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A Multicenter Clinical Evaluation of Data Logging in Cochlear Implant Recipients Using Automated Scene Classification Technologies

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Keywords

Cochlear implant listening habits · Automatic SCAN · Cochlear implants in noise · Data logging

Abstract

Currently, there are no studies assessing everyday use of cochlear implant (CI) processors by recipients by means of objective tools. The Nucleus 6 sound processor features a data

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logging system capable of real-time recording of CI use in different acoustic environments and under various categories of loudness levels. In this study, we report data logged for the different scenes and different loudness levels of 1,366 CI patients, as recorded by SCAN. Monitoring device use in cochlear implant recipients of all ages provides important information about the listening conditions encountered in recipients' daily lives that may support counseling and assist in the further management of their device settings. The findings for this large cohort of active CI users confirm differences between age groups concerning device use and exposure to various noise environments, especially between the youngest and oldest age groups, while similar levels of loudness were observed.

Table 1. Age classification of cochlear implant users

Age group, years	Patients, *n*	Gender	
		female	male
0–2	121	60	61
3–5	206	101	105
6–10	229	109	120
11–13	100	54	46
14–18	137	62	75
19–30	119	55	64
31–40	72	48	24
41–50	104	63	41
51–65	128	71	57
66–75	105	45	60
>75	45	25	20
	1,366	693	673

Introduction

Recent developments in cochlear implant (CI) technology have focused on improving the "real-life hearing" of implanted people. It is well known that, in everyday life, speech intelligibility is often degraded owing to noisy conditions. Various studies with normal-hearing individuals have reported that a high signal-to noise ratio (SNR), approximately 15 dB, is required for good speech understanding [Bradley and Sato, 2008; Wróblewski et al., 2012]. At +5 dB SNR, sentence recognition for adults with normal hearing is approximately 95% correct; instead, the mean performance of CI recipients is reduced significantly in poorer SNR conditions, where the score falls to 20% correct [Wolfe et al., 2013a, b]. Until recently, the assessment of how long a CI is used daily by a patient could only be obtained through the use of questionnaires and the speech-in-noise ability analysis performed by clinicians during audiological evaluations. Such tools, however, are unable to thoroughly reproduce the "real-world" listening conditions encountered by CI users.

The new Nucleus 6 system sound processor incorporates an algorithm to accurately classify and store information about recipients' daily exposure to the various listening environments. These data can thus be used through data logging and a technique known as automatic scene classifier (SCAN) [Case et al., 2011; De Ceulaer et al., 2015; Mauger et al., 2014].

The SCAN analyzes microphone input signals and classifies the sound environment into 1 of 6 scenes (speech in noise, speech, noise, wind, quiet, and music). The same scenes are divided into subclasses of loudness: less than 40 dB sound pressure level (SPL), from 40 to 49 dB SPL, from 50 to 59 dB SPL, from 60 to 69 dB SPL, from 70 to 79 dB SPL, and ≥80 dB SPL. For each scene, SCAN automatically selects the most appropriate microphone directionality and activates input processing based on the determined listening environment. The data logging records how often certain scenes are detected by SCAN, reports the average daily time a recipient has used the device, the listening environments experienced since the last visit to the clinic, the loudness of listening environments, and the program, volume, and sensitivity settings used by recipients.

According to a study by Easwar et al. [2016], different aspects make the use of CI data logging advantageous. Indeed, it improves the accuracy of the device use, it provides better resolution of the data obtained, and it can quantify lack of stimulation due to a disconnected transmission coil or inappropriate use of the device.

This report summarizes the results obtained from the data logging analysis performed on a large cohort of active CI patients from 30 Italian clinics. The aim of the study was to analyze the features of the different daily scenes and loudness experienced by CI in different age groups. This information will be used to provide normative data on CI data logging.

