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Reliability and Accuracy of Chirp Based Multiple Auditory Steady State Response (MSSR) and Auditory Brainstem Response (ABR) in Children

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ABSTRACT

Objective: The purpose of this study was to compare the reliability and accuracy of chirp-based Multiple Auditory Steady State Response (MSSR) and Auditory Brainstem Response (ABR) in children.

Methods: The prospective clinical study was conducted at Selayang Hospital (SH) and Hospital Canselor Tuanku Muhriz (HCTM) within one year. A total of 38 children ranging from 3 to 18 years old underwent hearing evaluation using ABR tests and MSSR under sedation. The duration of both tests were then compared.

Results: The estimated hearing threshold of frequency specific chirp MSSR showed good correlation with ABR especially in higher frequencies such as 2000 Hz and 4000Hz with the value of cronbach alpha of 0.890, 0.933, 0.970 and 0.969 on 500Hz, 1000Hz, 2000Hz and 4000Hz. The sensitivity of MSSR is 0.786, 0.75, 0.957 and 0.889 and specificity is 0.85, 0.882, 0.979 and 0.966 over 500Hz, 1000Hz, 2000Hz and 4000Hz. The duration of MSSR tests were shorter than ABR tests in normal hearing children with an average of 35.3 minutes for MSSR tests and 46.4 minutes for ABR tests. This can also be seen in children with hearing loss where the average duration for MSSR tests is 40.0 minutes and 52.0 minutes for ABR tests.

Conclusion: MSSR showed good correlation and reliability in comparison with ABR especially on higher frequencies. Hence, MSSR is a good clinical test to diagnose children with hearing loss.

Keywords: Auditory brainstem response, Auditory steady state response, Chirp stimuli.

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INTRODUCTION

Auditory Brainstem Response (ABR) is an electrophysiological test in testing auditory pathway with sound stimuli. ABR recordings are being observed and review by the examiner to ascertain whether a response is present. ABR is currently the gold standard for threshold estimation for infants and young children who cannot provide accurate behavioral responses[1]. It has a high positive predictive value of 94.7% and high negative predictive value of more than 99.8%[2]. ABR have lower intensity output in certain frequencies in comparison to ASSR and hence ABR provide limited information especially in severe to profound hearing loss[3].

In severe to profound hearing loss patients, hearing threshold would be tested with auditory steady state response (ASSR). ASSR is another electrophysiological test used in determining hearing threshold in response to auditory stimuli. It's uses amplitudes and phases in the spectral domain and is a statistics-based mathematical detection of hearing threshold. However, ASSR is not widely used, as it takes longer to be completed.

The hearing threshold in severe to profound hearing loss is very important in making further decision in the management of the patient. It allows a more accurate hearing aid setting and fitting. Meanwhile, the absence of response in ASSR test at maximum intensities mean unusable hearing and this could predict poor result if the patient is to be fitted on a hearing aid. This could assist early decision for cochlear implantation[4].

In 2007, Claus Elberling had introduced chirp-based stimuli, which counteracts the temporal dispersion in the cochlea and provides a shorter detection time and a higher signal-to-noise ratio than other previous stimuli[5]. Chirp-based stimuli help in generating optimum neural synchrony by compensating for frequency specific travel time in the cochlea (target hair cells will fire simultaneously and this will generate maximal response allow response to be detected even near threshold). With the new stimuli, the amplitude of response produced is stronger, and hence detection of the hearing threshold is easier and more accurate.

Guidelines from the British Cochlear Implant Group suggest that hearing loss of an average of 90 dBHL over frequencies of 2 and 4 kHz without hearings aids should be considered for cochlear implantation if they do not benefit from acoustic hearing aids[6]. In April 2019, National Institute for Health and Care Excellence (NICE) updated the guideline by defining severe to profound hearing loss above 80 decibels at 2 or more frequencies (500 Hz, 1000 Hz, 2 000 Hz, 3 000 Hz and 4 000 Hz). In addition to the hearing test, adults must score less than 50% on a word test and children must not be developing age appropriate speech, language and listening skill[7]. This study was conducted to compare the reliability, duration taken to complete chirp stimuli multiple MSSR and ABR in children. This study was approved by research and ethical committee (FF-386)[8].

