CAN ARTICULATION INDEX BETTER ESTIMATE SPEECH INTELLIGIBILITY ON ADULT COCHLEAR IMPLANT USERS COMPARED TO AIDED PURE TONE THRESHOLDS?

NUR BAIZURA SALAHUDDIN

HEARLIFE HEARING CARE CENTRE SDN. BHD. UNIT 13-2, MEDAN KLANG LAMA 28, JALAN KLANG LAMA, 58200 KUALA LUMPUR, WILAYAH PERSEKUTUAN KUALA LUMPUR.

nurbaizurasalahuddin@gmail.com

SAIFUL ADLI JAMALUDDIN (CORRESPONDING AUTHOR)

DEPARTMENT OF AUDIOLOGY AND SPEECH-LANGUAGE PATHOLOGY, KULLIYYAH OF ALLIED HEALTH SCIENCES, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA

jsaiful@iiumn.edu.my

MARINA ALISAPUTRI

DEPARTMENT OF AUDIOLOGY AND SPEECH-LANGUAGE PATHOLOGY, KULLIYYAH OF ALLIED HEALTH SCIENCES, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA

marina@iium.edu.my

NURLIN ALI HANAFIAH

DEPARTMENT OF AUDIOLOGY AND SPEECH-LANGUAGE PATHOLOGY, KULLIYYAH OF ALLIED HEALTH SCIENCES, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA

nurlin@iium.edu.my

DINSUHAIMI SIDEK

KULLIYYAH OF MEDICINE, INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA, DEPARTMENT OF EAR, NOSE AND THROAT AND HEAD AND NECK SURGERY, BANDAR INDERA MAHKOTA 25200 KUANTAN, PAHANG, MALAYSIA

dinsuhaimi@iium.edu.my

ABSTRACT

Introduction and objective: Aided pure-tone audiometry is often performed on cochlear implant (CI) users to evaluate speech sound accessibility. This study examines the relationship of speech recognition thresholds (SRT) of CI users using 1) Bisyllabic Malay Speech Audiometry (BMSA) and 2) Malay Matrix Sentence Test (MMST) with pure-tone audiometry aided thresholds (PTA_{AT}) as well as the articulation index (AI). **Methods**: In this cross-sectional study, SRT measurements for all three speech tests were collected from nineteen (average device age of 4.2 ± 3.7 years) post-lingual adult CI users. Participants had a median age of 37 years old (IQR = 17.5) and PTA_{AT} of 34 dB HL (IQR = 5.5). **Results:** Median SRT of BMSA and MMST were 45 dB SPL (IQR = 7.5 dB) and -4 dB SNR (IQR = 4.9 dB SNR), respectively. Spearmen's rank-order correlation revealed no statistically significant correlations between average PTA_{AT} and the SRT of BMSA ($r_s(19) = 0.396$, $p = 0.09$) and MMST ($r_s(19) = 0.135$, $p = 0.582$). Spearmen's rank-order correlation also revealed no statistically significant correlations between average AI and the SRT of BMSA ($r_s(19) = -0.169$, $p = 0.489$) and MMST ($r_s(19) = 0.035$, $p = 0.887$). **Conclusion:** Both PTA_{AT} and AI are poor estimators of speech perception abilities with and without competing noise. Speech tests should be routinely performed on CI users as neither aided thresholds nor AI are reliable measures of speech-sounds accessibility.

KEYWORDS: Articulation index (AI), Aided pure tone thresholds, Speech Recognition Threshold (SRT), Cochlear Implant (CI).

INTRODUCTION

Cochlear implant users are routinely evaluated with speech perception testing because one of the primary aims of cochlear implantation is to improve understanding of speech. An ideal test would be reliable and highly sensitive to different conditions, for example, tests that are typically done in quiet such as the AB words list (Boothroyd, 1968) or the Hearing in Noise Test (Nilsson et al., 1994) and the Quick SIN (Killion et al., 2004) for testing speech perception in background noise. It is understood that many CI users achieve excellent speech understanding in acoustically quiet conditions however they are likely to exhibit poor speech perception abilities in presence of background noise (Fetterman & Domico, 2002). An important contributing factor to this poor speech-in-noise performance is the limited transmission of low-frequency sound information through the implants or reduced spectral resolution from limited number of electrodes (Spriet et al., 2007). There are pre-, per- and post-operative factors that could affect speech perception performance; keen readers may refer to Lazard et al., (2012) and Blamey et al., (2012) for further reading on this topic.

