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Artikel Asli/*Original Articles*

Superior Temporal Gyrus (STG) and Cerebellum Show Different Activation Profile during Simple Arithmetic Addition Task in Quiet and in Noisy Environment: An fMRI Study

(Girus Temporal Superior (STG) dan Serebelum Menunjukkan Profil Pengaktifan Berbeza semasa Tugasan Hasil Tambah Aritmetik Mudah dalam Persekitaran Senyap dan Bising: Satu Kajian fMRI)

AHMAD NAZLIM YUSOFF, TENG XIN LING, AINI ISMAFAIRUS ABD HAMID & SITI ZAMRATOL-MAI SARAH MUKARI

ABSTRACT

Despite a vast number of studies that were focused on the roles of superior temporal gyrus (STG) and cerebellum as sensory area, little is known about their involvement in cognitive function such as attention and perception. The present fMRI study aimed to identify this cognitive role from brain activation profile of STG and cerebellum obtained from an arithmetic addition task. Eighteen healthy right hand dominance male adults participated in this study. They were instructed to solve single-digit addition tasks in quiet and noisy background during the fMRI scan. Both the in-quiet and in-noise addition tasks activated the bilateral STG and cerebellum (lobule VI and lobule VII) significantly but differentially. In both quiet and noisy conditions, STG activation is dominant in the left hemisphere while cerebellum showed a right hemisphere dominance. Bilateral STG and cerebellum (lobule VI) activation decreasedin noise, conversely cerebellum (lobule VII) activation increased in noise. These asymmetrical activation indicated hemispheric lateralization and differential behaviors of both brain areas in different environment while performing simple arithmetic addition task.

Keywords: Cognitive; perception; statistical parametric mapping; cerebral cortex; cerebellum

ABSTRAK

Meskipun banyak kajian tertumpu ke atas peranan girus temporal superior (STG) dan serebelum sebagai kawasan deria, hanya sedikit diketahui mengenai keterlibatan kawasan deria tersebut dalam fungsi kognitif seperti daya tumpuan dan tanggapan. Kajian fMRI ini bertujuan untuk menentukan peranan kognitif ini daripada profil pengaktifan otak bagi STG dan serebelum yang diperolehi daripada tugasan hasil tambah aritmetik. Lapan belas lelaki dewasa dominan tangan kanan yang sihat menyertai kajian ini. Mereka diarahkan untuk menyelesaikan tugasan hasil tambah digit tunggal dalam latar belakang senyap dan hingar semasa imbasan fMRI. Kedua-dua tugasan hasil tambah dalam senyap dan hingar mengaktifkan STG dan serebelum (lobus VI dan lobus VII) bilateral secara bererti tetapi secara berbeza. Dalam kedua-dua keadaan senyap dan hingar, pengaktifan STG adalah dominan pada hemisfera kiri manakala serebelum menunjukkan dominasi hemisfera kanan. Pengaktifan STG bilateral dan serebelum (lobus VI) berkurang dalam hingar, sebaliknya pengaktifan meningkat dalam hingar bagi serebelum (lobus VII). Pengaktifan ini menunjukkan kelateralan hemisfera dan perbezaan kelakuan kedua-dua kawasan otak tersebut dalam persekitaran berbeza semasa melaksanakan tugasan hasil tambah aritmetik mudah.

Kata kunci: Kognitif; tanggapan; pemetaan statistik berparameter; korteks serebrum; serebelum

INTRODUCTION

Mental arithmetic involves a complex cognitive operation. It comprises of a set of distinct functional processes and requires working memory resources (Lemaire 1996; Uittenhove & Lemaire 2013a; Uittenhove & Lemaire 2013b). Mental arithmetic sub-classes are addition, subtraction, multiplication and division. Mentally solving problems in all these sub-classes involves attention, processing numbers and working memory (Dehaene et al. 2003). Working memory consists of four interacting components, which are the central executive, episodic buffer (Baddeley 2000a) and two subsidiary slave systems; visual-spatial sketchpad and a phonological (speech) loop (Baddeley 2000b). Fayol et al. (1987) suggested 3 cognitive operations that are involved in solving arithmetic problems, which are information storage, data organization and executive control. Other studies on adults showed that the execution of mental arithmetic involved a mixture of fact retrieval from memory and procedures (LeFevre et al. 1996a; LeFevre et al. 1996b). Arithmetic addition is considered a simple task which can be solved merely by retrieval of rote table knowledge (Zhou et al. 2007).

