

Changes in auditory memory performance following the use of frequency-modulated system in children with suspected auditory processing disorders

Cila Umat, MAud, PhD, Siti Z. Mukari, MSc, AuD, Nurul F. Ezan, BAudio (Hons), Normah C. Din, BHSc (Psych), MAClinPsych.

ABSTRACT

الأهداف: دراسة التغيرات في الذاكرة السمعية قصيرة المدى بعد استخدام نظام تعديل التردد في الأطفال المحتمل أصابهم باضطراب سمعي ودراسة ميزة تركيب نظام تعديل التردد بجانب واحد وجانبين.

الطريقة: أجريت هذه الدراسة الطويلة بقسم أمراض السمع والنطق، كلية العلوم الصحية، جامعة ماليزيا كبانغسان خلال الفترة من سبتمبر 2007م إلى أكتوبر 2008م واشتملت هذه الدراسة الطويلة على 53 طفل بجالان كونتان، كولالمبور انطبقت عليهم معايير الدراسة. حيث تراوحت أعمارهم من 7-10 أعوام تم تقسيمهم إلى 3 مجموعات، حيث اشتملت المجموعة الضابطة على 15 طفل لم يتم تركيب نظام تعديل التردد لهم، و 19 طفل تم تركيب نظام تعديل التردد بجانب واحد، و 19 طفل تم تركيب النظام لكلا الجانبين. استخدم الأفراد نظام تعديل التردد خلال ساعات الدراسة لمدة 12 أسبوع. تم قياس الذاكرة العاملة، ومؤشر التعلم الأفضل، وحفظ المعلومات باستخدام اختبار التعلم الشفوي السمعي قبل وبعد استخدام نظام تعديل التردد وبعد نهاية عام من استخدام نظام تعديل التردد.

النتائج: كانت هنالك اختلافات مهمة إحصائياً في معدل درجات الذاكرة العاملة $p=0.000$ ، ومؤشر التعلم الأفضل $p=0.005$ ، وحفظ المعلومات $p=0.019$ في معدل الدرجات لأوقات مختلفة حيث كان معدل درجات الاستخدام عالياً بشكل مستقر مقارنة بالأداء قبل التركيب في القيمة الأساسية $p>0.05$. بينما لم يكن هنالك اختلاف مهم إحصائياً في الأداء بين المجموعة التي استعملت النظام بجانب واحد وجانبين.

خاتمة: أن استخدام نظام تعديل التردد له أثر طويلاً في تحسين الذاكرة السمعية قصيرة المدى لبعض الأطفال المحتمل أصابهم باضطراب سمعي وقد لا يكون هنالك ضرورة لاستخدام نظام تعديل التردد في كلا الجانبين لتحسين أداء الذاكرة السمعية.

Objectives: To examine the changes in the short-term auditory memory following the use of frequency-modulated (FM) system in children with suspected auditory processing disorders (APDs), and also to compare the advantages of bilateral over unilateral FM fitting.

Methods: This longitudinal study involved 53 children from Sekolah Kebangsaan Jalan Kuantan 2, Kuala Lumpur, Malaysia who fulfilled the inclusion criteria. The study was conducted from September 2007 to October 2008 in the Department of Audiology and Speech Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia. The children's age was between 7-10 years old, and they were assigned into 3 groups: 15 in the control group (not fitted with FM); 19 in the unilateral; and 19 in the bilateral FM-fitting group. Subjects wore the FM system during school time for 12 weeks. Their working memory (WM), best learning (BL), and retention of information (ROI) were measured using the Rey Auditory Verbal Learning Test at pre-fitting, post (after 12 weeks of FM usage), and at long term (one year after the usage of FM system ended).

Results: There were significant differences in the mean WM ($p=0.001$), BL ($p=0.019$), and ROI ($p=0.005$) scores at the different measurement times, in which the mean scores at long-term were consistently higher than at pre-fitting, despite similar performances at the baseline ($p>0.05$). There was no significant difference in performance between unilateral- and bilateral-fitting groups.

