CHAPTER 6

RESULTS AND DISCUSSION

Chapter aim: To present and discuss the results according to the formulated sub-aims and to contextualise the findings against the literature.

"Advice is judged by results, not by intentions."

~ Cicero (Atkinson, 2004:184)

6.1 DISCUSSION OF RESULTS

The aims for this study are represented in Figure 1 and the results will be discussed as it was obtained under each sub aim.

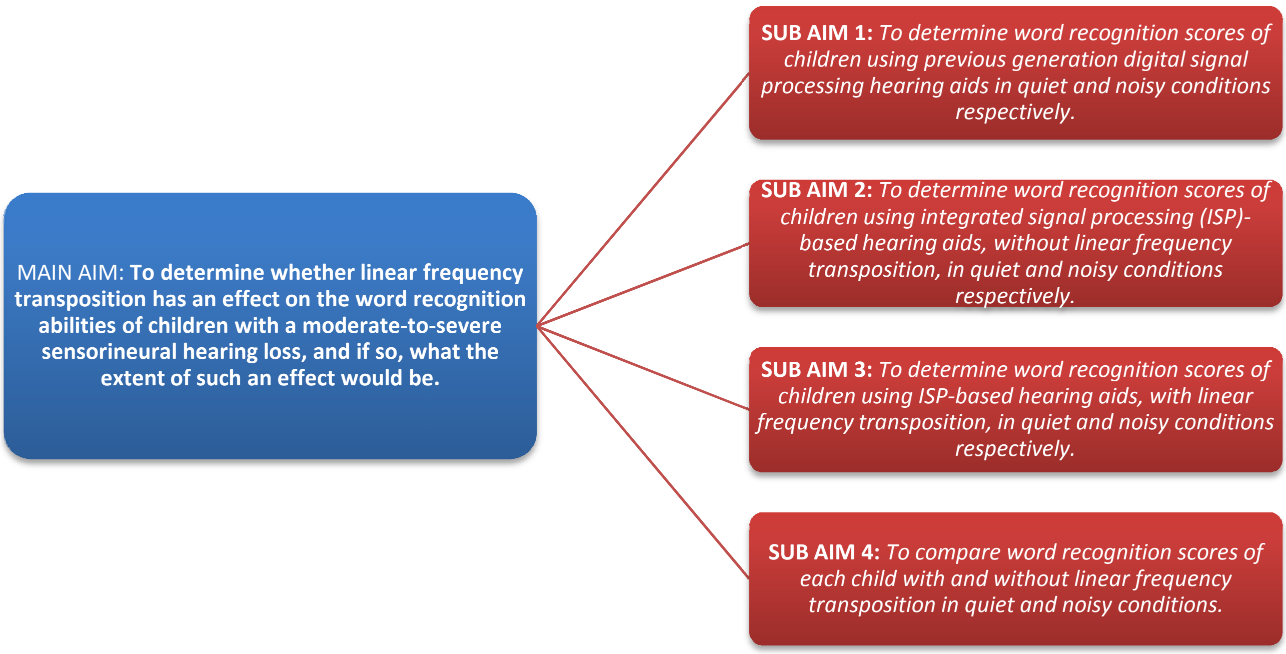
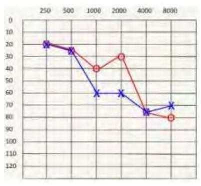
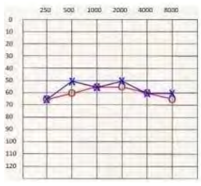
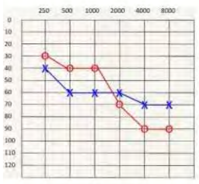
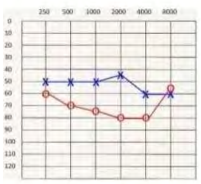
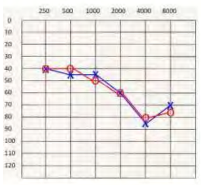
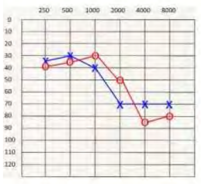


Figure 1: Discussion of results according to sub aims

6.1.1 Description of the subjects

Seven subjects were selected for this study. The characteristics of these subjects are presented in Table 1:

Table 1: Characteristics of subjects (n=7)

Subject & audiogram	*Age*	*Gender*	*High frequency pure tone average*	*Age at diagnosis*	*Duration of hearing aid use*	*Duration of time spent in educational programme*	*Duration of time that child has received speech-language therapy*
Child A 	7 years 7 months	Female	R: 62dB L: 68dB	4 years 9 months	2 years 10 months	1 year 6 months	2 years 8 months
Child B 	5 years 11 months	Female	R: 60dB L: 57dB	2 years 10 months	3 years 1 month	3 years	1 year 8 months
Child C 	6 years 11 months	Male	R: 72dB L: 67dB	2 years 4 months	4 years 7 months	3 years 8 months	3 years 7 months
Child D 	6 years 7 months	Female	R: 72dB L: 55dB	2 years 10 months	3 years 9 months	3 years 1 months	3 years 2 months
Child E 	6 years 6 months	Male	R: 72dB L: 72dB	2 years 9 months	3 years 9 months	3 years 8 months	2 years 8 months
Child F 	6 years 1 month	Female	R: 72dB L: 70dB	4 years 11 months	1 year 2 months	1 year 1 month	11 months
Child G 	6 years 8 months	Male	R: 77dB L: 75dB	5 years 0 months	1 year 8 months	1 year 5 months	1 year 9 months

The median age of the subjects (n=7) at the time of selection for this study ranged between 5 years 11 months and 7 years 7 months, with a median age of 6 years 7 months. The age of diagnosis ranged from 2 years 4 months to 5 years 0 months, with a median age of 3 years 8 months. Four of the subjects were diagnosed before 3 years of age, but none were diagnosed within the first 3 months after birth, as stated as an objective by the Joint Committee on Infant Hearing Screening (Joint Committee on Infant Hearing, 2007:8). Thus, all the subjects were diagnosed late according to international standards, as wide-spread universal newborn hearing screening have not yet been implemented in South Africa and are only available in a few select areas. The time that the subjects have been wearing amplification up until selection of the subjects ranged from 1 year 2 months to 4 years 7 months, with a median of 3 years 0 months. Four of the subjects presented with sloping hearing losses, two subjects presented with a flat hearing loss, and one subject presented with an asymmetrical hearing loss (in the right ear a sloping hearing loss and left ear a flat loss). The subjects have been receiving speech therapy ranging from 1 month before diagnosis of the hearing loss, to 1 year 5 months after diagnosis, and thus only a small number of the subjects have received prompt early intervention which is important for the development of oral speech and language skills. All subjects use English as their first language.

The subjects' own previous generation digital signal processing (DSP) hearing aids vary in the number of channels and advanced signal processing schemes utilised. These differences are summarised and presented in Table 2:

Table 2: A summary of the subjects' own previous generation DSP hearing aids

SUBJECT		CHANNELS	ADVANCED FEATURES*	EAR SIMULATOR DATA (IEC 118-0)		
				Full-on gain	Peak OSPL90	Frequency range
Child A		2	OM; SSE	65 dB SPL	132 dB SPL	230 – 5900 Hz
Child B		3	OM; SSE; DNR	62 dB SPL	136 dB SPL	200 – 7000 Hz
Child C	**Right ear**	6	OM; SSE; DNR	70 dB SPL	134 dB SPL	<100 – 4600 Hz
	Left ear	6	OM; SSE; DNR	63 dB SPL	130 dB SPL	<100 – 4700 Hz
Child D		2	OM	66 dB SPL	125 dB SPL	150 – 5500 Hz
Child E		3	OM; SSE; DNR	65 dB SPL	132 dB SPL	230 – 5900 Hz
Child F		6	Adaptive DM; SSE; DNR	61 dB SPL	137 dB SPL	<100 – 7000 Hz
Child G	**Right ear**	2	OM	66 dB SPL	125 dB SPL	150 – 5500 Hz
	Left ear	2	OM	74 dB SPL	138 dB SPL	120 – 5400 Hz

***DNR = Digital noise reduction; DM = Directional microphone; OM = Omni-directional microphone; SSE = Spectral speech enhancement**

It is clear from Table 2 that most of the subjects used hearing aids that have at least one feature of advanced digital processing schemes, and that none of the hearing aids provide amplification for frequencies higher than 7000 Hz.

6.1.2 Word recognition scores of children using previous generation DSP hearing aids

The first sub aim for this study was to determine the word recognition scores of the subjects using their previous generation DSP hearing aids in quiet and noisy conditions. These results were obtained during Weeks 1 to 2 (Phases 1 to 3) of the data collection procedure. During the first assessment, otoscopy, tympanometry and pure tone audiometry were performed in order to confirm the nature and configuration of the hearing loss. The total harmonic distortion of each hearing aid was checked before the aided assessments, in order to establish the working condition of the hearing aid. All hearing aids were found to be functioning within acceptable distortion limits. The hearing aid fitting of each subject was then verified in order to confirm that the gain targets were met for soft speech (55 dB SPL), and average speech at 70 dB SPL according to the DSL m[i/o]. The Speech Intelligibility Index (SII) (as calculated by the Audioscan Verifit) for each ear was noted for speech at soft (55 dB SPL) and average (70 dB SPL) levels. The SII is calculated using the listener's hearing threshold, the speech spectrum and the noise spectrum for a given speech-in-noise condition. The speech and noise signals are filtered into frequency bands. The frequency bands are weighted by the degree that each band contributes to intelligibility by a band-importance function. The factor audibility is calculated from the signal-to-noise ratio (SNR) in each band, which gives an indication of the audibility of speech in that band. The SII is then derived from the audibility calculated across the different frequency bands, weighted by the band-importance function, and gives an indication of the proportion of speech that is audible to the listener (Rhebergen & Versfeld, 2005:2181). A number between zero and unity, where zero indicates no audibility of speech and unity indicates that all speech information is available to the listener, represents the SII. Functional gain thresholds were established at the frequencies 500, 1000, 2000 and 4000 Hz for each ear specifically in order to validate the hearing aid fitting. All fittings were accurately verified and validated according to the guidelines set by paediatric amplification guidelines (Bentler et al., 2004). Word recognition scores were then determined for each subject by using words from the Word Intelligibility by Picture Identification test (WIPI) (Ross & Lerman, 1971). A list of 25 words was presented at 55 dB HL with no signal-to-noise ratio. Then a second list of different words was presented at 55 dB HL with a signal-to-noise ration of +5 dB, followed by the presentation of a third list of words at 35 dB HL, also with no signal-to-noise ratio. Speech noise was used to simulate a more adverse listening condition.

Otoscopy and tympanometry were repeated during the second and third assessments in order to determine any changes in middle ear status which may have an effect on the hearing thresholds. All subjects' middle ear functioning were within normal limits. The percentage of total harmonic distortion of the hearing aids was also checked before conducting the WIPI, and all the subjects' hearing aids were found to be functioning within acceptable distortion levels. The WIPI was then performed under identical conditions during the second and third assessments as described above. Three sets of word recognition scores were thus obtained for each subject in order to establish a baseline word recognition score, and the average score of the three sets was calculated.

