm)	NOV	P value	Coordinate (x, y, z, mm)	NOV
STG	L	6.06	-66, -26, 6	1131	6.79	-56, -2, -2	1165	8.42	-64, -18, 6	1079	7	-58, -26, 8	963
	R	5.09	46, -20, 2	1120	6.52	44, 8, 20	824	10.33	54, 8, -12	2058	9.27	62, -14, -2	1307
MTG	L	6.60	-66, -38, 8	525	5.92	-62, -14, 0	246	7.56	-58, -6, -8	700	6.50	-58, -32, 8	343
	R	5.22	70, -34, -2	326	4.69	66, -26, -2	62	8.91	60, -8, -16	1161	6.24	58, 0, -14	463

Footnote. L and R, left and right hemispheres; NOV, number of activated voxels; STG and MTG, superior and middle temporal gyri, respectively peaked for group-2 participants before decreases with increasing age, as opposed to the N condition in which NOV peaked for group-3 participants. However, the results of linear regression analysis revealed that only four areas showed significant effects. These areas are the bilateral MTGs (left: $P = 0.046$, $b = -2.78$, F (1, 50) = 4.98, $R^2 = 0.077$; right: $P = 0.004$, $b = 0.39$, F (1, 50) = = 8.95, $R^2 = 0.152$) during SQ. During SN, these were left MTG ($P = 0.001$, $b = -0.55$, F (1, 50) = 22.05, $R^2 = 0.306$), and left cerebellum ($P = 0.043$, $b = -0.282$, F (1, 50) = 4.32, $R^2 = 0.08$).

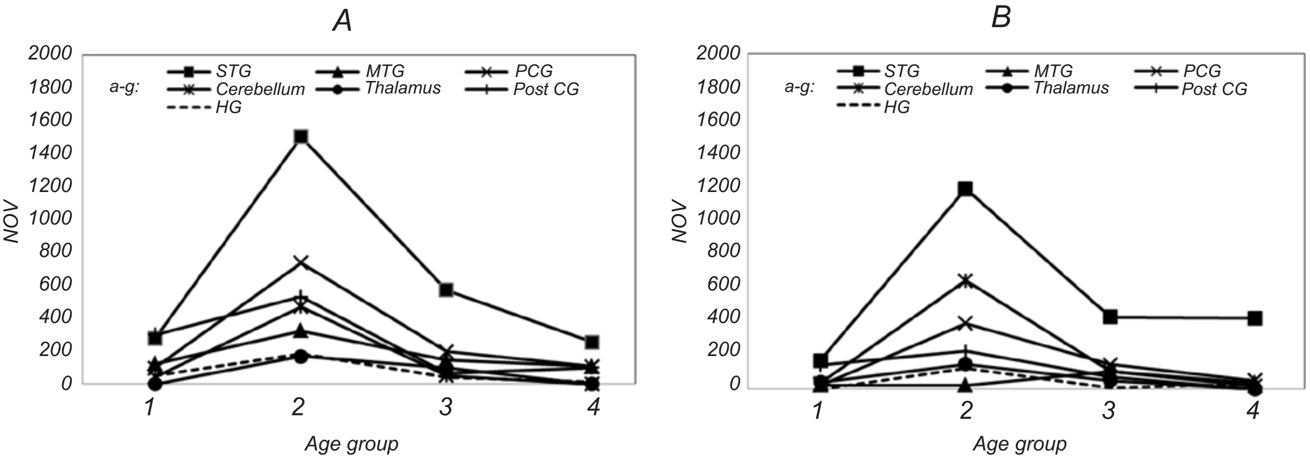


F i g. 2. Profile of brain activation (number of activated voxels, NOV) for the bilateral superior temporal gyri (STGs) and middle temporal gyri (MTGs) across the age groups 1–4. a) left STG, b) right STG, c) left MTG, and d) right MTG.

