

Comparison of Speech Perception Performance Between Sprint/Esprit 3G and Freedom Processors in Children Implanted With Nucleus Cochlear Implants

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Objective: To compare speech perception performance in children fitted with previous generation Nucleus sound processor, Sprint or Esprit 3G, and the Freedom, the most recently released system from the Cochlear Corporation that features a larger input dynamic range.

Study Design: Prospective intrasubject comparative study.

Setting: University Medical Center.

Subjects: Seventeen prelingually deafened children who had received the Nucleus 24 cochlear implant and used the Sprint or Esprit 3G sound processor.

Intervention: Cochlear implantation with Cochlear device.

Main Outcome Measures: Speech perception was evaluated at baseline (Sprint, $n = 11$; Esprit 3G, $n = 6$) and after 1 month's experience with the Freedom sound processor. Identification and recognition of disyllabic words and identification of vowels were performed via recorded voice in quiet (70 dB [A]), in the presence of background noise at various levels of signal-to-noise ratio (+10, +5, 0, -5) and at a soft presentation level (60 dB [A]). Consonant identification and recognition of disyllabic words, trisyllabic words, and sentences were evaluated in live voice. Frequency discrimination was measured in a subset

of subjects ($n = 5$) by using an adaptive, 3-interval, 3-alternative, forced-choice procedure.

Results: Identification of disyllabic words administered at a soft presentation level showed a significant increase when switching to the Freedom compared with the previously worn processor in children using the Sprint or Esprit 3G. Identification and recognition of disyllabic words in the presence of background noise as well as consonant identification and sentence recognition increased significantly for the Freedom compared with the previously worn device only in children fitted with the Sprint. Frequency discrimination was significantly better when switching to the Freedom compared with the previously worn processor.

Conclusion: Serial comparisons revealed that that speech perception performance evaluated in children aged 5 to 15 years was superior with the Freedom than previous generations of Nucleus sound processors. These differences are deemed to ensue from an increased input dynamic range, a feature that offers potentially enhanced phonemic discrimination. **Key Words:** Cochlear implant—Input dynamic range—Sound processor—Speech perception.

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Cochlear implants provide children affected by severe-to-profound hearing loss with an adequate auditory signal necessary for the development of speech perception (1). Nevertheless, cochlear implantation shows wide variability in outcomes largely related to individual factors such as duration of deafness, age at implantation, length of device use, degree of residual hearing, and cognitive and linguistic factors (2–4). In addition, both device type (5–7) and sound processing coding strategy

(5,8,9) have been taken into account as variables that could influence the outcome of cochlear implantation.

Until recently, little consideration has been given to the range of acoustic input amplitudes mapped into the electrical output intensity range known as input dynamic range (IDR). Spahr and colleagues (10) evaluated speech perception in a group of postlingually deafened implanted patients with identical levels of performance and concluded that differences in speech perception found in subjects using different types of implant devices are mainly related to differences in the IDR values of the external sound processor. Specifically, they found that performances on speech perception tests for patients using the Esprit 3G were poorer compared with subjects wearing

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other types of devices in difficult listening conditions such as lower level speech presentation or speech in the presence of background noise. They hypothesized that this was the result of a narrower IDR available in the Esprit 3G processor. An increase in the instantaneous IDR (IIDR) as implemented and evaluated by James and colleagues (11) in the Nucleus 24 Sprint processor, achieved by lowering the default base level, resulted in improved performance in tasks of consonant identification at soft levels. Similarly, the increase of IIDR values in the Nucleus SPEAR3 research processor resulted in improved scores on Consonant-Nucleus-Consonant (CNC) word recognition at low presentation levels (12).

Nucleus Freedom is the most recent cochlear implant system released by Cochlear Ltd. Sydney, Australia. Compared with the previous generation of sound processors, the Sprint and Esprit 3G, one of the most relevant features of the Freedom is the availability of an increased IDR, from 30 to 40 dB. To date, many children who had received the Nucleus 24 cochlear implant series before the release of the Freedom are still using Sprint or Esprit 3G. Given the backward compatibility of the Freedom sound processor with the previous Nucleus 24 cochlear implant series, the question is raised as to whether switching to the Freedom could potentially offer further improvement in speech perception ability for these patients. To date, no studies have addressed this question, specifically in the population of implanted children. Balkany and colleagues (13) reported, from an evaluation of performance with the Freedom sound processor for adult CI users, a relative improvement in word recognition scores on CNC word recognition compared with the performance of different CI user groups using the previous generation of Nucleus sound processors.

In an intrasubject comparative study, we evaluated speech perception performance in a group of 17 children implanted with the Nucleus 24 cochlear implant after 1 month's experience with the Freedom and compared

the results to performance with the previously used sound processor, Sprint or Esprit 3G. To evaluate speech perception abilities required in everyday listening environments, speech stimuli were also presented at soft levels and in the presence of increasing amounts of background noise.