The targets set by the DSL m[i/o] for soft and average speech sounds in the range of 250 to 4000 Hz were matched as closely as possible. Child A's hearing aids only have two channels, and thus it is not possible to adjust the gain for 2000 and

4000 Hz separately. In order to provide audibility at 4000 Hz, the gain at 2000 Hz was also increased. The target was matched at 4000 Hz, but at 2000 Hz the subject received approximately 10 dB more gain than prescribed, although the maximum power output of the hearing aid remained within the target for 2000 Hz. Similarly, Child D also received slightly more gain at 1000 to 4000 Hz and Child F at 1000 Hz due to the limitations in fine-tuning possibilities of the hearing aids. All the other subjects' hearing aid output was matched within 5 dB of the targets in both ears, except Child C. The targets set by the DSL m[i/o] were met in the left ear for this subject, but not in the right ear at 4000 Hz, due to the limitation of the maximum power output of the hearing aid. The SII of each subject calculated by the Audioscan Verifit for soft and average speech sounds is depicted in Table 3:

Table 3: The SII calculated for soft and average speech sounds

SUBJECT	Speech Intelligibility Index			
	Soft speech at 55 dB SPL		Average speech at 70 dB SPL	
	Right ear	*Left ear*	*Right ear*	*Left ear*
Child A	78	65	78	74
Child B	62	63	73	75
Child C	65	49	73	70
Child D	43	80	57	79
Child E	58	61	67	70
Child F	66	61	72	69
Child G	61	32	71	51

Although the targets are matched within 5 dB, a more severe hearing loss will yield a lower SII, as it is the case with Child C, D and G, who present with an asymmetric hearing loss, with a more severe high frequency hearing in the left ear. A SII between 45 and 90 should yield a connected speech recognition score of 90% and higher (Studebaker & Sherbecoe, 1999). Only Child D and Child G presented with a SII of less than 45 in only one ear.

The aided thresholds of the subjects using their previous digital signal processing hearing aids are depicted in Figures 2 to 8:

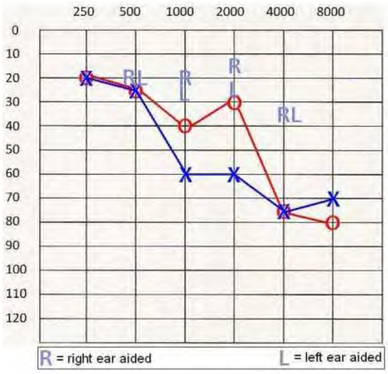


Figure 2: Child A – aided thresholds

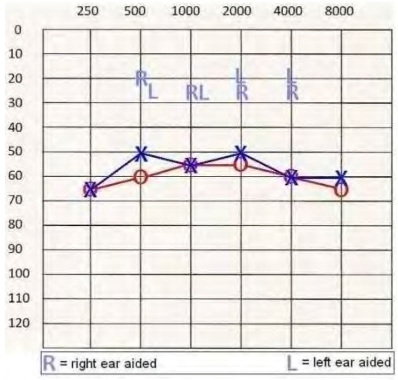


Figure 3: Child B – aided thresholds

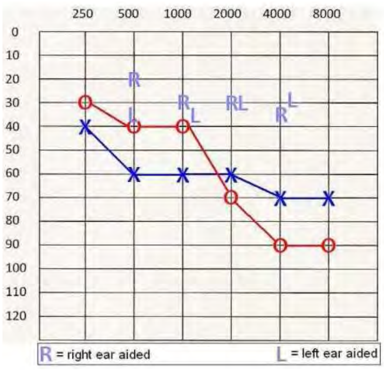


Figure 4: Child C – aided thresholds

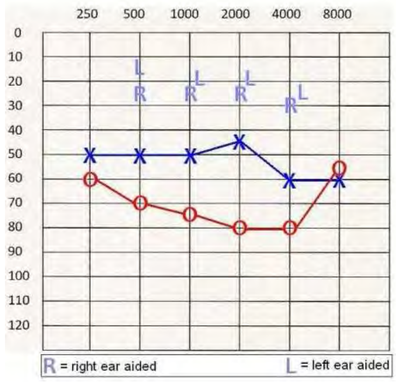


Figure 5: Child D – aided thresholds

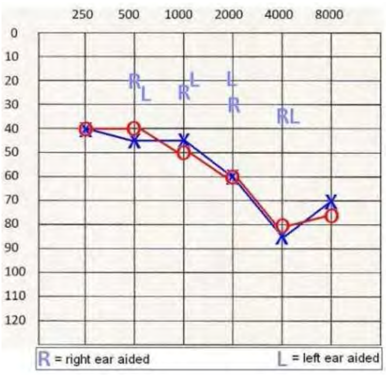


Figure 6: Child E – aided thresholds

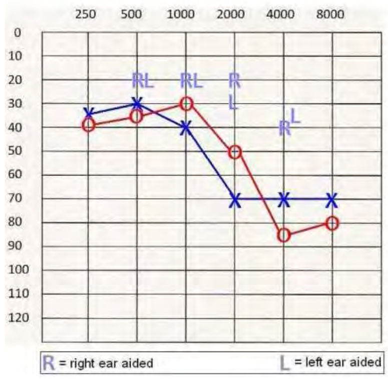


Figure 7: Child F – aided thresholds

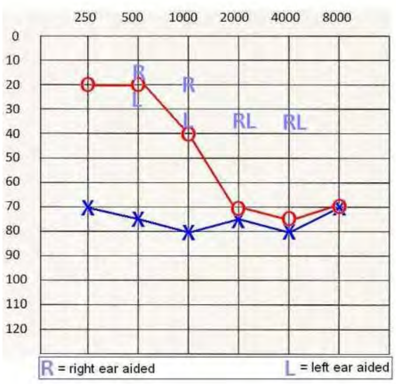


Figure 8: Child G – aided thresholds

All subjects presented with an aided threshold of 35 dB HL or less in the better ear at 4000 Hz. Child B presented with the lowest aided threshold in the better ear at 4000 Hz (20 dB HL) and Child A, E, F and G with the highest aided threshold of 35 dB HL in the better ear at 4000 Hz. Northern and Downs (2002:323) state that an aided threshold of 35 dB HL is acceptable if the unaided threshold at that frequency is more than 100 dB HL. An aided threshold of 25 dB HL can be achieved if the unaided thresholds lie between 75 and 100 dB HL, and if the unaided threshold is 50 dB HL or better, then the aided thresholds should reflect normal or near-normal aided hearing levels of 15 to 20 dB HL. Although the targets were objectively matched for all subjects for soft input levels, all subjects except Child B and D presented with higher aided thresholds in the high frequencies than expected according to the values presented in Northern and Downs (2002:323). This is consistent with the results obtained by Nelson (2003), where an average aided threshold for 4000 Hz was obtained at 30 dB HL, which is also slightly lower than the expected value (Nelson, 2003:28). This may indicate a lower outer hair cell potential in the cochlea in some of the subjects in the high frequencies, which may be consistent with dead regions in the cochlea (Miller-Hansen et al., 2003:106).

The word recognition scores obtained is summarised and presented in Table 4:

Table 4: Word recognition scores of subjects using previous generation DSP hearing aids (n=7)

CHILD	WORD RECOGNITION SCORES			AVERAGE SCORE		
	QUIET CONDITION: 55dB	NOISY CONDITION: 55dB +5 dB SNR	QUIET CONDITION: 35 dB	QUIET CONDITION: 55dB	NOISY CONDITION: 55dB +5 dB SNR	QUIET CONDITION: 35 dB
Child A	96%	88%	56%	96%	88%	77%
	96%	87%	88%			
	96%	88%	87%			
Child B	75%	68%	24%	74%	66%	33%
	72%	62%	24%			
	76%	68%	50%			
Child C	79%	84%	28%	77%	84%	34%
	76%	83%	28%			
	76%	84%	46%			
Child D	87%	76%	28%	80%	76%	53%
	72%	71%	52%			
	80%	80%	79%			
Child E	50%	60%	28%	61%	58%	39%
	60%	62%	48%			
	72%	52%	42%			
Child F	87%	40%	32%	78%	64%	48%
	68%	75%	44%			
	80%	76%	67%			
Child G	71%	60%	40%	68%	65%	49%
	76%	67%	44%			
	56%	68%	62%			

The first test condition (words presented at 55 dB with no SNR) yielded word recognition scores ranging from 61% to 96%, with Child A that scored the highest percentage of words correctly identified, and Child E with the lowest score obtained. The scores of the three assessments did not differ by more than 5% for three of the subjects, namely Child A, B and C. Child D and Child G's word recognition scores for the three assessments differed by 15%, the scores for Child F differed by 19% and the scores for Child E differed by 22%. The three scores for this test condition was then added and divided by three to obtain an average score. This was done in order to account for a lapse in concentration, disinterest in the listening task and poor motivation to complete the listening task. Child A presents with the highest average score of 96% and Child E with the lowest average score of 61%, similar to the findings described above. Papso and Blood (1989) provided norms for the WIPI in quiet and noisy conditions: normal-hearing children presented with word recognition scores of 88 to 100%, with a median of 94%. In noisy conditions with a SNR of +6 dB HL, these children presented with word recognition scores of 56 to 92%, with a median of 78% (Papso & Blood, 1989:236). Of all the subjects, only Child A presented with word recognition scores in quiet conditions of 88 to 100%, which is critical for the development of oral speech and language skills.

The scores obtained from the second test condition (words presented at a level of 55 dB HL with a SNR of +5dB) were analysed similarly. Child A obtained the highest score of 88%, and Child F the lowest score of 40%. The difference in scores of the three assessments for Child A, B and C did not differ by more than 5% again for this test condition. The scores obtained from Child D, E and G did not differ by more than 10%. The scores from Child F differed by 36%. When the average scores of the three assessments were calculated, Child A presented again with the highest score of 88%, and Child E with the lowest score of 58%. Although all the subjects presented with word recognition scores of 56 to 92%, only Child A and Child C presented with word recognition scores above the median of 78% for normal hearing children in a challenging listening situation (Papso & Blood, 1989:236), whereas Child E presented with poor word recognition abilities in the presence of background noise. This indicates that it may be very difficult for Child E to cope in a classroom, where noise levels can be very high in comparison with the teacher's voice (Mills, 1975: 771).

The third test condition yielded varied word recognition scores across all the subjects. The highest score of 77% was obtained by Child A, and the lowest score was obtained by Child B of 33%.

The results obtained during the second test condition are similar to the findings obtained with the first test condition, where Child A, B and C performed consistently across the assessments, and Child A obtained the highest score and Child E the lowest score. All the subjects except Child C presented with better word recognition scores in the first test condition than in the second test condition. This is most probably due to the introduction of noise in the second test condition, which creates a more challenging listening condition for children (Mills, 1975: 770). All subjects presented with lower word recognition scores in the third test condition than in the second. Once again, this may be due to the decreased audibility leading to an extremely challenging listening condition. The comparison between test scores for the first, second and third test conditions are presented in Figure 9:

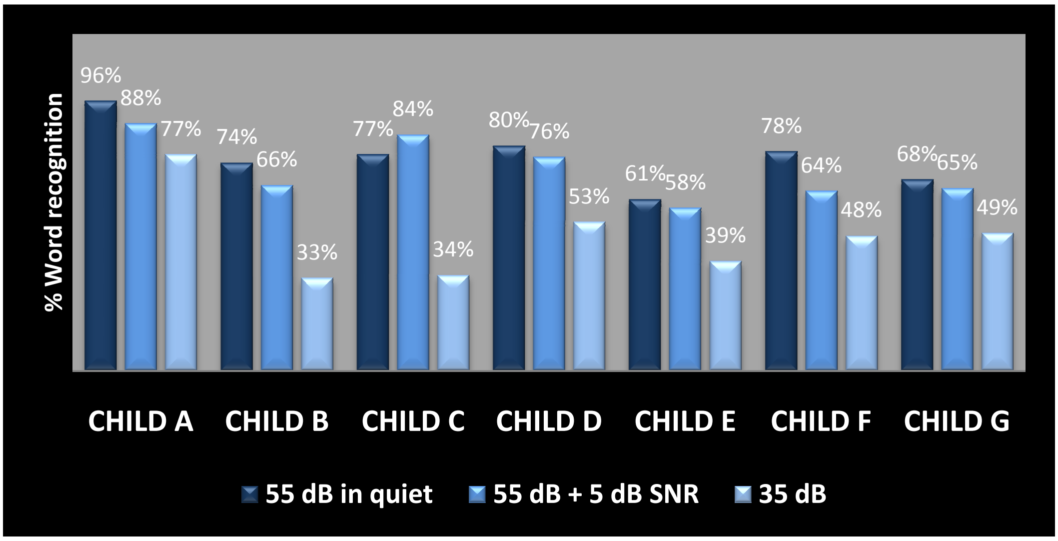


Figure 9: The difference between the test scores obtained for the first, second and third test conditions (n=7)

It is evident from these results that all the subjects (except Child C) tended to obtain the best word recognition scores in a quiet condition when the words were presented at a level of 55 dB HL. Slightly lower word recognition scores were obtained when the words were presented in a noisy condition with a SNR of +5 dB. The last condition where the words were presented at a very soft level of 35 dB HL proved to be a very challenging task for all the subjects, and word recognition scores that were obtained in this condition were considerably lower than when it was presented at 55 dB HL.