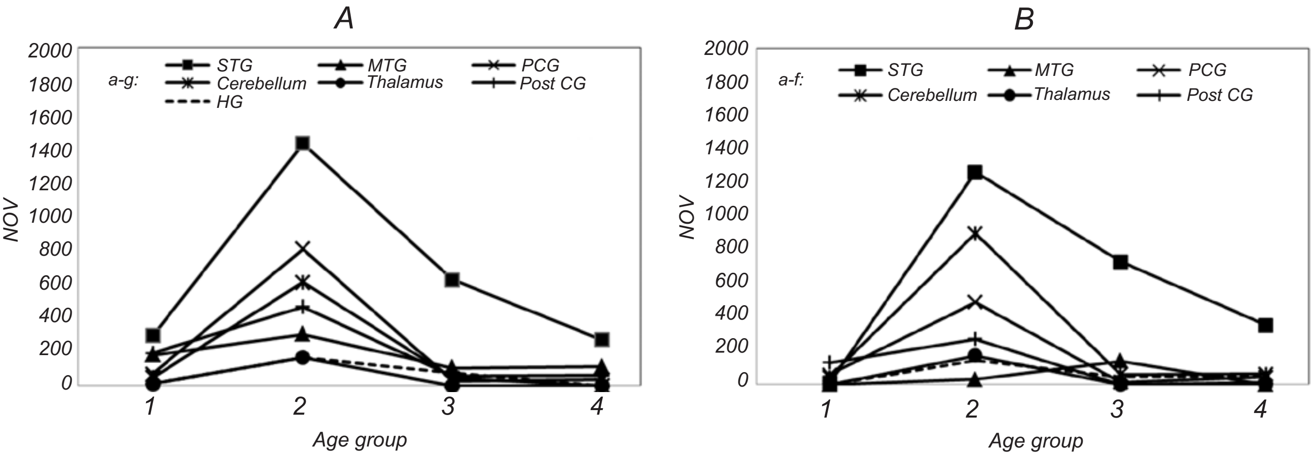
Comparisons between SQ and SN demonstrated significant decreases in brain activation in the left PCG (in groups 3 and 4), left post-CG (in group 4), left HG (in groups 1, 2, and 4), and right MTG (in group 4) under the latter condition. However, the right HG showed an increased level of activation in group-4 participants during SN. Other activated areas showed no significant differences in both tasks.

DISCUSSION

In our previous study [18], we found that the performance accuracy during the speech perception task in a quiet environment (SQ) is comparable with the speech perception task in a noisy background (SN) for young participants with ages varying between 20 to 29 years. The respective relative difference in the behavioral performance between both tasks was accompanied by the increase in activation in the left superior temporal gyrus (STG), left middle temporal gyrus (MTG), and bilateral cerebellum during SN. We proposed that such increase in brain activation in these areas during SN were to compensate the interference from background noise.The purpose of our present study was to examine further the effects of 5-dB SNR background babble noise across four age groups with the age range between 20 to 65 years old. As aging is accompanied by many deleterious effects, it is very important to know whether similar results are



F i g. 3. Brain activation profile for seven brain areas (a–g) during the speech perception task under quiet condition (SQ) acrossg roups 1–4 in the left (A) and right (B) hemispheres; a) SCG, b) MTG, c) PCG, d) cerebellum, e) thalamus, f) post CG, and g) HG.



F i g. 4. Brain activation profile for seven brain areas (a–g) of two hemispheres (A, B) during the speech perception task under noisy condition (SN) across groups 1–4. Designations are similar to those in Fig. 3.

T a b l e 3. Numerical Data Obtained from Group Analysis across Four Groups of Participants during the Speech Stimuli Task Under Quiet Condition (SQ)