Conclusion: The use of FM might give a long-term effect on improving selected short-term auditory memories of some children with suspected APDs. One may not need to use 2 FM receivers to receive advantages on auditory memory performance.

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From the Department of Audiology & Speech Sciences, (Umat, Mukari, Ezan), Health Psychology Unit (Din), Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia

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Address correspondence and reprint request to: Dr. Cila Umat, Department of Audiology & Speech Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, Kuala Lumpur 50300, Malaysia. Tel. +60 (3) 92895005. Fax. +60 (3) 26986039. E-mail: cila@medic.ukm.my

Auditory processing disorder (APD) is defined as “a deficit in the perceptual processing of auditory stimuli and the neurobiological activity underlying that processing”.^{1,2} Children with APD often show difficulties in processing sounds, especially in adverse environments, such as noisy classrooms. If remain untreated, APD may cause poor speech perception, reduced on-task behavior, and poor academic performance, leading to negative psychosocial impact.³ They usually have comorbid attention problems that may affect their sound processing and memory storage. Diagnosis is made when someone scores 2 standard deviations, below normal in at least 2 auditory processing tests (which include dichotic listening, auditory sequencing, and speech in noise).⁴ Attention is important for perception and understanding of complex sounds, such as speech.⁵ Noise distracts APD children easily. The lack of attention in noisy classroom may explain part of their difficulties in understanding teachers’ instructions, reducing the efficiency, or speed of information processing in their short-term auditory memory. According to the information-processing model, various subsystems such as memory, thought, and other higher level executive functions are ‘connected’ to each other. Awareness of each of these subsystems is important for perception to take place.⁶ A recent study by Moore et al⁷ indicated that APD is mainly an attention problem. The American National Standard Institute (ANSI) S12.60-2002 specifies a maximum 35dBA for unoccupied classrooms, and a maximum reverberation time of 0.6 sec to ensure optimum learning environment.⁸ However, Crandell and Smaldino⁹ for example, found that classroom noise levels varied from 41 dBA in an unoccupied room to 68 dBA in occupied rooms. The ambient noise levels of classrooms in Malaysia are much higher than that reported by Crandell and Smaldino.^{9,10} Ooi¹¹ found the surrounding noise levels measured in 117 classrooms in 13 primary schools in Malaysia during teaching sessions ranged between 52.4-93.8 dBA, with a mean of 67.5 ± 4.0 dBA. In unoccupied rooms, the mean ambient noise level measured was 61.5 ± 3.2 dBA. Typical size of classrooms in Malaysia is approximately 8 meters wide, 7 meters long, and approximately 4 meters in height. The walls, floors, and ceilings are made up of hard surfaces, and acoustically non-treated. In general, each classroom in primary schools in Malaysia has approximately

36-40 students. Poor acoustics and high number of children in a class risk learning in mainstream schools in all children, especially those with auditory-related and language problems. This is because learning in mainstream schools is mainly based on comprehension of spoken language.¹² Children, even with no other hearing-related problems need higher signal-to-noise ratios (SNRs) than adults to understand speech. This is partially due to their lower level linguistic skills, lack of world experience, and attention.¹³ Children with APD need even higher SNRs than normal hearing children to improve processing of auditory signals. The frequency-modulated (FM) system is an option for managing APD children in classroom setting. The FM system consists of a microphone, a transmitter, and a receiver. The microphone, which is approximately 10 cm from the mouth of the speaker, minimizes the problem with distance and reverberation in signal transmission, hence, improving the SNRs for a more conducive listening environment. For instance, a study reported an SNR benefit of approximately 16-18 dB to users of Edulink FM.¹⁴ In another study conducted, it reported that children with attention deficit hyperactivity disorders (ADHD) and APDs showed improved performance on specific sound perception tasks after a year of fitting a personal MicroEar® FM.¹⁵ This study examined the changes in short-term auditory memory performances following the use of a personal ear-level FM system on a group of school-aged children suspected with APDs. The working hypothesis was that children with suspected APDs had better attention, and therefore, a higher index of auditory memory performance with higher SNRs.^{16,17} We aimed to find out if subjects who were fitted with the FM would show better performance over time in various short-term auditory memory measures than the control group. The benefits of bilateral over unilateral FM fitting on auditory memory performance were also examined.