Materials and Methods

The study was approved by each institution's review board and is in accordance with the Helsinki declaration. This prospective study initially included 1,485 CI recipients gathered from 30 Ital-

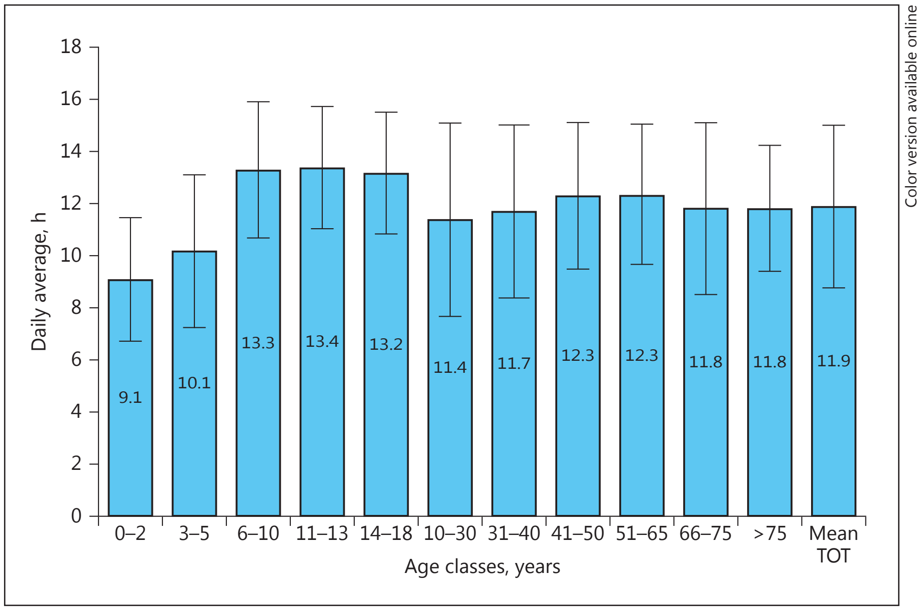

Fig. 1. Average daily use of the cochlear implant by age. Mean TOT, daily average use of the device regardless of age class.

ian ENT clinics. Ultimately, 118 patients were not included due to inappropriate use, or nonuse, of the device. Different reasons for nonuse of the device as reported by CI patients were generally related to poor adaptation to the new system, including the adaptation phase (40%), new processor (13%), serious physical problems (11%), and unknown (36%). Most of the excluded patients (74 subjects) were younger than 18 years and 54 were pediatric (<10 years old). In particular, 32 subjects were in preschool, 46 in school, 12 were young adults, 22 were working adults, and 6 subjects were >75 years (seniors).

The remaining 1,366 CI patients (693 females and 673 males) were divided into 11 age groups, as shown in Table 1. All CI patients were implanted with a Nucleus device and had experience with the new sound processor CP910 for at least 6 months.

The patient data were obtained from Custom Sound software (Cochlear, Sidney, Australia). Each clinic collected patient files anonymously in a new software database. Logging data were extracted with a specific tool that interrogates the Custom Sound database. All files were sent to the coordinating center for statistical analysis.

Statistical analysis was performed using the statistical package MedCalc 16.21 (Marienkerke, Belgium). For each patient, gender, age, 6 scenes (music, wind, speech in noise, speech in quiet, quiet, noise), and 6 classes of loudness were considered. The daily average use was obtained from the sum of all the average durations of the exposure scenes. Each value provides the average exposure time expressed in minutes.

Results

The study was performed by stratifying CI patients according to the 11 age classes shown in Table 1. Each age range was well represented, and the sample illustrates the study population. Thus, the distribution by age (child vs. adults) was nearly equally divided at 58% and 42% with respect to the total number, as well as for gender (female = 693, male = 673) and for youngest versus eldest (9 and 11%). The largest combined cohorts were 3–10 year olds (more than a 3rd of the total). Teenagers (11–18 years) made up 17% of the study group, and working adults (arbitrarily chosen as between 31 and 65 years) were represented by 22% of the CI users.

The group aged >75 years was the smallest, with 45 subjects. For the central limit theorem, this group may be considered as representative of the studied population because it involves more than 30 cases.