Anatomical areas	Hemisphere	Group 1			Group 2			Group 3			Group 4		
		P value	Coordinates (*x, y, z,* mm)	*NOV*	*P* value	Coordinates (*x, y, z,* mm)	*NOV*	*P* value	Coordinates (*x, y, z,* mm)	*NOV*	*P* value	Coordinates (*x, y, z,* mm)	*NOV*
STG	L	6.61	–60, –12, 12	276	13.13	–56, –6, 0	1504	12.72	–58, –20, 2	571	6.04	–58, –32, 10	253
	R	7.23	46, –24, –4	170	12.45	64, –10, 6	1192	14.30	54, –16, –8	430	8.11	64, –18, 0	422
MTG	L	5.59	–54, –28, –4	122	9.90	–62, –14, 0	322	8.49	–58, –20, 0	145	5.91	–58, –32, 8	106
	R	4.92	48, –22, –8	25	6.15	69, –20, –4	23	11.42	52, –16, –10	108	4.60	–58, –16, 0	38
PCG	L	5.09	–50, –4, 46	96	8.71	–54, –6, 34	737	8.79	–42, 2, 38	196	7.83	–42, –8, 44	105
	R	4.64	50, –8, 36	23	9.24	50, –4, 40	393	6.66	46, 0, 34	148	5.68	44, –6, 42	51
IFG	L	–	–	–	8.83	–44, 22, 28	1185	–	–	–	–	–	–
	R	–	–	–	6.38	48, 18, –12	184	12.74	48, 12, 34	14	–		
MFG	L	–	–	–	8.01	–44, 14, 14	512	8.00	–24, 0, 50	88	–	–	–
	R	–	–	–	5.53	40, 16, 4	44	7.42	28, 4, 56	20	–		
Cerebellum	L	5.34	–4, –74, –24	42	8.18	–24, –62, –28	469	10.23	–40, –68,–28	51	4.12	–33, –1, 9	28
	R	6.40	26, –64, –30	35	9.69	34, –60, –30	646	8.86	36, –58, –32	108	4.59	38, –78, –24	19
Thalamus	L	–	–	–	5.82	–4, –8, 8	168	9.52	–6, –20, 12	96	–	–	–
	R	4.96	0, –12, 8	42	5.78	2, 14, 12	150	7.78	4, –16, 6	51	–	–	–
Post CG	L	7.67	–62, –10, 14	300	9.56	–56, –6, 16	530	8.19	–58, –2, 20	66	6.96	–44, –10, 40	99
	R	5.25	56, 10, 22	145	8.19	56, –4, 30	227	6.31	56, –2, 22	73	–	–	–
HG	L	5.58	–32, –30, 10	50	6.08	–36, –30, 14	185	6.55	–48, –16, 6	42	4.61	–42, –26, 10	11
	R	–	–	–	6.92	40, –20, 6	124	5.57	60, –4, 6	10	6.69	64, –4, 6	31

F o o t n o t e s. PCG, precentral gyrus; IFG, inferior frontal gyrus; MFG, middle frontal gyrus; IPL, inferior parietal lobes; SPL, superior parietal lobes; Post-CG, postcentral gyrus, and HG, Heschly's gyrus; "–", difference is insignificant. Other designations are similar to those in Table 2.

T a b l e 4. Numerical Data Obtained from Group Analysis across Four Groups of Participants during the Speech Stimuli Task Under Noisy Condition (SN)