Many functional imaging studies suggested that both brain hemispheres were involved during mental calculation (Dehaene et al. 2003; Dehaene 1992). The left hemisphere was found to be more activated than the right hemisphere during the performance of arithmetic calculation both in quiet and in noisy environment (Yusoff et al. 2008). It was also found that the total number of activated voxel during arithmetic task is higher in a noisy environment compared to in quiet (Aini Ismafairus Abd Hamid et al. 2011). Previous neuroimaging studies demonstrated activation of STG and cerebellum during the performance of auditory working memory tasks (Abdul Manan et al. 2013) and temporal pole activation during arithmetic task (Hughdal et al. 2004; Aini et al. 2011; Yusoff et al. 2008), most probably due to auditory types of stimuli. STG was found to be activated due to its central role in the auditory processing (Aini et al. 2011), whereas the cerebellum was involved in attention during a cognitive task even though it has often been thought to be only responsible for motor coordination and balance (Desmond & Fiez 1998). Other regions that are involved in arithmetical attention and cognition are the supplementary motor area (SMA), insula and cingulate cortex (Kong et al. 2005; Kazui et al. 2000). Areas such as superior and middle frontal gyrus support working memory and fact retrieval demand during arithmetic operations (Wong et al. 2008). They showed activation during arithmetic tasks regardless of tasks, complexities and operators (addition, subtraction) (Kong et al. 2005).

Everyday communication sometimes occurs in clamorous environment such as in school, in a market or at a foodcourt. Listening to spoken words in these conditions resulted in the engagement of different cognitive networks (Scott et al. 2004). This is presumably due to mechanisms involved in the suppression of irrelevant information and the concentration on the task (Söderlund et al. 2010). Previous studies have consistently revealed that performing a cognitive task in quiet and in a noisy environment activated similar areas in the cerebellum and STG (Desmond & Fiez 1998; Abdul Manan et al. 2013). However, these activations were not fully understood as the cerebellum was thought primarily to be responsible for motor function and balance while STG is for auditory function. Although our previous study (Manan et al. 2013) revealed the involvement of these two areas in number processing, the knowledge of how they function is still lacking and their possible role in arithmetic operations remains debated.

In the present study, we investigated the influence of background on the activation of bilateral STG and cerebellum during the performance of simple addition task using a functional magnetic resonance imaging (fMRI) technique. The fMRI data were analyzed using statistical parametric mapping (SPM8). The objectives of the study were to identify the activation pattern of the STG and the cerebellum during simple arithmetic addition task and how noisy background influenced the activation pattern of the two regions.

METHODOLOGY

PARTICIPANTS

Eighteen native, fluent Malay-speaking, male adults voluntarily participated in the present study. All the participants agreed to participate by filling in the informed consent and screening forms and signing them, after being given full explanation of the nature and risks of the research. This research was approved by the Universiti Kebangsaan Malaysia (UKM) Ethics Committee for research (Code NN-049-2009). The participants were UKM staffs conveniently recruited (by words of mouth) from UKM Kuala Lumpur campus and were screened according to the Malaysian Certificate of Education to obtain a group of participants who could perform simple mathematical operations. Only those who passed their mathematics papers were enrolled in this study. None of the participants were professional mathematician or actively involved in teaching mathematics. The participants were interviewed on their health condition prior to the scanning session. All the participants were tested for handedness using the Edinburgh Handedness Inventory (Oldfield 1971). The participants were also tested for their middle ear condition and hearing level using a tympanometer (Model GrasonStadler Inc. GSI33) and a pure-tone audiometer (Model GrasonStadler Inc. GSI61) respectively, by a qualified Audiologist. All participants were paid after the completion of all the required procedures. Pure tone audiometry (PTA) was conducted in the frequency range of 250 Hz to 8000 Hz. Both devices were calibrated to the American National Standard Institute (ANSI).