A study by Ali et al., (2017) revealed that 62.24 % of audiologist in Malaysia either never or seldom perform speech audiometry in their practice. This would suggest dependency on the pure tone audiogram to interpret a patient's ability to hear speech sounds or reliance on disability type questionnaires (Goh et al., 2018; Rajan Devesahayam et al., 2018). The use of pure tone thresholds is especially problematic to make assumptions about hearing speech sounds particularly in noise as discussed in Killion & Niquette, (2000). Another method of using audiometric data to estimate accessibility to speech sounds is called the articulation index (AI). Using AI supposedly allows better representation of speech sounds between octave frequencies of 250 Hz to 6000 Hz because pure-tone thresholds are often averaged within a smaller range of octave frequencies to accommodate for easy calculations. AI can be easily measured based on complete audiograms using the count-the-dot method (Mueller & Killion, 1990) and is a known measure used for evaluating hearing aid performance (Fabry

& Van Tasell, 1990). This study aims to evaluate the applicability of using AI to estimate speech perception performance as compared to average pure tone thresholds.

METHODS AND MATERIALS

This is a quasi-experimental cross-sectional study using convenience sampling. Nineteen post lingual MED-EL™ CI users aged between 21 and 60 years old with median age of 37 years old (IQR = 17.5) were involved in this study. Three participants were bilateral CI users and two were bimodal users however, only data using unilateral CI were used for each participant. In terms of device experience, implant usage ranged between 0.6 to 15 years with median of 3 years (IQR = 3.7) of experience. Inclusion criteria for participants include native Malay speakers, normal pre-implant temporal bone anatomy on the implant side, free from surgical complications and more than 8 active electrode channels.

Participants were tested in an audiometric cabin at the Hearlife Hearing Care Centre in Kuala Lumpur. Average aided hearing thresholds of 500, 1000, & 2000 Hz (PTA_{AT}) were recorded using the MAICO MA 42 two-channel diagnostic audiometer (MAICO Diagnostics GmbH, Berlin, Germany). The AI was calculated using the count-the-dot method and was verified by 2 audiologists. The speech recognition thresholds were recorded for each participant using two speech tests; the BMSA which is a test in quiet (SRT) and the MMST which is a test with competing speech-shaped background noise (SRTn). The MMST was recorded using a closed-set test format measured using the adaptive step approach. Additionally, the maximum score was also recorded for the BMSA (MS). The BMSA was presented via the audiometer whereas the MMST was presented using a Windows™ PC using an external Creative X-Fi 2.1 SoundBlaster sound card (Sound Blaster X-Fi Surround 5.1 Pro, Creative Labs, Singapore). Free-field sound samples were delivered via the PreSonus Eris® E3.5 Powered Studio Monitors (PreSonus Audio Electronics Inc, USA). One training list was conducted for every subject for the MMST prior to data collection to reduce the procedural training effect of the test.

RESULTS

Data were analysed using the open source JASP statistical software version 0.18.1.0. (JASP, University of Amsterdam). The normality of the data was investigated using the Shapiro-Wilk Test Multivariate analysis for normality which revealed the distribution for $PTA_{AT,}$ AI, SRT and SRTn departed significantly from normality where, $W = 0.809$ p value < 0.01. Based on this outcome, the non-parametric test Spearman Rank Order Correlation was used to investigate the relationships between $PTA_{AT,}$ AI, SRT and SRTn.

The median PTA_{AT} was 34 dB HL (IQR = 5.5) with the worst average hearing thresholds recorded at 45 dB HL. The median AI was 0.43 (IQR = 0.19) with the lowest AI of 0.11 from a participant with a PTA_{AT} of 43 dB HL and highest AI of 0.8 from a participant with PTA_{AT} of 24 dB HL. In terms of speech perception scores, the median SRT of BMSA and MMST were 45 dB SPL (IQR = 7.5 dB) and -4 dB SNR (IQR = 4.9 dB SNR), respectively. Figures 1 and 2 shows the boxplots and jitter elements of the $PTA_{AT,}$ AI, SRT and SRTn.