MATERIALS AND METHODS

Subjects

Seventeen implanted children (7 female and 10 male subjects; mean age at implantation, 3.8 yr [range, 2–10 yr]; mean age at testing, 8.2 yr [range, 4–15 yr]) were included in this study. All children underwent cochlear implantation with the Nucleus device at the University of Padua Service of Audiology and Phoniatrics. Subjects used either the Sprint (n = 11) or Esprit 3G (n = 6) sound processor before switching to the Freedom sound processor. Inclusion criteria were age at implantation of younger than 10 years, no evidence of mental retardation, oral communication, and auditory-oral therapy. Details of etiology, age at onset of deafness, age at implant, age at testing, device type, and processing strategy and rate are reported in Table 1.

Freedom processors were provided by the Italian National Health Service. No financial support was received from Cochlear Ltd.

Procedures

In this study, speech perception was evaluated in 2 groups of children, one using Sprint (Group 1; mean age at testing, 8.5 yr) and the other using Esprit 3G (Group 2; mean age at testing, 7.0 yr). The results of speech perception tests measured after 1 month's experience with the Freedom were compared with baseline speech perception scores obtained with the previously worn device.

All children used the advanced combination encoding (ACE) processing strategy (rates, 900–1,200 impulse per second [imp/s]) (Table 1). In the group using Sprint, microphone sensitivity had been set to 12 in all but 3 subjects (Subjects 3, 10, and 11), each with a sensitivity of 14. The sensitivity value was maintained when switching to the Freedom processor. Children

TABLE 1. Patient demographics

Subject	Sex	Etiology	Age at deafness onset (yr)	Age at implant (yr)	Age at testing (yr)	Ear implanted	Device	Strategy	Rate (imp/s)
1	F	Unknown	Congenital	2	5	R	C124R/Sprint	ACE	900
2	F	CMV infection	Congenital	3	9	R	C124R/Sprint	ACE	1,200
3	M	Genetic (Cx26)	Congenital	3	10	R	C124M/Sprint	ACE	900
4	M	Familiarity	Congenital	3	11	R	C124M/Sprint	ACE	900
5	M	Unknown	Congenital	4	9	L	C124R/Sprint	ACE	1,200
6	F	Familiarity	Congenital	8	15	R	C124M/Sprint	ACE	900
7	M	Unknown	Congenital	2	6	R	C124R/Sprint	ACE	1,200
8	F	Unknown	Congenital	3	9	R	C124R/Sprint	ACE	900
9	M	Hypoxia	Congenital	3	7	L	C124R/Sprint	ACE	1,200
10	F	Familiarity	Congenital	2	8	R	C124R/Sprint	ACE	1,200
11	M	Familiarity	Congenital	2	6	R	C124R/Sprint	ACE	1,200
12	M	Unknown	Congenital	9	13	R	C124R/Esprit 3G	ACE	900
13	M	Meningitis	3	6	9	R	C124R/Esprit 3G	ACE	1,200
14	M	Genetic (Cx26)	Congenital	3	6	L	C124R/Esprit 3G	ACE	1,200
15	F	Unknown	Congenital	2	4	R	C124R/Esprit 3G	ACE	1,200
16	M	Unknown	Congenital	5	9	R	C124R/Esprit 3G	ACE	1,200
17	F	Genetic (Cx26)	Congenital	2	4	R	C124R/Esprit 3G	ACE	1,200

ACE indicates advanced combination encoding; CMV, cytomegalovirus; Cx26, connexin 26; L, left ear; F, female; M, male; R, right ear; imp/s, impulse per second.

wearing the Esprit 3G used 20 electrodes instead of 22, thus showing 2 nonactivated basal electrodes. The same configuration was maintained when switching to the Freedom processor. With the Esprit 3G, microphone sensitivity had been set to the default value of 21 dB in all but 2 children (Subjects 12 and 16) who used the automatic sensitivity control. When switching to the Freedom processor, sensitivity was set to the default value of 12.

The baseline test session was performed within 1 day of switching to the Freedom sound processor. No change to signal processing parameters such as processing strategy, rate of stimulation, and current levels was implemented with the switch to the Freedom. The second test session was performed after 1 month's experience with the Freedom processor.

Audiometric Evaluation

Hearing thresholds were measured in a sound-attenuated room with subjects wearing their sound processor on user settings. Warble tone stimuli were presented in the free field at octave frequencies of 250 to 4,000 Hz (Interacoustic AC30 Audiometer, JBL TLX130 loudspeakers). Visual reinforcement or play audiometry was used to condition and reward responses in children aged younger than 6 years at testing.

Speech Perception Tests

- a. *Identification and Recognition Speech Tests (Recorded Speech Materials)*. All tests were performed in a sound-attenuated room. Speech stimuli were presented in the free field through 1 loudspeaker placed 1 m away from the front of the subject's head. Competing background noise was presented from 2 additional loudspeakers placed laterally at an angle of 90 degrees on each side of the subject's head at a distance of 1 m. Competing noise used was speech noise (Interacoustics AD 229E) calibrated in the free field by means of a Brüel and Kjær 4165 microphone (mounted on the 800 B Larson-Davis sound level meter) placed in a position corresponding to the subject's head.