DEMOGRAPHICAL DATA

The average age and standard deviation of the participants were 23.2 ± 2.5 years (ranged between 20 to 30 years). All participants reported no history of psychiatric or neurological disorder and no current use of any psychoactive medications. All participants were confirmed to be right handed with average laterality index (LI_{ave}) of 87 in the range of sixth to seventh right. In a study by Deutsch (1978), left-handed participants have been found to perform the pitch discrimination tasks significantly better than the right-handed. Based on this finding and on the fact that both arithmetic and pitch memory processing would involve working memory, it is important that the participants should not be mixed in terms of their handedness to avoid confounding effects. The participants were found to have no hearing impairment and no history of long time exposure to loud noise to be inappropriate for auditory stimulus presentation. The participants' hearing levels for both ears are not greater than 30 dB (HL) in the respective range of frequency used for the pure tone audiometry (PTA) test.

STUDY PARADIGM

The experimental tasks consisted of simple arithmetic addition problems that need to be solved by the participants. Each arithmetic addition problem consisted of four digits that were randomly selected from numbers 0 to 9, e.g. (2 + 1 + 5 + 4). Each digit may appear twice such as (6 + 2 + 4 + 2) but not more than twice. The arithmetic addition problems were recorded in a CD ROM using a male voice. The language used was Bahasa Melayu. The male speaker read the arithmetic addition problems (written in number form on a piece of paper) during recording. Prior to the recording, the voice was verified by a Speech Pathologist for a correct pronunciation and intonation. There were altogether 60 arithmetic addition problems that were recorded as stimuli. The recordings were alternately done in quiet (known as Addition in Quiet – AIQ) and in the presence of white noise as background (known as Addition in Noise – AIN). For AIN, the 83-dB stimuli were embedded in 80-dB noise to obtain a signal to noise ratio (SNR) of 3dB. The alternating sequence of the 30 arithmetic addition problems in quiet and 30 arithmetic addition problems in the noisy background was fixed so that all participants attended to the same experimental task. A complete arithmetic addition problem sets are given elsewhere (Aini 2011).

Prior to the functional magnetic resonance imaging (fMRI) scans, all the participants were given detailed instructions on how to respond to the stimuli and were allowed to train for about 15 minutes before the commencement of the fMRI experiment. The training used the exact sequence of tasks arranged for the experiment. The participant to be scanned was laid down supine in the MRI gantry. The participant was required to put on the MRI headphones (transmission of sound stimulus through an air tube) for the delivery of instructions and stimuli and the radiofrequency (RF) head coil for signal transmission and reception. The participants were also instructed not to move their head during the scan as it can cause signal intensity changes over time from any one voxel and present a serious confound in fMRI studies. To minimize head movement, immobilizing devices were used together with the head coil.

A sparse fMRI paradigm was used for this study (Aini et al. 2011), as shown in Fig. 1. This type of paradigm had previously been used in auditory studies (Hall et al. 1999; Binder et al. 2004). The recorded stimuli were presented using a digital playback system during the silent gaps between volume acquisitions and did not overlap with the sound produced by the scanner. Thus, the effects of the scanner sound on the MRI images were avoided. The duration of the stimuli was 6 s. As mentioned above, each participant was subjected to two different conditions, which were AIQ and AIN. The participants were instructed to listen carefully to the 6-s stimuli and were required to start performing the calculations (imaginary) immediately after hearing the first digit. The participants were required to provide an answer verbally as quickly and as accurately as possible to the addition tasks in 3-5 s after the last digit. Participant's response in answering is important in order to evoke responses in the respective brain areas and to ensure that the participants remain alert and focused throughout the scanning session. All participants have been able to respond to all the tasks given. All participants' answers were recorded outside the scanner and were reported in a separate communication (Aini et al. 2001). No participant skipped any of the AIQ or AIN tasks.