It was also found that five out of the seven subjects obtained the highest word recognition scores in the quiet condition with words presented at 35 dB HL during the third assessment. This may be due to familiarisation of the listening task, rather than familiarisation of the words presented, as these words differed from previous lists and the same effect was not seen in the word recognition scores obtained during the other test conditions.

Decreased audibility and a poor SNR pose a very challenging listening environment for hearing aid users, and thus it is expected for the word recognition scores to deteriorate as the listening condition gets more challenging (Dillon, 2000:6; Davis et al., 1986) especially for children (Shield & Dockrell, 2008:133), who need a higher SNR than adults in order to perform the same on word recognition tasks (Mills, 1975:770). Also, speech stimuli presented at 35 dB HL give an indication of a child's ability to hear over a distance (Roeser & Downs, 2004:291). Distance hearing is very important for passive learning and over-hearing, as children with poor distance hearing may need to be taught some skills directly whereas other children with good distance hearing may learn those skills themselves (Flexer, 2004:134).

Pearson product-moment correlation coefficients were also used to determine if there is any correlation between the SII calculated by the Audioscan Verifit and the word recognition scores. The best SII score of either the left or right ear of each subject was taken and compared to the word recognition score. The highest correlation was found for the SII calculated for soft speech input (55 dB SPL), and the word recognition scores obtained in the third test condition. Figure 10 presents a comparison between the word recognition scores obtained at 35 dB (with no SNR) and the SII calculated by the Audioscan Verifit:

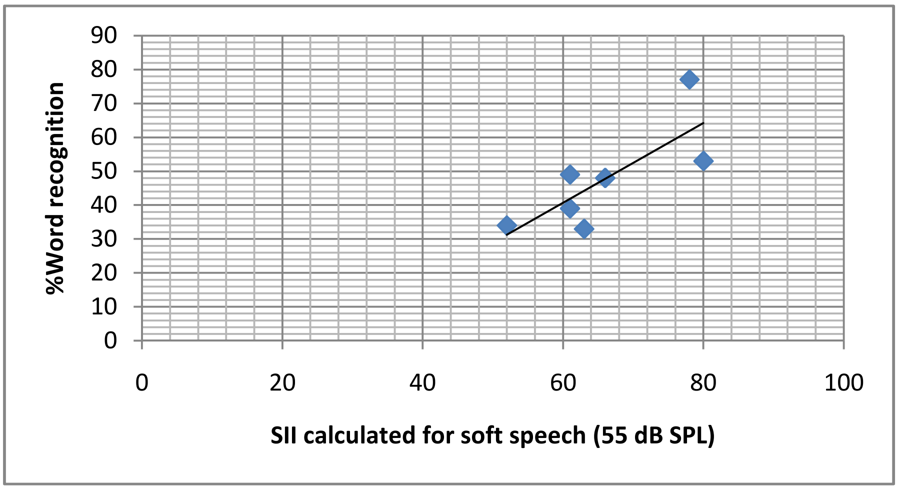


Figure 10: A comparison of the SII for soft speech levels and the word recognition scores obtained

It can be seen that the subjects who presented with the highest word recognition scores, also presented with the highest SII calculated by the Audioscan Verifit, and that the other subjects presented with lower word recognition scores as well as a lower SII score. The trend line on the graph represents the positive correlation of 0.8 between the word recognition score of all the subjects and the SII calculated. The general trend seems to be that where the word recognition score is higher, the calculated SII is also higher.

Although there seemed to be a considerable amount of variation in the three assessment scores for some of the subjects, the positive correlation between the SII and the word recognition scores for at least one test condition seemed consistent, adding towards the validity of the results obtained.

These results seem to highlight the importance of assessing children’s speech recognition in quiet as well as in noisy situations, as the word recognition scores deteriorated with the introduction of background noise. The scores obtained in noisy situations might give a better indication of the child’s real-life performance with the hearing aids, because most of the typical listening environments that children is exposed to, presents with background noise. It is thus important for the paediatric audiologist to choose amplification with features aimed at enhancing speech in noisy situations for the child with hearing impairment.

6.1.3 Word recognition scores of children using ISP-based hearing aid without linear frequency transposition.

The second sub aim for this study was to determine the word recognition scores of the subjects using ISP-based hearing aids without linear frequency transposition in quiet and noisy situations. These results were obtained during Weeks 3 to 4 (Phase 5) of the data collection procedure. After the fitting of the ISP-based hearing aid, each subject was allowed 12 days of acclimatisation. During the following assessment, otoscopy and tympanometry were performed in order to establish whether there are any changes in middle ear functioning. All subjects’ middle ear functioning was confirmed to be within normal limits. The total harmonic distortion of the hearing aids was checked before the aided assessments, and all hearing aids were found to be functioning within acceptable limits. Given that all subjects' hearing thresholds remained the same and that the hearing aid fittings were verified according to paediatric amplification guidelines at the time of the fitting, verification of the fitting was not repeated on the day of the assessment. The SII was again noted for soft speech (55 dB SPL) during the verification of the hearing aids. Functional gain thresholds were then established at the frequencies 500, 1000, 2000 and 4000 Hz for each individual ear in order to validate the fitting. Similarly to the assessments conducted with the subjects' previous digital signal processing hearing aids, word recognition scores were then determined using the WIPI. A list of 25 words was presented at 55 dB HL with no SNR. Then a second list of different words was presented at 55 dB HL with +5 dB SNR, followed by the presentation of a third list of words at 35 dB HL, also with no SNR. Speech noise was again used to simulate a more adverse listening condition.

The features of the ISP-based hearing aids are listed in Table 5:

Table 5: Features of the ISP-based hearing aids

CHANNELS	ADVANCED FEATURES	EAR SIMULATOR DATA (IEC 118)		
		Full-on gain	Peak OSPL90	Frequency range
15	Adaptive directional microphone; spectral speech enhancement; digital noise reduction	67 dB SPL	131 dB SPL	100 – 10000 Hz

The ISP-based hearing aids are thus much more advanced than the previous generation DSP hearing aids, with an increased flexibility for matching the targets set by the DSL more closely. Thus, the targets of all the subjects were closely matched across all the frequencies. The SII for soft and average input levels are noted in Table 6:

Table 6: The SII for soft and average input levels for the ISP-based hearing aids

SUBJECT	Speech Intelligibility Index			
	Soft speech at 55 dB SPL		Average speech at 70 dB SPL	
	Right ear	***Left ear***	***Right ear***	***Left ear***
Child A	77 *(78)**	56 *(65)*	78 *(78)*	72 *(74)*
Child B	59 *(62)*	67 *(63)*	75 *(73)*	79 *(75)*
Child C	60 *(65)*	53 *(49)*	64 *(73)*	71 *(70)*
Child D	31 *(43)*	67 *(80)*	53 *(57)*	78 *(79)*
Child E	62 *(58)*	59 *(61)*	68 *(67)*	71 *(70)*
Child F	67 *(66)*	53 *(61)*	73 *(72)*	69 *(69)*
Child G	58 *(61)*	28 *(32)*	70 *(71)*	52 *(51)*

*The values in brackets are the SII obtained with the previous generation DSP hearing aids.

The SII for some of the subjects were less with the ISP-based hearing aids than with the previous generation DSP hearing aids. Large differences of more than five were noted for Child A, C, D and F, as these were the subjects whose previous digital signal processing hearing aids posed limitations to fine-tuning, and they received slightly more amplification at certain frequencies than prescribed. In order to avoid the down- and upwards spreading of masking due to over-amplification at some of the frequencies, the targets should be matched closely, even if it results in a lower SII. Only Child D and G presented with a SII of less than 45 in one ear. The aided thresholds of all the subjects are depicted in Figures 11 to 17:

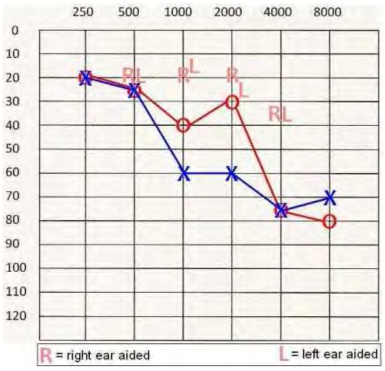


Figure 11: Child A – aided thresholds

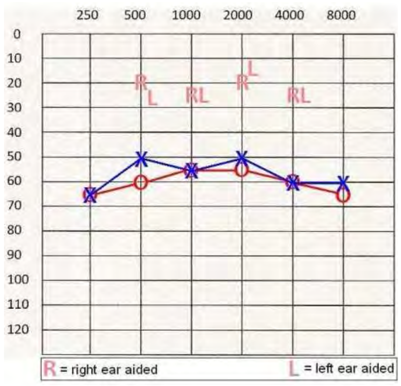


Figure 12: Child B – aided thresholds

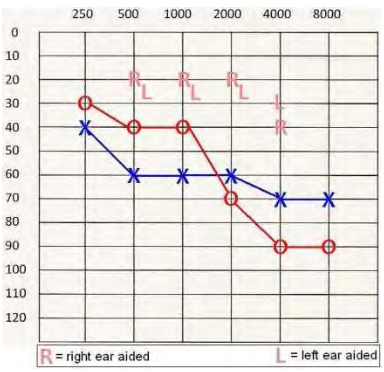


Figure 13: Child C – aided thresholds

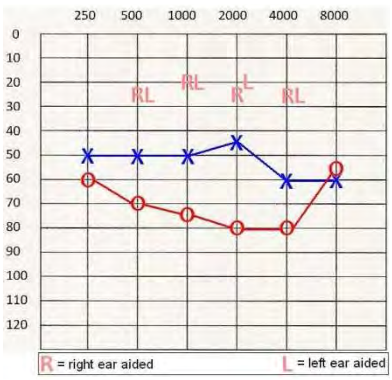


Figure 14: Child D – aided thresholds

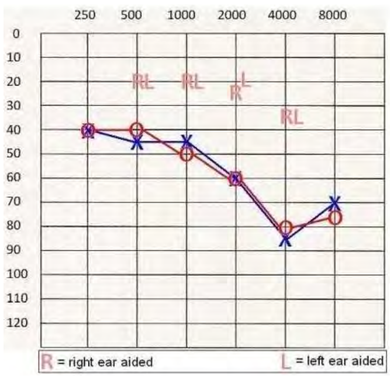


Figure 15: Child E – aided thresholds

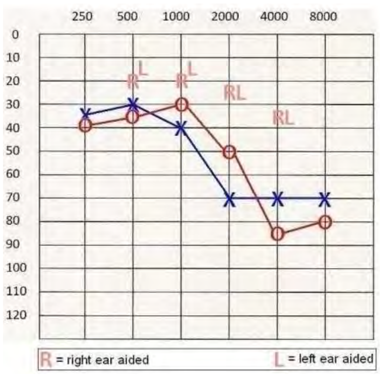


Figure 16: Child F – aided thresholds

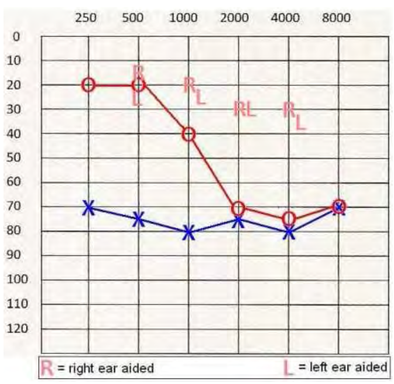


Figure 17: Child G – aided thresholds

All subjects presented with the same aided thresholds within 5 dB compared to the aided thresholds obtained with the previous generation DSP hearing aids, except for the following subjects: Child A presented with a 10 dB increase at 1000 Hz in the left ear, Child C presented with a 15 dB increase at 500 Hz in the left ear, and a 10 dB increase at 1000 Hz in both ears, and at 2000 Hz in the right ear. Child G presented with a 10 dB increase in the left ear at 1000 Hz.