Speech material comprised digital anechoic recordings of a native Italian female speaker (performed in a recording studio). The speech stimulus intensity was kept at 70 dB (A). Both stimuli and noise files were stored on computer for transfer directly to the loudspeakers. Speech and noise files were normalized for output intensity levels at the signal-to-noise ratio (SNR) of 0 dB.

The speech stimuli used for the word identification test were obtained from an Italian adaptation (Test di Identificazione Parole Infantili [TIPII]) (14) of the Northwestern University-Children's Perception of Speech Instrument (15). Closed-set word identification was performed by presenting the subject with one of 4 randomly chosen lists, each list consisting of 25 items, each item including 4 disyllabic words (i.e., chance 25%). For vowel identification, vowels were administered randomly (chance 20%). The child was instructed to respond by selecting the appropriate picture (TIPII) or transcription of the stimuli (vowel identification) presented on a computer touch screen. Responses were automatically stored, and the percentage of correctly identified items was computed for each test.

Word recognition ability was evaluated through random presentation of disyllabic words from the same lists as used for the TIPII word identification test. Children were requested to respond by repeating the words they heard.

TIPII, vowel identification, and recognition of disyllabic word tests were administered at 70 dBA in quiet and in the

presence of competing noise presented at various SNRs (+10, +5, 0, -5). TIPII was also performed at 60 dBA in quiet to evaluate speech perception performance at a soft presentation level.

- b. *Identification and Recognition Tests (Live Voice)*. All tests were performed in the auditory-only listening condition using live-voice presentation and were administered by a speech therapist experienced in controlling the intensity of her voice (70–75 dBA as monitored in free field by means of an 800 B Larson-Davis sound level meter).

Consonant identification was evaluated by presenting consonant confusion matrices compiled from 2 presentations, each comprising the 16 consonants, b d f g k l m n p r s t v z j tʃ, presented in an "a-consonant-a" context (chance 6%).

The test battery of open-set tests included the recognition of disyllabic words, trisyllabic words, and sentences. The speech material was obtained from the protocol of patient candidacy for cochlear implantation adapted for the Italian language (14,16). In 11 subjects (mean age 9.8 yr), the recognition of both disyllabic and trisyllabic words was evaluated by means of one of 10 randomly chosen lists, each including 20 items. The lists of words were phonetically balanced so that their frequency was similar to that represented in normal conversation in the Italian language. For the sentence recognition task, subjects were randomly presented with one of 3 lists of 20 items each. In younger children (mean age 5.3 yr), a simplified version of the same test was used.

For speech tests performed in live voice, subjects were asked to respond by repeating the speech signal perceived. Sentences were scored considering an exact repetition of the presented items except for articles.

Frequency Discrimination

Frequency discrimination was measured at 0.5, 1, 2, and 4 kHz by using tones with 2.5-millisecond rise time and 200-millisecond duration, which were presented in free field at an intensity of 30-dB sound level (SL). We used the same psychophysical procedure as that reported by Zeng et al. (17). The stimulus paradigm consisted of a 3-interval, 3-alternative, forced-choice, 2-down and 1-up procedure. Briefly, children were presented with 3 pure tones, 1 (signal tone) showing a higher frequency compared with the other 2 (standard tones). The standard and signal stimuli were presented in a random order (3-alternative). The presentation of each tone was visually marked by a flashing circle on the touch screen of a computer (3-interval). Children were asked to select the tone with the higher frequency by touching the corresponding flashing light on the touch screen (forced-choice). The difference in frequency between the standard and signal tone was reduced after 2 consecutive correct responses and increased after 1 incorrect response (2-down and 1-up procedure). Then, an adaptive procedure was performed to determine the smallest frequency difference detected by each subject. Responses were automatically tracked by computer software, and the smallest pitch difference detectable by each subject was calculated.

Because of the complexity of the task and the response mode, this test was performed with only a subset of 5 children from the study group (Subjects 4, 11, 12, 13, and 16).

Data Analysis

Performance in each test condition was scored as a percent of correct responses. Group performance values described in the text and illustrated in the figures represent mean \pm 1 standard error.

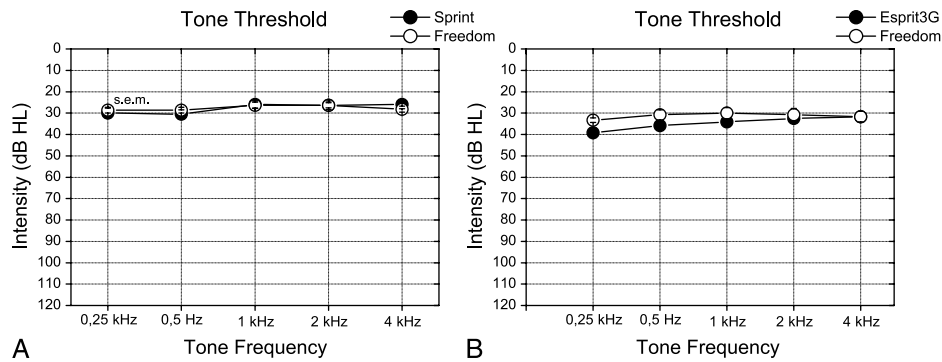


FIG. 1. Means and standard errors of the hearing thresholds with cochlear implant obtained from children using Sprint (A) or Esprit 3G (B) processor at baseline (full circles) and after 1 month's experience with the Freedom (empty circles). Note that thresholds at low frequencies improved when switching to the Freedom in the group of children using the Esprit 3G processor. In this and in the subsequent figures, one bar indicates 1 standard error (s.e.m.).