Average Daily Length of Use

The daily average use of the CI was 13 h/day for the age classes ranging from 6 to 18 years. The daily average use tended to be lower in the first 5 years of life (9–10 h), and highest for subjects aged 6–18 years (13.3 h). For those older than 19 years, the average duration of use was 11–12 h (Fig. 1). It is important to specify that there was considerable variability in the CI daily duration of use between the different clinics.

A further insight into these data is provided by Table 2, in which an alternative classification is shown according to education and time spent at work. The categorizations in Table 2 are arbitrary; for instance, young adults could be included in the working-age category. However, both the mean number of hours of CI use and the duration of use differ only minimally across all adult categories.

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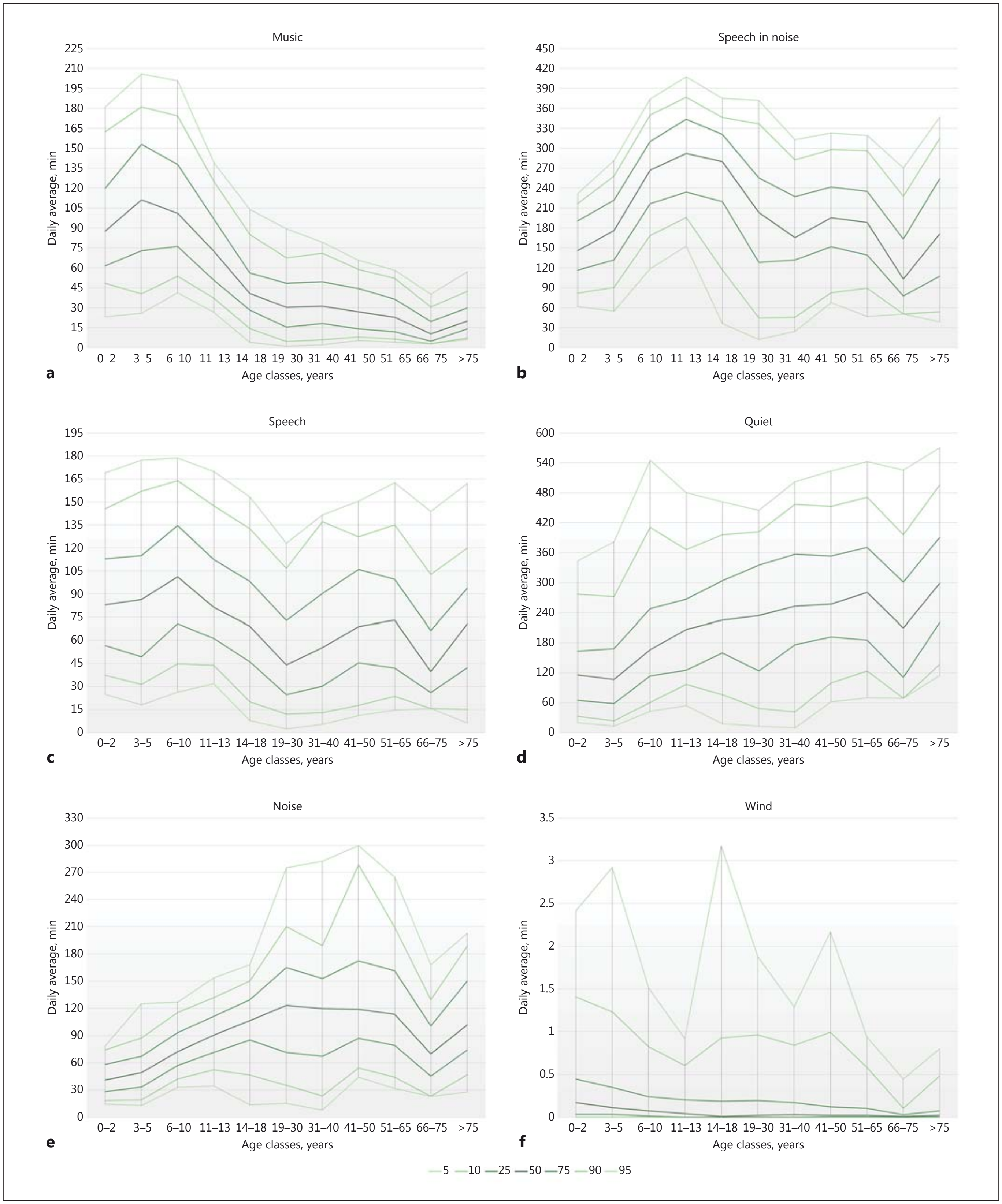

Fig. 2. Scene subclasses (in percentiles) regardless of age: music (**a**), speech in noise (**b**), speech in quiet (**c**), quiet (**d**), noise (**e**), and wind (**f**).