MATERIALS AND METHODS

The prospective study was conducted within one year at Selayang Hospital (SH) and Hospital Canselor Tuanku Muhriz (HCTM) Hospital. The population of the study was the children who were referred to the Otorhinolaryngology Department of A and B Hospital for hearing assessment or hearing test (involved normal hearing and also hearing loss patients). Children between 3 and 18 years old who can cooperate in play audiometry or Pure Tone Audiometry (PTA) were included in the study. Meanwhile patients with external ear canal or middle ear problems, conductive or mixed hearing loss were excluded. All patients are consented by their parents.

A total of 38 children was included in this study. The medical officer in charge conducted history taking, clinical examination and otoscopic examination while experience audiologist performed 226-Hz tympanometry and pure tone audiometry or play audiometry test. Pure tone or play audiometry by air conduction were established for frequencies of 500, 1000, 2000 and 4000Hz in a sound proof room with calibrated (meet the applicable specifications of ANSI S3.6-2004) audiometer (AD629, Interacoustics) first for all the patients. Children aged 3 to 4 years old, play audiometry were done with circumaural earphones. Meanwhile, in children aged 4 and above, pure tone audiometry was conducted for hearing assessment. Then on the same day (immediately after the play audiometry or pure tone audiometry tests) we will proceed with the ABR and MSSR (Interacoustic, Eclipse). Sound stimuli for ABR and MSSR were presented via insert ear phones and both tests were done using the same surface electrodes which are being placed over both mastoid regions. For ABR and ASSR, another two electrodes were applied over the forehead (positive) and also cheek (ground). Sanibel snap electrodes was used for both tests. Impedance is set below 3K Ohm.

For children who are less cooperative chloral hydrate 50 mg/kg was given to induce participants to be fully asleep, an insert probe is used for ABR and MSSR tests. However, for elder children who is able to cooperate and sleep during the test, no medication will be given.

Normal hearing is described as 20dB and below, mild hearing loss is between 25-40dB, 41-60dB is moderate hearing loss and 61-90dB is severe hearing loss while higher than 90dB is profound hearing loss. Chloral hydrate (50mg/kg) was given to the patient for sedation. ABR and MSSR tests were conducted when the child is fully asleep. Normal hearing is described as 20 dB HL and below, mild hearing loss is between 25-40 dB HL, 41-60 dB HL is moderate hearing loss and 61-90 dB HL is severe hearing loss while more than 90 dB HL is profound hearing loss. We did ABR and MSSR for all the patients and supplemented with play audiometry or pure tone audiometry for all of them to verified the accuracy of the ABR and MSSR results.

RESULTS

This study showed that the MSSR test had good sensitivity especially at 2000 Hz and 4000 Hz. It showed good specificity especially at 1000, 2000 and 4000 Hz. It has a good negative predictive value but moderate positive predictive value. Agreement between MSSR in comparison with ABR test showed moderate agreement at 500 Hz and substantial agreement at 1000 and 2000 Hz and good agreement at 4000 Hz. The Kappa agreement, sensitivity, specificity, positive predictive value and negative predictive value are better at higher frequencies (Table 1).

The efficiency showed that MSSR is capable to correctly identify hearing loss and normal hearing children. It showed high efficiency especially at higher frequencies such as 1000 Hz, 2000 Hz and 4000 Hz (Table 2). The difference score of ABR versus MSSR is very small, ranging from -5 to 5. Hence, the threshold determined using ABR and MSSR is very close and similar to each other in average. It showed a strong agreement between the two tests with the value ranged from 0.808 to 0.954 (Table 3). The correlation improved when the frequency increased. However, the Pearson's is not the best test for agreement. Cronbach Alpha and Intraclass Correlation are better instruments to test for the agreement.