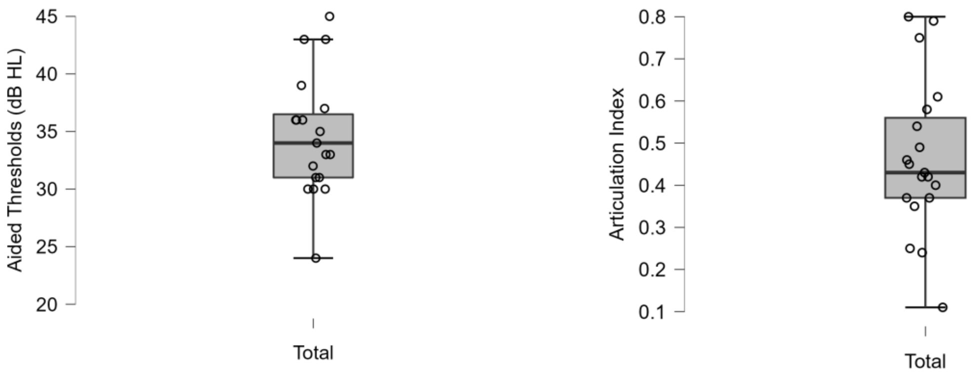

Figure 1: Distribution of average aided hearing thresholds of 500, 1000 & 2000 Hz (PTA_{AT}) and articulation index (AI) (n=19)

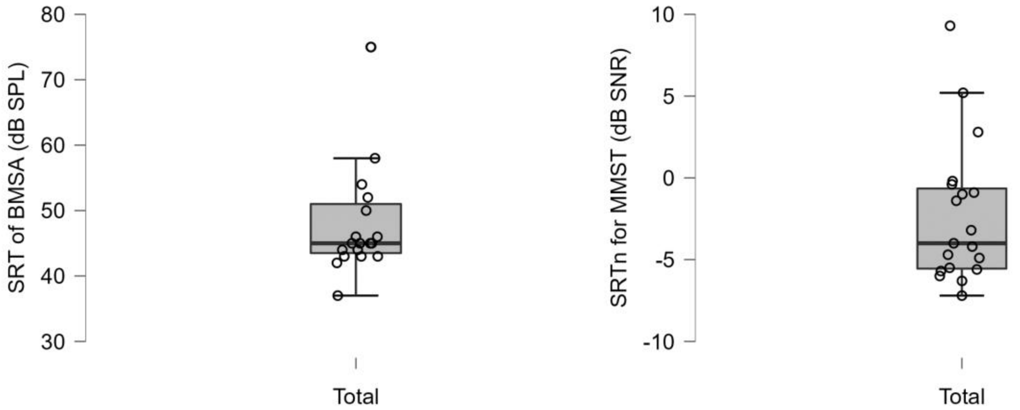

Figure 2: Distribution of speech recognition thresholds for BMSA (SRT in dB SPL) and the MMST (SRTn in dB SNR) (n=19)

We also recorded the maximum scores obtainable by the participants using the BMSA. The median maximum score using the BMSA was 87.5 dB HL (IQR=16.25) with two participants obtained the maximum score of 100% and the lowest score recorded was 45%. The distribution of the BMSA maximum score is shown in Figure 3.

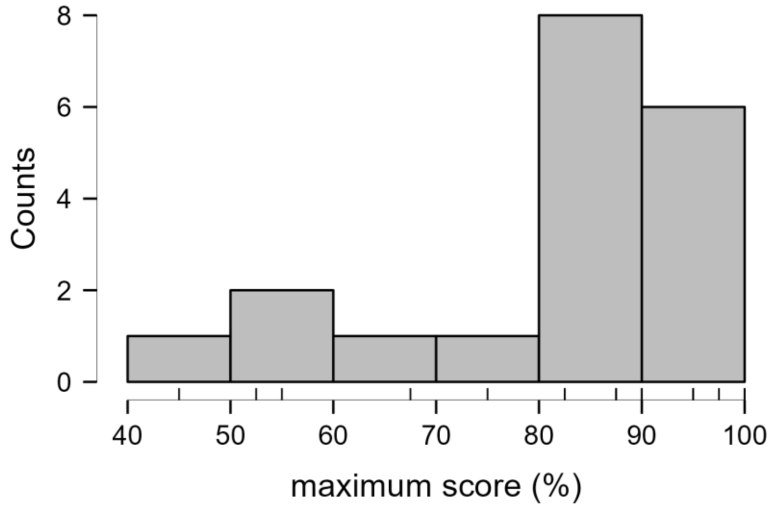

Figure 3: Histogram showing the distribution of maximum score using the BMSA.