Table 2. Categories of users according to age groups and their data-logged duration of use

Groups	Age range, years	Average use, h/day	% of total (n = 1,366)
Preschool	0–5	9.6	9
School age (including teenagers)	6–18	13.3	49
Young adults	19–30	11.4	9
Working adults	31–65	12.1	22
Retired and seniors	≥66	11.8	11

The Features of the Exposure Environments

The exposure environments considered consisted of 6 scenes: music, speech in noise, speech in quiet, quiet, noise, and wind, as shown in Figure 2a–f. Each value represents the average exposure time expressed in minutes. The values are expressed in percentiles.

Music Scene

Analysis shows that, on average, children ranging in age from 3 to 5 years spent more time in this scene; about 50% of the subjects spent 118 min per day, in a time range from 85 min (25th percentile) to 155 min (75th percentile). The average time of exposure to the music scene decreased steadily from 6 to 18 years of age (from 103 min in the 6–10 years age group to 45 min in the 14–18 years age group), while in recipients aged from 19 to over 75 years, the time remained stable at 22 min per day on average (Fig. 2a).

Speech in Noise Scene

Implanted patients from all age groups spent, on average, 219 min per day in the speech in noise scene. The greatest exposure was achieved by the age classes ranging from 6 to 18 years.

In particular, an average exposure time of 306 min (25th percentile, 247 min; 75th percentile, 347 min) was found in the 11–13 years age class. For the 6–10 years class, the analysis revealed an average exposure time of 277 min (25th percentile, 228; 75th percentile, 315), and for the 14–18 years class, an average exposure time of 288 min (25th percentile, 243 min; 75th percentile, 328 min; Fig. 2b).

Speech in Quiet Scene

In this scene, the highest exposure time was shown for the age range from 6 to 10 years. In this scene, children spent, on average, 104 min per day (25th percentile, 76 min; 75th percentile, 138 min). The lowest time spent in this scene was represented by age classes ranging from 19 to 30 years, with an average of 47.5 min per day (25th percentile, 31 min; 75th percentile, 75 min; Fig. 2c).

Quiet Scene

From the distribution of the data, it was observed that the time spent by patients in the quiet scene grows steadily with increasing age. The 3–5 years age class is the group that spent the least amount of time in the quiet scene, with an average of 111 min per day (25th percentile, 72 min; 75th percentile, 176 min). The age class represented by those over 75 years spent more time in quiet compared to all the other age classes, with an average of 305 min per day (25th percentile, 230 min; 75th percentile, 397 min; Fig. 2d).

Noise Scene

The implanted patients who spent most time during the day in the noise scene belonged to the 19–65 years age range. In fact, these patients spent, on average, 123 min per day in the noise scene. Implanted children in the 0–2 years age class spent only 42 min a day in this scene (25th percentile, 32 min; 75th percentile, 60 min; Fig. 2e).

Wind Scene

Exposure to wind, in terms of minutes per day, was very low for all of the classes analyzed. The highest value observed was represented by children aged 0–2 years, with an average of 0.183 min per day (Fig. 2f).

Acoustic Features of the Loudness of the Scene

Six levels of loudness recorded by SCAN were evaluated (<40 dB SPL, 40–49 dB SPL, 50–59 dB SPL, 60–69 dB SPL, 70–79 dB SPL, and ≥80 dB SPL). The values provide the average exposure time expressed in minutes for each subclass of loudness. In Figure 3, the values are expressed in percentiles.