It showed a strong correlation between ABR and MSSR and good agreement at lower frequencies and very good agreement at 2000Hz and 4000Hz (Table 4). The agreement improved with higher frequencies. The four scatter plots graphs showed the reading of MSSR in comparison with ABR in all four frequencies (Figure 1-4). The MSSR reading showed positive correlation with ABR with most of the reading located around MSSR=ABR line. The correlation was better on higher frequencies as can

Table 1: Sensitivity, specificity, positive predictive value, negative predictive value and Kappa agreement of tests of MSSR in comparison with ABR.

	ABR					
Fc (Hz)	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Efficiency (%)	Kappa agreement
500	78.6	70.8	61.1	85.0	73.7	0.466
1000	75.0	86.5	72.0	88.2	82.9	0.609
2000	95.7	86.8	75.9	97.9	89.5	0.768
4000	88.9	98.3	94.1	96.6	96.0	0.889

Table 2: Means, standard deviation and difference scores of ABR threshold versus MSSR.

	Hearing Threshold (dBHL)		Difference Scores (dB)
	ABR	MSSR	ABR- MSSR
500Hz	29.28 (27.224)	28.09 (30.822)	1.1842 (18.32791)
1000Hz	28.22 (27.126)	24.8 (28.384)	3.4211 (13.74071)
2000Hz	25.07 (27.135)	29.87 (29.314)	-4.8026 (9.60697)
4000Hz	22.96 (27.217)	18.88 (32.193)	4.0789 (10.28625)

Table 3: Pearson's agreement value of MSSR in comparison with ABR.

		ABR			
Fc (Hz)		500	1000	2000	4000
MSSR	Pearson's correlation	0.808	0.878	0.945	0.954
	P value	<0.0005 [0.652]	<0.0005 [0.771]	<0.0005 [0.893]	<0.0005 [0.910]

Table 4: Intraclass correlation agreement value of MSSR in comparison with ABR.

		ABR			
Fc (Hz)		500	1000	2000	4000
MSSR	Intraclass correlation	0.801	0.878	0.942	0.969
	P value	<0.0005 [0.641]	<0.0005 [0.771]	<0.0005 [0.887]	<0.0005 [0.939]

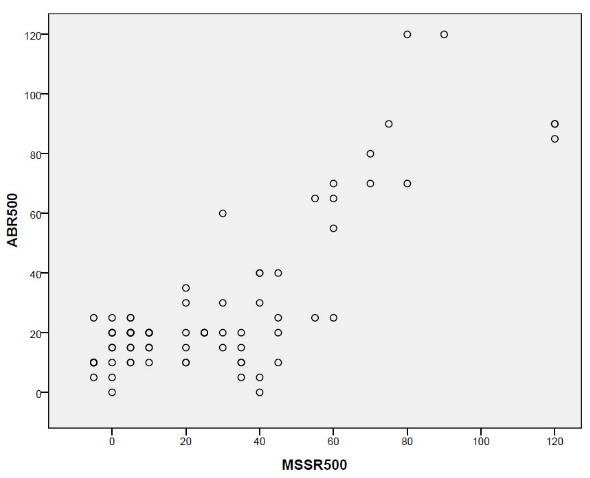

Figure 1: Scatter plot graph for the distribution of the result of patients on ABR and MSSR test at 500Hz.

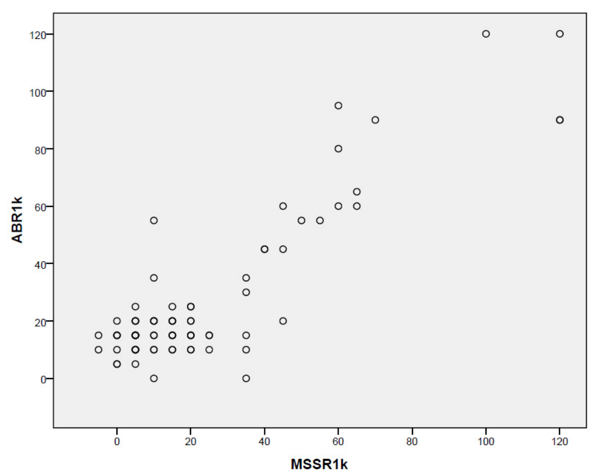

Figure 2: Scatter plot graph for the distribution of the result of patients on ABR and MSSR test at 1000Hz.