Methods. This study involved 60 primary school children between 7-10 years old, recruited from one of the mainstream schools in Kuala Lumpur (Sekolah Kebangsaan Jalan Kuantan 2, Kuala Lumpur). Subjects were native Malay speakers, and had poor academic performance. They obtained less than 60% score in the Malay language comprehension subject in the midterm school examination. Initially however, 90 students went through the screening procedure to ensure they fulfilled the inclusion criteria. To participate, subjects had: to pass a hearing screening, which was set at 20 decibels (dB) hearing level (HL) at octave frequencies from 500-4000 Hz on both ears; bilateral normal middle ear function as indicated by a type A tympanogram;¹⁸ normal performance intelligent quotient (IQ) with

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performance IQ score more than or equal to 80;¹⁹ and failure in one of the APD screening tests that is, the Malay Double Dichotic Digit Test (DDDT),²⁰ or the Pitch Pattern Sequence Test (PPST),²¹ in which performance was more than 2 standard deviations below normal. Subjects who were reported by a class teacher to have poor record on school attendance were excluded. Those who showed symptoms of ADHD, which include inattention, impulsivity, and hyperactivity, as reported by school teachers were also excluded. The exclusion criteria were set to ensure compliance of the FM usage throughout the school hours and study period. Selected subjects were then divided into 3 groups consisting of 20 subjects each: Group 1 - control group (without the FM); Group 2 - the unilateral-fitting FM group; and Group 3 - the bilateral-fitting FM group. All subjects in the unilateral group had the FM fitted on their right ear. Subjects in each group were matched according to their age and IQ scores. Table 1 shows the age and performance IQ of all children across study groups. The FM usage was during school time (4-5 hours per day), and the subjects wore the FM for 12 weeks of school. Daily inspection of the battery and devices was performed by one of the investigators throughout the study period to ensure compliance of the usage.

This study was part of a bigger study on the benefits of using FM system on normal hearing children with suspected APDs. The study was approved by the Universiti Kebangsaan Malaysia (UKM) Human Ethical Committee to be conducted on human subjects starting from July 2007 to June 2009. However, the data collection for the study reported here was from September 2007 to October 2008. The study was conducted according to the principles of Helsinki Declaration. Consent forms, and information sheet for parents regarding the study was distributed through the school's principal. Further consent for testing was obtained from the school's authority.

Screening test procedure. All hearing screening tests were conducted by the third investigator in the school, in a quiet room, where noise fluctuated between 40.8-44.3 dB A, whereas the IQ tests were conducted by a clinical psychologist in Malay. The Malay DDDT²⁰ was used in this study for screening APD. This test was carried out by presenting pairs of different digits to both ears simultaneously at comfortable level. Subjects were required to repeat all numbers they heard according to 2 listening conditions, that is, directed right-ear first and directed left-ear first. The PPST was performed using the compact disc (CD) version of PPST material produced by AUDiTEC.²¹ It consists of 40 sequences of triads of pure tone with 2 different frequencies. Stimuli used were 880 Hz (low), and 1122 Hz (high) pure tones that were 200 milliseconds (ms) in duration each.²¹