The functional imaging session consisted of 120 series of trials (or measurements); 30 trials for AIQ, 30 trials for AIN and 60 trials for baseline (stimulus not given). The sequence was AIQ-BASELINE-AIN-BASELINE-AIQ, as can be seen in Fig. 1. A long (11 s) inter-measurement interval was used to allow for the hemodynamic response to decline after each given stimulus. The acquisition time was 5 s, with each functional measurement producing 35 axial slices in the 5-s duration (one image slice per 143 ms). The measurement started with AIQ. The imaging time for each session was 32 minutes, which produced 120 × 35 = 4200 images in total.

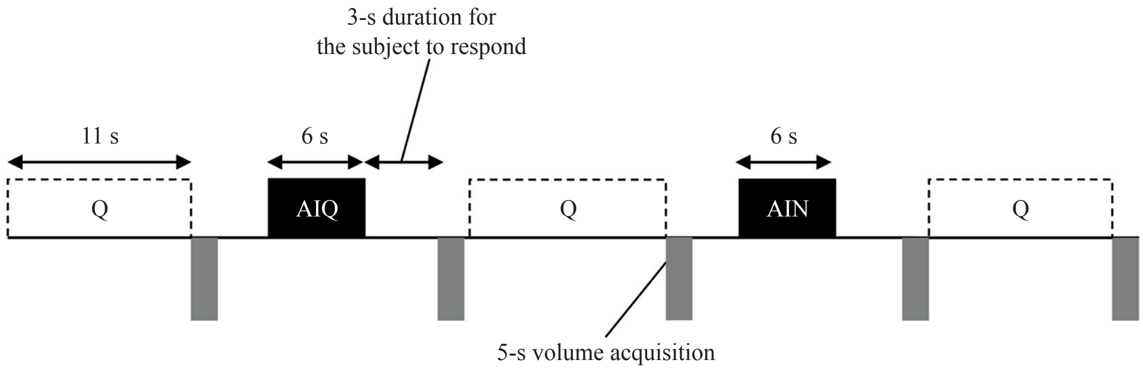


FIGURE 1. The experimental paradigm used in this study

DATA ACQUISITION

The fMRI scans were conducted in the Department of Radiology, UKM Medical Centre. Functional images were acquired using a 1.5 T magnetic resonance imaging (MRI) system (Siemens Avanto, Erlangen, Germany) equipped with blood oxygenation level-dependent imaging protocol, echo-planar imaging capabilities and radiofrequency head coil used for signal transmission and reception. Echo-planar imaging (EPI) pulse sequence was used to produce T2*-weighted images. The imaging parameters are repetition time (TR) = 16000 ms, acquisition time (TA) = 5000 ms (interval between two scans = 16000 ms − 5000 ms = 11000 ms), echo time (TE) = 50 ms, field of view (FOV) = 192 × 192 mm, flip angle = 90°, matrix size = 128 × 128, and slice thickness = 3 mm. In addition, high resolution anatomical images of the entire brain were obtained using a T1-weighted multiplanar reconstruction (MPR) spin-echo pulse sequence with the following parameters: TR = 1620 ms, FOV = 250 × 250 mm, flip angle = 90°, matrix size = 128 × 128, and slice thickness = 1 mm.

DATA ANALYSIS

All the T2*- and T1-weighted images were analyzed at the Diagnostic Imaging & Radiotherapy Program, Faculty of Health Sciences, UKM Kuala Lumpur. Image analyses were performed using a personal computer. Matlab (7.6 R2008a Mathworks Inc., Natick, MA, USA) -based Statistical Parametric Mapping (SPM8) (Functional Imaging Laboratory, Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College of London) was used in the analysis. The T1 and T2*-weighted images which were initially in DICOM (.dcm) formats were transformed into Analyze (.hdr, .img) format using SPM8. Functional images from each measurement were realigned using the 6-parameter affine transformation translationally (x, y, and z) and rotationally (pitch, roll and yaw) to reduce artefacts from participant movement and to make within- and between-participant comparisons meaningful. Following realignment, a mean image of the series was used to estimate some warping parameters that mapped it onto a template that conformed to a standard anatomical space, i.e., EPI template provided by the Montreal Neurological Institute (MNI). The normalization procedure used a 12-parameter affine transformation, where the parameters constituted a spatial transformation matrix. The images were then smoothed using a 6-mm full-width-at-half-maximum Gaussian kernel. The activated voxels were identified by the general linear model approach by estimating the parameters of the model and deriving the appropriate test statistic (t statistic) for every voxel. Statistical inferences were finally obtained based on Gaussian random field theory.

