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Benefit of the UltraZoom Beamforming

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Technology in Noise in Cochlear Implant Users

4

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5

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15

Advanced Bionics

16

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17

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18

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19

de-France VI. Subjects obtained no reward or personal gain from taking part in the study. The

20

study was conducted in accordance with the Declaration of Helsinki and followed Good Clinical

21

Practice Guidelines.

22

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INTRODUCTION

25

26 Exchange of the sound processor of cochlear implants (CI) allows existing implant recipients to
27 take advantage of any advances in sound processor technology by exchanging or upgrading their
28 current processor to a newer model [1,2]. Funding of processor upgrade differs from one country
29 to another. Considering the high prices of the processors, the benefit provided by new processors
30 must be demonstrated.

31 In 2013, Advanced Bionics (AB, Stäfa, Switzerland) introduced the Naída CI Q70 (Naída CI)
32 sound processor. As well as being compatible with the newest AB cochlear implant systems, it
33 was also compatible with the existing HiRes 90K[®] and CI[®] cochlear implant systems and
34 therefore existing recipients of AB devices, who were using older sound processor types, could be
35 upgraded to the newer technology. In addition to the functions and sound processing technology
36 already available in the previous generation sound processors, the Naída CI introduced an
37 acoustic signal processing beamforming technology called UltraZoom, which was already used in
38 Phonak hearing aids (Nyffeler, Reference Note 1). The intention was to help AB implant
39 recipients to communicate more easily and effectively in noisy environments, which still remains
40 a challenge, even for the best performing recipients [3].

41 UltraZoom is an adaptive multi-channel dual-microphone beamformer that focuses on input
42 originating from in front of the listener, while attenuating sounds coming from the sides and from
43 the rear (Fig. 1). It works by exploiting timing and phase differences in the signal arriving at two
44 spatially separated front and back omnidirectional microphones, positioned on top of the
45 processor. The inputs from the two microphones are subtracted from each other, after applying an
46 appropriate delay, and a front-facing directionality pattern is created, reducing input from the rear
47 hemisphere and creating a null point where sounds are completely attenuated. The adaptive nature
48 of UltraZoom allows it to constantly change the directionality of the null, based on the loudest

49 noise source in 33 separate channels, thus suppressing moving noise sources as well as static ones
50 [4].

51 Previous studies evaluating adaptive beamforming technology with ~~Cochlear Ltd.~~ CI devices
52 have shown that it can significantly improve the perception of speech in noise [5-98]. Geißler et
53 al. [4] tested UltraZoom as implemented in the Naída CI in 10 subjects, and showed significant
54 improvement in speech perception in noise in a variety of challenging and realistic conditions,
55 when compared to the Harmony sound processor. However, subjects had no take-home
56 experience with the new sound processor and therefore it is not known if they would have been
57 able to transfer these gains shown in the laboratory, into the real world. This is a potential issue
58 for all beamforming technologies, as CI users report smaller subjective benefits than expected
59 from laboratory testing [5]. In part, this may be due to the fact that listeners often find themselves
60 in situations where speech and noise sources are not sufficiently spatially separated, particularly
61 in reverberant environments, which results in cancellation of the speech signal as well as the
62 noise and reduces the signal to noise advantages gained [910,112]. In the previous studies where
63 subjective measures have been reported, two failed to show a significant improvement in
64 subjective performance with the beamforming technologies using the Speech Spatial Qualities
65 questionnaire, even though the objective results did show a significant benefit [5, 910]. Only
66 Mosnier et al. [1] did show a significant improvement in performance in both objective and
67 subjective measures using the Abbreviated Profile of Hearing Aid Benefit (APHAB) [1213],
68 when subjects using Cochlear Ltd. devices were upgraded to the newer CP810 speech processor
69 with additional directionality.

70

71 The objectives of this study were to compare the performance of a group of existing AB cochlear
72 implant users, who were upgraded to the new Naída CI sound processor, in a test of speech
73 perception in noise with and without UltraZoom and to compare their subjective performance

74 with their current sound processor, to their subjective performance after upgrading to the new
75 Naída CI sound processor.

76

77

METHODS

Subjects

78
79 From February to November 2015, 34 adult subjects aged between 21 and 89 years old (mean
80 52.8 ± 18.5) were prospectively enrolled in a single tertiary ~~referent~~ referral center. Subjects were
81 required to have at least one CII/HiRes 90K cochlear implant, a postlingual onset of severe-to-
82 profound hearing loss ($\times 6$ years of age) and French as their first language. The demographic data
83 of these subjects is presented in Table 1. Nine subjects were unilaterally implanted, 11 bilaterally
84 implanted and 14 were bimodal users with a hearing aid on the contralateral ear. All subjects
85 were experienced CI users (5 to 14.7 years, mean 6.9 ± 1.8) who were due to get a processor
86 upgrade to the Naída CI as part of their routine clinical care. A repeated measures design was
87 used, where subjects acted as their own controls.