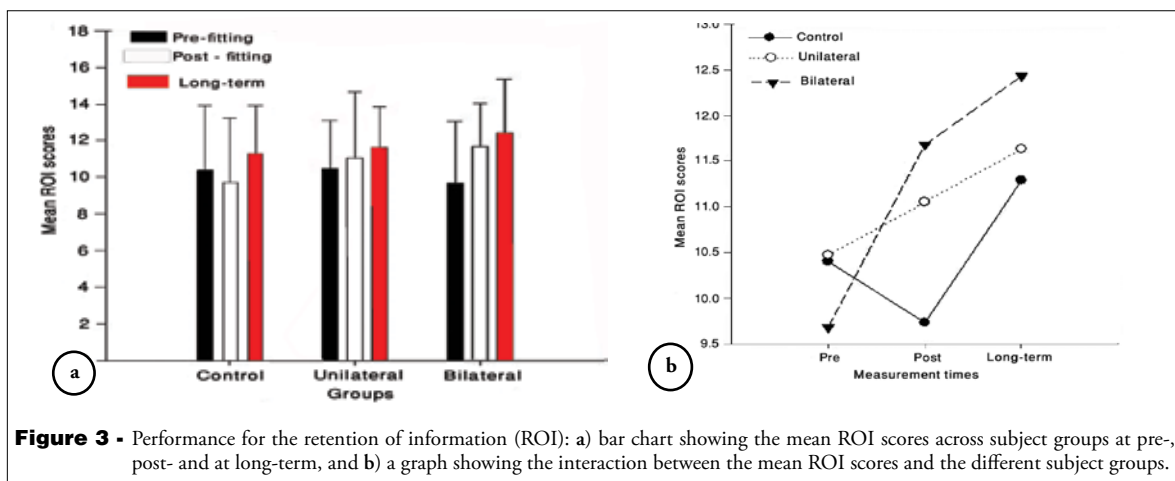
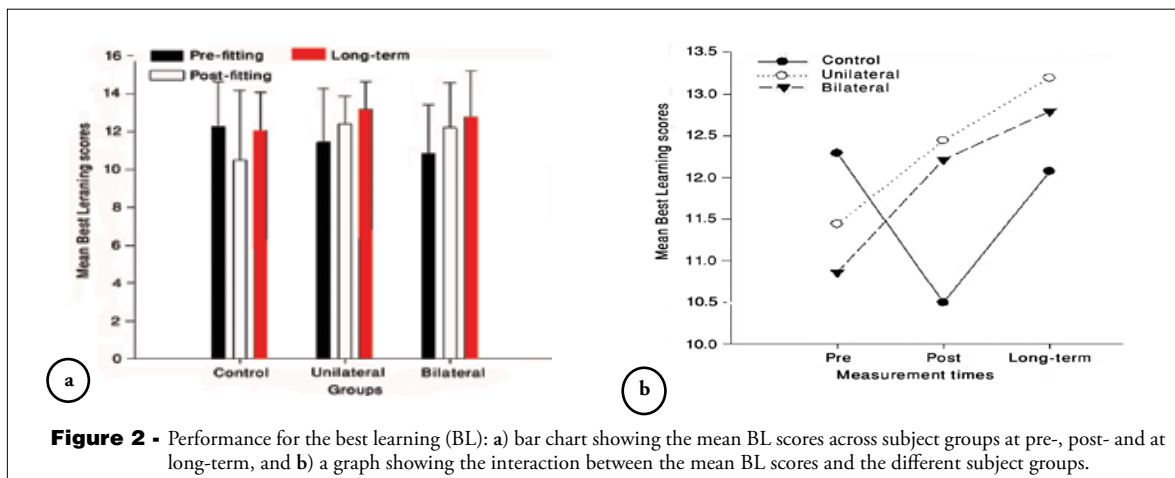
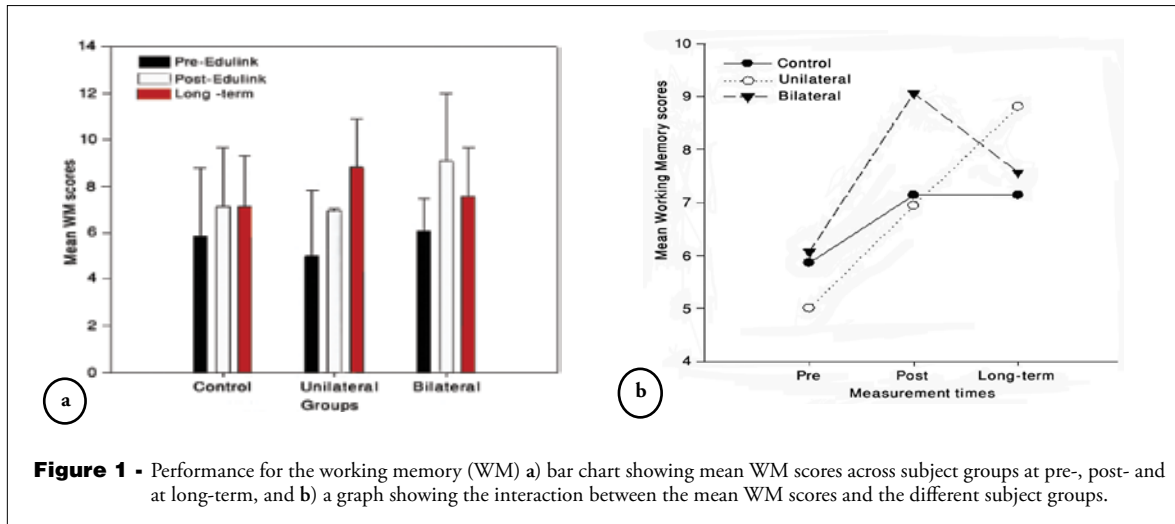
Sequences of pure tones were given with 2 tones from the same frequency, and one from the other frequency. The tones were presented at a comfortable volume through the headphones and subjects had to recognize the different pure tones in each sequence, providing the correct linguistic labeling, such as "high-high-low" or "low-high-low". They were considered failed if their score was less than 37% for subjects aged 7 years old, or less than 74% for subjects aged 8 and 9 years old.²² According to Museik and Pinheiro,²³ low scores are associated with auditory dysfunction related to various learning disabilities, and to define lesions of the auditory areas of the cerebrum.

