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7 **Beyond Words: Non-verbal auditory cognitive impairments in Alzheimer's**

8 **Disease dementia**

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12 Meher Lad[1]*, Charlotte Deasy[2], Christopher J Plack[3,4], John-Paul Taylor[1,5]**, Timothy D

13 Griffiths[6]**

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15   1. Translational and Clinical Research Institute, Faculty of Medical Sciences, Newcastle

16   University, Newcastle upon Tyne, NE2 4HH

17   2. Cumbria, Northumberland, Tyne and Wear NHS Foundation Trust

18   3. Manchester Centre for Audiology and Deafness, The University of Manchester

19   4. Department of Psychology, Lancaster University

20   5. Newcastle NIHR Biomedical Research Centre, Newcastle University

21   6. Biosciences Institute, Newcastle University

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24 * Corresponding Author

25 ** Joint senior author

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30   **ABSTRACT**

31

32   *Background:* Verbal speech-in-noise (SIN) measures are impaired in early Alzheimer's disease

33   (AD) but may be confounded by linguistic and cultural factors. We investigated whether non-

34   verbal auditory memory could predict cognitive impairment in AD.

35

36   *Methods:* We evaluated 158 cognitively healthy individuals, 26 with mild cognitive impairment

37   (MCI), and 28 with AD dementia using the Addenbrooke's Cognitive Examination (ACE-III),

38   pure-tone audiometry, verbal SIN tests, and non-verbal auditory memory tests for basic sound

39   features. Group differences were assessed adjusting for age, sex, and education. Logistic

40   regression and receiver operating characteristic (ROC) analyses compared model fit of verbal

41   and non-verbal auditory variables.

42

43   *Results:* All auditory cognition measures were significantly associated with cognition. Non-verbal

44   measures provided a better fit to diagnosis than verbal measures (AIC difference >10), although

45   ROC analyses showed no significant differences between models.

46

47   *Conclusions:* Non-verbal auditory measures are effective measures in distinguishing between

48   cognitively healthy, MCI, and AD dementia individuals.

49

50

51   *Keywords:*

52   hearing, auditory cognition, Alzheimer's disease, biomarkers, non-verbal memory, speech-in-noise

53

INTRODUCTION

54

55

56   Central hearing impairments can accompany cognitive impairment in Alzheimer's disease (AD)

57   and may precede the onset of dementia [1,2]. The underlying mechanisms linking central

58   hearing and cognitive impairment in AD are not fully understood but some hypotheses suggest

59   that it may relate to overlapping neuroanatomical substrates involved in speech-in-noise (SIN)

60   hearing and neurodegeneration in AD [3]. This overlap implies that central auditory measures

61   could serve as early indicators of neurodegenerative changes in AD, offering an avenue for

62   screening and diagnostic assessments for AD dementia.

63

64   Verbal central auditory tasks have been commonly studied in people with AD dementia [4].

65   These tests commonly use digits, words or sentences as stimuli and performance is determined

66   by a threshold measurement which signifies the ability of a person to correctly identify these on

67   a background of artificial or natural sounds. In the digits-in-noise (DIN) test, a person is usually

68   played three numbers on a background of white noise whereas in a sentence-in-babble test the

69   stimulus consists of a short sentence on a background of multitalker babble. In cross-sectional

70   studies, performance in both of these tasks reduces at a group-level from cognitively healthy to

71   people with mild memory complaints to those with a dementia diagnosis [1]. Poor performance

72   on both of these tests has also been linked to an increased risk of dementia, particularly AD, in

73   independent studies [2,4].

74

75   Performance on these tests has been related to neurodegenerative biomarkers underlying the

76   disease process [5]. One cross-sectional study showed an association between cerebrospinal

77   fluid biomarkers of AD and performance on speech-in-noise perception tests. Poor auditory

78   performance was correlated with high total-tau and phosphorylated-tau levels, after statistically

79   adjusting for the effects of age, education, sex APOE4 status and pure-tone audiometry results.

80   Tau deposition in the brain is associated with cognitive impairment in AD and raised

81   phosphorylated-tau in the cerebrospinal fluid is associated with a greater risk of AD dementia in

82   the future [6,7]. Although this study was conducted in healthy individuals, this finding suggests a

83   relationship between central hearing ability and neurobiological processes linked to an

84   increased risk of AD dementia.

85

86   Speech-in-noise measures may, however, be confounded by linguistic proficiency, cultural

87   background and educational attainment. These tests may therefore be less applicable to people

88   from under-represented groups who are non-native speakers or those with low literacy levels.