Statistical analysis was performed using the R free-software environment for statistical computing (<http://cran.r-project.org/>). Statistical significance was set at $p < 0.05$. Differences in speech perception scores at 2 time points (evaluation at baseline and with the Freedom sound processor) in tests performed using live voice and for TIPI presented at 60 dBA were obtained through use of the paired t -test.

Linear mixed-effect models including a random effect for the subject were used for statistical analyses of tone thresholds, speech perception scores, and frequency discrimination at several tone frequencies (0.25, 0.5, 1, 2, and 4 kHz for tone thresholds and 0.5, 1, 2, and 4 kHz for frequency discrimination) or levels of noise (quiet; SNR, +10, +5, 0, -5), and at the 2 time points (baseline and 1 month's experience with the Freedom sound processor). The best model was selected by comparing pairs of nested models using likelihood ratio-based tests. For the purpose of this study, the ordinal variable level of noise was treated as quantitative by assigning scores to the ordered categories (1 = 'quiet', 2 = 'SNR + 10', 3 = '+5', 4 = '0', 5 = '-5'). In assigning scores to the ordered levels, a sensitivity analysis was conducted to verify that conclusions were independent on score choice.

RESULTS

All children reported subjective preference for the Freedom sound processor. After 1 month's experience with the

Freedom, children or their parents reported an increased sensitivity to soft sounds (6 subjects), improved speech perception at soft presentation levels (7 subjects) or in the presence of background noise (2 subjects), and better understanding on the telephone (2 subjects) and for the television (5 subjects).

Audiometric Evaluation

Figure 1 reports the means and standard errors of hearing thresholds with cochlear implant obtained from subjects using the Sprint (Fig. 1A) or Esprit 3G (Fig. 1B) sound processor at baseline testing and after 1 month's experience with the Freedom. As indicated by mixed linear analysis, no significant differences in hearing thresholds were observed with the Freedom compared with the Sprint processor ($p = 0.9$) (Fig. 1A). In contrast, there was a statistically significant decrease of 3.33 ± 1.16 dB in the hearing thresholds measured with the Freedom compared with the values obtained with the Esprit 3G processor ($p = 0.006$) (Fig. 1B). There was a significant decrease in threshold as a function of tone frequency in both groups (-0.77 ± 0.25 , $p < 0.01$, for Sprint; -1.08 ± 0.41 , $p < 0.01$, for Esprit 3G).

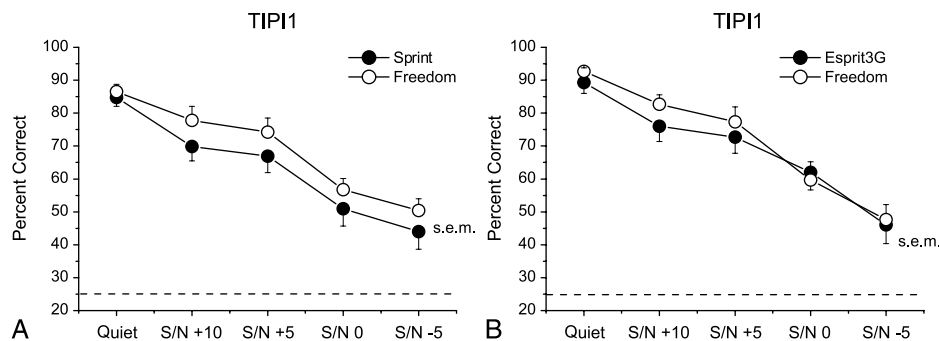


FIG. 2. Mean percentage of correct scores for identification of disyllabic words (TIPI1) obtained at 70 dBA in quiet and in the presence of various levels of background noise is reported at baseline (full circles) and after 1 month's experience with the Freedom (empty circles) in children using the Sprint (A) or Esprit 3G (B) processor. Scores increased when switching to the Freedom compared with the previously worn processor in both groups of children. The increase was significant for the group previously using the Sprint (mixed linear analysis, $p = 0.006$). The horizontal dashed line indicates the chance test score.