Fitting

88
89 At the baseline visit, subjects were fitted with a loaner sound processor for the purposes of
90 testing, identical to their current processor. This was to ensure that all microphones were new and
91 working optimally. It was programmed with their current clinical program, including the speech
92 enhancement algorithm ClearVoice[®] [13,14] as well as the T-Mic[®] microphone setting
93 (microphone placed within the concha) [6,14,15], if this was used on an everyday basis. They
94 were then upgraded to a new Naída CI sound processor, programmed with the same current
95 clinical program and an identical clinical program plus UltraZoom. The T-Mic microphone and
96 ClearVoice algorithm continued to be used with the Naída CI if they had been used with the
97 original processor. They were given a minimum of a two months take-home trial with the Naída
98 CI sound processor, where they were encouraged to use UltraZoom in appropriate situations,

99 where speech was coming from the front and noise from the back and sides of the recipient. The
100 Advanced Bionics SoundWave[®] programming software was used and all program parameters
101 remained the same, unless the subject was not happy with the sound quality, in which case
102 alterations to the current clinical program were made accordingly. All bilateral CI users except
103 one were upgraded on both sides.

104 *Speech perception measures*

105 Speech understanding in quiet was evaluated with two lists of seventeen monosyllabic words
106 each (Lafon lists) presented at 60 dB SPL from a source based at one meter in front of the subject.
107 Speech understanding in noise was measured with the Matrix sentence test in French [4516],
108 which is an adaptive test based on the Oldenburg sentence test (OISa) [4617]. The subjects were
109 asked to repeat semantically unpredictable sentences, which always had the same structure:
110 Name, Verb, Number, Common name and Colour. A speech reception threshold (SRT) was
111 automatically measured by adjusting signal to noise ratio until a 50% word understanding score
112 was reached. A lower SRT means a better performance. Prior to testing, at least two practice lists
113 (each containing 20 sentences) were presented to the subject to avoid training effects during the
114 test.

115 Sentences were presented from a loudspeaker located one meter in front of the subject (0-degree
116 azimuth). Non-correlated stationary speech shaped noise (SSN) was presented at a fixed level of
117 65 dB SPL simultaneously from all three loudspeakers positioned at +/-90° and 180° to simulate
118 a diffuse noise environment. The level of the speech signal was varied to adjust the signal to noise
119 ratio. A low to moderately reverberant room was used, with a T_{60} of around 0.3 seconds.

120 Subjects were evaluated while listening with the technology that they utilized in their daily
121 environments; participants with a Naída CI processor on one ear and a contralateral hearing aid
122 were tested with both devices together, bilateral participants (two Naída CI processors or one

123 Naída CI processor with another processor type contralaterally) were tested with both devices
124 turned on. The contralateral hearing aid was not fitted or changed during the follow-up period.

125 At the baseline visit, speech perception was measured with words in quiet with the current sound
126 processor and sentences in noise with the current sound processor and the new Naída CI sound
127 processor in the omnidirectional microphone mode, without UltraZoom. At the follow up visit,
128 two months later, speech perception was measured in quiet with the Naída CI processor without
129 UltraZoom and in noise with the Naída CI sound processor with and without UltraZoom (Table
130 2). The order of the speech test lists and the test conditions were randomized using a
131 randomization table prepared before the start of the study. At the end of the study the subjects
132 returned home with the new Naída CI sound processor.

133 *Subjective Testing*

134 Subjects self-assessment of their hearing with the different sound processors and programs was
135 recorded using the APHAB [4213]. This 24-item self-assessment inventory requires recipients to
136 report the amount of trouble they are having with communication in various everyday situations.
137 Benefit is calculated by comparing the recipient's reported difficulty in listening in the specified
138 scenarios. There are four subscales: Ease of Communication (EC), Reverberation (RV),
139 Background Noise (BN), and Aversiveness (AV). Scores are given on a scale from A to G where
140 A is "I always experience this" and G "I never experience this". A percentage score from 1% to
141 99% is allocated to each category of response to give a mean percentage for each section. The
142 average score for each subsection, recorded at baseline with the previous sound processor, was
143 compared to the average score recorded at the two month follow up visit with the Naída CI sound
144 processor. A global score was also calculated, which is the mean of the scores for all the items in
145 the three EC, RV and BN subscales.

146 *Statistics*

147 The results for each test session were compared independently. Scores for words in quiet and the
148 Matrix sentence test in noise were not normally distributed, so a non-parametric Wilcoxon paired

149 test ~~were~~ was used. Individual scores in quiet were compared using the binomial model described
150 by Thornton and Raffin [18]. The different subsections of the APHAB data were compared using
151 a series of non parametric Wilcoxon tests. A p value of less than 0.05 was considered to be
152 significant, A power calculation showed that in order to detect a difference of 2 dB with sufficient
153 power (80%) and at a significance level of $p=0.05$, a minimum of 17 subjects was required for the
154 objective testing.