89   Such factors may lead to inaccurate measurements in these populations. Non-verbal measures

90   of auditory cognition may be able to overcome these issues.

91

92   We used previously developed auditory cognitive tests to investigate how verbal and non-verbal

93   metrics related to one another in ageing [8,9]. Auditory memory (the general ability to hold

94   sound objects in mind) for basic sound features correlated with SIN perception ability as

95   measured by sentence-in-babble thresholds. Verbal measures of auditory memory are also

96   important determinants of SIN ability in older adults and those with hearing loss [10]. In previous

97   work, we have found significant relationships with auditory memory for frequency and

98   amplitude-modulation rate precision. We used a novel auditory paradigm which measured

99   auditory memory as a continuous resource that is flexibly distributable to a sound object and

100   provides a fine-grained measure of memory, rather than conventional discrete measures [11].

101   Further work established that including these measures in a linear model with educational

102   attainment and verbal speech-in-noise measures allowed an accurate prediction of cognitive

103   measures that are widely used as screening tools for dementia diagnosis [8].

104

105   In this study, we test the utility of non-verbal measures only in classifying a diagnosis of AD

106   diagnosis. We hypothesised that non-verbal measures would be as effective as verbal SIN

107   measures in distinguishing cognitive status among participants, including those of AD dementia.

108   Therefore, the objectives of this study were: (1) to assess the utility of non-verbal auditory

109   cognitive measures in distinguishing between different cognitive statuses associated with AD,

110   and (2) to compare the effectiveness of non-verbal auditory measures with traditional verbal

111   speech-in-noise tests in classifying cognitive impairment in AD.

112

113   We found that non-verbal auditory measures are as effective as verbal tests in distinguishing

114   cognitive status among participants, including those with AD dementia. Non-verbal measures

115   provided a better statistical fit for classifying cognitive status and were equally effective in

116   discriminating between cognitively healthy individuals, those with mild cognitive impairment

117   (MCI) and those with AD dementia. These results suggest that non-verbal auditory cognitive

118   tests are valuable tools for detecting cognitive impairment associated with AD and may offer a

119   more inclusive and generalisable approach for early detection and monitoring across diverse

120   populations.

121

122 **METHODS**

123

124 *Participants*

125 Participants were recruited from the AudCog study, an ongoing observational study

126 investigating auditory measures in cognitive health and disease. Inclusion criteria for cognitively

127 healthy individuals included age between 50 and 85 years, normal cognitive screening scores

128 (ACE-III ≥ 88) and no history of neurological or psychiatric disorders. Participants with MCI and

129 AD dementia were also recruited and were diagnosed based on established clinical criteria by a

130 neurologist or psychiatrist with specialist experience in dementia [12].

131

132 Participants were recruited from a variety of sources including local volunteer databases, the

133 Join Dementia Research register and through the friends and family of patients from Memory

134 Clinics for cognitively healthy participants. People with MCI and AD dementia were recruited

135 through local memory and cognitive neurology clinics. In order to maximise diversity, equity and

136 inclusion, we appealed to all individuals regardless of culture, race, gender or sexual orientation.

137 A total of 212 participants were recruited: 158 cognitively healthy controls, 26 with MCI, and 28

138 with AD dementia. Demographic characteristics and auditory measurements are detailed in

139 Table 1.

140

141 *Study Design*

142 This study had a cross-sectional observational design. In-person written consent was obtained

143 from all participants. All participants had one visit to the Auditory Laboratory at Newcastle

144 University or a home visit was conducted to the participant's home. After the consenting

145   process, participants underwent a pure-tone audiometric test followed by auditory cognitive

146   assessment. Finally, the cognitive screening test (described below) was administered. The

147   recruitment period occurred from March 2022 to March 2024. Ethical approval was obtained

148   from the Oxford C NHS Research Ethics Committee (21/SC/0139) and written informed consent

149   was obtained from all participants. The study was performed in accordance with the ethical

150   standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

151

152   *Auditory Assessments*

153   Pure tone audiometry (PTA) testing was performed on both ears from 250 Hz to 8 kHz at octave

154   intervals for air conduction using an Interacoustics AD629 Diagnostic Audiometer and RadioEar

155   DD450 circumaural headphones according to British Society of Audiology testing guidelines

156   [13]. Pure tones were manually presented as short bursts twice starting at 30 dB HL then

157   increased in 5 dB HL increments until comfortably audible if necessary. Then 5 dB HL

158   reductions were made until the tone was not audible. This process was repeated twice, and the

159   lowest audible volume was chosen as the value for a particular frequency. If maximum

160   amplification at 100 dB HL could not be perceived, then this was used as the ceiling value at a

161   particular frequency. The overall mean of high frequency values between 4 and 8 kHz for the

162   best ear was taken as the threshold value for an individual for further analysis. This value was

163   chosen as high-frequency thresholds are suspected to deteriorate first in age-related hearing

164   loss and previous research from our group has suggested that PTA thresholds in this range

165   correlate with speech-in-noise difficulties [14,15].