The results obtained during the word recognition assessments are depicted in Table 7:

Table 7: Word recognition scores of subjects using ISP-based hearing aids without linear frequency transposition (n=7).

CHILD	WORD RECOGNITION SCORES		
	QUIET CONDITION: 55dB	NOISY CONDITION: 55dB +5 dB SNR	QUIET CONDITION: 35 dB
Child A	100%	96%	92%
Child B	84%	88%	48%
Child C	96%	84%	60%
Child D	88%	80%	72%
Child E	80%	84%	52%
Child F	88%	84%	76%
Child G	72%	60%	52%

Results obtained during the first test condition, where the words were presented at 55 dB HL with no SNR, yielded scores of 72% to 100%, with Child A presenting with the highest score of 100%, and Child G with the lowest score of 72%. Four of the seven subjects (Child A, C, D and F) presented with acceptable word recognition scores of 88 to 100% for children who are developing speech and language skills (Papso & Blood, 1989:236), and Child A and C presented with word recognition scores above the median of 94% of normal hearing children in quiet conditions. Although all subjects showed an increase in word recognition scores, Child C and E showed a significant increase of more than 12% (Ross, personal communication, 2008).

The second test condition (where background noise was introduced) yielded scores ranging from 60% to 96%, with Child A presenting with the highest score of 96%, and Child G presenting again with the lowest score of 60%. All the subjects except Child G presented with acceptable word recognition scores of 56 to 92%, and all the subjects except Child G presented with word recognition scores above the median of 78% of normal hearing children in noisy conditions. Child A, B, D, E, and F showed an increase in word recognition scores compared to the word recognition scores of this test condition when using previous generation DSP hearing aids, and Child B, E and F showed a significant increase of more than 12%. Child C showed no improvement in word recognition scores and Child G presented with a 5% decrease in word recognition score, which may be not significant (Ross, personal communication, 2008).

The third test condition yielded scores that were closer in range, ranging from 48% to 92%, with Child A presenting with the highest score of 92%, and Child B presenting with the lowest score of 48%. All subjects demonstrated an increase in word recognition scores. All subjects except Child G showed a significant increase of more than 12% (Ross, personal communication, 2008).

As expected, the results from Phase 5 of the data collection procedure also follow the same pattern as the results obtained during Phases 1 to 3, where there is a steady deterioration in word recognition scores as the listening condition became more challenging. Figure 18 depicts the difference in word recognition scores across the three test conditions:

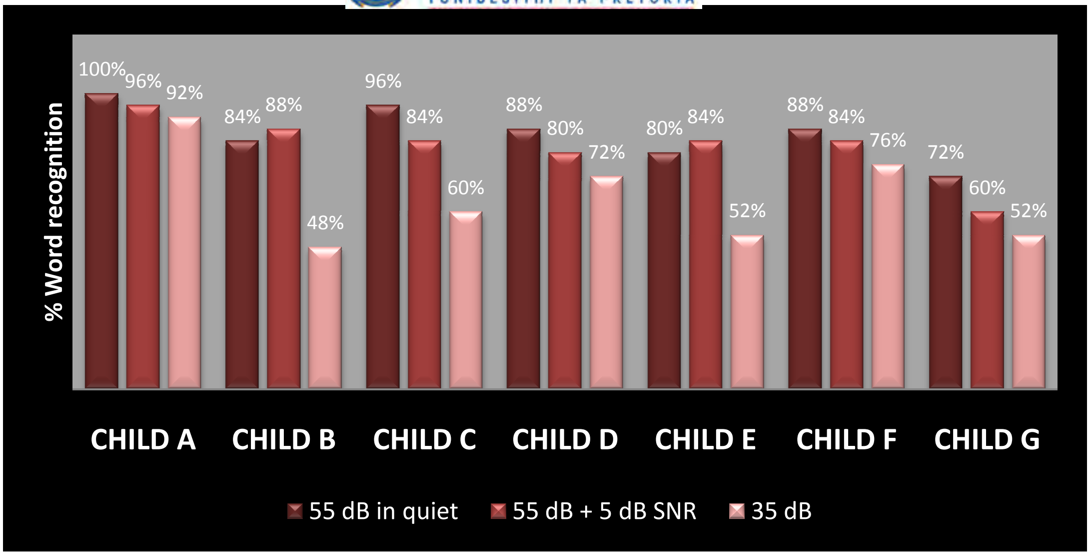


Figure 18: A comparison between word recognition scores of subjects across all the test conditions (n=7)

Child B and Child E presented with lower word recognition scores in the first test condition compared to the second test condition. This difference in word recognition score is 4% in each case, and this constitutes a one-word difference between the two scores, which is unlikely to be statistically significant (Ross & Lerman, 1970:51).

When the SII calculated for words presented at 55 dB SPL is compared to the scores obtained during the third test condition, it can be seen that there seems to be a strong positive correlation of 0.8 between the SII and the word recognition score. The trend line indicates the strong positive correlation between the SII and the word recognition score as depicted in Figure 19:

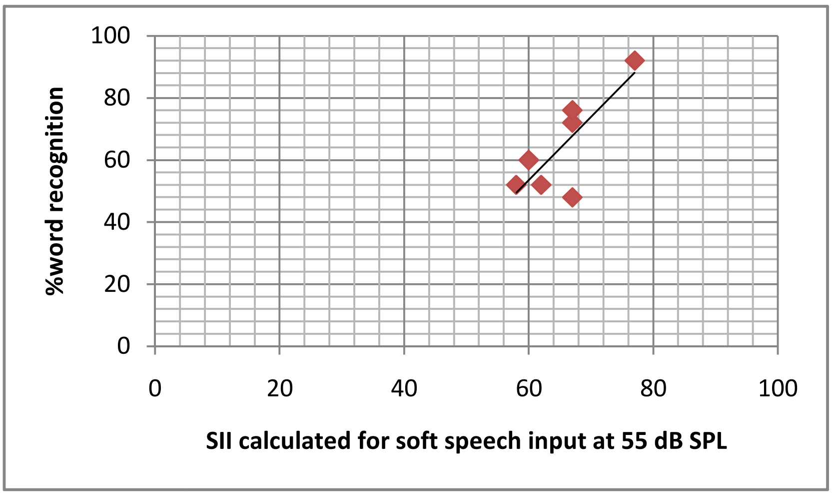


Figure 19: A comparison of the SII calculated for soft speech input (55 dB SPL) and word recognition scores obtained at 35 dB HL

As mentioned previously, children with mild to moderate-severe sensorineural hearing loss would benefit from amplification that uses wide dynamic range compression with a low-compression threshold, moderate compression ratio, and fast attack time and which would provide increased compression to limit the maximum output of the hearing aid (Palmer & Grimes, 2005:513). The previous digital signal processing hearing aids used by the subjects in this study met all these requirements, but still more subjects presented with acceptable word recognition scores when they used integrated signal processing. These results have shown that integrated signal processing may provide the child with hearing impairment with more consistent audibility in a variety of listening conditions. This is significant for the paediatric audiologist choosing amplification for the child with a moderate to severe sensorineural hearing loss (MSSHL), as these ISP-based hearing aids are more expensive than previous generation DSP hearing aids, and the audiologist must make cost-effective decisions regarding amplification for children.

6.1.4 Word recognition scores of children using ISP-based hearing aids with linear frequency transposition

The third sub aim of the study was to determine the word recognition scores of the subjects using ISP-based hearing aids with linear frequency transposition. These results were obtained during Weeks 5 to 6 (Phase 7) of the data collection procedure. Otoscopy and tympanometry were performed in order to monitor middle ear functioning. All subjects presented with normal middle ear functioning at the time of testing. The hearing aids were checked for harmonic distortion, and all the hearing aids were found to be working within acceptable distortion levels. Functional gain thresholds were determined for frequencies 500, 1000, 2000 and 4000 Hz, in order to validate the fitting.

Similar to the assessments conducted with the subjects' previous digital signal processing hearing aids and ISP-based hearing aids without linear frequency transposition, word recognition scores were again determined using the WIPI. A list of 25 words was presented at 55 dB HL with no SNR. Then a second list of different words was presented at 55 dB HL with +5 dB SNR, followed by the presentation of a third list of words at 35 dB HL, also with no SNR. Speech noise was used again to simulate a more adverse listening condition.

The linear frequency transposition start frequencies were calculated by the hearing aid manufacturer's software, and these frequencies for each subject are depicted in Table 8:

Table 8: The linear frequency transposition start frequencies for each subject

SUBJECT	LINEAR FREQUENCY TRANSPOSITION START FREQUENCY
Child A	4000 Hz (both ears)
Child B	6000 Hz (both ears)
Child C	Right ear: 2500 Hz; Left ear: 6000 Hz
Child D	6000 Hz (both ears)
Child E	3200 Hz (both ears)
Child F	Right ear: 3200 Hz; Left ear: 2500 Hz
Child G	6000 Hz (both ears)

Ear-specific start frequencies were recommended for all the subjects, and different start frequencies were recommended for the right and left ears of two subjects.