155

156

RESULTS

157

Speech perception testing

159 When subjects were tested in quiet, there was no difference in group performance between the
160 previous sound processor(s) at baseline and the Naída CI processor(s) in omnidirectional mode
161 after two months use (median score of 53.8% ranging from 5% to 94% and median score of
162 52.5% ranging from 0% to 97%, respectively) (Wilcoxon paired test, $Z=0.37$, $p>0.05$) (Fig. 2+).
163 Analysis of individual scores using the binomial model, described by Thornton and Raffin
164 (1978), showed that four out of the 34 subjects had a significant improvement in scores between
165 the baseline and second test sessions (18). One subject saw a significant reduction in speech score
166 in quiet in the second test session, but scores in noise between sessions did not reflect this. All
167 other subjects had non significant differences between scores of less than 20% (Table 3).

168 Twenty-one out of the 34 subjects had sufficiently good performance in quiet with the previous
169 sound processor(s) at the initial session to be able to perform the Matrix test in noise (median
170 scores of 64% for monosyllabic words versus 23% in the group of 13 subjects who were not able
171 to perform test in noise). Matrix test at the follow-up session was only performed in this group of
172 21 patients. At the initial baseline session, there was no significant difference between the
173 recipients' previous sound processor(s) (median SRT of -1.1 dB) and the Naída CI sound
174 processor(s) (median SRT of -1.2 dB) for performance in noise when using the omnidirectional

175 microphone (Wilcoxon paired test, $Z=1.01$, $p>0.05$) (Fig. 32A, a lower SRT means a better
176 performance).

177 At the follow up session, after two months experience with the Naída CI sound processor(s), the
178 median SRT score with Naída CI with UltraZoom was -4 dB (range: +4.8; -10.5 dB) compared to
179 -0.45 dB (range: +6.5; -8.0 dB) with the Naída CI in omnidirectional mode (without Ultrazoom).
180 The use of UltraZoom significantly improved the median SRT by 3.6 dB (range: +0.5; -7.8 dB)
181 (Wilcoxon paired test, $Z=3.91$, $p<0.0001$) (Fig. 32B).

182 **Subjective evaluation**

183 APHAB questionnaires were completed by all 34 subjects. When performance on the APHAB
184 questionnaire was compared across the sessions, significant differences between the scores with
185 the existing sound processor(s) at baseline and the Naída CI sound processor(s) for speech
186 understanding in noisy environments (Wilcoxon paired test, $Z=3.57$, $p<0.001$), aversive situations
187 (Wilcoxon paired test, $Z=2.10$, $p<0.05$) and globally (Wilcoxon paired test, $Z=2.19$, $p<0.05$) were
188 obtained.

189 When looking at the APHAB outcomes for the group of 21 subjects who were able to perform the
190 Matrix test, a significant improvement when using the Naída CI sound processor(s) compared to
191 the previous processor(s) was found for speech understanding in noisy environments (Wilcoxon
192 paired test, $Z= 2.84$, $p<0.01$) and in aversive situations (Wilcoxon paired test, $Z= 2.10$, $p<0.05$)
193 (Fig. 43A). For the 13 subjects who were not able to perform the Matrix test at baseline, a
194 significant improvement when using the Naída CI sound processor(s) compared to the previous
195 processor(s) was also shown for speech understanding in noise (Wilcoxon paired test, $Z=2.13$,
196 $p<0.05$) (Fig. 43B).

197

198

198 **DISCUSSION**

199

200 This study showed that for the 21 subjects who were able to complete the testing in difficult noisy
201 conditions, the use of UltraZoom provided a significant improvement in performance of 3.6 dB
202 SRT. The diffuse noise test conditions used in this study were designed to be challenging to
203 represent the most common noise condition that CI users encounter in everyday life. The addition
204 of some reverberation in the testing room also helped to simulate a real world condition and is
205 particularly relevant for beamforming technologies as when the target and interfering noise
206 become more spatially diffuse, beamforming performance can degrade [4011, 4112].

207 Our results were in line with the improvement seen by Geißler et al. [4] in a study evaluating 10
208 adult Harmony users who had been converted to the Naída CI, but had no take home experience
209 with the new processor. Subjects had been evaluated using the same adaptive test as in our study,
210 but in more challenging conditions with five loudspeakers used to create the noise environment
211 and a higher reverberation time of 0.6s. In our study, twenty-six out of the 34 subjects were using
212 the T-Mic in standard condition which already provides some directionality [6]. Some subjects
213 also used the ClearVoice static noise reduction technology, which in combination with
214 UltraZoom, has been shown to provide the greatest improvement in performance in noise [4,
215 4314]. We ~~chose~~ chose to keep the use of ClearVoice and/or the T-Mic constant across all test
216 conditions and for both sound processor types in order to have no impact on the results.