Group random effects (RFX) analysis was used in obtaining the average brain activation. For AIQ and AIN, significant statistical inference was made at $p = 0.05$, corrected for multiple comparisons with a threshold of 10 voxels. Results of the random effects analysis (task-specific) were reported as the number of activated voxels in a cluster of activation and the corresponding t values at voxel of maximum intensity. The anatomies of the activated brain regions were confirmed using Anatomy toolbox (Eickhoff et al. 2005).

RESULTS

BRAIN ACTIVATION

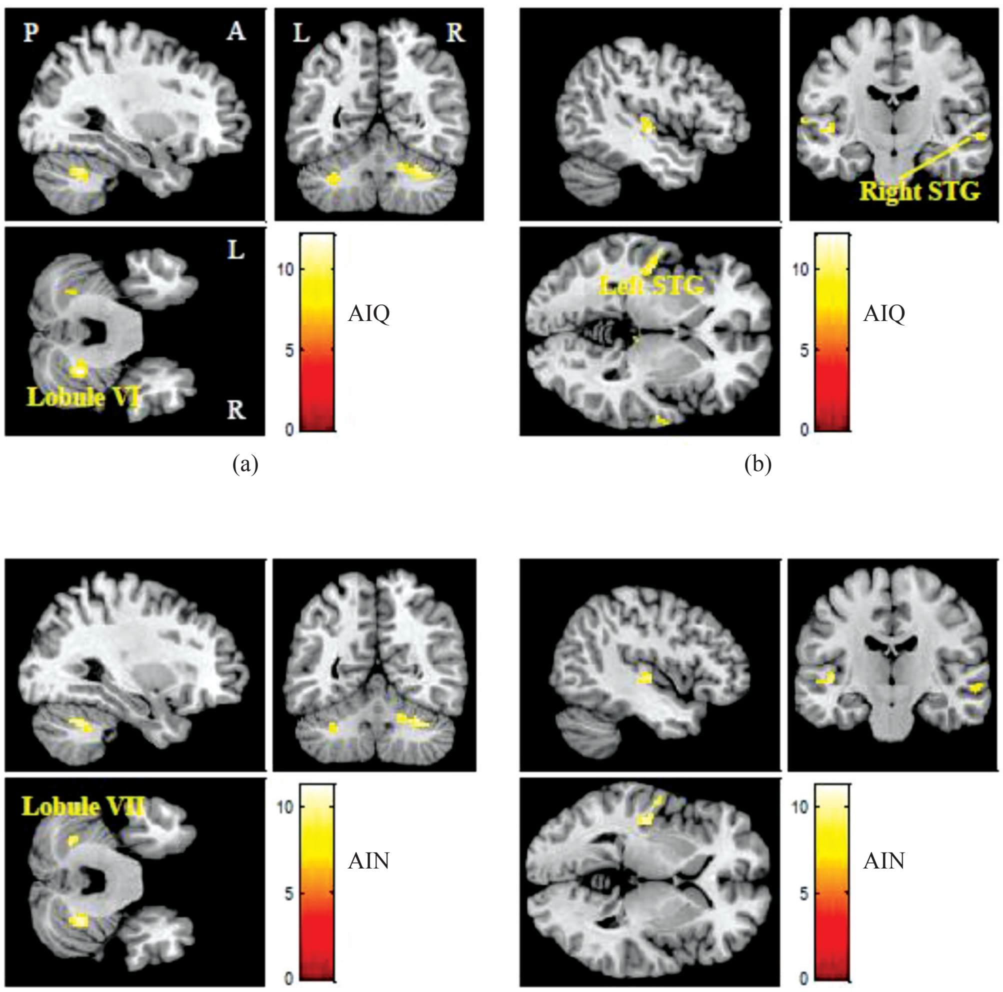
Based on the analysis of random effects (RFX), there were seven significantly ($t > 8.5$, $p_{FWE} < 0.05$ corrected for multiple comparisons, $k = 10$ voxels) activated regions during both the AIQ and AIN conditions; they were bilateral STG, cerebellum (right lobule VI and left lobule VII) and temporal pole and SMA. AIQ and AIN seemed to activate the same brain regions. Table 1 displays the corresponding regions, together with their number of activated voxels