To investigate the relationship between factors, the Spearmen's rank-order correlation was performed. Firstly, there was a statistically significant and strong negative correlation between the PTA_{AT} and AI, where $r_s(19) = -0.91$, $p_{value} < 0.01$. The test also showed that the two speech tests performed had no statistically significant correlations where, $r_s(19) = 0.262$, $p_{value} = 0.297$. Additionally, correlation analysis revealed a statistically insignificant correlation between the maximum score and SRT of BMSA where, $rs(19) = -0.24$, $p_{value} = 0.371$. The correlation plots between the AI and PTA_{AT} as well as the speech recognition thresholds of BMSA and MMST is shown in the Figure 4 below.

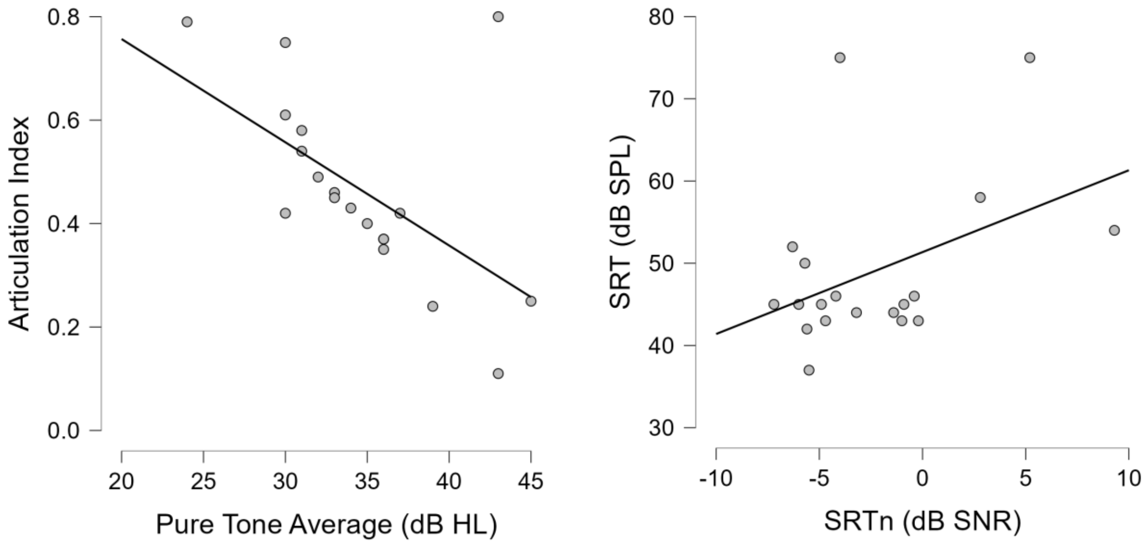

Figure 4: Correlation plots between articulation index (AI) and pure tone average (PTA_{AT}) and Speech recognition thresholds of BMSA (SRT) and MMST (SRTn)

Figure 5 shows the correlation plots between PTA_{AT} and AI and the two speech tests. The PTA_{AT} and AI did not show statistically significant correlations between the two speech tests. Spearmen's rank-order correlation revealed PTA_{AT} and the SRT of BMSA of $r_s(19) = 0.396$, $p_{value} = 0.09$ and PTA_{AT} and

MMST of $r_s(19) = 0.135$, $p_{value} = 0.582$. Spearmen's rank-order correlation revealed AI and the SRT of BMSA of $r_s(19) = -0.169$, $p_{value} = 0.489$) and AI and the MMST of $r_s(19) = 0.035$, $p_{value} = 0.887$.