217 There is considerable variation in the degree of improvements reported for beamforming
218 technology. In previous studies, when compared to the omnidirectional microphone or the T-Mic,
219 UltraZoom improved speech reception thresholds in noise from 4 up to 9.8 dB in optimum
220 conditions [4,4314] (Advanced Bionics, Reference Note 2). Many factors can explain this
221 variation, such as the speech materials and noise type used, the configuration of the speaker array,
222 the microphone and program configurations compared. In addition, the head alignment of the
223 subject with the speech source can also affect the level of benefits of any adaptive beamformer.
224 Even though instructions about head position were provided to subjects prior to testing, this is

225 something which remained difficult to control over the whole duration of the session. However,
226 these testing conditions reflected real life conditions and show the wide range ~~what level~~ of
227 benefit a CI user could expect from using this new technology in ~~their~~ daily life. Unfortunately,
228 one of the limitations of adaptive SRT procedures is that a calculation of individual significant
229 SRT differences cannot be made based on the binomial model. The other limitation is that the
230 Matrix test was only performed in the group of the better performers, meaning that we cannot
231 ruled out that some poorer performers from the baseline session were finally able to do the test at
232 the follow-up session. Therefore, no information can be provided on the percentage of subjects
233 whose performance improved significantly when using the beamformer.

234

235 The purpose of providing beamforming to CI users is to improve their ability to communicate in
236 the everyday noisy environments we all encounter. Whilst many studies have shown the benefits
237 of this technology in a laboratory setting [4,5,7,8], a subjective evaluation by subjects is required
238 to show that these benefits can be achieved in real world scenarios. Moreover, the upgrade
239 process was part of the routine clinical practice of the clinic, so both good and poor performers
240 were enrolled. As a result, almost forty percent of the subjects in our study who had poor speech
241 comprehension score in quiet were unable to do the Matrix test in difficult noisy environment
242 before upgrade, but may still have some subjective benefit of the speech processor upgrade. The
243 APHAB results shown here indicate a significant subjective improvement for the listening in
244 background noise, aversiveness and global sections when using the Naída CI sound processor. To
245 check whether the poorer performers benefited from the new sound processor, the APHAB
246 questionnaire was analysed for this particular population and still showed a significant benefit in
247 the background noise section. It is particularly interesting to observe this improvement in poorer
248 performers, for whom the objective improvement could not be shown through the Matrix test. It
249 highlights the importance of evaluating subjective feedback from CI recipients to assess their
250 level of comfort in everyday life. Some previous studies using different subjective measures have

251 been unable to show a subjective benefit along side the laboratory benefits shown [5,8]. Only
252 Mosnier et al. [1] did show a significant benefit on the APHAB when subjects upgraded from the
253 older Cochlear Esprit 3G and Freedom sound processors to the newer CP810. This lack of strong
254 evidence of for any subjective benefits of beamforming is not just an issue for its use in cochlear
255 implants, but is also a criticism for its use with hearing aids [4719]. The subjective results are
256 limited by the fact that the APHAB in common with most of the subjective measurement tools
257 available, relies on asking subjects about predetermined situations, which may not be relevant or
258 equally important to all subjects. An additional limitation of any study where subjects are
259 upgraded to newer technology and cannot be blinded to the sound processor used is that
260 responses may be biased towards the newer technology.

261

262 The results of the speech perception testing at baseline show that group performance with the new
263 Naída CI sound processor in noise was the same as with the subjects' existing sound processor
264 when using the same programs and omnidirectional microphone settings. This provides clinicians
265 with confidence that subjects can be upgraded to the Naída CI without a change in performance
266 when used with the standard microphone settings and do not require any training period.
267 However, the subjects recruited were all using the Harmony sound processor, so these findings
268 can only be applied to recipients who are currently using this sound processor type.

269 The improvements in recipients' use of beamforming in real world environments may result from
270 a better understanding by clinicians of how to use the technology and appropriately counsel
271 recipients and better implementation of the beamforming algorithm, improving its robustness [9].
272 Indeed, appropriate counselling on the use of UltraZoom is crucial as recipients are required to
273 manually change the program depending on the listening situation encountered. Therefore, it is
274 important to provide recipients with concrete real life examples of situations where this feature
275 helps speech understanding. However, this might be less relevant with the newest generation of

276 sound processors, which offers automatic selection of the microphone settings depending on the
277 incoming signal i.e. UltraZoom is switched on and off automatically depending on the
278 environment.

279 To conclude, this study showed that all subjects were successfully upgraded to the new Naída CI
280 Q70 sound processor. Once upgraded, subjects who were able to perform the French Matrix test
281 in noise with their previous processor could take advantage of the UltraZoom beamforming
282 technology on the new sound, so that their ability to communicate in noise was improved.
283 Subjective results with the APHAB questionnaire, confirmed these objective results, showing
284 improvements in median scores in the whole group, but also in the group of poorer performers,
285 for listening in background noise when using the Naída CI Q70 sound processor. This study
286 highlighted the importance of upgrading CI recipients to new technology and of including
287 adaptive tests in noise and subjective feedback evaluation as part of the process.

288

289 **Author contribution statements:** I.M. is the main researcher, designed experiments, analyzed
290 data and wrote the paper. J.F., D.A., A.L., S.B., E.A.D., M D. performed experiments. N.M.
291 provided writing assistance. D.B. and O.S. provided critical revision. All authors discussed the
292 results and implications and commented on the manuscript at all stages.