166

167   People wore Sennheiser Momentum 4 over-ear headphones for central auditory tests. Central

168   hearing tests included verbal speech-in-noise perception tests using digits (Digits-in-Noise, DIN)

169   and sentences (Speech-in-Babble, SIB). In these tests, the level difference between speech and

170   background (white noise for DIN and 16-talker babble for SIB) is varied adaptively until a signal-

171   to-masker ratio (in dB) at speech recognition threshold is obtained for each individual [8].

172   Participants had two practice trials at the beginning of the task to familiarise themselves with the

173   stimuli at an SNR of 10 dB. An adaptive 1-up, 1-down psychophysical paradigm was

174   implemented whereby a correct response resulted in the SNR being reduced and an incorrect

175   one caused the SNR to increase. The starting SNR was 0 dB and the step sizes decreased

176   from 5 to 2 dB after 3 reversals, which then reduced to 0.5 dB after 3 more reversals. The run

177   terminated after 10 reversals and the SNR at the last 5 reversals was averaged to calculate the

178   DIN threshold for each participant. Lower SNR values indicate a better performance. For the

179   DIN task, select the digits they had heard from a keypad shown on the screen. For the SIB task,

180   target sentences had the form 〈name〉〈verb〉number〉〈adjective〉〈noun〉(e.g. "Alan

181   gives four pretty flowers") and participants had to click on the correct word from a list of five

182   columns (10 options for each word) shown on the screen with the same structure.

183

184   Non-verbal auditory tests measure Auditory Memory (AuM) precision for basic sound features

185   over several seconds. These tests are usually self-directed and take approximately 5-10

186   minutes. This tests short-term memory performance for two basic sound features: frequency of

187   pure-tone and temporal fluctuation (modulation rate of amplitude-modulated white noise) [9]. A

188   one-second tone or AM modulated white noise stimulus is presented to a participant after which

189   they are asked to 'find' the sound on a horizontal scale on a computer screen. Participants

190   move a mouse and click on the line to produce a sound at that location. They can make as

191   many clicks as they want with no set time limit. After they were satisfied with their choice, they

192   would advance to the next trial by pressing the 'Enter' key on a keyboard. Frequencies that

193   determined the pure-tone sounds were chosen from a uniform distribution between 440 and 880

194   Hz and AM rates for the white noise stimulus were 5–20 Hz with a sinusoidal function used to

195   apply this modulation. Hanning windows were applied to all synthetic sounds to avoid clicks and

196   the beginning and end of the stimuli. The task consisted of 32 trials with the frequency and AM

197   rate matching trials being interleaved. Participants had a short break after 16 trials. A Gaussian

198   function was used to estimate the standard deviation of the errors in each trial across the whole

199   experiment and the inverse of this value, the precision, was used for further analysis. Thus, one

200   obtains precision scores for frequency AuM (AuMF) and AM rate AuM (AuMA). Studies in vision

201   have found that this measure better reflects the memory resource a participant can allocate in a

202   given task [16]. Participants had two practice trials with each stimulus (2 for frequency and 2 for

203   AM rate AuM) at the beginning of the task to familiarise themselves with the stimuli.

204

205   *Cognitive Assessment*

206   All participants underwent a cognitive screening test using the Addenbrooke's Cognitive

207   Examination 3rd Edition (ACE-III). A score of 88 is commonly used to delineate cognitive

208   impairment [17]. The ACE-III demonstrated variable sensitivity (ranging from 82% to 97% for

209   dementia at thresholds of 82 and 88) and specificity (ranging from 4% to 77% for dementia)

210   across different thresholds and patient populations, with more variability observed in specificity.