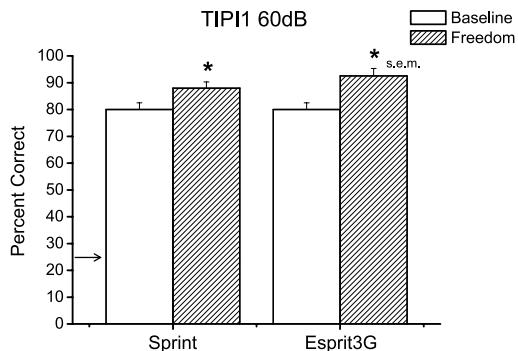


FIG. 3. Mean percentage of correct scores for identification of disyllabic words (TIPI1) obtained at a soft presentation level (60 dBA) from children using the Sprint or Esprit 3G processor at baseline and after 1 month's experience with the Freedom. Scores significantly increased when switching to the Freedom compared with the previously worn device in both groups of children (paired *t*-test: Sprint $t = 3.87$, $p < 0.05$; Esprit 3G $t = 3.11$, $p < 0.05$). The horizontal arrow indicates the chance test score. In this and in the subsequent figures, the asterisk indicates $p < 0.05$.

Recorded Tests

Test di Identificazione Parole Infantili 1 (TIPI1)

Means and standard errors of correct scores for identification of disyllabic words (TIPI1) at baseline and after 1 month's experience with the Freedom are reported in Figure 2. Mixed linear analysis revealed that there was a statistically significant difference of $5.81 \pm 2.03\%$ after 1 month's experience with the Freedom compared with the evaluation obtained at baseline with the Sprint processor ($p = 0.006$) (Fig. 2A). In contrast, no significant effect of using the Freedom processor was observed for TIPI1 scores obtained from children previously using the Esprit 3G processor ($p = 0.16$) (Fig. 2B). There was a significant decrease in scores as a function of level of noise in both groups (-9.69 ± 0.72 , $p < 0.001$, for Sprint/Freedom; -10.68 ± 0.78 , $p < 0.001$, for Esprit 3G/Freedom).

Mean scores on identification of disyllabic words (TIPI1) measured at a soft presentation level (60 dBA) (Fig. 3) increased from 80% at baseline to 88% and 93% when

switching to the Freedom for children previously using the Sprint or Esprit 3G processors, respectively. Differences were significant for both groups (paired *t*-test: Sprint $t = 3.87$, $p < 0.05$; Esprit 3G $t = 3.11$, $p < 0.05$).

Vowel Identification

Baseline mean scores on identification of vowels are reported in Figure 4 together with the corresponding values obtained after 1 month's experience processor. No significant changes in percentage of correct responses were observed when switching to the Freedom for the group of children previously using the Sprint processor (mixed linear analysis, $p = 0.71$) (Fig. 4A). In contrast, a statistically significant improvement of $8.89 \pm 3.33\%$ was obtained with the Freedom for the group of children previously using the Esprit 3G processor ($p = 0.01$) (Fig. 4B). There was a decrease in scores as a function of level of noise which was significant for both groups (-8.88 ± 0.67 , $p < 0.001$, for Sprint/Freedom; -9.33 ± 1.18 , $p < 0.001$, for Esprit 3G/Freedom).

Recognition of Disyllabic Words

Mean recognition scores for disyllabic words obtained with the Freedom showed a significant improvement of $7.51 \pm 2.34\%$ compared with the previously worn processor for the group of children previously using the Sprint (mixed linear analysis, $p = 0.002$) (Fig. 5A). No changes in percentage of correct responses were observed when switching to the Freedom in the group of subjects previously using the Esprit 3G processor ($p = 0.13$) (Fig. 5B). The decrease in percent correct scores as a function of level of noise was significant for both groups (-15.50 ± 1.04 , $p < 0.001$, for Sprint/Freedom; -15.76 ± 2.52 , $p < 0.001$, for Esprit 3G/Freedom).

Tests in Live Voice

Consonant Identification

Mean consonant identification scores evaluated via live-voice presentation increased by 20% when switching to the Freedom in the group of children previously

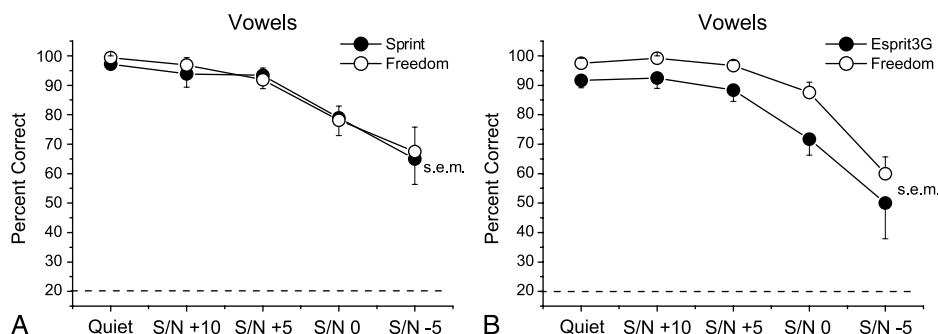


FIG. 4. Mean percentage of correct scores for vowel identification obtained from children using the Sprint (A) or Esprit 3G (B) processor at baseline (full circles) and after 1 month's experience with the Freedom (empty circles). A significant increase in score was observed when switching to the Freedom only for the group of children using the Esprit 3G processor (mixed linear analysis, $p = 0.01$). The horizontal dashed line indicates the chance test score.