Test procedure. Following the screening procedures, subjects who fulfilled the selection criteria were tested on their short-term auditory memory performance using the Rey Auditory Verbal Learning Test (RAVLT).²⁴ The RAVLT is a commonly used neuropsychological measure that assesses verbal learning ability and memory.^{25,26} In general, it assesses the cognitive function of a person in terms of encoding, storing, and retrieving information. The RAVLT tests administered in this study were the working memory (WM), best learning (BL) and retention of information (ROI). Test measurements were conducted at pre-FM fitting, which served as the baseline performance for all subjects, after 12 weeks of FM fitting to obtain the post-FM fitting results, and after one year of not using the FM to examine the long-term effect of FM usage on the short-term auditory memories of the subjects. In the RAVLT, there are 2 lists of word items - List A and List B. Subjects were presented with 15 words from list A with a presentation rate of one word per second, and at a comfortable conversation level of approximately 65 dB sound pressure level (SPL). Subjects were asked to recall and repeat back all the words in List A. The score of the first trial (trial I) in List A corresponds to WM and attention. List A needs to be repeated 5 times and the fifth trial (trial V) is a measure of BL. Subjects were then presented with 15 different words from list B and were required to recall all the words in List B (trial VI). List B is to distract the subject's memory of the first list. The last trial (trial VII) is the free recall trial of List A and was administered after trial VI was completed. The total score in trial VII represents the storage or ROI. It also shows the incremental learning of words across the trials.

Data were analyzed using repeated measures analysis of variance (ANOVA) to examine the differences in the mean scores for all auditory memory measures at the different measurement times (pre, post-fitting, and at long-term), and also between the 3 subject groups. A $p < 0.05$ was considered statistically significant.

Results. Although 60 subjects fulfilled the inclusion criteria at the beginning of this study, 7 subjects dropped out due to various reasons, such as family moving to other places, and parents opted to discontinue from taking part in the study. As such, 53 subjects, 19 girls,

and 34 boys, with a mean age of 7.92 ± 0.92 years, and a mean performance IQ of 106.75 ± 13.06 participated. Fifteen subjects were in the control group, and 19 each in the unilateral and bilateral groups. At the long-term measurement period (that is, after one year of not using



the FM), 9 subjects did not return for the RAVLT due to various reasons. A one-way ANOVA showed that between-group subject scores were not significantly different from each other at pre-fitting for all the 3 types of short-term auditory memory ($p>0.05$).