The output of the hearing aids below these values in Table 7 were verified with the Audioscan Verifit, and were closely matched to the targets set by the DSL m[i/o]. The SII was not noted, as this would not be accurate due to the linear frequency transposition. The output from the hearing aids were then visualised with the SoundTracker software to verify that the transposed sounds are still audible. All subjects' transposed sounds were visualised as audible. The aided thresholds obtained with linear frequency transposition are depicted in Figures 20 to 26:

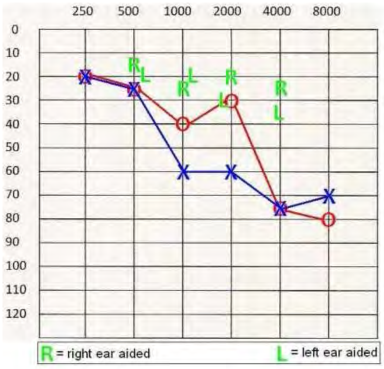


Figure 20: Child A – aided thresholds

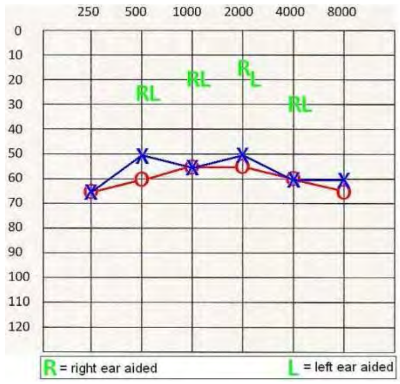


Figure 21: Child B – aided thresholds

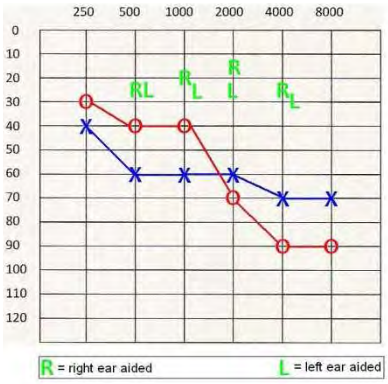


Figure 22: Child C – aided thresholds

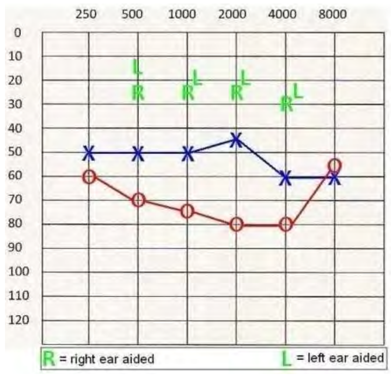


Figure 23: Child D – aided thresholds

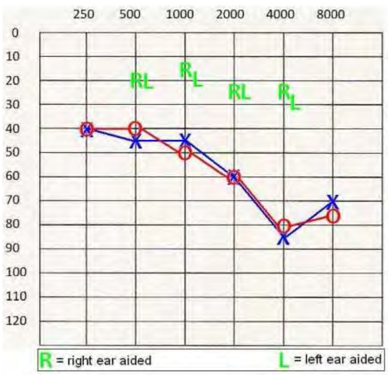


Figure 24: Child E – aided thresholds

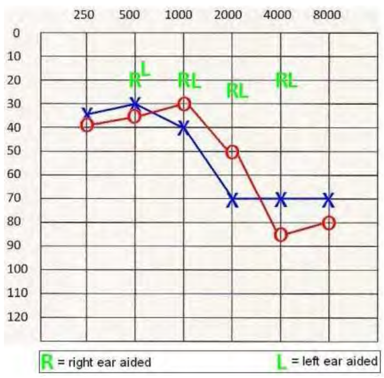


Figure 25: Child F – aided thresholds

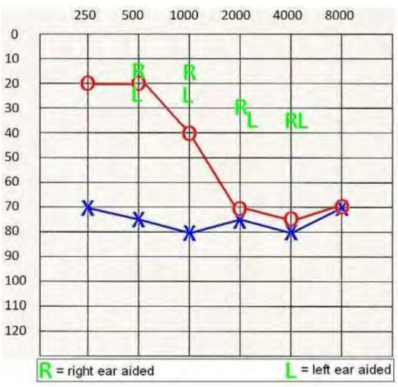


Figure 26: Child G – aided thresholds

All the subjects presented with the same aided thresholds within 5 dB of the aided thresholds obtained with ISP-based hearing aids without linear frequency transposition, except for the following subjects: Child A presented with a 10 dB increase at 4000 Hz in the right ear, Child C presented with a 15 dB increase at 4000 Hz in the right ear, Child E presented with a 10 dB increase at 4000 Hz in the right ear, and Child F presented with a 15 dB increase at 4000 Hz in both ears.

Word recognition scores obtained for the first, second and third test conditions are depicted in Table 9:

Table 9: Word recognition of subjects using ISP-based hearing aids with linear frequency transposition

CHILD	WORD RECOGNITION SCORES		
	QUIET CONDITION: 55dB	NOISY CONDITION: 55dB +5 dB SNR	QUIET CONDITION: 35 dB
Child A	92%	92%	80%
Child B	96%	68%	52%
Child C	100%	100%	92%
Child D	92%	84%	48%
Child E	67%	60%	60%
Child F	88%	92%	80%
Child G	92%	76%	60%

The results obtained from the first test condition yielded scores ranging from 67% to 100%, with Child C presenting with the highest score of 100%, and Child E with the lowest score of 67%. All subjects except Child E presented with acceptable word recognition scores of 88 to 100%, and Child A and B presented with word recognition scores higher than the median of 94% for children with normal hearing.

The second test condition yielded results ranging from 60% to 100%, with Child E presenting with the lowest score of 60% and Child C with the highest score of 100%. All subjects presented with word recognition scores of 56 to 92%, and four subjects presented with word recognition scores above the median of 78% for normal-hearing children.

Word recognition scores obtained from the third test condition ranged from 48% to 92%, with Child D presenting with the lowest score of 48%, and Child C presenting with the highest score of 92%.

The scores obtained from these test conditions also showed a steady decrease as the listening condition became more challenging for all subjects except Child F. These differences in word recognition scores across all three conditions are depicted in Figure 27:

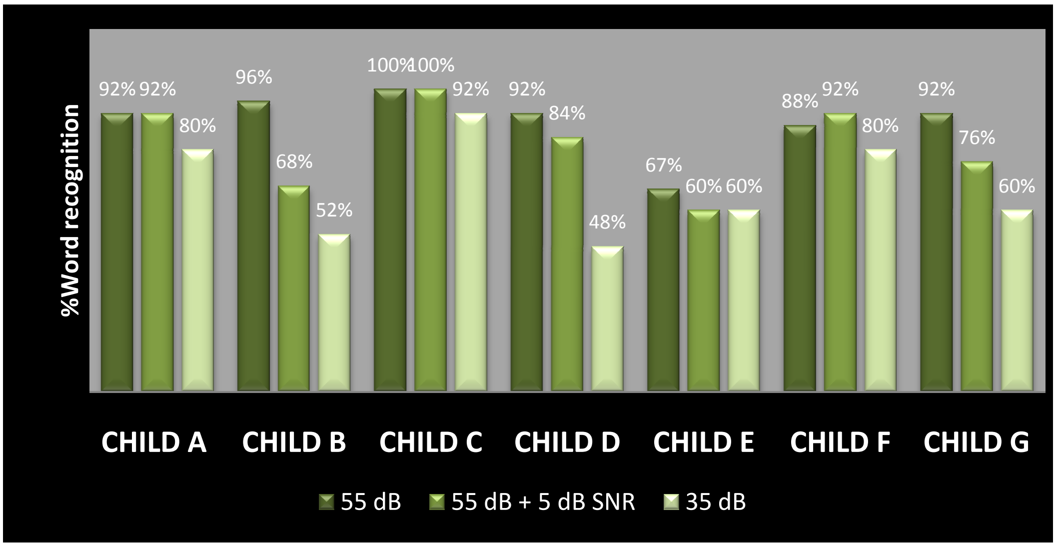


Figure 27: A comparison of word recognition scores when using an ISP-based hearing aid with linear frequency transposition (n=7)

Child F presented with a higher word recognition score in the second test condition. This is a difference of 4%, which indicates a one-word difference, and may also be clinically insignificant (Ross & Lerman, 1971:51).

It is evident from these results that linear frequency transposition may provide children with hearing loss with more audibility of the high frequency sounds, and their word recognition skills may improve as a result of this. This is consistent with recent studies by Auriemmo et al. (2008:54), where an improvement in word recognition scores were also seen in the case studies described.

6.1.5 A comparison of the word recognition scores obtained by subjects using ISP-based hearing aids with and without linear frequency transposition

A comparison was made between the word recognition scores obtained from Phases 5 and 7 for the three test conditions using the previous DSP hearing aids and the ISP-based hearing aid with and without linear frequency transposition. This was done in order to attempt to isolate linear frequency transposition as a possible variable when measuring word recognition scores.

Figure 28 depicts a comparison between the word recognition scores obtained during the first test condition with all three types of signal processing:

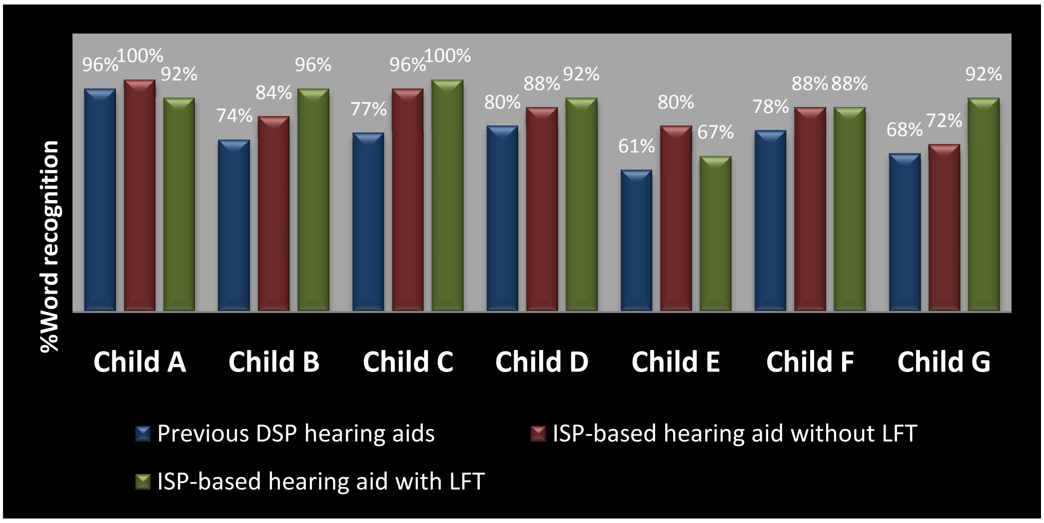


Figure 28: A comparison of word recognition scores obtained during the first test condition (55 dB in quiet) (n=7)

It can be seen that all subjects presented with better word recognition scores when they used the ISP-based hearing aid without linear frequency transposition as when they used the previous DSP hearing aids. Child B, C, D, and G showed an increase in word recognition scores when they used the ISP-based hearing aid with linear frequency transposition, and Child B and G presented with a significant increase of 12% or more (Ross, personal communication, 2008). Two subjects presented with a decrease in word recognition scores, although the difference in Child A is only 4%, constituting a one-word difference, and may be clinically insignificant (Ross & Lerman, 1970:51). Child E presented with a significant decrease of 13% in word recognition score compared to the ISP-based hearing aid without linear frequency transposition (Ross, personal communication, 2008), and no difference in word recognition scores were seen in Child F.

The average scores of all the subjects' word recognition scores for each hearing aid type or setting was calculated and compared. This comparison is depicted in Figure 29:

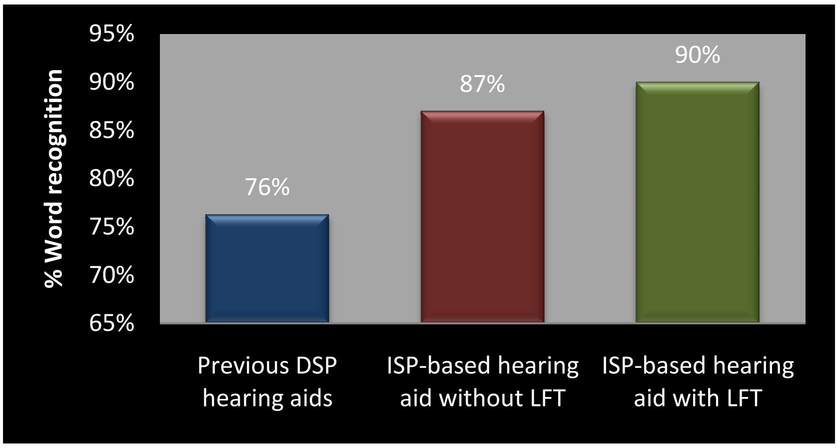


Figure 29: A comparison of the average word recognition scores of the subjects for the first test condition (55 dB in quiet) (n=7)

A paired t-test revealed a statistical significant difference between the average scores obtained for the first test condition when the subjects used the ISP-based hearing aids without linear frequency transposition (p=0.024), compared to their word recognition scores when they used their own previous generation DSP hearing aids.