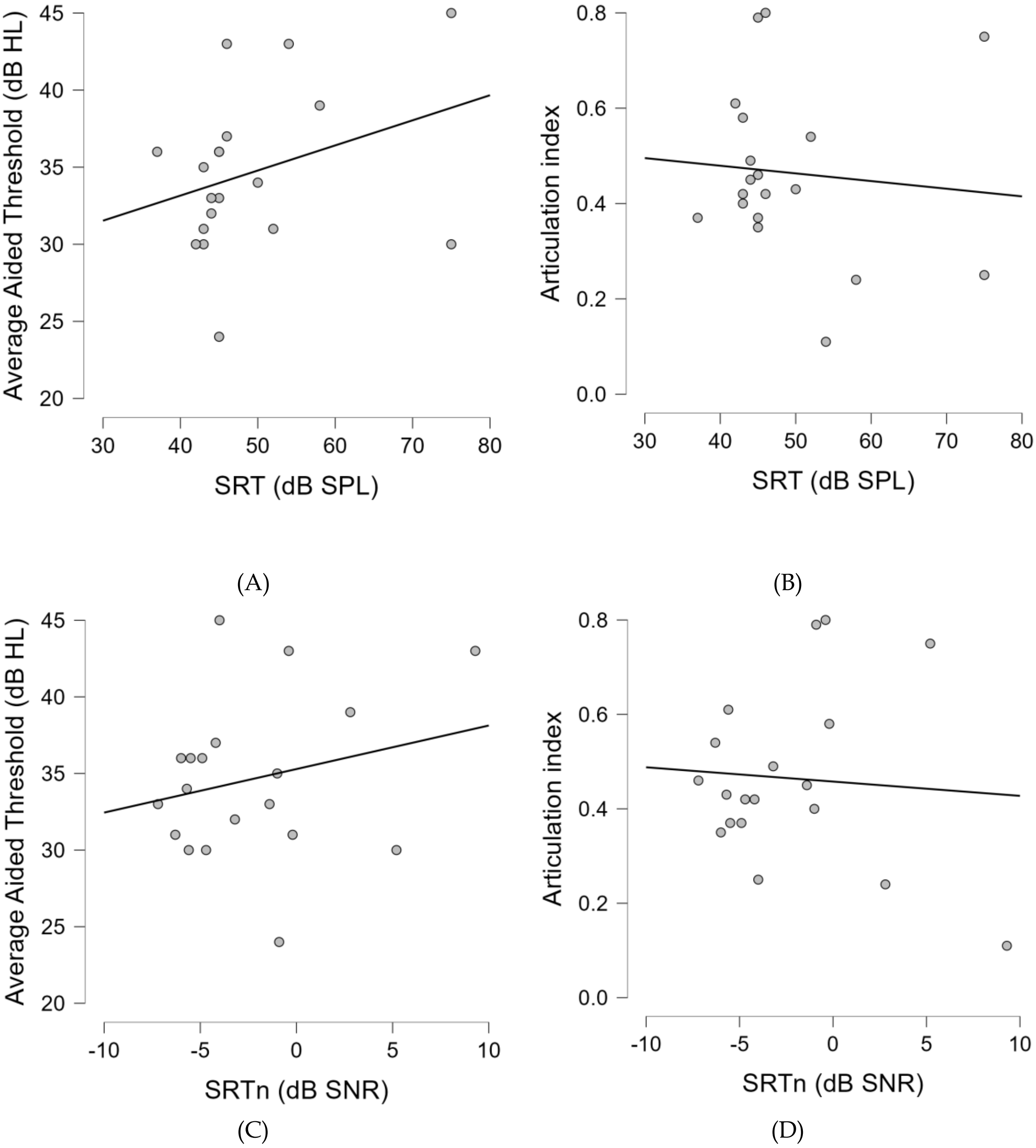

Figure 5: (A) Relationship between average aided thresholds (PTA_{AT}) and speech recognition thresholds using BMSA (SRT), (B) Relationship between articulation index (AI) and speech recognition thresholds using BMSA (SRT), (C) Relationship between average aided thresholds (PTA_{AT}) and speech recognition thresholds using MMST (SRTn), (D) Relationship between articulation index (AI) and speech recognition thresholds using MMST (SRTn)

DISCUSSION

As expected, the AI value and PTA_{AT} revealed a strong inverse correlation between the factors as the values from AI were derived from the level of aided hearing thresholds obtained from the participants. Despite this significant correlation, close inspection of the data showed that for two participants with same average aided hearing thresholds of 43 dB HL had largely different AI values (0.4 and 0.8) assigned to them. This is due to the fact that the AI is also dependent on the level and the configuration of hearing loss. Hearing loss that is predominantly high frequency would lead to lower AI scores as 74% of the assigned dots are allocated to hearing above 1000 Hz (Pavlovic, 1987).