For all age classes, for most of the time in which the processor was switched on, the most frequent levels of loudness were between 40 and 69 dB SPL. In particular, implanted patients spent, on average, 127 min per day at 40–49 dB SPL, 193 min per day at 50–59 dB SPL, and 185 min per day at 60–69 dB SPL. Less time per day was spent in other levels of loudness (56 min at <40 dB SPL, 88 min at 70–79 dB SPL, and 20 min at ≥80 dB SPL; Fig. 3a–f).

The age group ranging from 31 to >75 years spent more time on average in the 40–49 dB SPL level of loudness than the younger patients (157 min per day; Fig. 3b). Children belonging to the groups ranging from 3 to 13

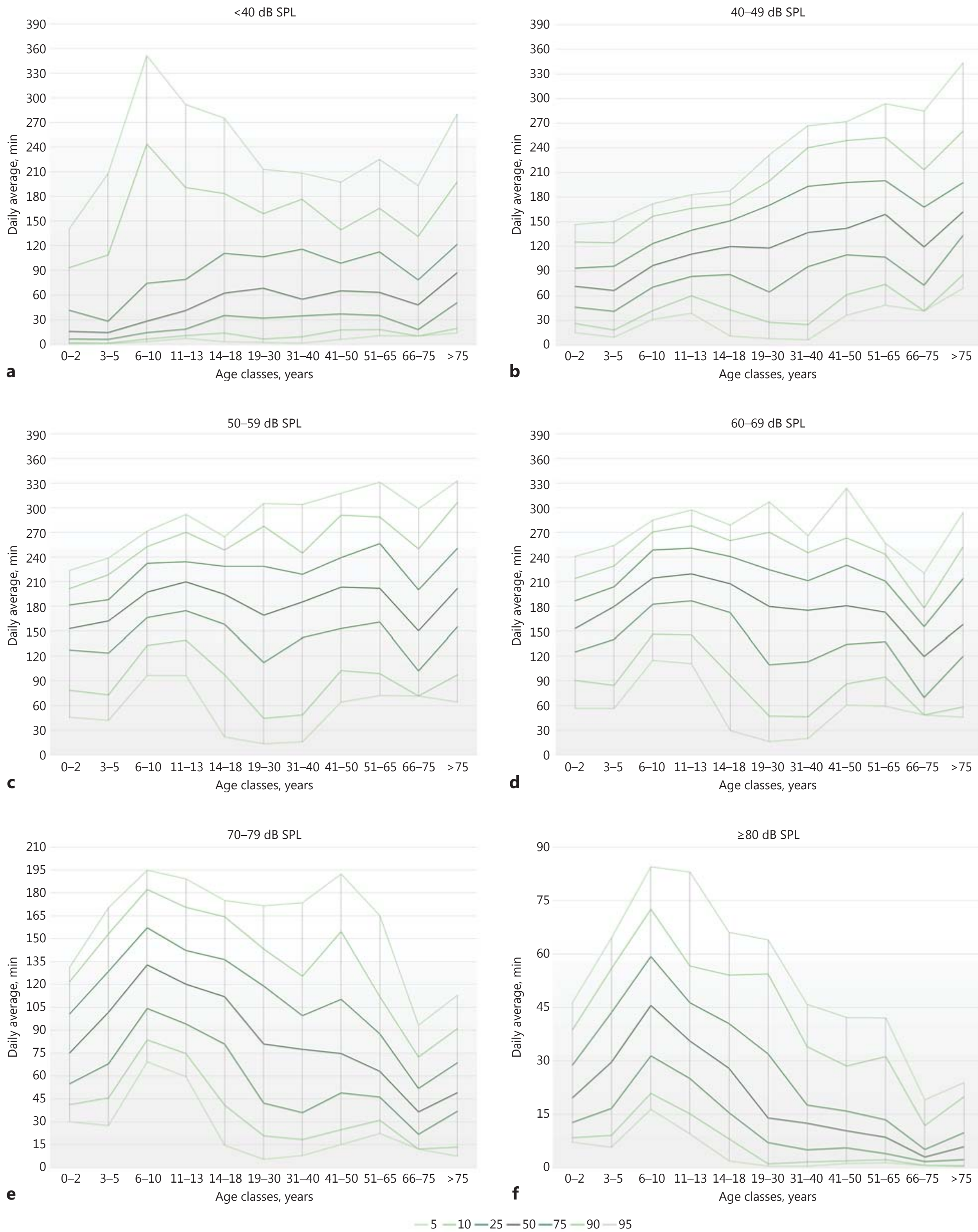

Fig. 3. Loudness subclasses regardless of age: <40 dB SPL (**a**), 40–49 dB SPL (**b**), 50–59 dB SPL (**c**), 60–69 dB SPL (**d**), 70–79 dB SPL (**e**), and ≥80 dB SPL (**f**).

Color version available online

Table 3. Summary of average daily (weighted average) use per environmental scene per age group (data-logged minutes)

	0–5 years	6–10 years	11–18 years	19–30 years	31–65 years	≥66 years
Music	113.5	113	62	37	31	24
Speech in noise	177	273	290	210	169	175
Speech in quiet	94	109	86	54	76	76.5
Quiet	146	219	249	246	292	326
Noise	54	78	107	133	134.5	107
Wind	0.53	0.28	0.43	0.56	0.32	0.21

Table 4. Summary of average daily (weighted average) use per loudness group (data-logged minutes)

	0–5 years	6 –10 years	11–18 years	19–30 years	31–65 years	≥66 years
<40 dB SPL	41	81	89.5	86	86	101
40–49 dB SPL	79	104	123	125	161	178
50–59 dB SPL	162	204	207	179.5	205	205
60–69 dB SPL	174	220	218	181	181	158
70–79 dB SPL	98	137	121	89	82	58
≥80 dB SPL	30	48	36	23	15	9

years spent more minutes each day in the 50–69 dB SPL subclasses of loudness (Fig. 3c, d).

The greatest exposure in subclasses with the highest loudness (70–79 dB SPL and ≥80 dB SPL) was recorded in the 6–10 years age range. The groups ranging in age from 3 to 18 years achieved more than 100 min per day in the 70–79 dB loudness subclass, while 3–13 groups were exposed to loudness ≥80 dB SPL for more than 30 min per day. The oldest age classes (≥66 years) spent less than 1 h at 70–79 dB SPL, and less than 10 min at loudness levels ≥80 dB SPL per day (Fig. 3e, f).