Anatomical Areas	Hemisphere	Group 1			Group 2			Group 3			Group 4		
		P value	Coordinates (*x*, *y*, *z*, mm)	*NOV*	*P* value	Coordinates (*x*, *y*, *z*, mm)	*NOV*	*P* value	Coordinates (*x*, *y*, *z*, mm)	*NOV*	*P* value	Coordinates (*x*, *y*, *z*, mm)	*NOV*
STG	L	5.78	–50, 12, –18	293	12.98	–56, –6, 0	1431	18.25	–58, –18, 4	624	8.47	–56, –10, 4	270
	R	5.73	44, –26, –4	10	11.39	66, –10, 6	1262	12.69	52, –12, –6	730	7.46	62, –18, 0	354
MTG	L	5.81	–54, –28, –4	179	10.73	–62, –14, 0	304	8.12	–66, –20,–10	104	6.96	–58, –10, –6	111
	R	5.22	43, –12, 1	121	6.93	68, –20, –4	30	12.31	66, –18, –10	141	5.43	52, 7, 11	102
PCG	L	4.74	–48, –8, 42	67	10.06	–56, 0, 34	807	7.38	–28, –4, 48	28	5.01	–44, –8, 44	35
	R	5.24	50, –8, 38	58	9.83	52, –2, 40	491	6.66	44, 0, 34	15	4.84	48, –6, 40	44
IFG	L	7.56	–40, 22, 14	331	7.4	–44, 24, 22	914	6.81	–36, 24, 16	12	–	–	–
	R	–	–	–	8.48	46, 18, –12	219	5.11	46, 14, 4	18			
MFG	L	–	–	–	6.35	–36, 4, 62	95	12.01	–24, 0, 50	68	–	–	–
	R	–	–	–	5.24	52, 2, 52	46	10.51	30, 6, 54	103			
Cerebellum	L	5.04	–28, –60, –32	46	10.14	–24, –60,–26	610	6.41	–38, –66,–30	45	4.14	–32, –11, 7	15
	R	5.61	24, –66, –28	46	11.63	36, –60, –30	899	7.39	24, –66, –24	62	5.89	38, –78, –24	63
Thalamus	L	4.88	–2, –14, 8	11	6.56	–4, –8, 8	165		–		–	–	–
	R	–	–	–	7.19	2, –16, 10	173						
Post CG	L	5.35	–62, –2, 18	191	8.42	–50, –8, 32	466	8.15	–58, –4, 20	57	5.06	–46, –10, 40	58
	R	5.5	50, 10, 36	131	9.75	42, –10, 32	271	–	–	–	4.24	56, –6, 36	12
HG	L	5.72	–34, –30, 6	14	5.86	–40, –20, 2	166	8.96	–48, –16, 6	76	–	–	–
	R	–	–	–	6.73	42, –20, 4	142	6.16	50, –16, 4	48	5.44	62, –2, 6	49

F o o t n o t e s. Designations are similar to those in Table 3.

reproducible across all four age groups, or the 5-dB SNR background noise would only cause significant interference in older groups of the participants. This study also explored the effects of 5-dB SNR background babble noise to the sensory/cognitive cortical activation across the examined age groups.

This study provides the interplay between cognitive and sensory cortical activities pertaining to SQ and SN in four groups of the participants. Our findings support the dedifferentiation hypothesis. The latter postulated that the neurophysiological characteristics of an aging brain pertaining to sensory/cognitive demanding tasks include a reduction in the behavioral performance and brain activation in the sensory- and cognitive-associated areas.

The N condition in the present fMRI study served as the control. The main purpose of this condition was to evaluate the effects of aging on auditory processing. Noise placed great requirements on participant’s attention, speech recognition, and speech production [32]. The multi-talker noise qualified as babble noise and used in this study shares many characteristics of speech and may, therefore, activate brain areas associated with language processing, such as the bilateral STGs and MTGs. Such activations in the STG and MTG have been reported by previous studies [32, 33].

The comparing between the left STG and right STG revealed that activation of the former showed no significant differences across age groups. Conversely, the right STG showed activation changes across groups with a steady increase in brain activation peaked in group 3; this index, however, decreased in group 4. Our results proposed that both hemispheres were engaged differently during the task used. This is due to the fact that the right hemisphere is more specialized for attention than the left one [34]. The N condition places great requirements on attention; therefore, it is not surprising that brain activation of the left STG showed no significant differences across age groups.

Attention is thought to involve a distinctive neural network that interacts with other brain systems to facilitate various cognitive processes; it is generally agreed that attention functions to orient a subject to sensory events, to detect specific signals for subsequent processing, and to maintain vigilance over time [35].

The brain activities of the right STG and bilateral MTGs were the highest in group 3 and decreased somewhat in group 4. This suggests that different processing demands were required for each group of participants to process the speech task.This result strongly suggests that older brains will engage and recruit brain areas differently than younger ones to accomplish the same task, and this was confirmed in the previous study [36].