When the word recognition scores obtained during the second test condition are compared across the three types of signal processing, the following results can be seen in Figure 30:

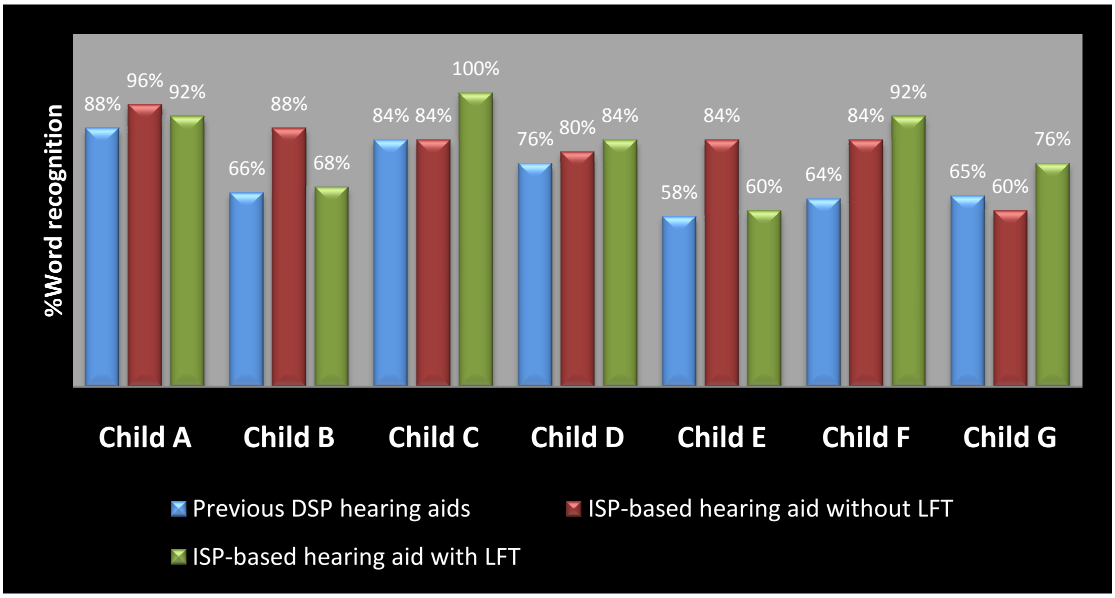


Figure 30: A comparison of word recognition scores obtained during the second test condition (55 dB +5 dB SNR) (n=7)

Five subjects presented with better word recognition scores when they used the ISP-based hearing aids without linear frequency transposition compared to the previous DSP hearing aids. One subject showed no improvement in word recognition scores, and one subject presented with a 5% decrease in word recognition score.

Child C, D, F and G presented with an increase in word recognition score when they used the ISP-based hearing aids with linear frequency transposition. Child C and Child G presented with a significant increase in word recognition score of more than 12% (Ross, personal communication, 2008). Child A, B and E presented with a decrease in word recognition scores, and the decrease was significant for Child B and E (Ross, personal communication, 2008).

The average scores of the second test condition were also calculated and compared. A statistical significant difference was found for the comparison between the previous DSP hearing aids and the ISP-based hearing aids with linear frequency transposition (p=0.048). This comparison is depicted in Figure 31:

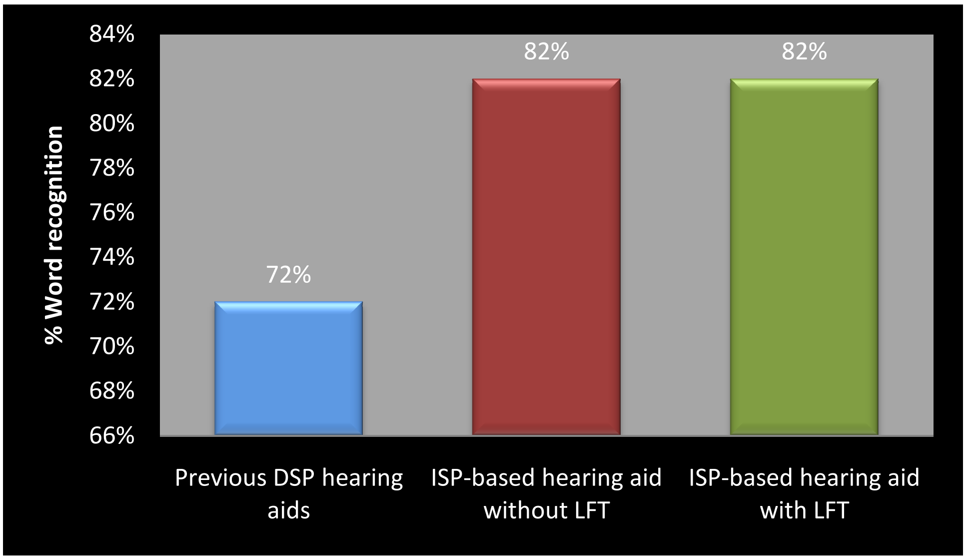


Figure 31: A comparison of the average word recognition scores obtained during the second test condition (55 dB + 5 dB SNR) (n=7)

It is clear from Figure 31 that the ISP-based hearing aids may increase the average word recognition scores of the subjects, and that no difference is seen in average word recognition scores between ISP-based hearing aids with or without linear frequency transposition.

The comparison of the word recognition scores obtained during the third test condition is depicted in Figure 32:

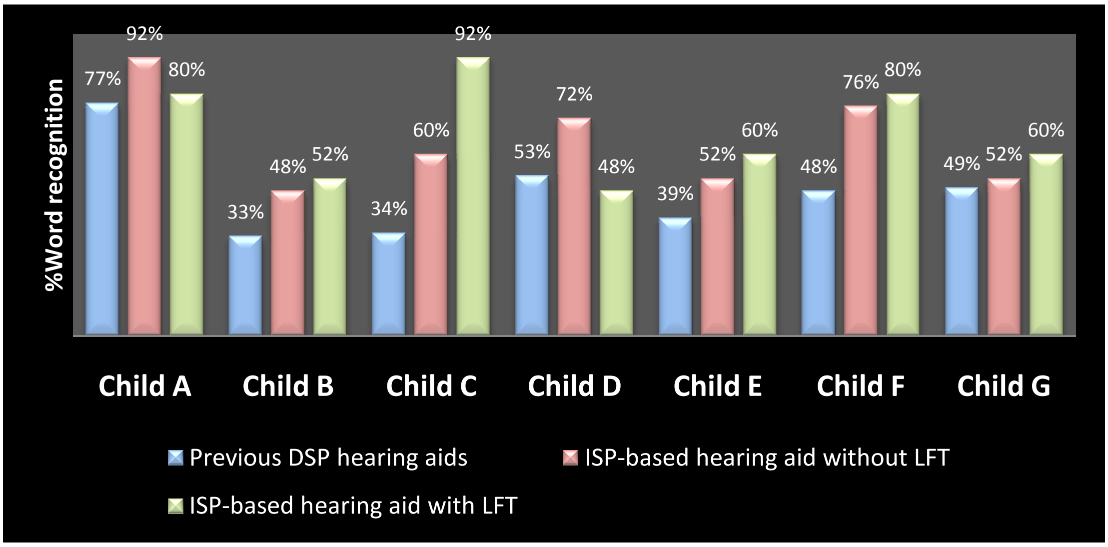


Figure 32: A comparison of word recognition scores obtained during the third test condition (35 dB in quiet) (n=7)

All subjects presented with better word recognition scores when they used the ISP-based hearing aids without linear frequency transposition compared to their previous generation DSP hearing aids. Child B, C, E, F and G presented with an increase in word recognition score, of which the increase was significantly more than 12% for Child C. Child A and Child D presented with a significant decrease in word recognition score of more than 12% (Ross, personal communication, 2008).

Distance hearing is very important for children, as language and vocabulary is also learned by "overhearing" conversations, and teachers in the classroom are usually at a distance. Thus, good audibility of speech sounds at 35 dB HL is crucial for academic success and development of "social" language (Flexer, 2004:134)

A paired t-test revealed a statistical significant difference in average word recognition scores between the previous DSP hearing aids and the ISP-based hearing aids without linear frequency transposition (p=0.014). These results are depicted in Figure 33:

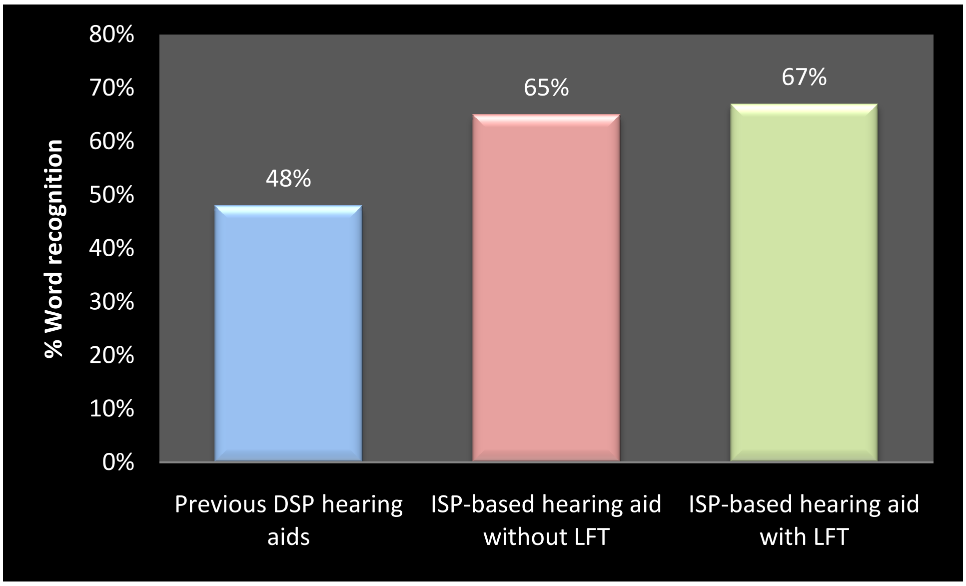


Figure 33: A comparison of the average word recognition scores obtained during the third test condition (35 dB in quiet) (n=7)

According to Papso and Blood (1989:236), a word recognition score of 88 to 100% in quiet with a median of 94% and 52 to 92% in noise with a median of 78% is acceptable for children who are still developing language. The number of subjects who presented with the scores between 88 to 100% and the number of those subjects who presented with scores above the median of 94% is depicted in Figure 34. The number of subjects represented by the top of the bars is those who presented with a word recognition score above that of the median of 94% for the first test condition across all three signal processing strategies:

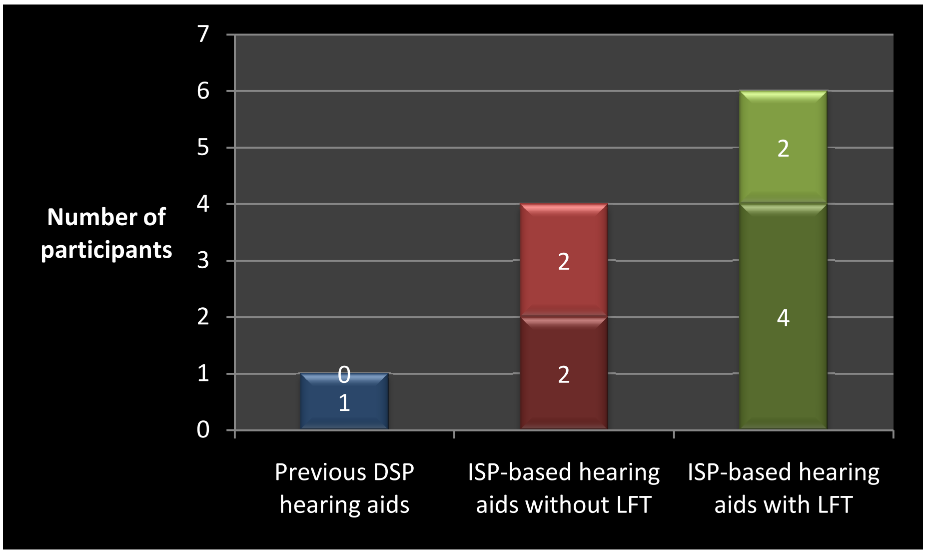


Figure 34: The number of subjects presenting with acceptable word recognition scores for the first test condition (55 dB in quiet) (n=7)

It can be seen from Figure 34 that more subjects presented with acceptable word recognition scores of 88 to 100% when they used the ISP-based hearing aids without linear frequency transposition for the first test condition, and even more subjects presented with these scores when they used the ISP-based hearing aids with linear frequency transposition.