This study confirms findings from previous studies where CI users showed predictably good speech intelligibility in quiet (Dowell et al., 1987; Fetterman & Domico, 2002). Seventy-four percent (n=14) participants scored a maximum score of 80% to 100% on the BMSA test which suggests good speech perception in acoustically favourable conditions for most users. For the BMSA, we found that the suprathreshold speech perception did not correlate with listening to speech at threshold levels. This pattern is consistent with the other correlation tests for the AI and PTA_{AT} with the SRT of BMSA. The difference in performance between threshold is most likely due to signal processing factors specifically the varying amount of effective frequency bands that could be used to code speech (Shannon et al., 1995). The findings in this study also suggests that threshold values are inadequate to assume speech intelligibility in quiet. Therefore, in order to get best results from CI users in acoustically quiet environments, speech signals need to be adequately audible. For speech perception in noise, both PTA_{AT} and AI were found to be not correlated to the SRTn in the MMST. This is also consistent with previous findings as CI users are inclined to show poorer speech perception in noise compared to in-quiet tests (Fetterman & Domico, 2002 & Dowell et al., 1987).

Speech intelligibility for both tests used in this study was independent of the average aided pure tone thresholds or its derivatives such as the AI. This is a logical outcome as pure tone hearing is primarily dependent on peripheral hearing abilities whereas speech perception is dependent on individual cognitive abilities (Moore & Shannon, 2009). Therefore, clinician must not be too dependent on aided audiograms to assume accessibility to speech sounds. Performing speech tests both in quiet and in noise would give in-depth understanding of individual CI user abilities. Clinicians can record and understand about at-threshold and -suprathreshold speech listening abilities as well as the effects of implant device configuration and sound pre-processing strategies.

LIMITATION OF STUDY

Despite the findings from this study, we would like to highlight areas that are known to have direct effect on the speech intelligibility of CI users but was not considered in the analysis. For example, the effect of pre-implant residual hearing (Cullen et al., 2004), duration without aided hearing (Blamey et al., 1992) and duration of implant use (Cesur et al., 2020)was not investigated.

CONCLUSION

Both PTA_{AT} and AI were found to be poor estimators of speech intelligibility in both in-quiet and in-noise speech tests. Speech testing should be repeatedly conducted on CI users before and after implantation to objectively observe progress with the device.

DECLARATION OF INTEREST

We would like to acknowledge the research grant sponsorship by the MED-EL Malaysia Sdn. Bhd., registered under IIUM Research Management Centre (SPP21-060-0060)

REFERENCES

Ali, A., Hickson, L., & Meyer, C. (2017). Audiological management of adults with hearing impairment in Malaysia. *International Journal of Audiology*, *56*(6), 408–416. https://doi.org/10.1080/14992027.2017.1305515

Blamey, P., Artieres, F., Başkent, D., Bergeron, F., Beynon, A., Burke, E., Dillier, N., Dowell, R., Fraysse, B., Gallégo, S., Govaerts, P. J., Green, K., Huber, A. M., Kleine-Punte, A., Maat, B., Marx, M., Mawman, D., Mosnier, I., O'Connor, A. F., … Lazard, D. S. (2012). Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants: An update with 2251 patients. *Audiology and Neurotology*, *18*(1), 36–47. https://doi.org/10.1159/000343189

Blamey, P. J., Pyman, B. C., Gordon, M., Clark, G. M., Brown, A. M., Dowell, R. C., & Hollow, R. D. (1992). Factors predicting postoperative sentence scores in postlinguistically deaf adult cochlear implant patients. *Annals of Otology, Rhinology & Laryngology*, *101*(4), 432–348.