Our findings related to brain activation during SQ and SN confirmed the dedifferentiation hypothesis, according to which reduced brain activation in the sensory- and cognitive-associated areas is accompanied by a decrease in the performance accuracy across the four age groups. We found positive correlation between brain activation and behavioral scores in group-2, group-3, and group-4 participants, with the exception of the right MTG and right HG. These changes in the brain activation pattern across the four age groups were suggested to be due to significant reorganization and pruning underwent by the brain [37]. This could also be understood as a result of neural inhibition that caused a decrease in the overall hemodynamic response [6, 38]. Our findings support those by Li and Lindenberger [39] who suggested that the reduction in brain activation across age groups may reflect age-related changes in recruiting the specialized brain areas, and the decrease is just one of the examples of the effects of aging on the brain functions. Brain activation showed an increase in activity from group 1 to group 2, and it peaked at group 3.This situation has been proposed to reflect possible compensatory processes associated with normal aging. The idea that such compensatory processes were involved has been further supported by the behavioral performance result. We also found that the intensity of brain activity decreased in group 4. These patterns of brain activation from group 3 to group 4 might be related to neural changes in the form of structural or volumetric effects induced by aging [40].

It is interesting to note that our present study found rather strong positive correlations ($P < 0.05$, $r > 0.7$) between the spatial extent of activation and age for the sensory (STG and MTG) and attention (cerebellum and thalamus) areas. This indicates that there are global changes in all activated areas for both SQ and SN conditions. Moreover, the functions of these areas are interrelated to each other [8]. It is important to note that, in order for the decreased activation to be truly dedifferentiation, such activation must be linked to the behavioral performance, as was really found in this our study. Positive correlation between brain activation and the behavioral performance across age groups is quite consistent with the dedifferentiation hypothesis.

An important part of speech stimuli processing is sound-to-meaning processing. It has been suggested that the ventral auditory pathway, especially between bilateral superior to middle temporal areas, is involved in such processing [41]. Our results showed age-related decreases in the bilateral STGs and MTGs during both SQ and SN. The inconsistency between our present study and that by Wong et al. [3], which found age-related increases in the ventral temporal areas during language processing, is perhaps due to some differences in task requirements and sensory modalities.

The comparison between SQ and SN in the present study did not show any differences that are general to both cognitive and sensory areas, but rather an increase in some and a decrease in others. The pattern of brain activation showed significant decreases in brain activation in the left PCG (in groups 3 and 4), left post-CG (in group 4), left HG (in groups 1, 2, and 4), and right MTG (in group 4) during SN. The right HG showed an increase in the activation intensity in group-4 participants during SN. However, the performance accuracy under SQ and SN conditions revealed the existence of significant difference between tasks only in group 4 ($P = 0.001$). In theory, speech stimuli presented against noise should create greater processing demands than speech stimuli in quiet, which is portrayed by higher brain activation [42], or by increased activation in the attentional network areas during the task, as more attention should be given in order to compete between the disturbance (background noise) and the main speech stimuli [43]. However, our study demonstrated the results differing from those by Wong et al. [3] and Kujala and Brattico [32], which demonstrated greater demands in cognitive processing in the presence of background noise. The discrepancy of the present results and previous ones is perhaps due to differences in the types of background babble noise used, which are dissimilar in the frequency, temporal pattern, and modulation content. Taken together, the decrease in brain activation (in the left PCG, left post-CG, left HG, and right MTG) during SN are suggested to serve as a beneficial strategy to compensate the effects of background noise (for participants of groups 1–3). This is supported by a previous finding that suggested that noise exerts a complex effect on neural functions underlying speech processing [32], and its effect may be either enhancing or suppressive, depending on the type of the process [24, 44–46]. Furthermore, Lim et al. [37] found that connections in the brain tend to get more streamlined over time, which can allow the subject for faster and more efficient information processing. Still, a plenty of long-range connections are preserved, especially of those that play a role in integration of information. However, future research is needed to disentangle the underlying causal relationships in the activation and deactivation of these areas across the three age groups during SN condition.

The decrease in the performance accuracy in group-4 participants during SN is expectable. Throughout a normal human development, changes took place in the brain to tolerate the effects of background noise on processing of auditory speech stimuli. Naturally, it is especially difficult for older adults to discriminate speech stimuli (during SN) under challenging conditions, even if such subjects have no clinically significant losses of the auditory sensitivity. This may be due to their hearing capability that becomes increasingly compromised. This can also be explained by changes in attentional pathway processing and changes in the auditory system itself [47].