293

294 **Compliance with Ethical Standards**

295 **Conflict of Interest:** One of the authors (NM) is employee of Advanced Bionics. Other authors
296 declare they have no conflict of interest.

297 **Ethical approval:** All procedures performed in studies involving human participants were in
298 accordance with the ethical standards of the institutional and/or national research committee and
299 with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

300 **Informed consent:** Informed consent was obtained from all individual participants included in
301 the study.

302

303

304

305

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367

368

FIGURES LEGENDS

369 **Fig. 1: Polar plot showing UltraZoom performance on KEMAR left ear.**

370 **Fig. 21: Performance score in quiet with the subject's original sound processor(s) at**
371 **baseline and with the Naída CI sound processor(s) in omnidirectional mode at the follow-up**
372 **visit.** Results are expressed as percentage of words correct for the lists of monosyllabic words in
373 quiet for the 34 subjects. The box plots show the first and third quartile values and the central
374 square, the median value. The whiskers indicate the non-outliers values for each group.

375 **Fig. 32: Performance in noise for the 21 subjects who were able to perform MATRIX test in**
376 **noise. A. At baseline with the subject's original sound processor(s) and with the Naída CI**
377 **sound processor(s) in omnidirectional mode (without UltraZoom); B. At the follow-up visit**
378 **with the Naída CI sound processor(s) in omnidirectional mode and with UltraZoom.**

379 Results are expressed as the speech reception thresholds (SRT, dB) for the Matrix sentence test in
380 noise. A lower SRT means a better performance. The box plots show the first and third quartile
381 values and the central square, the median value. The whiskers indicate the non-outliers values for
382 each group. The asterisks indicate a statistically significant difference in performance (***)
383 $p < 0.0001$)

384 **Fig. 43: Median scores for the APHAB self-assessment questionnaire at baseline with the**
385 **subject's original sound processor(s) and at the follow-up visit with the Naída CI sound**
386 **processor(s). A. For the 21 subjects who were able to perform MATRIX test in noise; B. For**
387 **the 13 subjects who were not able to perform MATRIX test in noise**

388 Scores are given for each of the four sub sections and a global value for the average of the Ease of
389 Communication, Reverberation and Background Noise sections. The box plots show the first and
390 third quartile values and the central square, the median value. The whiskers indicate the non-
391 outliers values for each subscale and each group. The asterisks indicate a statistically significant
392 difference in performance (* $p < 0.05$, ** $p < 0.01$)

393

394 **Table 1 : Demographic details of the population**

Number of subjects	34
Age at testing, years	53 ± 18.5 [21-89]
Age at implantation, years	46 ± 18.7 [7-80]
Duration of CI use, years	6.9 ± 1.8 [5.1-14.7]
Male/Female	16/18
Listening modality	
Unilateral CI	9
Bilateral CI (a)	11
Sequentially implanted	6
Simultaneously implanted	5
Bimodal (b)	14
T-Mic microphone	
Yes	26
No	8

395 Data are presented as mean ± SD [range] or number. CI: cochlear implant. (a) All bilateral CI
396 users except one were upgraded on both sides. (b) CI on one side and hearing aid on the other
397 side.

398

399 **Table 2: Tests conducted at each visit.**

400

Baseline	<ul style="list-style-type: none">- Lists of words in quiet with the previous processor (s)- Speech test in noise with signal coming from the front with the previous processor(s) and the Naída CI processor (s) without UltraZoom in a random order- APHAB questionnaire completed with regards to the previous processor(s) use
Follow-up at 2 months after Naída CI upgrade	<ul style="list-style-type: none">- Lists of words in quiet with the Naída CI processor(s) without UltraZoom- Speech test in noise with signal coming from the front with the Naída CI processor(s) with and without UltraZoom in a random order- APHAB questionnaire completed with regards to the Naída CI processor(s) use

401

402

403 **Table 3. Individual scores for speech perception testing in quiet for Lafon words at baseline**
 404 **with the previous sound processor and at the follow-up visit with the Naida CI processor in**
 405 **omnidirectional microphone mode.**
 406

<i>Subject ID</i>	Lafon Words Score (%)			<i>Subject ID</i>	Lafon Words Score (%)	
	Previous Processor	Naida Omni			Previous Processor	Naida Omni
1	37.5	58.5		18	52	55
2	73	52.5		19	17	29
3	67	61		20	76	58.5
4	76	67		21	55.5	82
5	35	17		22	17	41
6	23	20		23	85	82
7	26	43.5		24	14	23
8	61	49.5		25	5	0
9	35	38		26	58.5	11
10	79	73		27	23	14
11	94	94		28	46.5	52.5
12	58	58.5		29	11	17
13	64	52		30	64	79
14	38	46.5		31	61	70
15	29	32		32	82	73
16	32	58		33	35	35
17	64	67		34	94	97