Working memory. Repeated measures ANOVA revealed that the mean WM scores at the 3 measurement periods were significantly different from each other ($F [2, 82]=14.33, p=0.001$). Bonferroni post hoc analyses indicate that WM scores at post-FM usage, and at long-term were significantly higher from scores obtained at pre-fitting ($p=0.001$). There was also a significant interaction between the WM scores and subject groups, ($F [4, 82]=2.98, p=0.024$) suggesting the difference in the mean scores at different measurement points was dissimilar in the 3 subject groups. However, there was no significant difference between the unilateral and the bilateral fitting groups ($p>0.05$). Figure 1a shows the mean WM scores for the 3 groups at pre-, post- and at long-term, while Figure 1b demonstrates the interaction between the mean WM scores and subject groups.

Best learning. The repeated measures ANOVA yield that the mean BL scores were significantly different from each other at the 3 measurement times ($F [2, 82]=4.16, p=0.019$). Bonferroni post hoc analyses indicate that the mean BL score at long-term was significantly higher from the mean score obtained at pre-FM ($p=0.02$). There was also a significant interaction between the mean BL scores and subject groups ($F [4, 82]=2.73, p=0.034$). For the unilateral and bilateral groups, the mean BL scores increased with time but the difference in performance in these 2 groups was not significant ($p>0.05$). For the

control group, the mean scores showed a more random pattern across the measurement times. The results are illustrated in Figure 2a, which shows the mean BL scores for the 3 subject groups at pre-, post-fitting and at long-term, and Figure 2b, which demonstrates the interaction between the mean BL scores and subject groups.

Retention of information. The mean ROI scores at pre, post- and long-term were significantly different from each other ($F [2, 82]=5.72, p=0.005$), but there was no significant interaction between the ROI scores and subject groups ($F [4, 82]=1.47, p>0.05$). These results were shown in Figures 3a and 3b. Post hoc Bonferroni yields the significant difference was between the mean scores at long-term, which was significantly higher than at pre-FM usage with a mean difference of 1.76. However, the between-group mean scores were not significant ($p>0.05$).

Discussion. This study aimed to measure changes in the short-term auditory memory performance in children with suspected APDs following 12 weeks of using a personal, ear-level FM system, and after a year of not using the FM. The first main finding of this study indicated that for all 3 auditory memories measured, the mean scores were significantly different across measurement times: $p=0.001$ for the WM, $p=0.019$ for the BL and $p=0.005$ for the ROI. We hypothesized earlier that by using the FM system, which help to improve the SNR,¹⁴ and thus, improves the listening environment, a child with suspected APDs would have a better attention in class, and therefore, faster processing of auditory information.⁵ The mean WM scores at post-fitting and

Table 1 - Age and intelligent quotient of children across the study groups.

Subject	Control group		Unilateral FM		Bilateral FM	
	Age	IQ	Age	IQ	Age	IQ
1	7	103	7	103	9	118
2	7	125	7	105	7	123
3	7	96	7	133	7	95
4	7	91	7	116	7	104
5	7	81	7	104	7	121
6	7	135	7	119	7	110
7	8	109	7	112	7	94
8	8	96	7	109	7	115
9	8	104	7	104	7	125
10	8	107	8	90	7	96
11	9	107	8	84	8	103
12	9	105	9	85	8	123
13	9	107	9	107	8	116
14	9	92	9	90	9	119
15	9	92	9	119	9	119
16	-	-	9	125	9	109
17	-	-	9	94	9	95
18	-	-	9	86	9	123
19	-	-	7	110	9	105
Mean ± SD	7.93 ± 0.88	103.30 ± 13.53	7.95 ± 0.97	105.00 ± 14.08	7.89 ± 0.94	111.21 ± 10.87