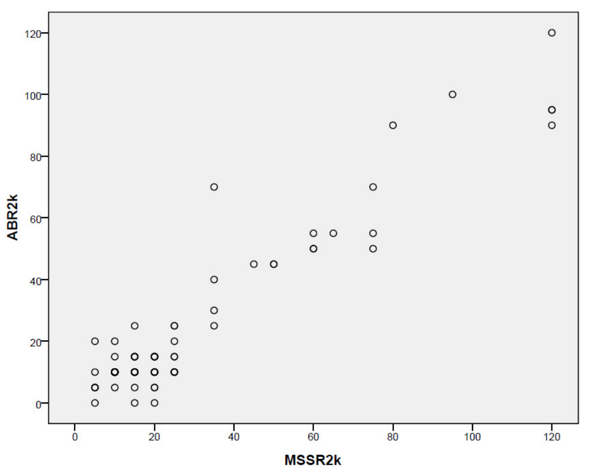

Figure 3: Scatter plot graph for the distribution of the result of patients on ABR and MSSR test at 2000Hz.

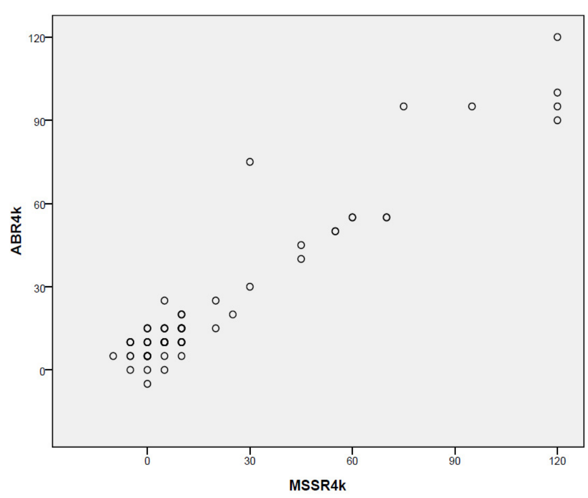

Figure 4: Scatter plot graph for the distribution of the result of patients on ABR and MSSR test at 4000Hz.

be seen in the graph that more readings fallen over the line on higher frequencies

The duration of the ABR test ranged from 20 to 79 minutes. Mean duration for ABR test on hearing loss ears is 52.04 minutes (range of 34 to 72 minutes). Meanwhile, the duration for ABR test in normal hearing ranged from 28 to 79 minutes with the mean of 46.43 minutes. The MSSR tests ranged from 15 to 73 minutes. In hearing loss ears, the range was 30 to 70 minutes while in normal hearing was 17 to 73 minutes. The mean of MSSR test in hearing loss was 40.04 minutes and normal hearing was 35.33 minutes. The difference between duration of both tests was not significant as P value was 0.059. ABR and MSSR tests generally take a shorter time to be completed on normal hearing ears but a longer time when patients had hearing loss especially severe to profound hearing loss. MSSR was done as single stimulus test on each ear when hearing loss more than 80dB to prevent interaction

DISCUSSION

Conventional ASSR uses Single Amplitude-Modulated (AM) and/or Frequency-Modulated (FM) stimuli. It tests each frequency over each ear at a particular time. The usage of the conventional ASSR is limited due time limiting factor and hence ASSR is not a first line assessment. It is a time-consuming test (1 to 2 hours per patient) with an average of 88 minutes[9]. The average test duration was 45 min for ABR on one threshold in both ears[10].