407
 408
 409

Figure 1

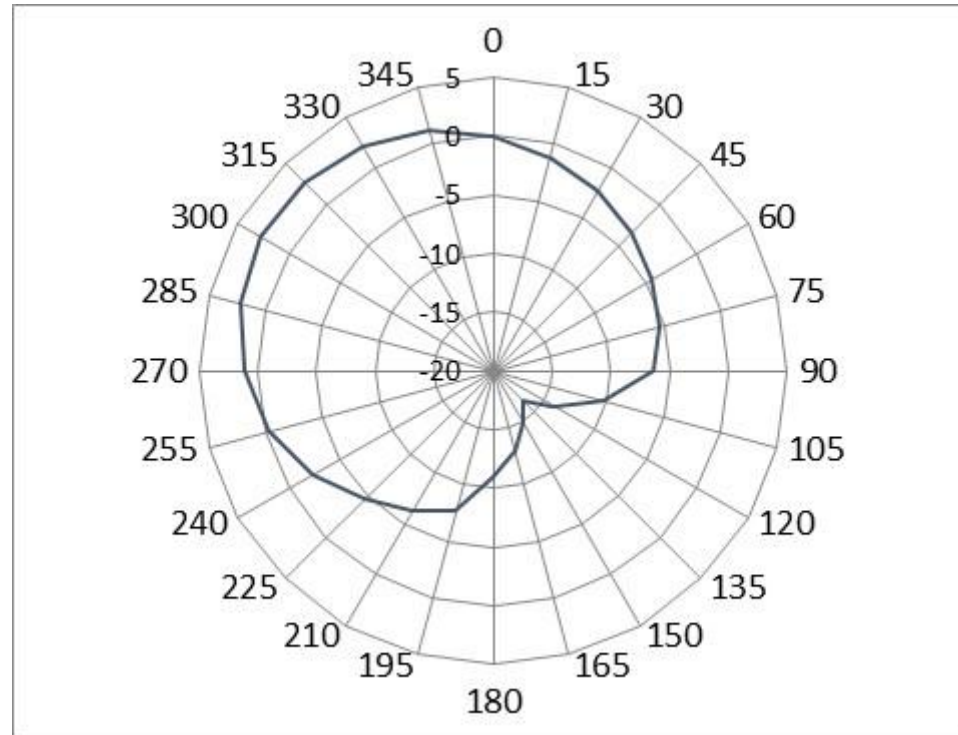


Figure 2