SD - standard deviation, FM - frequency modulation

at long-term were significantly different from pre-fitting indicating the use of FM system might be helpful in improving attention and consequently, faster auditory information-processing of some of the suspected APD children. A working memory is a 'place' in the cognitive system in which information can be kept for a limited time, while at the same time it continuously processes the incoming signals.²⁷ In other words, the role of the working memory capacity is to store and process information in a limited time period. Petkov et al¹⁷ for example, proposed that attention effects might index enhanced memory storage or faster information processing. The use of the FM system therefore, might have contributed to the improved WM scores. However, comparing the mean WM scores across study groups, while the unilateral fitting group showed the expected improvement at post-fitting and at long-term, similar trend was not evidenced in the bilateral-fitting group. As for the BL and ROI, only the mean scores at long-term were significantly higher than at pre-fitting, but not after 12 weeks of FM usage. However, for both the unilateral and bilateral-fitting groups, the mean scores showed consistently steady increment at post-fitting, and at long-term as compared to pre-FM fitting. The results for the control group across measurement times for these 2 auditory memory measures (BL and ROI) were fairly random. These findings suggest that in some children with suspected APDs, their ability to remember repeated information as examined in BL had been improved (Figure 2b), and so was the ability to recall information after it has been disrupted, as measured in ROI (Figure 3b). A few studies have shown the association between auditory plasticity and behavioral learning and associative memory characteristics in that learning involves different patterns of sound representation in the auditory cortex.^{28,29} As such, the increased frequency representation of behaviorally important stimuli (in this study, the words in List A of RAVLT that were presented repeatedly) induced plasticity. Consequently, it enhances memory index as evidenced from the results of this study.

Taken together, the above findings imply that the use of FM might facilitate, or improve short-term auditory memory storage and processing of some of the children with suspected APDs at first information-entry (the WM), after the information has been repeated several times (the BL), and even when there was a distraction in information (the ROI). The fact that the long-term effect was more significant than at post-fitting for BL and ROI, suggests that the use of FM for a brief 12 weeks trial period (approximately 3 months) could potentially enhance the short-term auditory memory performance of these children in the long run, even after they are not using the FM system. In other words, subjects who

had the experience of using the FM remembered things better than those who had not been given the similar experience after one year of not using the FM. As such, clinicians should encourage the use of FM as part of the management program for children with suspected APDs to improve their efficiency in information-processing, and enhanced auditory memory performance in the long run.

The study also examined whether the results for the bilateral fitting group were more superior to the unilateral fitting group. It was hypothesized that by using 2 FM receivers, the advantage in terms of SNR improvement was higher due to binaural summation, and as such, should increase the auditory memory performance more than subjects fitted with only one FM. Nevertheless, we did not see any significant difference between subjects in the unilateral and bilateral fitting groups for all the 3 auditory memory measures. This finding indicates that the improvements observed in the memory scores for the FM-fitting groups across time were not related to the number of FM receivers being fitted, at least in the present group of subjects. The implication of this finding is that clinicians may not need to prescribe 2 FM receivers for children with suspected APDs to have the advantage of using the FM system on the short-term auditory memory measures.

The study was limited by the fact that children in the control group were not fitted with a 'dummy' FM either unilaterally or bilaterally to avoid bias. This was mainly due to the non-availability of such a device for the purpose of this study. Furthermore, this study recruited only children in one school. Therefore, there could be a variation in acoustic environment at different schools, even though this factor had been minimized by choosing typical classrooms in Malaysian schools. For future research, it would be recommended to have a placebo study design, which includes the use of experimental and dummy devices for the study groups. To further consolidate the present findings, it is recommended that future studies involves the use of radiography, such as functional magnetic resonance imaging (fMRI) to index changes in the auditory memory associative areas in the auditory cortex following the use of the FM system.

In conclusion, the use of FM systems might give a long-term benefit in terms of improving the users' short-term auditory memory performance albeit a unilateral fitting. Clinicians should encourage the use of the FM system among their pediatric patients suspected with auditory processing disorders.

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