Multiple ASSR was discovered in 20039. In multiple ASSR, multiple AM tones in different frequencies and modulated at different rates, were presented as stimuli to one or both ears together. Hence, both ears can be tested simultaneously over multiple frequencies at the same time. In our study, it is shown that new stimuli applied in MSSR enabled the MSSR test to be conducted in a shorter period compared to ABR. Besides that, with the discovery of new chirp-based stimuli, it allows the test to be done in a shorter period of time[11]. In our study, the average duration of time taken to complete the MSSR test in normal hearing children was 35 minutes and 40 minutes in children with hearing loss. Meanwhile, ABR test took an average of 46 minutes to complete in normal children and 52 minutes in children with hearing loss. Recent study, average ABR time based on 86 measures is 32.38 min with SD of 18. 23 and average ASSR times based on 86 measures is 19.71 min with SD of 8.73. For both ABR and ASSR, the fastest test times are found when the hearing is in the normal range[12]. MSSR can also be used on profound sensorineural hearing loss (90 dB HL) patients, for whom the ABR cannot be applied[11]. Hearing threshold level differences (up to 10 dB) between the pure-tone audiometry and the ASSR estimation can be achieved and it is effective on higher degree of hearing loss, especially the severe to profound loss[13, 14].

An average hearing threshold between ABR and MSSR is small. The different scores of thresholds between ABR and MSSR ranges from -4.8dB to 4.1dB. The average hearing thresholds of ABR are 29.28dB, 28.22dB, 25.07dB and 22.96dB over 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Meanwhile in MSSR, the average hearing thresholds are 28.09dB, 24.8dB, 29.87dB and 18.88dB over 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. This showed the average threshold between the two tests are very close and is less than 5dB.

Besides that, the new stimuli, chirp-base used in MSSR is frequency specific compared to click-based ABR which is widely used but less frequency specific[11]. Hence, click-based ABR only allows an estimate over a hearing threshold over a broad range of higher frequencies. While tone-burst-elicited ABRs are more frequency-specific, it could be a challenge in recording and determining the hearing threshold especially at near-threshold levels and lower frequencies. ABR gives a good prediction and estimation of hearing threshold especially in high frequencies but the precision across frequencies especially lower frequencies remains less than ideal.

With chirp-based stimuli, larger neural responses are generated in ASSRs compared to previous stimuli[15]. Hence, with the combination of both multiple and chirp-based stimuli, a frequency specific and efficient MSSR test could be applied in more widely manner. However, the chirp-based stimuli employed in ABR and MSSR in our study showed good correlation between the two tests, and it is frequency specific.

Our study includes normal hearing children and children with hearing loss; hence sensitivity and specificity could be determined in the study. The sensitivity and specificity of MSSR was comparable with ABR. ABR used for field screening screen have field sensitivities of 90% and specificity is typically 93%[16]. MSSR have been tested and having high sensitivity of 100% and specificity of 95%[17]. However, the mean threshold at 500 Hz was significantly poorer compared to the higher frequencies[18]. In our study, there were more normal ears being tested as having hearing loss at 500 Hz, which accounted for a false positive rate of 29.2%. When compared to ABR, the sensitivity and specificity of MSSR were 78.6% and 70.8% at 500Hz.

Meanwhile, in 1000Hz, we recorded a better sensitivity and specificity, a value of 75.0% and 86.5% respectively. However, the sensitivity and specificity improved at higher frequencies. This corresponded to a study[19], which found that mean thresholds improved significantly with increasing frequency.

In 2000Hz, sensitivity and specificity of MSSR were 95.7% and 97.9% and at 4000Hz, the sensitivity and specificity of MSSR were 88.9% and 98.3% in comparison with ABR. This showed that at 2000 Hz and 4000 Hz, there was equivalent high sensitivity and specificity. Hence, MSSR could be a good screening tool for children in the future. It had been noted that MSSR to be effective screening method with 92–96% sensitivity value and 100% specificity value[20].