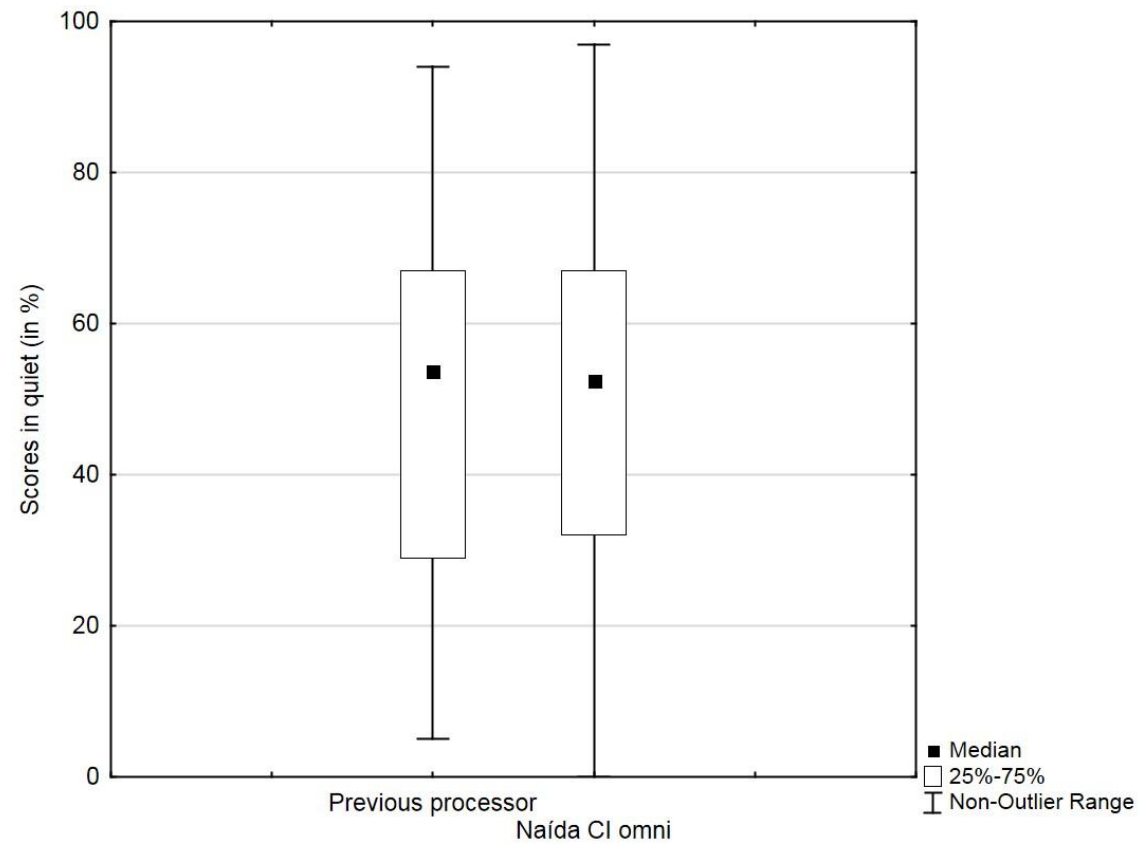


Figure 3A

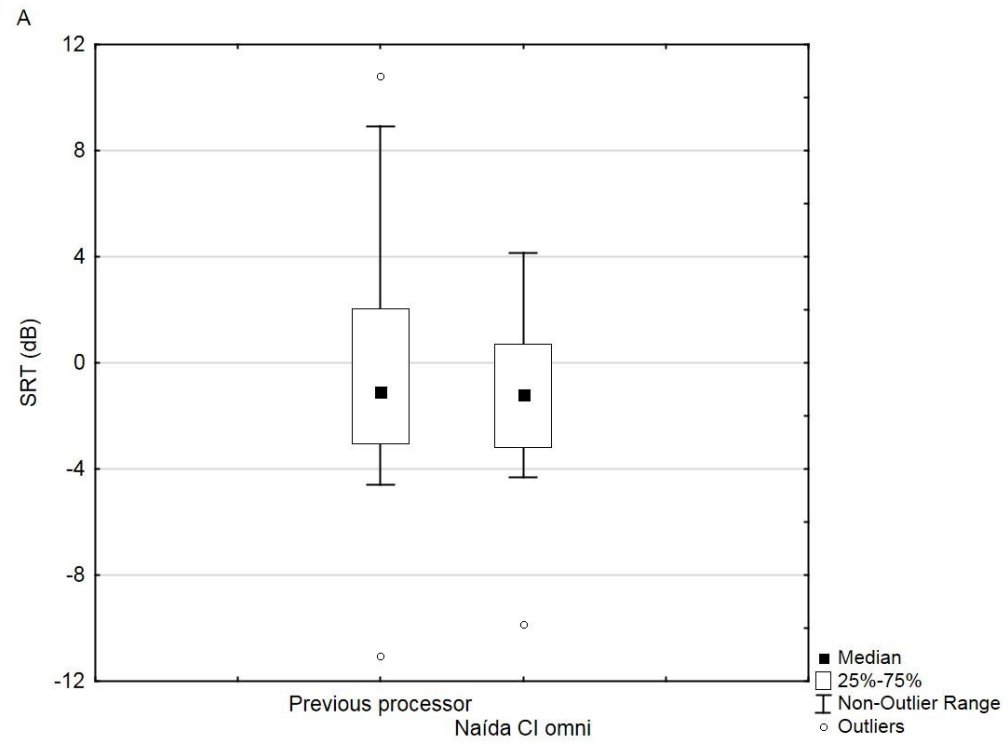


Figure 3B