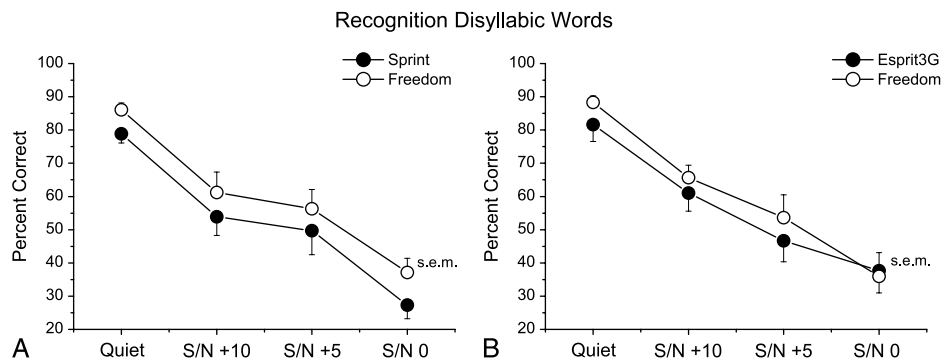


FIG. 5. Mean percentage of correct scores for recognition of disyllabic words (TIP1) obtained in quiet and in the presence of various levels of background noise at baseline (*full circles*) and after 1 month's experience with the Freedom (*empty circles*) in children using the Sprint (A) or Esprit 3G (B) processor. Recognition scores increased when switching to the Freedom compared with the previously worn device, and the increase was significant for the group of children using the Sprint processor (mixed linear analysis, $p = 0.002$).

using the Sprint (Fig. 6). The difference was statistically significant (paired t -test $t = 2.57$, $p < 0.05$). In contrast, no significant differences were found in the group of children previously using the Esprit 3G.

Open-Set Tests

Mean correct scores for recognition of disyllabic words, trisyllabic words, and sentences are reported in Figure 7 for both groups of children. For those previously using the Sprint, scores increased for all materials, with significant improvement with the Freedom processor (Fig. 7A) for recognition of disyllabic words (paired t -test: $t = 2.30$, $p < 0.05$) and sentences (paired t -test: $t = 2.34$, $p < 0.05$), which increased by 7% and 5%, respectively. Although mean scores calculated for disyllabic and trisyllabic words were higher when measured with the Freedom compared with baseline evaluation, differences were not statistically significant for the group of children previously using the Esprit 3G (Fig. 7B).

Scores on recognition of disyllabic words evaluated in live voice were consistent with those obtained on recorded tests. In the group of children using the Sprint, mean identification scores in quiet were 79.5 ± 4.5 and 78.9 ± 2.8 for live and recorded voice, respectively, and they increased to 86.4 ± 3.6 and 86.1 ± 2.1 when switching to the Freedom. Mean scores obtained from children using the Esprit 3G in quiet were 83.3 ± 7.0 and 81.7 ± 5.1 for live and recorded voice, respectively, and increased to 89.2 ± 4.4 and 88.3 ± 2.0 when switching to the Freedom. No significant differences were found between live and recorded voice test scores in each condition (paired t -test).

Sprint and Esprit 3G Processors Versus Freedom: Frequency Discrimination

Frequency discrimination was evaluated at baseline and after 1 month's experience with the Freedom in a subset of subjects including 2 children previously using the Sprint (Subjects 4 and 11) and 3 children previously using the Esprit 3G (Subjects 12, 13, and 16) (Fig. 8). A mixed linear analysis revealed that the smallest frequency difference per-

ceived showed a statistically significant decrease of 41.87 ± 11.41 when tested with the Freedom compared with the previously used processor ($p = 0.003$). The change in frequency discrimination as a function of tone frequency was significant (28.81 ± 9.22 , $p < 0.001$).

DISCUSSION

The results of this study demonstrate that identification of disyllabic words measured in a group of 17 children at a soft presentation level was significantly higher when tested with the Freedom compared with the previous generation of Nucleus sound processors, Sprint, or Esprit 3G. Also, frequency discrimination significantly improved when switching to the Freedom sound processor in both groups of children. Moreover, identification of disyllabic words in a noisy background, consonant identification, and open-set speech recognition significantly improved when switching to the Freedom compared with the previously worn device in the group of patients fitted with the Sprint processor.

