Benefit of the UltraZoom beamforming technology in noise in cochlear implant users

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INTRODUCTION

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 90KÎ and CIIÎ 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 [5-9~~8~~]. 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 [9~~10~~,~~11~~12]. 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, 9~~10~~]. 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) [~~12~~13],

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**

78 *Subjects*

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 (× 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.

88 *Fitting*

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 ClearVoiceÎ [~~13~~14] as well as the T-MicÎ 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 SoundWaveÎ 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 [~~15~~16],

108   which is an adaptive test based on the Oldenburg sentence test (OlSa) [~~16~~17]. 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   Subjectøs self-assessment of their hearing with the different sound processors and programs was

135   recorded using the APHAB [1213]. 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 õI always experience thisö and G õI never experience thisö. 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
158 *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~~1~~).

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 recipientsø 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. 3~~2~~A, 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. 3~~2~~B).

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. 4~~3~~A). 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. 4~~3~~B).

197

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 [~~10~~11, ~~11~~12].

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   ~~13~~14]. We ~~choose~~ 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,~~13~~14] (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 lifeø 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 [~~17~~19]. 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 subjectsø 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 recipientsø 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 Ssubjective 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.

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366   White paper.

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368

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

370 **Fig. 2~~1~~: 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. 3~~2~~: 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. 4~~3~~: 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 Bilateral CI (a) Sequentially implanted Simultaneously implanted Bimodal (b)	 9 11 6 5 14
T-Mic microphone Yes No	 26 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	- 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	- 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 Naída CI processor in**
405 **omnidirectional microphone mode.**
406