Figure 35 depicts the number of subjects who presented with word recognition scores between 56 and 92% for the second test condition across all three signal processing technology. The top of the bars represent the number of subjects who presented with word recognition scores above the median of 78%:

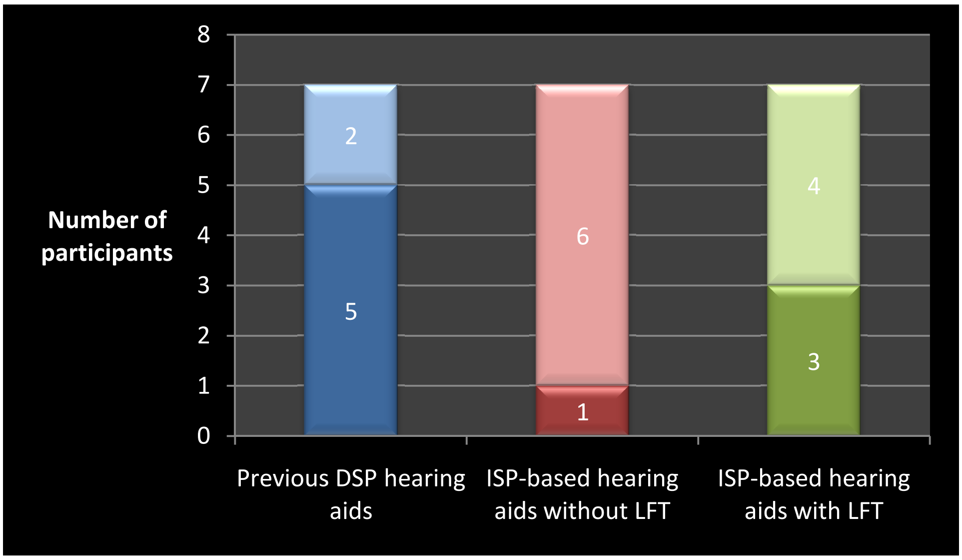


Figure 35: The number of subjects presenting with acceptable word recognition scores for the second test condition (55 dB + 5 dB SNR) (n=7)

It can be seen from Figure 35 that all the subjects presented with word recognition scores comparable to those of normal hearing children in noisy conditions. The majority of the subjects performed above the median when they used the ISP-based hearing aids with and without linear frequency transposition.

Pearson product-moment correlation coefficients were used to determine whether there is any correlation between the word recognition scores obtained, and the age of the subjects, the gender of the subjects, the pure tone average in the high frequencies, the time that has elapsed since the first hearing aid fit, the time they have spent in an educational programme and the time the subjects spent in speech-language therapy before the study commenced.

A positive correlation of 0.2 to 0.8 was found between the ages of the subjects, and the word recognition scores in all three test conditions. Older subjects tended to present with higher word recognition scores. This may be due to the increased concentration span of the subjects, as well as the increased development of listening skills. The female subjects also seemed to present with higher word recognition scores than the male subjects (correlation coefficient of 0.2 to 0.7), except for the third test condition where the ISP-based hearing aids with linear frequency transposition was used. Here the male subjects tended to present with better word recognition scores overall. A negative correlation between the high frequency pure-tone average (PTA) and the word recognition scores were also observed for all the test conditions (correlation coefficient of -0.1 to -0.5), which means that word recognition decreases as the degree of hearing loss increases. This is consistent with the results obtained when the WIPI was developed (Ross & Lerman, 1970:51). A positive correlation was found for the third test condition when the ISP-based hearing aids with linear frequency transposition were used (0.4). This might indicate that the subjects with a higher PTA might benefit more from linear frequency transposition when the test stimuli were presented at very soft input levels. The higher the PTA, the more transposition is needed, and may thus present the subject with better audibility of soft high frequency sounds. A weak correlation was found between the time that has elapsed since the first hearing aid fit and the obtained word recognition scores. A positive correlation was found for the first and second test condition when the previous DSP and ISP-based hearing aids without linear frequency transposition were used, and a negative correlation was found for the third test condition when the same hearing aids were used. No significant correlation was found between the word recognition scores obtained with the ISP-based hearing aids and the time that has elapsed since the first hearing aid fit. This seems to indicate that the longer the subject has worn hearing aids, the better the word recognition seems to be, except for when the words were presented in the third test condition where the audibility of the words presented, was decreased. This might indicate that the amount of time that the subject has been wearing the hearing aids is irrelevant when the audibility of the signal is extremely compromised.

Surprisingly, there seemed to be a weak or negative correlation between the word recognition scores obtained and the time that has elapsed since admission to the educational programme and the time that the subjects have been receiving speech therapy. This may be due to the small sample size used in this study, and a larger sample size might have yielded other correlations.

6.2 CONCLUSION

The signal processing scheme of hearing aids in children may have a marked positive effect on the word recognition performance of children with moderate-to-severe sensorineural hearing loss. Digital hearing aids that comply with the minimum requirements set by Bentler et al. (2004) do provide audibility in quiet conditions if they are well-fitted, but advanced digital signal processing may provide more consistent audibility in quiet as well as adverse listening conditions. For some children with moderate-to-severe sensorineural hearing loss, linear frequency transposition may provide even better audibility across a variety of listening conditions, regardless of the configuration of hearing loss. Linear frequency transposition may also decrease the intelligibility of speech for some children, as was seen in this study. Thus, paediatric audiologists should be well aware of the performance of children with moderate-to-severe sensorineural hearing loss and the possible effect of advanced digital signal processing across a variety of listening environments such as quiet and noisy conditions, as well as distance hearing. Candidacy criteria for linear frequency transposition are not yet available, and linear frequency transposition cannot be dismissed as a possible strategy for providing the child with moderate-to-severe sensorineural hearing loss with high frequency information that would otherwise have been unavailable. Validation of the hearing aid fitting should incorporate assessments that include a variety of listening conditions in order to demonstrate the efficacy of the fitting at least. Thus, linear frequency transposition may provide some children with moderate-to-severe sensorineural hearing loss with more high frequency speech cues in order to improve their word recognition in quiet as well as noisy environments.

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CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER AIM: To present a conclusion to the research problem by describing the crux of each sub-aim and by critically evaluating the study.

"Approach each new problem not with a view of finding what you hope will be there, but to get the truth…"

~ *Bernard Barruch* (1954:39)

7.1 INTRODUCTION

Consistent audibility of all speech sounds is a prerequisite for the child with hearing loss to develop oral speech and language skills (Kuk & Marcoux, 2002:504-505). Speech should therefore be audible not only in quiet situations, but also in noisy situations and if spoken from a distance (Stelmachowicz et al., 2000:209). The prevalence rate and aetiology of moderate to severe sensorineural hearing loss (MSSHL) in children are closely linked to the socio-economic context of the society in which the child and his/her family resides (Fortnum, 2003:162). These differences in prevalence rate and aetiology culminate in different outcomes for children with MSSHL in the domains of communication, socio-emotional development and education (Ching et al., 2008). These outcomes are thus dependent on the ability of the child to recognise spoken words. The auditory system is pre-wired for speech perception by the time a baby is born, and children with normal hearing are born with 14 weeks of listening experience due to the early prenatal maturation of the inner ear of the auditory system (Werner, 2007:275; Northern & Downs, 2002:128). Children with MSSHL should therefore be identified and fitted with amplification technology as soon as possible after birth in order to minimise the effect of auditory deprivation (Sininger et al., 1999:7). Amplification technology must therefore assist in the detection of speech at a peripheral level in order to induce normal or near-normal neural connections to form in the brain (Hnath-Chisolm et al., 1998:94). Different signal processing schemes are available in hearing aid technology at present that strive to accomplish this goal, but evidence-based studies are needed in order to proof whether these signal processing schemes are considered as "best practice" for children (Palmer & Grimes, 2005:506). Therefore, this study aimed to determine word recognition of children with MSSHL fitted with linear frequency transposition technology, in order to provide some information regarding the efficacy of this signal processing strategy.

7.2 CONCLUSIONS

Word recognition is considered to be an essential part of the ability to develop oral speech and language skills. Assessments that measure the ability of children with hearing-impairment to recognise spoken words are consequently considered to be a good indicator of the audibility of speech sounds that their hearing aids provide. Therefore, the assessment of word recognition skills was used to measure the efficacy of linear frequency transposition in children with moderate-to-severe sensorineural hearing loss, and to provide some indication of the efficiency of this type of technology.

7.2.1 Word recognition skills of children using previous generation digital signal processing hearing aids

The most important findings for the word recognition scores of children using previous generation digital signal processing hearing aids are as follows:

In quiet conditions at 55 dB hearing level

Only one child presented with an acceptable word recognition score that reflects sufficient audibility to develop oral speech and language skills optimally. This was found despite the fact that all the targets set by the DSL m[i/o] were met for the hearing aid fittings, and all functional aided thresholds were 35 dB HL or better in at least one ear. Previous generation hearing aids are rarely able to provide gain above 6000 Hz (Ricketts et al., 2008:160), and this is clearly not enough high frequency audibility when providing amplification to children with moderate-to-severe sensorineural hearing loss. Although hearing aids are verified and validated appropriately, audiologists cannot assume that children with moderate-to-severe sensorineural hearing loss are receiving enough high frequency amplification, and routine assessment of word recognition are needed in order to obtain valuable information about high frequency audibility and processing.

In noisy conditions with a signal-to-noise ratio of +5 dB

Despite using previous generation hearing aid technology, all subjects presented with acceptable word recognition scores in order to hear optimally in the presence of background noise. Only two children presented with word recognition scores above the median for children with normal hearing. Lower word recognition scores are considered acceptable in the presence of background noise due to the decreased audibility of the speech signal. Digital noise reduction, spectral speech enhancement as well as directionality of the microphones may in some cases increase audibility of the speech signal in noise so that the word recognition score is still considered acceptable for children with moderate-to-severe sensorineural hearing loss. Children with hearing aids that do not employ advanced signal processing strategies may be at a distinct disadvantage when exposed to noisy environments such as a classroom. Educational audiologists should provide training in the form of informational sessions for teachers regarding the shortcomings of previous generation amplification.

In quiet conditions at 35 dB hearing level

Two children presented with very low word recognition scores when using previous generation hearing aids. Distance hearing can be extremely problematic when the compression threshold of a hearing aid is not low enough in order to amplify soft sounds to an audible level. Children who are fitted with hearing aids that provide poor distance hearing often miss important cues and information in the classroom where the teacher’s voice is usually carried over a distance. It is thus necessary to assess whether a child can hear over a distance, as distance learning is important for passive learning and overhearing (Flexer, 2004:134). Appropriate steps must be taken in order to improve the child’s distance hearing, such as treating classrooms in order to reduce reverberation, and the provision of FM systems.

7.2.2 Word recognition scores of children using integrated signal processing (ISP)-based hearing aids without linear frequency transposition compared to previous digital signal processing hearing aids.