TABLE 1. Activated regions during AIQ and AIN with their number of activated voxels (NOV), coordinates of maximum intensity (x, y, z) and the t value

Condition	Region	NOV	x	y	z	t
AIQ	R Cerebellum (lobule VI)	148	30	-60	-28	12.13
($p < 0.05$	L Cerebellum (lobule VII)	51	-32	-58	-34	10.04
corrected for	R STG	55	62	-18	-2	10.81
multiple comparisons)	L STG	90	-46	-20	2	10.88
	R Temp Pole	10	50	14	-6	8.69
	L Temp Pole	48	-50	10	-6	10.48
	SMA	24	4	12	60	9.50
AIN	R Cerebellum (lobule VI)	119	30	-60	-28	11.27
($p < 0.05$	L Cerebellum (lobule VII)	86	-32	-56	-36	10.98
corrected for	R STG	38	64	-20	0	9.10
multiple comparisons)	L STG	82	-44	-22	4	10.20
	R Temp Pole	14	62	4	-4	9.06
	L Temp Pole	88	-50	8	-8	10.31
	SMA	24	-2	8	62	10.00

Abbreviations: AIQ = addition in quiet, AIN = addition in noise, STG = superior temporal gyrus, SMA = supplementary motor area, Temp Pole = temporal pole, R = right, L = left

(*NOV*) coordinates of maximum intensity and the respective t values. The maximum intensity voxel ($t = 12.13$ for AIQ, $t = 11.27$ for AIN) was observed at coordinates 30/-60/-28, which were in the right cerebellum (lobule VI). The total number of activated voxels (NOV) were 426 during AIQ and 451 during AIN. Asymmetrical leftward (left higher than right) height and spatial extent of activation were observed in the STG and temporal pole for both the AIQ and AIN conditions. In contrast, the activations for cerebellum were rightward (right higher than left) for both the AIQ and AIN conditions. The SMA shows a similar spatial extent of activation either in quiet or in noise. Bilateral STG and right cerebellum show a decrease in both the height and spatial extent of activation in noisy condition. The left cerebellum, however, showed an increase in the two activation parameters during AIN. The brain activation maps for AIQ and AIN overlaid onto sectional T1 weighted images indicating the bilateral STG and cerebellum are shown in Figs. 2 (a-d), respectively.



(c) (d)

FIGURE 2. Activated brain regions obtained from group ($N = 18$) random effect analysis (RFX) for AIQ and AIN. The activation maps were overlaid onto the standard T1 images at selected locations to display the activation in the bilateral cerebellum (a & c) and STG (b & d). R: right, L: left, A: anterior, P: posterior. Color codes represent increasing t value from red to white

DISCUSSION

In this study, we examined the brain activation during the performance of a simple addition task in a quiet and in a noisy surrounding. We aimed to investigate the task-specific brain activation between two important brain regions, which are the STG and cerebellum during the task performance under different background conditions. Therefore, we identified task-specific activation patterns and focused on the STG and cerebellum as the key regions (ROIs).

BRAIN ACTIVATION PATTERN

Group random effects (RFX) analysis showed that AIQ and AIN activated similar regions, which are the bilateral

STG and temporal pole, right cerebellum (lobule VI), left cerebellum (lobule VII) and supplementary motor area (SMA). The activation map showed similar cerebellar and cortical regions were involved in both tasks. This suggests that the arithmetic addition task used throughout this study excited similar regions within the brain regardless of whether the task is performed in a quiet or in a noisy condition.