In summary, our results showed that a complex network is activated during both SQ and SN. Both processing modes have been found to be affected by aging. Moreover, the effects of aging were more pronounced in the presence of 5-dB SNR background babble noise, especially in group-4 (old) participants. Both SQ and SN conditions activated a network of the brain areas connecting the frontal lobe, temporal lobe, cerebellum, and thalamus. The behavioral performance showed a decrease in its accuracy with increasing age for both conditions. Comparisons between conditions revealed a significant difference only in group 4 (older adult group). The main activated areas showed very close brain activation patterns across four groups of the participants with increasing age. Our present study confirms the dedifferentiation hypothesis, as decreased brain activation in speech stimuli processing in the sensory/cognitive neural networks is accompanied by a worse behavioral performance across age groups.

Acknowledgment. We thank S. Samian from the Department of Radiology, Universiti Kebangsaan Malaysia Medical Centre, for the assistance in fMRI scans. We also thank M. Hairol Isa from the Jabatan Kesihatan Masyarakat Universiti Kebangsaan Medical Centre for his valuable help in managing older participants. This work has been supported by the Research University Grant UKM GUP-SK-07-020-205.

Written informed consent was obtained from all participants after full explanation of the nature and risks of the study in accordance with the protocol approved by the Institutional Ethics Committee (IEC) of the Universiti Kebangsaan Malaysia. (Ref. num.: UKM 1.5.3.5/244/NN-075-2009).

The authors of this communication, H. A. Manan, A. N. Yusoff, E. A. Franz, and S. Z.-M. S. Mukari, confirm the absence of any conflict related to commercial or financial interests, to interrelations with organizations or persons in any way involved in the research, and to interrelations of the co-authors.

REFERENCES

1. J. S. Martin, M. A. James, and J. F. Jerger, "Some effects of aging on central auditory processing," *J. Rehab. Res. Develop.*, **42**, No. 2, 25-44 (2005).
2. C. M. P. Wong, J. X. Jin, G. M. Gunasekera, et al., "Aging and cortical mechanism in speech perception in noise," *Neuropsychology*, **47**, 693-703 (2009).
3. R. J. Salvi, A. H. Lockwood, R. D. Frisina, et al., "PET imaging of the normal human auditory system: responses to speech in quiet and in background noise," *Hearing Res.*, **170**, 96-106 (2002).
4. J. Walton, H. Simon, and R. D. Frisina, "Age-related alteration in the neural coding of envelope periodicities," *J. Neurophysiol.*, **88**, 565-578 (2002).
5. T. Shimizu, K. Makishima, M. Yoshida, and H. Yamaghisi, "Effects of background noise of English speech for japanese listeners," *Auris Nasus Larynx*, **29**, 121-125 (2002).
6. R. Cabeza, "Hemispheric asymmetry reduction in older adults: the Harold Model," *Psychol. Aging*, **17**, 85-100 (2002).
7. R. Cabeza, N. D. Anderson, J. K. Locantore, and A. R. McIntosh, "Aging gracefully: compensatory brain activity in high-performing older adults," *NeuroImage*, **17**, 1394-1402 (2002).