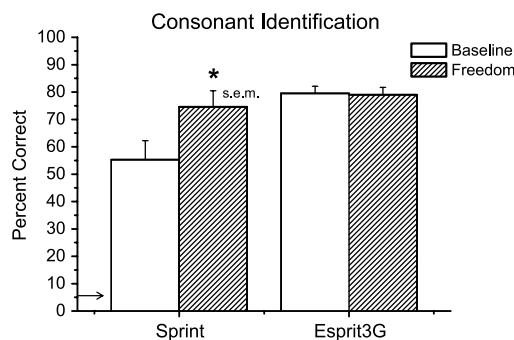


FIG. 6. Mean percentage of correct scores for consonant identification obtained from children using the Sprint or Esprit 3G processor at baseline and after 1 month's experience with the Freedom. Scores significantly increased when switching to the Freedom only for the group of children using the Sprint processor (paired t -test: $t = 2.57$, $p < 0.05$). The *horizontal arrow* indicates the chance test score.

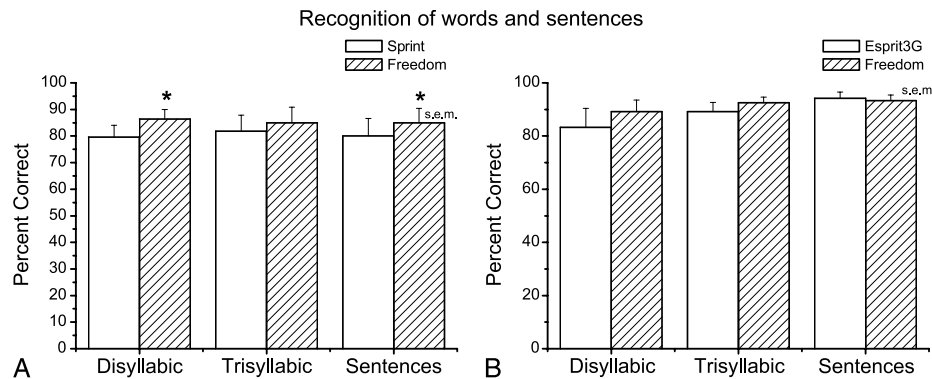


FIG. 7. Mean percentage of correct scores for recognition of disyllabic words, trisyllabic words, and sentences obtained from children using the Sprint (A) or Esprit 3G (B) processor at baseline and after 1 month's experience with the Freedom processor. Scores tended to be higher with the Freedom compared with the previously worn device in both groups of children. The increase was significant for recognition of disyllabic words (paired *t*-test: $t = 2.30$, $p < 0.05$) and sentences (paired *t*-test: $t = 2.34$, $p < 0.05$) only in the group using the Sprint.

To date, no studies have been performed in children using the Nucleus cochlear implant, comparing speech perception performances with different processors. This is a relevant issue because the newly released Freedom is compatible with almost all the past generation of internal Nucleus implant devices and has several new features compared with the earlier generation of sound processors such as the Sprint and Esprit 3G, the main one being the increase of the IDR that has been widened from 30 to 40 dB. To our knowledge, the only study addressing this problem was the Nucleus Freedom North American Trial (13). Scores obtained on the CNC word recognition test for 1 group of postlingually deafened adults using the Freedom were higher compared with those obtained for another group of implanted adults using the previous generation of Nucleus processors. Although the researchers suggest that examination of the preoperative subject demographics indicated no significant differences that could account for differences in postoperative outcomes between the groups, no definite conclusions could be drawn because groups of patients using different sound processors had not been matched on preoperative speech recognition scores. Alternatively, performance of patients wearing different types of sound processors might have been better evaluated using a within-subjects design as in the study reported here.

In our study, no changes in strategy, rate of stimulation, and current and base levels were performed when switching to the Freedom from the previously used sound processor. Microphone sensitivity was also unchanged in the group of children using the Sprint, and thus, the most remarkable difference imposed on this group was the relative widening of the IDR. In contrast, in the group using the Esprit 3G, microphone sensitivity was additionally, albeit slightly, increased in the Freedom processor and set to the default value of 12, which is 6 dB higher than the sensitivity previously set on the Esprit 3G processor. Looking at the sound field thresholds obtained with the cochlear implant, only the group of children using the Es-

prit 3G showed a small but significant improvement at low frequencies when switching to the Freedom. An improvement in sound field thresholds has also been observed in postlingually deafened adults when increasing microphone sensitivity in the Sprint processor (11), leaving the IIDR unchanged. In contrast, no changes were found on increasing the IIDR without changing microphone sensitivity (11). On the basis of these findings, it is reasonable to hypothesize that the threshold improvement seen for the Esprit 3G group when switching to the Freedom resulted from increased microphone sensitivity rather than from a larger IDR.

Children included in this study showed better identification and recognition scores after 1 month's experience with the Freedom compared with the previously worn processor. We think that the improvement of

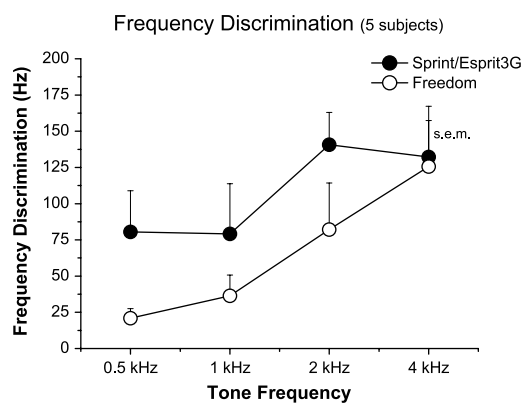


FIG. 8. Means and standard errors of the smallest difference in frequency perceived at several tone frequencies from a subset of 5 children are reported at baseline (full circles, Sprint/Esprit 3G) and after 1 month's experience with the Freedom processor (empty circles). The smallest difference in frequency perceived was significantly lower when switching to the Freedom compared with the previously worn processor (mixed linear analysis, $p = 0.003$).