Boothroyd, A. (1968). Developments in speech audiometry. *British Journal of Audiology*, *2*(1), 3–10. https://doi.org/10.3109/00381796809075436

Cesur, S., Yüksel, M., & Çiprut, A. (2020). Data logging variables and speech perception in prelingually deafened pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology*, *133*. https://doi.org/10.1016/j.ijporl.2020.110003

Cullen, R. D., Higgins, C., Buss, E., Clark, M., Pillsbury, H. C., & Buchman, C. A. (2004). Cochlear implantation in patients with substantial residual hearing. *Laryngoscope*, *114*(12), 2218–2223. https://doi.org/10.1097/01.mlg.0000149462.88327.7f

Dowell, R. C., Seligman, P. M., Blamey, P. J., & Clark, G. M. (1987). Speech perception using a two-formant 22-electrode cochlear prosthesis in quiet and in noise. *Acta Oto-Laryngologica*, *104*(5–6), 439–446. https://doi.org/10.3109/00016488709128272

Fabry, D. A., & Van Tasell, D. J. (1990). Evaluation of an articulation-index based model for predicting the effects of adaptive frequency response hearing aids. *J Speech Hear Res*, *33*(4), 676–689.

Fetterman, B. L., & Domico, E. H. (2002). Speech recognition in background noise of cochlear implant patients. *Otolaryngology - Head and Neck Surgery*, *126*(3), 257–263. https://doi.org/10.1067/mhn.2002.123044

Goh, B. S., Fadzilah, N., Abdullah, A., Othman, B. F., & Umat, C. (2018). Long-term outcomes of Universiti Kebangsaan Malaysia Cochlear Implant Program among pediatric implantees. *International Journal of Pediatric Otorhinolaryngology*, *105*, 27–32. https://doi.org/10.1016/j.ijporl.2017.11.024

Killion, M. C., & Niquette, P. A. (2000). What can pure-tone audiogram tell about a patient's SNR loss? *The Hearing Journal*, *53*(3), 46–53.

Lazard, D. S., Vincent, C., Venail, F., van de Heyning, P., Truy, E., Sterkers, O., Skarzynski, P. H., Skarzynski, H., Schauwers, K., O'Leary, S., Mawman, D., Maat, B., Kleine-Punte, A., Huber, A. M., Green, K., Govaerts, P. J., Fraysse, B., Dowell, R., Dillier, N., … Blamey, P. J. (2012). Pre-, Per- and Postoperative Factors Affecting Performance of Postlinguistically Deaf Adults Using

Cochlear Implants: A New Conceptual Model over Time. *PLoS ONE*, *7*(11). https://doi.org/10.1371/journal.pone.0048739

Moore, D. R., & Shannon, R. V. (2009). Beyond cochlear implants: Awakening the deafened brain. *Nature Neuroscience*, *12*(6), 686–691. https://doi.org/10.1038/nn.2326

Mueller, H. G., & Killion, M. C. (1990). An easy method for calculating the articulation index. In *Hearing Journal* (Vol. 43, Issue 9, pp. 1–4).

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise The BKB sentence materials. *The Journal of the Acoustical Society of America*, *95*(June 1993), 1085–1099. https://doi.org/10.1121/1.408469

Pavlovic, C. V. (1987). Derivation of primary parameters and procedures for use in speech intelligibility predictions. *Journal of Acoustical Society of America*, *82*(2), 413–422. http://acousticalsociety.org/content/terms.

Rajan Devesahayam, P., Sabzah Mohd Hashim, S., Salahuddin, Z., Mohamed Izam Tengku Kamalden, T., Vijay Vijayan, K., & Hailani, I. (2018). Surgical and functional outcomes of cochlear implantation in post-lingual and cross-over patients: First 5-year review of the National Ministry of Health Malaysia cochlear implant programme. *Medical Journal of Malaysia*, *73*(6), 393–396.

Shannon, R. V, Zeng, F.-G., Kamath, V., Wygonski, J., & Ekelid, M. (1995). Speech Recognition with Primarily Temporal Cues. In *New Series* (Vol. 270, Issue 5234).

Spriet, A., Deun, V., Eftaxiadis, K., Laneau, J., Moonen, M., Van Dijk, B., Van Wieringen, A., & Wouters, J. (2007). Speech Understanding in Background Noise with the Two-Microphone Adaptive Beamformer BEAM™ in the Nucleus Freedom™ Cochlear Implant System. In *Ear & Hearing* (Vol. 28).