8. K. Z. H. Li and U. Lindenberger, “Relations between aging sensory/sensorimotor and cognitive functions,” *Neurosci. Biobehav. Rev.*, **26**, No. 7, 777-783 (2002).
9. D. C. Park and A. H. Gutchess, “Aging, cognition, and culture: a neuroscientific perspective,” *Neurosci. Biobehav. Rev.*, **26**, 859-867 (2002).
10. J. D. Schmahmann and D. N. Pandya, “Disconnection syndromes of basal ganglia, thalamus, and cerebrocerebellar systems,” *Cortex*, **44**, No. 8, 1037-1066 (2008).
11. M. Mather and L. L. Carstensen, “Aging and motivated cognition: the positivity effect in attention and memory,” *Trends Cogn. Sci.*, **9**, 296-502 (2005).
12. P. A. Reuter-Lorenz, J. Jonides, E. E. Smith, et al., “Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET,” *J. Cogn. Neurosci.*, **12**, 174-187 (2000).
13. C. L. Grady, “Introduction to the special section on aging, cognition, and neuroimaging,” *Psychol. Aging*, **17**, 3-6 (2002).
14. C. L. Grady, A. R. McIntosh, S. Beig, et al., “Evidence from functional neuroimaging of a compensatory prefrontal network in Alzheimer’s disease,” *J. Neurosci.*, **23**, 986-993 (2003).
15. P. A. Reuter-Lorenz and C. Lustig, “Brain aging: reorganizing discoveries about the aging mind,” *Current Opin. Neurobiol.*, **15**, 245-251 (2005).
16. R. Cabeza, S. M. Daselaar, F. Dolcos, et al., “Task independence and task specific age effects on brain activity during working memory, visual attention and episodic retrieval,” *Cerebr. Cortex*, **14**, No. 4, 364-375 (2004).
17. R. C. Oldfield, “The assessment and analysis of handedness: the Edinburgh inventory,” *Neuropsychologia*, **9**, 97-113 (1971).
18. H. A. Manan, A. N. Yusoff, E. A. Franz, and S. Z.-M. S. Mukari, “The effects of background noise on brain activity using speech stimuli on healthy young adults,” *Neurol. Psychiat. Brain Res.*, **19**, 180-191 (2013).
19. M. F. Folstein, S. E. Folstein, and P. R. McHugh, “Mini-mental state. A practical method for grading the cognitive state of patient for clinician,” *J. Psychiat. Res.*, **12**, 189-198 (1975).
20. C. W. Turner, B. J. Kwon, C. Tanaka, et al., “Frequency-weighting functions for broadband speech as estimated by a correlational method,” *J. Acoust. Soc. Am.*, **104**, No. 3, 1580-1585.
21. H. A. Manan, E. A. Franz, A. N. Yusoff, and S. Z.-M. S. Mukari, “Age-related brain activation during forward and backward verbal memory repeat tasks,” *Neurol. Psychiat. Brain Res.*, **20**, No. 4, 76-86 (2014).
22. H. A. Manan, E. A. Franz, A. N. Yusoff, and S. Z.-M. S. Mukari, “The effects of aging on the brain activation pattern during speech stimuli task: an fMRI study,” *Aging Clin. Exp. Res.*, **27**, No. 1, 27-36 (2015).
23. H. A. Manan, E. A. Franz, A. N. Yusoff, and S. Z.-M. S. Mukari, “The effects of aging to a fronto-parietal network and its impact on cognitive aging during backward repeat task,” *Neurol. Psychiat. Brain Res.*, **21**, No. 1, 64-72 (2015).
24. H. A. Manan, E. A. Franz, A. N. Yusoff, and S. Z.-M. S. Mukari, “Hippocampal-cerebellar involvement in enhancement of performance in word-based BRT with the presence of background noise: an initial fMRI study,” *Psychol. Neurosci.*, **5**, No. 2, 247-256 (2012), doi: 10.3922/ j.psns.2012.2.16.
25. H. A. Manan, E. A. Franz, A. N. Yusoff, and S. Z.-M. S. Mukari, “Age-related laterality shifts in auditory and attention networks with normal ageing: Effects on a working memory task,” *Neurol. Psychiat. Brain Res.*, **19**, 207-215 (2013).
26. D. A. Hall, M. P. Haggard, M. A. Akeroyd, et al., “Sparse” temporal sampling in auditory fMRI,” *Human Brain Mapp.*, **7**, No. 3, 213-223 (1999).
27. A. N. Yusoff, M. M. Ayob, M. H. Hashim, and M. I. Kassim, “Analisis data pengimejan resonans magnet kefungsian pra pemprosesan ruang menggunakan kaedah pemetaan statistik ber parameter,” *J. Sains Kesihatan Malaysia*, **4**, No. 1, 21-36 (2006).
28. A. N. Yusoff, M. Mohamad, M. M. Ayob, and M. H. Hashim, “Brain activations evoked by passive and active listening: A preliminary study on multiple subjects (Pengaktifan otak yang dicetus oleh pendengaran pasif dan aktif: Satukajian permulaan keatas subjek berbilang),” *J. Sains Kesihatan Malaysia*, **6**, No. 1, 35-60 (2008).
29. A. N. Yusoff, M. Mohamad, K. Abdul Hamid, et al., “Characteristics of the primary motor (M1) and supplementary motor (SMA) areas during robust unilateral finger tapping task,” *J. Sains Kesihatan Malaysia*, **8**, No. 2, 43-49 (2010).
30. A. N. Yusoff, “Kesan day a dan laju tepikan jari ke atas pengaktifan korteks berkaitan motor,” *J. Sains Kesihatan Malaysia*, **11**, No. 2, 41-49 (2013).
31. J. A. Maldjian, P. J. Laurienti, R. A. Kraft, and J. H. Burdette, “An automated method for neuroanatomic and cytoarchitectonical tas-based interrogation of fMRI data sets,” *NeuroImage*, **19**, 1233-1239 (2003).
32. T. Kujala and E. Brattico, “Detrimental noise effects on brain’s speech functions,” *Biol. Psychol.*, **81**, 135-143 (2009).
33. T. Kujala, Y. Shtyrov, I. Winkler, et al., “Long-term exposure to noise impairs cortical sound processing and attention control,” *Psychophysiology*, **41**, 875-881 (2004).
34. M. C. Stevens, V. D. Calhoun, and K. A. Kiehl, “Hemispheric differences in hemodynamics elicited by auditory oddball stimuli,” *NeuroImage*, **26**, No. 3, 782-792 (2005).
35. M. I. Posner and S. E. Petersen, “The attention system of the human brain,” *Annu. Rev. Neurosci.*, **13**, 25-42 (1990).
36. R. Cabeza and N. A. Dennis, “Frontal lobes and aging; Deterioration and compensation,” in: *Principles of Frontal Lobe Function*, D. T. Stuss and R. T. Knight (eds.), Oxford Univ. Press, New York (2012), pp. 628-652.