The positive predictive values for MSSR were 61.1%, 72.0%, 75.9% and 94.1% at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Meanwhile, its negative predictive values were much better compared to its positive predictive values. The negative predictive values of MSSR in comparison with ABR at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were 85.0%, 88.2%, 97.9% and 96.6%. Our study results corresponded with the study by Wendy et al in 2009[21], with the positive predictive value of 44%, 70%, 94% and 77% over 500 Hz, 1000 Hz, 2000Hz and 4000Hz and negative predictive of 100% over all the frequencies. This showed that the MSSR test could be a good diagnostic test as most of the negative result shows the children had normal hearing in comparison with low negative predictive values where there a large number of hearing loss patient will be detected as normal hearing children.

The MSSR test and ABR test had moderate agreement at 500 Hz, substantial agreement at 1000Hz and 2000Hz and almost perfect agreement at 4000 Hz. The Kappa agreement values of MSSR in relation to ABR at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were 0.466, 0.609, 0.768 and 0.889. The agreement in our test was slightly lower compared to a study by Hyo SL[22] with the agreement between ABR and ASSR in infants at 2000Hz and 4000 Hz were 0.92 and 0.92. This showed a very good agreement between MSSR and ABR especially in higher frequencies.

Reliability test also showed the MSSR had high reliability. A study conducted in Japan showed it had high reliability and it is frequency specific[23]. The study showed correlations coefficients increased as frequency increased from 500 to 4000Hz. The correlation could be tested with Pearson's correlation test. However, Cronbach Alpha and Intraclass correlations tests are better tests in this situation. Analysis using Pearson's correlations test showed high correlations between MSSR and ABR.

Table 5: Cronbach's Alpha agreement value of MSSR in comparison with ABR. All the values showed strong agreement.

		ABR			
Fc(Hz)		500	1000	2000	4000
MSSR	Cronbach's alpha	0.890	0.933	0.970	0.969

Table 6: Duration of MSSR and ABR tests.

	Mean (minutes)	
	Normal hearing	Hearing loss
Duration of ABR	46.43	52.04
Duration of MSSR	35.33	40.04

Pearson correlations score of MSSR over 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were 0.808, 0.878, 0.945 and 0.954 (Table 3).

Intraclass correlations test, it was valued at 0.801at 500 Hz and 0.878 at 1000 Hz. As the frequencies increased, the correlations improved. At 2000 Hz and 4000 Hz, the Intraclass correlations values were 0.942 and 0.969 (Table 4). Meanwhile in Cronbach alpha, the values of correlations between MSSR and ABR at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were 0.89, 0.933, 0.970 and 0.969 (Table 5). In these showed MSSR had significantly high reliability (Table 6).

MSSR test can stimulate and elicit neural response of the auditory pathway, which can be detected at intensity levels almost similar or close to behavioral threshold. Hence, MSSR could be used to predict the frequency specific behavioral hearing level in patients regardless of the subject state 19, 23, age 17, 21 and degree of hearing loss[21, 24, 25]. It can also be used on profound sensorineural hearing loss (90 dB HL) patients, for whom the ABR cannot be applied[11]. Hearing threshold level differences (up to 10 dB) between the pure-tone audiometry and the ASSR estimation can be achieved and it is effective on higher degree of hearing loss, especially the severe to profound loss[13, 14].

Another advantage of MSSR is it allows determination of hearing threshold at higher intensities, which are greater than 100dB. Threshold is important to decide on further management of patients and to determine whether hearing aids or cochlear implants are better options. However, the multiple frequency presentations are only recommended up to 80dB HL to avoid after interaction. The limitations of this study because it has a small sample size.

CONCLUSION

MSSR showed good correlation and reliability in comparison with ABR especially on higher frequencies. MSSR could be performed in a shorter time frame due to its ability to detect responses on simultaneous multiple stimuli. Hence, MSSR is a good clinical test to screen children for hearing loss and to determine hearing threshold in children.

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