As expected, AIQ and AIN revealed common activation in the STG as it is associated with auditory processing, especially when the input stimulus is delivered through hearing. The coordinates of maximum intensity for AIQ and AIN that occurred at the same anatomical points reveal that both the left and right hemisphere STG possesses similar processing centre, whether in quiet or in noisy condition. This result is consistent with previous studies, which show activations in very similar locations (primary auditory cortex) elicited by the presentation of auditory stimuli (Devlin et al. 2003; Wong et al. 2008). However, the processing centre for the left and right STG is not symmetrical but rather displaced by 16.13 mm during AIQ and 20.49 mm during AIN indicating hemispherical asymmetry characteristic of STG in processing the same stimuli.The present study also showed that performing the task in a quiet background evoked a wider spatial and a higher height extent of activation in the bilateral STG as compared to in a noisy background (Comparing Figures 2(b) and (d)). Nevertheless, the differences in the number of activated voxel (not greater than 20) and *t* values (not greater than 2) for the right and left STG in quiet and in noise are small (Table 1). In contrast, previous studies conducted on younger participants showed that the activation in bilateral STG increased with noise levels (Wong et al. 2008; Wong et al. 2009). Participants recruited in the studies of Wong et al. (2008, 2009) listened passively to the speech stimuli whereas in this study, participants were required to perform mental calculation at the end of stimulus presentation. The present study involves elements of working memory and requires the activation of the brain areas that are related to cognition. Thus, it is proposed that the spatial and height extent of activation in quiet that equals that in noise for STG is potentially due to the change in the processing strategy by STG when dealing with the simple addition task in a different background. One possible explanation is that the participants may have a better perception of the stimuli in quiet than in noise, therebyincreasing its activation and resulting in a small difference in the activation of the bilateral STG in quiet and in noise (Wong et al. 2008, 2009).

The present study also found that the simple addition task has resulted in significant activation in the cerebellum, temporal pole and SMA. These three regions have been known to be involved in cognitive functions such as working memory, attention, executive control, language and emotional tagging of perceptive processes (Dupont 2002; Petersen et al. 1988; Kong et al. 2005). For cerebellum, the fact that voxel of maximum intensity for AIQ and AIN are located in lobule VI in the right hemisphere and lobule VII in the left hemisphere, respectively suggested that the activation was related to numbering, encoding and retrieval under executive working memory demands such as solving simple addition task (Stoodley & Schmahmann 2009). The difference in the number of activated voxel for lobule VI in the right hemisphere and lobule VII in the left hemisphere in a quiet and in a noisy background is relatively larger than that of STG. The spatial extent of activation in lobule VI is wider in quiet than in noise while for lobule VII, the activation is wider in noisy condition.The *t* values show similar variation, but the differences are small.These results can be related to the enhancement and suppression of activation with the absence or presence of an experimental factor such as noise (Abdul Manan et al. 2013). In the absence of noise, e.g. in a quiet condition, lobule VI in the right cerebellum is dominant in the processing of the arithmetic addition task. In the presence of noise, the role of lobule VI is still dominant but is suppressed, as indicated by the decrease in the number of activated voxel (Abdul Manan et al. 2013). In contrast, the role of lobule VII is enhanced in noisy condition. It is suggested that in the presence of noise, the processing demand is shared between lobule VI and VII to accomplish the task.

In our recent work on verbal working memory via a backward repeat test (BRT), cerebellum was found to be involved in attenuating noise and/or increasing attention to task performance (Abdul Manan et al. 2012). In the study, cerebellum and hippocampus have been found to be involved in the enhancement of performance in word-based backward repeat test (BRT) with the presence of background noise. The increase in attention is attributed to the stochastic resonance mechanisms operating in the presence of noise. Stochastic resonance is a phenomenon by which the detectability of an input signal is increased through the presence of random interference such as noise, up to a finite level of intensity (Moss et al. 2004). Nevertheless, the role of the cerebellum in arithmetic working memory processing has yet to be fully understood, given a vast number of studies conducted. Based on the study of Abdul Manan et al. (2012) and Moss et al. (2004), the decrease in the spatial extent of cerebellum lobule VII in noisy environment could also point to the mechanism of stochastic resonance.