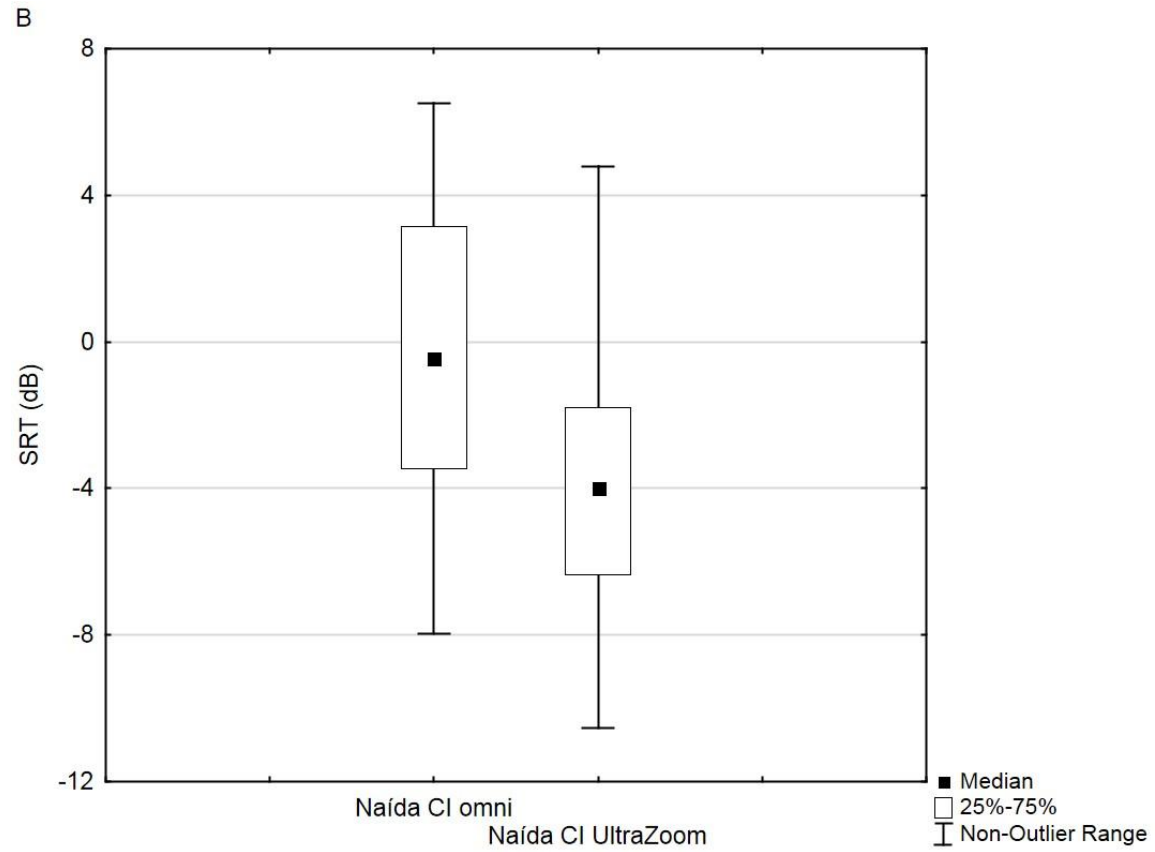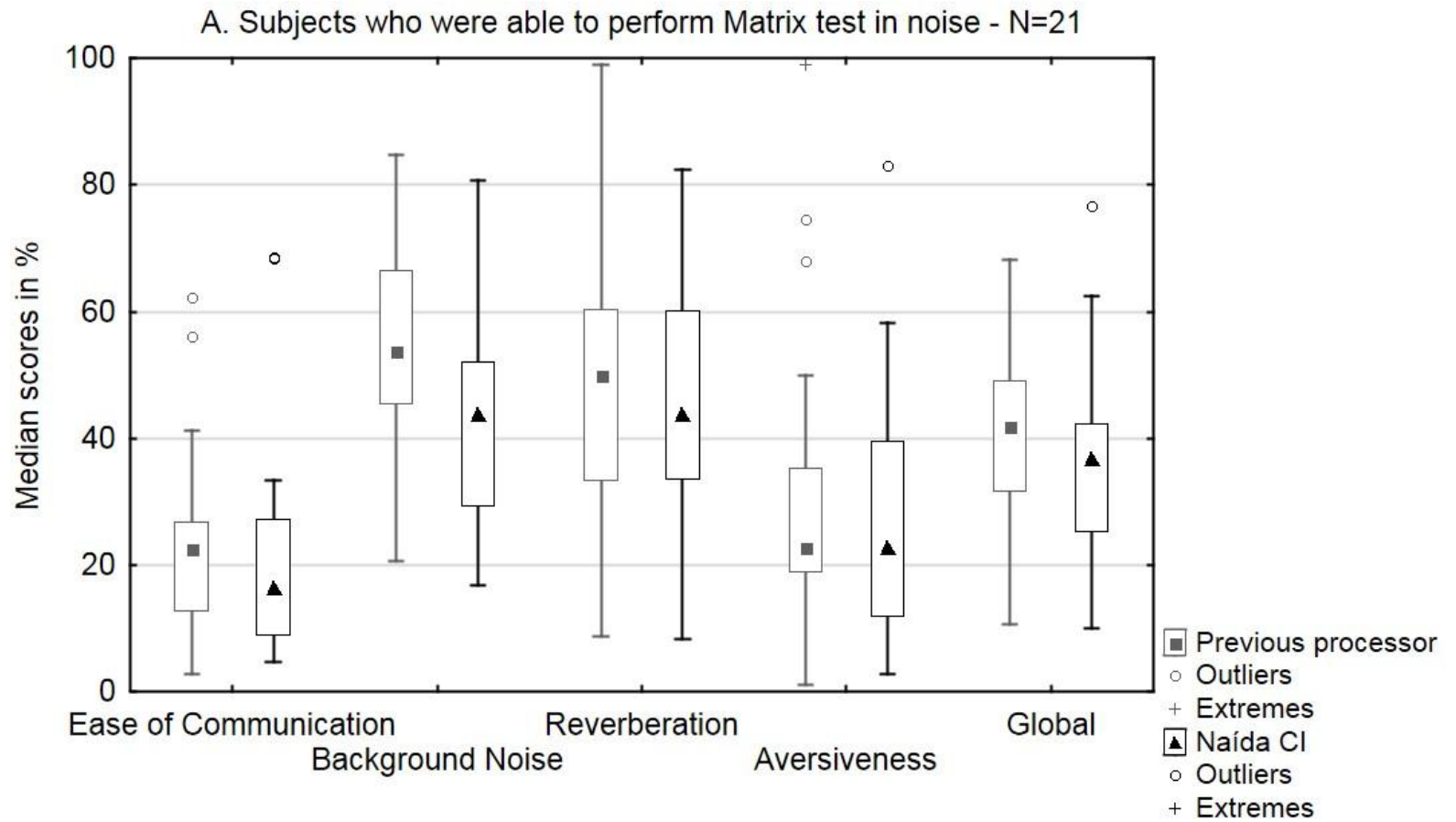| Subject ID	Lafon Words Score (%)		Subject ID	Lafon Words Score (%)	
	Previous Processor	Naida Omni		Previous Processor	Naida Omni
1	37.5	58.5	18	52	55
2	73	52.5	19	17	29
3	67	61	20	76	58.5
4	76	67	21	55.5	82
5	35	17	22	17	41
6	23	20	23	85	82
7	26	43.5	24	14	23