Summary of Data Logging

Table 3 summarizes the average daily use of the CI in different environmental scenes considering the classification made according to education and working time: preschool (0–5 years); primary school (6–10 years), secondary school (11–18 years), young adults (19–30 years), working adults (31–65 years), and seniors (≥66 years). The age groups ranging from 0 to 18 years, on average, spent more time in speech in noise compared to adult groups. Moreover, teenagers (11–18 years old) spent more time in speech in noise, in quiet, and in noise scenes compared to younger subjects.

From the evaluation of adult groups (>19 years), a longer use of the CI in a quiet scene was found than in other environments. Most of the groups spent the least time in the wind, speech in quiet, and music scenes, whilst subjects <10 years spent a shorter time in wind, noise, and speech in quiet scenes.

Table 4 summarizes the average daily use of the CI at the different levels of loudness considering the classification made according to education and working time. Subjects younger than 30 years spent a greater amount of daily time at the 50–69 dB level of loudness, while the other levels most affected were 70–79 dB SPL for children under 10 years and 40–49 dB SPL for subjects between 11 and 30 years of age. Groups aged >31 years spent more time at the 3 levels of loudness ranging from 40 to 69 dB SPL.

Discussion

A tool making it possible to perform a detailed analysis of CI users' real-life daily use has the potential to be very helpful. So far, the only way to evaluate speech processor use has been the administration of patient self-reports. However, these can often be misleading or unavailable, especially with older and younger subjects, and they have an intrinsic bias represented by under- or overestimation and inaccurate responses. Moreover, self-reports do not allow comparison of 1 patient with another or 1 patient over time [Perez and Edmonds, 2012]. This is the first study reporting normative data on the SCAN and data logging functions available with the Nucleus 6 sound processor, in a large cohort of CI users ranging from babies to elderly patients.