The study of Rueckert et al. (1996) showed that SMA was activated during single-digit mental calculation indicating that SMA is also a region related to working memory in addition to its well-known function in the execution of sequential movements. Furthermore, SMA was as well found to be activated in non-numerical tasks, including verbal production (Petersen et al. 1988).In this study, the height and spatial extent of activation suggested that the role of SMA in a quiet condition was found to equal its role in noisy condition indicating that SMA is not influenced by noise in the performance of the task.

The activation pattern for all regions obtained for both AIQ and AIN are found to be asymmetrical except for SMA, which is considered to be located in the mid sagittal plane. STG and temporal pole evoked the left hemisphere more extensively, whereas the cerebellum showed right-hemispheric preference. The left lateralization of the activation in STG and temporal pole is because the left hemisphere is more responsive to verbal stimuli while the right hemisphere STG is more responsive for non-verbal stimuli (Rottschy et al. 2012; Smith et al. 1996). Furthermore, many brain areas in the left hemisphere are known to be dominant in the processing of the arithmetic task such as solving addition problems (Arsalidou & Taylor 2011). On the other hand, the right lateralization of the cerebellum can be attributed to its involvement in working memory, which is relatively higher in the right hemisphere, especially in lobule VI, even under different environments (Stoodley and Schmahmann 2009).

The limitation of this study is the long scan time consumed by a sparse temporal sampling fMRI. A long inter-scan interval can become a disadvantage in using STS-fMRI, from which it will result in a longer total examination time. In many functional imaging studies, for example in a study on cognition such as arithmetic addition or subtraction, total scan time is crucial because it deals with subjects which could become restless in a long scan time (in order to have relatively high scan volumes which are statistically reasonable). This could lead to inconsistent activation towards the end of the fMRI session. The use of event related fMRI paradigm might be useful in the future fMRI studies on cognition.

CONCLUSION

In conclusion, single-digit addition task used for this study in which the stimuli were presented verbally in quiet and in noisy condition, evoked activation in the same brain regions, which were the bilateral STG and cerebellum (right lobule VI and left lobule VII), temporal poles and SMA. STG was found to be activated mainly due to its functional role in auditory processing and might also be due to its indirect involvement in cognition. Cerebellum, frontal and other brain regions showed activation as they played important roles during fact retrieval, working memory, attention and executive control. These results strengthen previous findings on the involvement of the bilateral cerebellum in arithmetic working memory processing. Differential activation observed for both STG and cerebellum revealed important activation characteristics for future studies on cognitive networks. Furthermore, significant activation in the STG and cerebellum discussed above validates the arithmetic task used in this study in the absence and presence of noise. The results also highlighted the importance of using RFX analysis in making inference about the brain activation based on anatomically closed hypothesis and especially when the number of participants is relatively small.

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Ahmad Nazlim Yusoff
Teng Xin Ling
Diagnostic Imaging & Radiotherapy Program
School of Diagnostic and Applied Health Sciences
Faculty of Health Sciences
Universiti Kebangsaan Malaysia
Jalan Raja Muda Abdul Aziz
50300 Kuala Lumpur, Malaysia

Aini Ismafairus Abd Hamid
Otto-Von-Guericke University Magdeburg
Biomedical Magnetic Resonance
Leipziger Str. 44, D-39120 Magdeburg
Germany

Centre for Neuroscience Research and Services
(P3Neuro)
Universiti Sains Malaysia Health Campus,
16150 Kubang Kerian, Kelantan

Corresponding author:A.N. Yusoff
Email address: nazlimtrw@ukm.edu.my
Tel.: +603 9289 7295
Fax: +603 2692 9032

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Siti Zamratol-Mai Sarah Mukari
Audiology Program
School of Rehabilitation Sciences
Faculty of Health Sciences,
Universiti Kebangsaan Malaysia
Jalan Raja Muda Abdul Aziz
50300 Kuala Lumpur, Malaysia

Insitut Telinga, Pendengaran dan Pertuturan
(Institute-HEARS)
Blok 8 Tingkat 3
Fakulti Sains Kesihatan
Universiti Kebangsaan Malaysia
Jalan Temerloh
53200 Kuala Lumpur