8	61	49.5	25	5	0
9	35	38	26	58.5	11
10	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
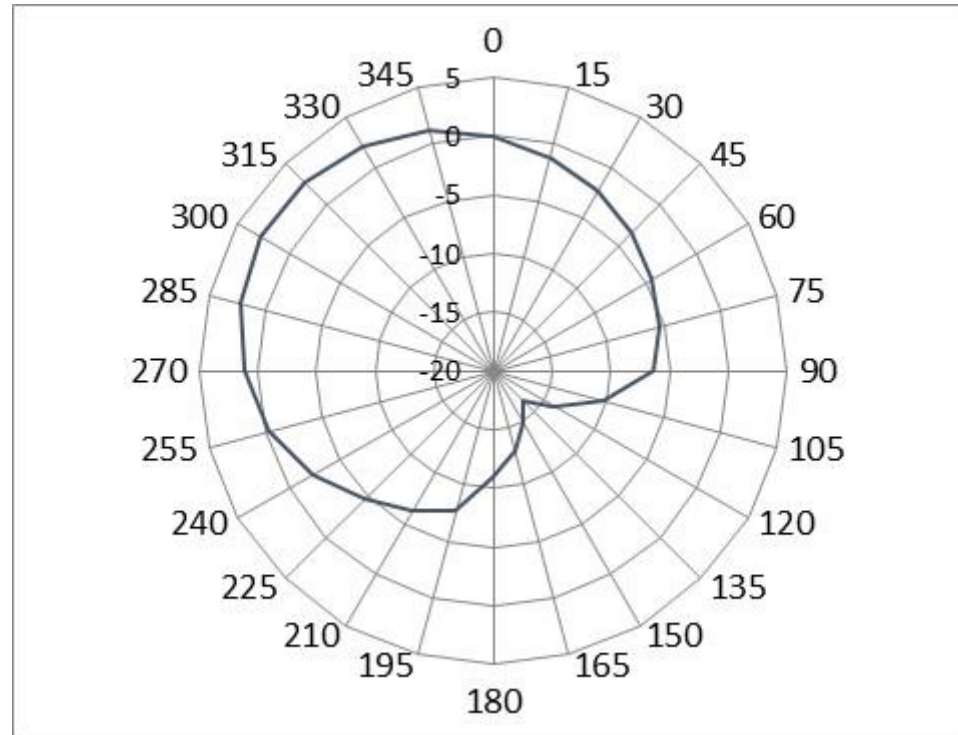
Figure 2
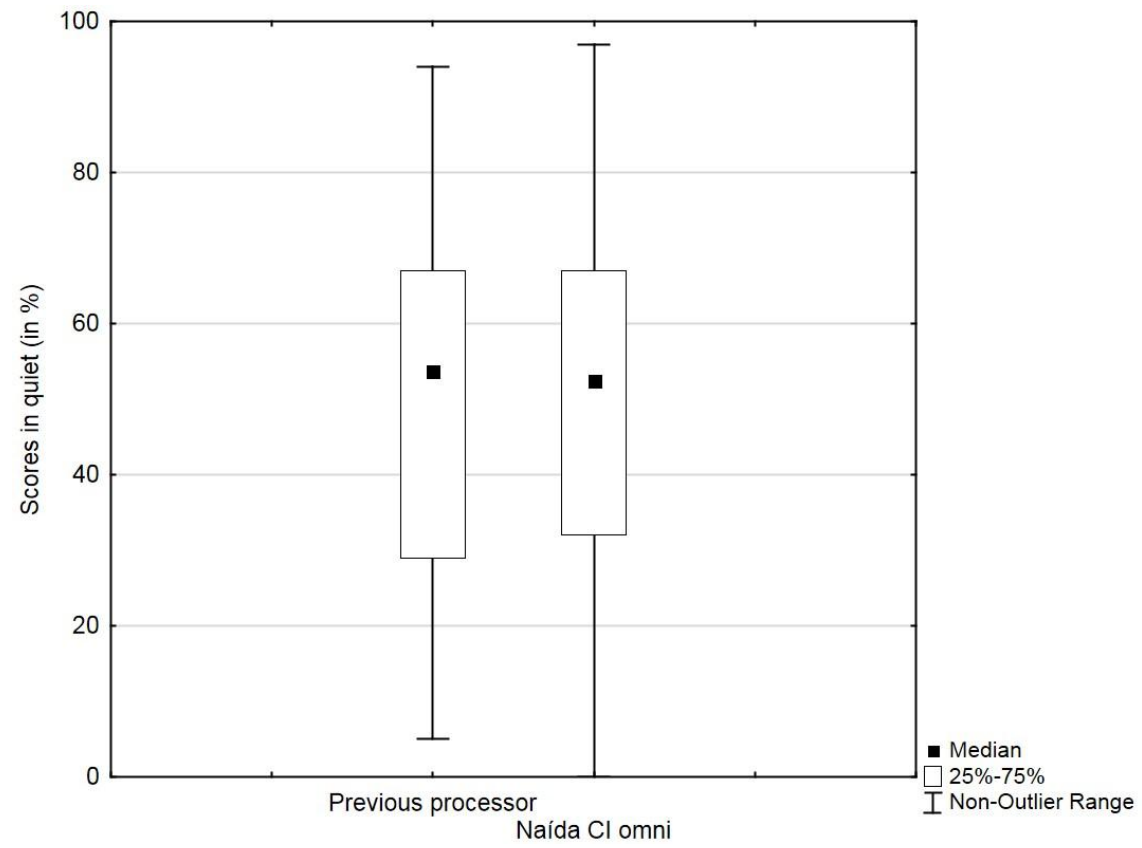
Figure 3A

Figure 3B

Figure4A

A. Subjects who were able to perform Matrix test in noise - N=21

Figure 4B

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