37. S. Lim, C. E. Han, P. J. Uhlhaas, and M. Kaiser, "Preferential detachment during human brain development: Age- and sex-specific structural connectivity in diffusion tensor imaging (DTI) data," *Cerebr. Cortex*, First published online: December 15, 2013, doi: 10.1093/cercor/bht33.
38. K. J. Anstey, M. A. Luszcz, and L. Sanchez, "A reevaluation of the common factor theory of shared variance among age, sensory function, and cognitive function in older adults," *J. Gerontol. Psychol. Sci.*, Ser. B, **56**, No. 1, 3-11 (2001).
39. S. C. Li and U. Lindenberger. "Cross-level unification: a computational exploration of the link between deterioration of neurotransmitter systems and dedifferentiation of cognitive abilities in old age," in: *Cogn. Neurosci. Memory,* Hogrefe and Huber, Berlin (1999).
40. T. A. Salthouse, "The processing-speed theory of adult age differences in cognition," *Psychol. Rev.*, **103**, 403-428 (1996).
41. G. Hickok and D. Poeppel, "The cortical organization of speech processing," *Nat. Rev. Neurosci.*, **8**, No. 5, 393-402 (2007).
42. A. H. Lockwood, R. J. Salvi, M. L. Coad, et al., "The functional anatomy of the normal human auditory system: Responses to 0.5 and 4.0 kHz tones at varied intensities," *Cerebr. Cortex*, **9**, 65-76 (1999).
43. R. H. Benedict, A. H. Lookwood, J. L. Shucard, et al., "Functional neuroimaging of attention in auditory modality," *NeuroReport*, **9**, 121-126 (1998).
44. D. Moss, L. M. Ward, and W. G. Sannita, "Stochastic resonance and sensory information processing: A tutorial and review of application," *Clin. Neurophysiol.*, **115**, 267-281 (2004).
45. D. Rousseau and F. Chapeau-Blondeau, "Suprathreshold stochastic resonance and signal-to-noise ratio improvement in arrays of comparators," *Phys. Lett.*, **321**, 280-290 (2004).
46. Y. Yamamoto, I. Hidaka, D. Nozaki, et al., "Noise-induced sensitization of human brain," *Physica A*, **314**, 53-60 (2002).
47. D. R. Frisina and R. D. Frisina, "Speech recognition in noise and presbycusis: Relations to possible neural mechanism," *Hear. Res.*, **106**, Nos. 1/2, 95-104 (1997).