Daily Average Use of the CI

With regard to the daily average use of the CI, subjects aged between 6 and 18 years showed the highest number of hours of actively while wearing the device (average of 13.3 h per day). Daily average use tended to be lower during the first 5 years of life (9–10 h), whereas for all age classes above 19 years (19 to >75) the average use was 11–12 h.

The reduced use of CI in children over their first years of life may be related to a longer time spent asleep each day. The total sleep duration is, on average, 14.2 h at 6 months of age and decreases to 8.1 h at 16 years of age. In particular, the most prominent decline in napping habits occurs between 1.5 and 4 years of age [Iglowstein et al., 2003].

It should also be considered that younger children are not particularly cooperative and they tend not to inform parents or caregivers (e.g., teachers) about CI detachment or malfunctioning. This means that if these problems are not recognized promptly the implant can remain switched off even for a long period of time.

Subjects in the primary and secondary school age groups (6–18 years) are the main CI users. This is possibly due to their involvement in many daily educational (school) and extra-educational activities (sport) which require good communication capabilities. Moreover, in most cases these subjects rely totally on their CI, since they have a long CI experience due to having been implanted in the first years of life for congenital hearing loss.

Because there are no published reference data for CIs, a comparison can only be made with data logging studies conducted on hearing aid users. In a study by Laplante-Lévesque et al. [2014], subjects with hearing aids reported an average daily use that was 1 h longer compared to objective measures such as data logging. This difference was explained by a different use of the device in the sample. In particular, patients using the hearing aids differently from day to day had significant mismatching between data-logged and self-reported hours of device use.

The correlation between the amount of experience and hours of daily use of the device is consistent with the findings of Walker et al. [2013], who stated that longer hearing aid use is related to older age, and younger children wore hearing aids less consistently than older children. Instead, stable daily average use (11–12 h) in adult groups (>19 years) may be attributed to the daily routine use of hearing aids prior to the CI. In accordance with our hypothesis, Laplante-Lévesque et al. [2014] studied a sample of 228 hearing aid users and found that mean device use was 10.5 h per day.

When monitoring implanted patients, it is important to evaluate the daily average use of the device, especially in the eventuality of a negative outcome that cannot be attributed to other specific reasons. In the case of limited daily use of the device, patients (or their caregivers) should be encouraged to use their device more to achieve a better outcome.

The current data logging process does not differentiate among daily exposures or among working days or weekends. For better counselling and to determine specific hearing strategies at different times or in different environments, it would help to have specific information about the use of the implant at different times of the week or in different parts of the same day.

Exposure Environments

Previous research (both in adult and in pediatric CI subjects) has shown that Nucleus 6 sound processor users obtain significant improvements in terms of speech intelligibility and perception in listening in noisy conditions. These results were achieved thanks to the noise reduction and SCAN technology features of the new processor [Plasmans et al., 2016; Wolfe et al., 2015].

It is certainly interesting to assess how many hours per day CI recipients spend in different environments and if any difference emerges across age groups. In our sample, the distribution of daily CI use in the 6 scenes changed according to the age class being considered. Indeed, subjects in the preschool and school groups (0–18 years) spent most of the day in the speech in noise scene, whilst adult groups (>19 years) spent a longer time in the quiet scene.

It is well known that noisy school environments are the scenes where children generally spend most of their time talking. Guidelines were thus drawn up in various countries for classroom acoustics, indicating ambient noise levels and reverberation times. Some guidelines [e.g., the American National Standard Institute, 2010] recommend SNR levels and reverberation times that are lower in classrooms for children with hearing loss than those with no deaf children. However, the acoustics of typical classrooms do not always meet these criteria.