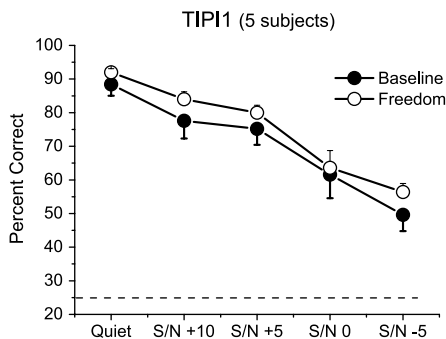


FIG. 9. Mean percentages of correct scores for identification of disyllabic words (TIPI1) are reported in quiet and in the presence of various levels of background noise for the group of children submitted to the frequency discrimination test at baseline (*full circles*) and after 1 month's experience with the Freedom (*empty circles*). Scores significantly increased when switching to the Freedom compared with the previously worn processor (mixed linear analysis, $p = 0.03$). The *dashed line* indicates the chance test score.

speech perception performances in difficult listening situations such as speech perception in noise and speech presented at low levels is mainly related to the increase in IDR, which has been widened in the Freedom compared with the previous generation of Nucleus sound processors. Studies conducted in postlingually deafened adults have shown that increasing IDR values resulted in better speech perception performances at soft presentation levels (10–12,18). Specifically, studies performed in patients using the Nucleus cochlear implant have shown that increasing IDR beyond 30 dB results in increased scores on CNC words or consonant perception at soft presentation levels, whereas no changes or poorer performance were observed on sentence perception test evaluated in noise (11–12). The group of children using the Sprint showed better performance when switching to the Freedom both in identification of disyllabic words at a soft presentation level and in the presence of background noise. Because no changes in microphone sensitivity were imposed in the Freedom, the performance improvements should only be attributed to a larger IDR. These findings are different from the results reported by James et al. (11) or Dawson et al. (12) who found no improvement of sentence perception scores in background noise when widening the IIDR; however, it should be taken into account that, in these studies, an increased IIDR resulted from an extension of the lower part of the loudness range with consequent maintenance or even worsening of the SNR for louder sounds. In contrast, a larger acoustic input amplitude has been mapped into the whole electrical intensity range in the Freedom compared with the previous generation of Nucleus processors, and this may explain why speech perception in noise was improved in children included in this study when switching to the Freedom processor.

Differently from the group of patients using the Sprint, those using the Esprit 3G showed a significant improvement in performance only in identification tests

administered at a soft level, whereas differences on identification scores in the presence of background noise, albeit higher, did not improve significantly when switching to the Freedom. The same was true for consonant identification and open-set speech recognition. We think that the reason for these differences is twofold. First of all, the number of children included in this group was small. Small differences in performance when using different sound processors might have been significant if the sample size had been larger. Moreover, we think that differences in performance between the 2 groups of patients when switching to the Freedom might ensue from differences in performance at baseline as children using the Esprit 3G showed better performance than their peers included in the Sprint group (compare Fig. 2, A and B). This was true except for vowel identification scores that, at baseline, were lower in the group using the Esprit 3G. Accordingly, a significant improvement in vowel identification when switching to the Freedom was found only in this group. This finding might result from the use of higher microphone sensitivity in the Freedom compared with the Esprit 3G processor because better scores on vowel identification task have been obtained by James et al. (11) on increasing microphone sensitivity in Sprint users.

Compared with the previously worn processor, the smallest pitch difference on test of frequency discrimination was significantly lower when tested with the Freedom. Studies in normal hearing listeners performed by manipulating the spectra of stimuli (19) or simulating cochlear implant processing (20) indicate that frequency resolution may influence the ability to perceive speech in the presence of background noise. The better the frequency resolution, the higher the listener's ability to take advantage of the temporal or spectral minima of complex sounds when segregating different sources (20). Therefore, we suggest that the improvement in speech perception performance in the presence of background noise obtained with the Freedom compared with the previously worn processor ensues from a better frequency resolution. This is also supported by the significant improvement ($4.72 \pm 2.09\%$) in identification of disyllabic words found in the group of five children enrolled in the frequency discrimination test (mixed linear analysis, $p = 0.03$) (Fig. 9).

In conclusion, the results of this study show that speech perception performances improve with the Freedom compared with previous generation Nucleus processors. On the basis of these findings, the substitution of earlier generation sound processors with an upgrade to the Freedom would be advisable for children implanted with the Nucleus cochlear implant to provide the potential for further improvement in their speech perception abilities.

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