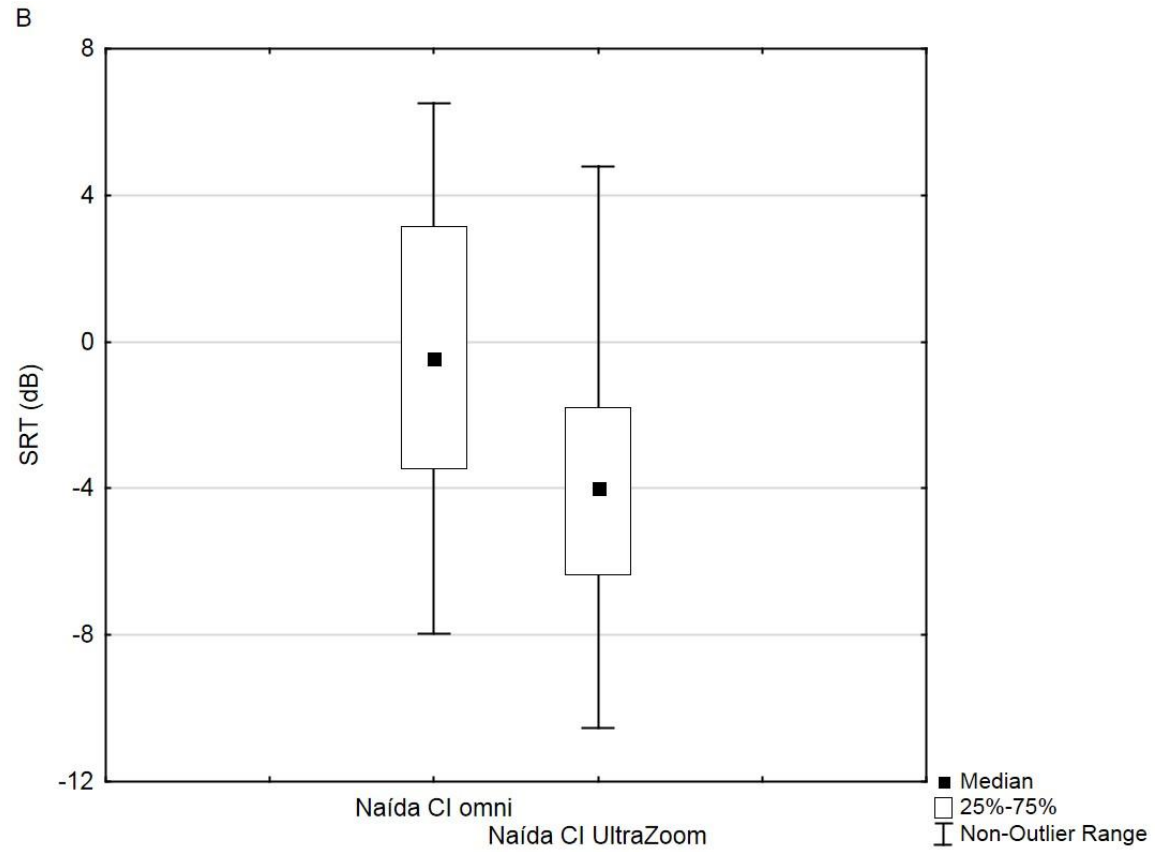


Figure4A

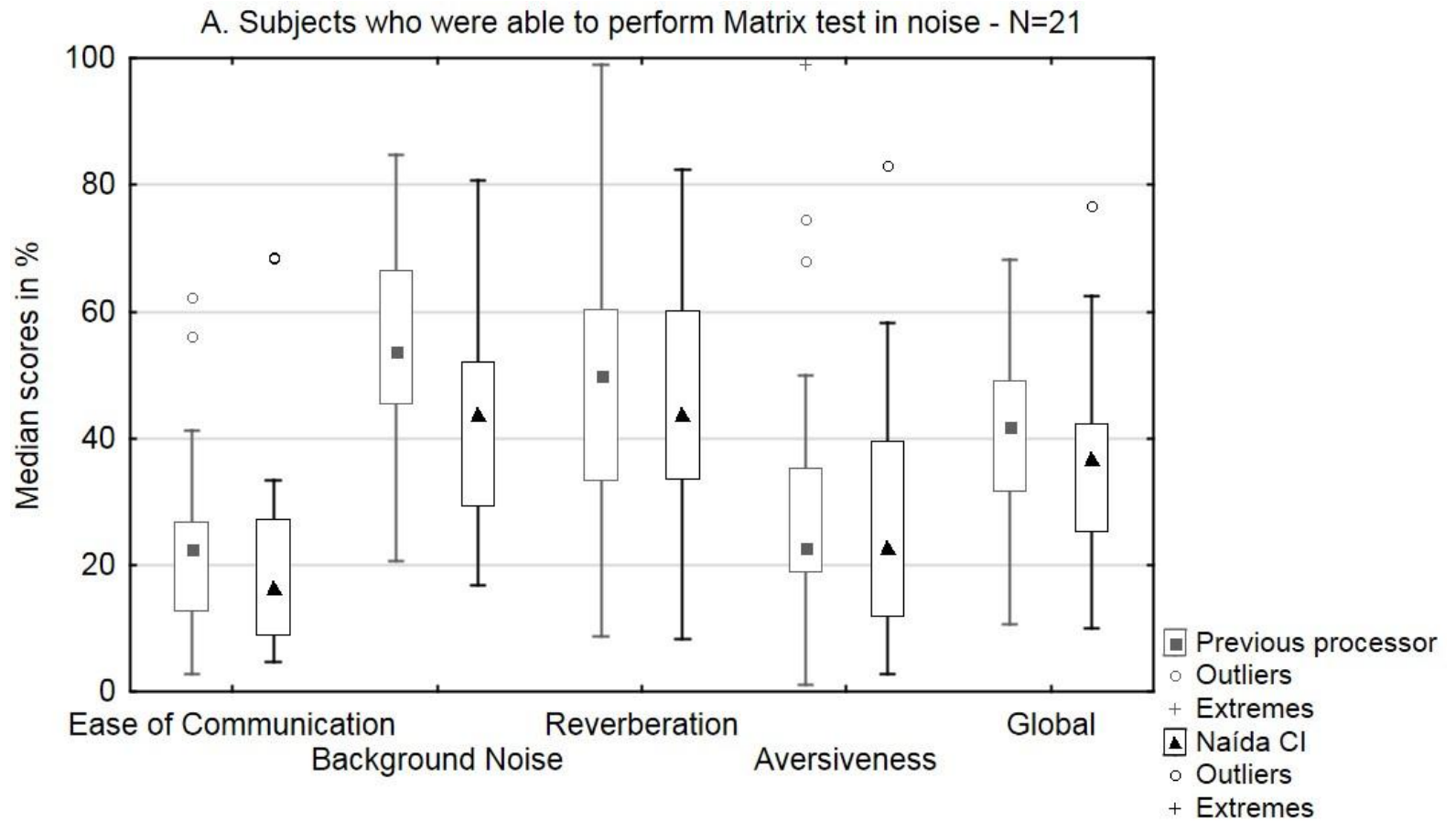


Figure 4B

*