Our study agrees with the literature that school-aged CI children, in particular the secondary school group (11–18 years), spend more time in these noisy environments. In addition, previous research has clearly demonstrated the benefit of a good SNR for speech understanding in children [Caldwell and Nittrouer, 2013; Gifford et al., 2011; Meister et al., 2015; Plasmans et al., 2016]. The use of hearing assistance technology for CI patients is therefore essential to improve speech recognition in classrooms.

It is interesting to note that, in our sample, the age groups that spent the longest time in the noise scene were not children but rather adults aged from 19 to 65 years. Children, mainly ranging from 6 to 18 years of age, spend time in noisy environments preeminently featuring a lot of speech.

The quiet scene was the most represented environment in the adult groups (aged from 19 to ≥66 years) and the second most frequent in child groups. A gradual increase in daily average CI use could be observed in the quiet scene from the preschool to the senior groups, with a peak in adults over 75 years of age.

In the elderly group, the time spent in the quiet scene was greater than the sum of noisy environments (speech in noise and noise), suggesting an increasing solitude with age.

Speech in quiet was the fourth most common scene among all groups. Together with the speech in noise scene, this scene was more represented in child groups, with a peak in the group ranging from 6 to 10 years of age. The least common exposure to this scene was in the 19–30 age group.

Children with CI spent several hours in the speech in quiet scene because their caregivers create a quiet communicative environment (e.g., during speech and language therapy or schoolwork in a small group of children). In particular, sessions of speech and language therapy are carried out in a quiet room where the therapist speaks close to the child. The duration of treatment is different between the age classes; children continue until the end of school (or more), whereas adults remain in treatment only in the first months after starting to use the CI. Thus, speech and language therapy and school time can be related to a longer time spent in the speech in quiet scene in child CI groups.

For younger subjects (<10 years of age), the time spent in music is 4-fold longer compared to adult groups (>19 years) when using the device, and this is probably due to speech therapy sessions and television programs for children that contain more music than the programs watched by the elderly.

In summary, the most represented environments in all groups are the speech in noise and quiet scenes, followed by music for children <10 years of age and noise for subjects >19 years of age. These data are important for careful and accurate counseling for the separate age groups. As for the differences found between children and adult CI subjects, it would be interesting to evaluate, in future research, how the different exposure times in the 6 scenes affect children's speech perception and production.

Loudness of the Scene

With regard to the levels of loudness, on average all groups spend more time at levels between 50 and 69 dB SPL. These are the typical levels of the human voice. Moreover, in our sample, children and young adults spent more daily time at higher levels of loudness than adults and senior groups. This is probably due to a longer time spent in noisy environments (school, gym, pub, etc.) at high levels of loudness. In contrast, as previously mentioned, elderly subjects spent more time in the quiet scene, which means a lower level of loudness.

Conclusion

The evaluation of the data recorded by SCAN showed different features for the exposure environments for each age class considered. In particular, we found some differences between children and adult CI recipients: child groups spend more time in noisy environments at high levels of loudness, whereas adult groups spend more daily time in the quiet scene at lower levels of loudness.

In the absence of previous studies related to daily average use, use in different environments, and levels of loudness, this study can be used by clinicians for comparing CI patient values to those of the representative age group. Our results show that data logging can provided valuable information for clinicians for the purpose of troubleshooting, counseling, program optimization, and therapeutic intervention planning for CI recipients. However, additional research is needed to evaluate the effectiveness of SCAN during real-world use, to see whether resultant implications gathered in real-life daily conditions will enhance the CI listeners' hearing experience, lead to alternative programming options, and better counseling support.

Moreover, it is important to gather information about the differing use of the CI on working days or at weekends, or at different times of the same day, to allow better counselling and to determine specific hearing strategies at different times or in different environments (for example, the use of the wireless system).

The results of our study provide some suggestions for future data logging. Analysis of exposure environments shows that very few implant recipients experience windy conditions. It is thus possible to drop the identification of wind scenes and replace them with more relevant categorizations of noise (e.g. babble vs. industrial vs. street atmospheres). Furthermore, for a specific mapping, it would be interesting to know the frequency bands of noise.

Disclosure Statement

The authors declare that no conflicts of interest exist. No sponsorship or funding was received for this study.

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