The most important findings for the word recognition scores of children using ISP-based hearing aids without linear frequency transposition are:

In quiet conditions at 55 dB hearing level

Four of the subjects presented with acceptable word recognition scores, and although all subjects showed an increase in word recognition scores, two subjects showed a significant increase in these scores. A possible reason for this occurrence may be that the higher level of technology utilised by these hearing aids provide a closer resemblance to the original signal, and a more accurate representation of the word is conducted to the higher centres of the brain. It is therefore imperative that paediatric audiologists provide the highest level of technology that is financially viable to children with moderate-to-severe sensorineural hearing loss, as this would increase the quality of the input-signal that may improve word recognition, and subsequent language learning.

In noisy conditions with a signal-to-noise ratio of +5 dB

All seven subjects presented with acceptable word recognition scores when using ISP-based hearing aids. Five subjects showed an increase in word recognition score and the increase in word recognition score of three subjects was significant. One subject showed no improvement in word recognition score and another subject presented with a decrease in word recognition score. The advanced digital signal processing strategies utilised by the ISP-based hearing aids increase the intelligibility of speech in a noisy environment, thus providing the child with moderate-to-severe sensorineural hearing loss with audibility in noisy as well as quiet listening environments. This increase in word recognition score may be of paramount importance in a classroom, where the signal-to-noise ratio (SNR) are compromised the majority of time, and audiologists therefore need to be aware of the benefit that advanced digital signal processing has on listening in a noisy situation.

In quiet conditions at 35 dB hearing level

All subjects demonstrated an increase in word recognition scores, and two subjects showed a significant increase in word recognition score when using the ISP-based hearing aids. The ISP-based hearing aids are able to detect and amplify soft speech sounds to a level where it is audible for the child and may increase distance hearing. Although all measures should be taken to increase distance hearing in a child, the provision of high technology levels may be the first step towards improved passive learning and "over-hearing."

7.2.3 Word recognition scores of children using ISP-based hearing aids with linear frequency transposition and compared to ISP-based hearing aids without linear frequency transposition

The most important clinical findings for the word recognition scores of children using ISP-based hearing aids with linear frequency transposition are:

In quiet conditions at 55 dB hearing level

When using ISP-based hearing aids with linear frequency transposition, six subjects presented with acceptable word recognition scores regardless of the configuration of hearing loss. Four subjects showed an increase in word recognition scores, and two subjects presented with a significant increase in word recognition score. One subject presented with the same word recognition score as with the ISP-based hearing aid without linear frequency transposition, and one subject presented with a significant decrease in word recognition score compared to the ISP-based hearing aid without linear frequency transposition. Linear frequency transposition technology may provide additional high frequency speech cues for some children, and may improve word recognition in quiet environments with good audibility. Configuration of hearing loss seems irrelevant to the decision whether or not a child may benefit from linear frequency transposition, and paediatric audiologists should consider choosing linear frequency transposition technology where possible for a trial period for all children with moderate-to-severe sensorineural hearing loss.

In noisy conditions with a SNR of +5 dB

All subjects presented with acceptable word recognition scores when using ISP-based hearing aids with linear frequency transposition. Four subjects presented with an increase in word recognition score, and two subjects presented with a significant increase in word recognition score. Three subjects presented with a decrease in word recognition scores, and the decrease was significant for two subjects. This also stresses the fact that linear frequency transposition may improve word recognition of some children with moderate-to-severe sensorineural hearing loss, whereas for others it may have a detrimental effect on word recognition score. Another possible reason for the significant decrease in word recognition score for two of the subjects may be that some fine-tuning may be required for the fitting of the linear frequency transposition, as guidelines for fine-tuning linear frequency transposition were published after the data-collection period of this study. However, as an improved word recognition score was noted for four of the subjects, the settings for linear frequency transposition may have been adequate for these subjects. Therefore, it may be necessary to fine-tune linear frequency transposition and only after the word recognition score is obtained with these settings, the decision must be made regarding whether or not the subject may benefit from linear frequency transposition in noise.

In quiet conditions at 35 dB hearing level

When using ISP-based hearing aids with linear frequency transposition, five subjects presented with an increase in word recognition score, of which the increase was significant for one subject. Two subjects presented with a significant decrease in word recognition score. Linear frequency transposition may improve a child's passive learning and overhearing, and may be essential in improving distance hearing in a child with moderate-to-severe sensorineural hearing loss. Distance hearing must therefore be measured and linear frequency transposition may be considered as a central component in providing a comprehensive management plan for the child with moderate-to-severe sensorineural hearing loss in order to improve classroom performance.

From the aforementioned discussion, it can be concluded that the majority of subjects showed an improvement in word recognition score in quiet and noisy conditions and therefore a trial period with linear frequency transposition hearing aids combined with regular word recognition assessments should be recommended for every child with moderate-to-severe sensorineural hearing loss in order to determine candidacy.

7.3 CLINICAL IMPLICATIONS

The clinical implication of these results indicates first of all that appropriate objective verification of hearing aid output and subjective validation (by means of a functional aided audiogram) may not give an accurate indication of the performance of a child with moderate-to-severe sensorineural hearing loss in quiet as well as noisy situations. This stresses the importance of conducting additional assessments in order to determine the performance of children with moderate-to-severe sensorineural hearing loss in quiet and noisy conditions. Secondly, although norms for word recognition scores are not available for soft speech levels (35 dB HL), it is still necessary to assess whether a child can hear over a distance, as distance hearing are important for passive learning and overhearing (Flexer, 2004:134). Word recognition assessments at soft speech levels of 35 dB HL measure whether speech is intelligible over a distance, not just audible. This has severe consequences for classroom instruction, and children with poor distance hearing need to be taught some skills directly in comparison with other children who may learn the same skills incidentally.

The ISP-based hearing aids are of a much higher technology level than the previous generation digital signal processing hearing aids and provided more audibility in noise to the subjects, as well as better distance hearing. The objective verification and subjective validation of these hearing aid fittings were performed in an identical manner as with the previous generation digital signal processing hearing aids. As with the previous fittings, all the targets were met according to the DSL m[i/o], and all the functional aided thresholds in at least one ear were 35 dB HL or better. Despite the similarities between the two fittings in the results from the verification and validation steps of the fitting process, all the subjects presented with better word recognition scores when using the ISP-based hearing aids. This gives an indication of the efficacy and efficiency of this specific kind of technology.

The clinical implication of this finding stresses the importance of providing the highest level of amplification technology that is possible financially to children with moderate-to-severe sensorineural hearing loss, as better audibility of speech sounds and words across a variety of listening environments would also increase the potential of a child with moderate-to-severe sensorineural hearing loss to develop oral speech and language skills comparable to those of their normal-hearing peers. Also, the ISP-based hearing aids would increase the chance of passive learning by over-hearing conversations, and classroom performance should also be more effective due to better audibility of the teacher's voice over a distance.

Linear frequency transposition technology in hearing aids may provide more audibility and intelligibility of speech to children across a variety of listening environments. At the same time, intelligibility may be decreased in certain listening conditions, and this type of technology may not be appropriate for al children. However, as clear candidacy criteria do not exist at present, linear frequency transposition cannot be dismissed as a possibility for individual children to increase the audibility of high frequency speech sounds until proven otherwise. It may thus be necessary for a trial fitting of the hearing aid to conduct assessments similar to these used in this study with individual children in order to determine the efficacy and efficiency of this type of technology for that specific child.

In this study, it was decided that Child C, F, and G may benefit from the ISP-based hearing aid with linear frequency transposition. Child A may also benefit from linear frequency transposition, as no significant decrease in word recognition score for all three conditions were found. Linear frequency transposition had a significant detrimental effect on intelligibility for Child B, D ad E, and these subjects may benefit the most from the ISP-based hearing aid without linear frequency transposition.

7.4 CRITICAL EVALUATION OF THE STUDY

A reflection on the positive and negative characteristics of this study is necessary in order to gain perspective and insight into the word recognition of children with moderate-to-severe sensorineural hearing loss using linear frequency transposition.

The main strength of this study is that it attempts to provide evidence regarding the use of linear frequency transposition in children within a unique ***South African*** context. Due to the non-existence of universal newborn hearing screening, all of the subjects in this study have only been diagnosed after two years of age. They have been exposed to audiology services within the public and/or private sector, and subsequently to different levels of amplification technology, depending on the socio-economic circumstances. Although all the subjects use English as the primary language, they come from different backgrounds and cultures. All these variables create a heterogeneous subject group, but freely representative of the multi-cultural diversity of the South African population. Thus, evidence regarding the use of linear frequency transposition in children from developed countries may yield different results from the results obtained through this study.

The main focus of current research on the use of linear frequency transposition and children in international studies is on ski-slope high frequency hearing losses with known cochlear dead areas specifically. Thus, another strength of this study is that it also provides information regarding the use of linear frequency transposition in children with different configurations of hearing loss, as it was found that children may benefit from linear frequency transposition regardless of the hearing loss configuration.

As there are very few studies available to date on the subject of children with moderate-to-severe sensorineural hearing loss and linear frequency transposition, this study also contributes towards the knowledge in this field.

The main weakness of the study is found in the small sample size. However, this study was dependent on a donation from a hearing aid company to provide ISP-based hearing aids with and without linear frequency transposition for all the subjects fitting the selection criteria at a specific school only and the subjects would otherwise have not been able to afford these high-cost hearing aids. Also, a smaller sample size meant that assessments could be conducted between other appointments at a school for deaf and hearing-impaired children, as only one audiologist were responsible for all the assessments and day-to-day appointments at the school.

Furthermore, it could be argued that ten to twelve days are not long enough for children to acclimatise to their new hearing aids. However, literature indicates that this may be sufficient to effectively evaluate outcomes, but that further effects may be seen if the child has worn the hearing aids longer (Marriage et al., 2005:45; Auriemmo et al., 2008:54).

The lack of double-blinding in the research design could also be considered a weakness in this study. It is not always possible to introduce blinding in a study (Palmer, personal communication, 2008), as was the case in this study due to the fact that only one audiologist was available for all the fittings and assessments.

7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations are made for future studies:

- A similar study with a large sample size may yield conclusive evidence regarding efficacy and clear candidacy criteria for the use of linear frequency transposition in children.
- Future studies regarding the effectiveness of linear frequency transposition in children should include functional performances in the form of questionnaires as well as audibility and discrimination of non-speech sounds.
- Culture-specific training programmes for high frequency speech sounds when linear frequency transposition is used can be included in future research.
- A follow-up study on the same subjects after they have used linear frequency transposition for a year may quantify the evidence of linear frequency transposition.
- Future studies on linear frequency transposition in children should include fine-tuning of the amount of linear frequency transposition that is needed for each child specifically according to guidelines published after the completion of this study's data collection.

7.6 CLOSING STATEMENT

Linear frequency transposition may increase or decrease the word recognition scores of children with moderate-to-severe sensorineural hearing loss significantly compared to the scores obtained while using high technology amplification without linear frequency transposition. Linear frequency transposition may thus provide the child with moderate-to-severe sensorineural hearing loss with more consistent audibility of all speech sounds across a variety of listening environments than hearing aids without linear frequency transposition. The variables that could indicate the success of linear frequency transposition in children is not yet known, and further studies are needed in order to delineate candidacy criteria. Until clear candidacy criteria become available, linear frequency transposition cannot be dismissed as a possible way of providing the child with moderate-to-severe sensorineural hearing loss with high frequency information that he/she would have otherwise missed.

“ Basic to the concept of hearing aid recommendations is a realistic understanding of what the aid can do for the patient…the goal in providing amplification to the child with a hearing impairment is to make speech audible at safe and comfortable listening levels at a sensation level that provides as many acoustic speech cues as possible…” (Northern & Downs, 2002:306)