211

212   *Statistical analysis*

213   All variable data were checked for normality by visually examining their distributions. AuM

214   values were log-transformed to achieve normality. Mean and standard deviation (SD) values

215   were calculated using absolute values in order to facilitate comparison between groups using an

216   Analysis of Variance (ANOVA). To assess group differences across cognitive and auditory

217   measures, one-way ANOVA was performed for each outcome variable: adjusted ACE-III total

218   score, DIN, SIB, AuMF and AuMA z-scores. Each ANOVA tested for differences across three

219   cognitive groups: Cognitively Healthy (CN), MCI, and AD Dementia. Post-hoc analyses using

220   Tukey's HSD test were conducted to explore pairwise group differences where applicable. All

221   analyses controlled for age, sex at birth, and educational status, and significance was set at $p <$

222   0.05. To aid analysis using linear models, these values were standardised using z-scores.

223

224   Multinomial logistic regression models were used to assess the association between the non-

225   verbal auditory measures and clinical diagnosis, using age, sex and educational attainment as

226   regressors of no interest. In order to compare this model to one created using verbal measures,

227   we used Bayesian Model Comparison: Model 1 with the DIN and SIB tests and Model 2 with

228   AuMF and AuMA. We used the Akaike Information Criterion (AIC) to define the best model. A

229   lower AIC with a difference of 2 from the other model was used to define an informative model

230   with parsimonious degrees of freedom. The models were also evaluated and compared (using

231   bootstrapped confidence intervals) for classification accuracy for diagnosis using Receiver

232   Operator Characteristic (ROC) curves.

233

234   All statistical analyses were conducted using Python programming language within Jupyter

235   notebooks and Visual Studio Code environments. We utilised several Python libraries to

236   perform data processing and statistical modelling. Specifically, we employed statsmodels for

237   implementing multinomial logistic regression models and assessing model parameters. The

238   patsy library was used for creating design matrices necessary for the regression analyses. To

239   evaluate multicollinearity among predictors, we calculated the Variance Inflation Factor using

240   functions from statsmodels.stats.outliers_influence. For data preprocessing, including

241   standardisation and label binarization, we used functions from scikit-learn (sklearn), specifically

242   the preprocessing module. The dataset was split into training and testing subsets using

243   train_test_split from sklearn.model_selection. Multinomial logistic regression models were

244   implemented using OneVsRestClassifier and LogisticRegression from sklearn.linear_model.

245   Receiver Operating Characteristic (ROC) curves were generated, and the Area Under the Curve

246   (AUC) values were calculated using functions from sklearn.metrics. This allowed us to assess

247   the discriminative power of the verbal and non-verbal auditory measures in classifying cognitive

248   status.

249

250

251   **RESULTS**

252

253   As shown in Table 1, cognitively healthy people were younger and better educated than those

254   with mild cognitive impairment or AD dementia and therefore these measures were used as

255   regressors of no interest along with sex at birth. Cognitive scores on the ACE-III also decreased

256   from cognitively normal to mild cognitively impaired people to people with a diagnosis of AD

257   dementia. Adjusted pure-tone audiometric thresholds did not differ between groups. The

258   unadjusted average audiograms for each group are shown in Figure 1.

259

260   Statistical analysis revealed significant differences in cognitive and auditory performance across

261   groups (Figure 2). ANOVA results showed that ACE-III total scores differed significantly

262   between groups ($F_{(2, 203)} = 325.47$, $p < 0.0001$), with lower scores in the MCI and AD groups

263   compared to cognitively healthy participants. Similarly, significant group differences were

264   observed in auditory measures: DIN ($F_{(2, 203)} = 9.24$, $p < 0.001$), SIB ($F_{(2, 203)} = 45.63$, $p <$

265   0.001), AuMF ($F_{(2, 203)} = 14.57$, $p < 0.0001$), and AuMA ($F_{(2, 203)} = 28.43$, $p < 0.001$). Figure

266   3 further highlights significant correlations between the ACE-III total score and auditory

267   measures. Strong correlations were observed for both verbal (SIB; $r = 0.74$, $p < 0.001$) and non-

268   verbal measures (AuMA; $r = 0.58$, $p < 0.001$), indicating that auditory processing, both verbal

269   and non-verbal, declines in parallel with cognitive impairment.

270

271   We conducted multinomial logistic regression analyses to compare the effectiveness of verbal

272   and non-verbal auditory measures in distinguishing between cognitively normal, mild cognitive

273   impairment, and AD dementia groups. Model 1, which included verbal measures, explained

274   26% of the variance in cognitive status (Log-likelihood: -110.56, AIC: 247). Within this model,

275   SIB had the largest effect on both mild cognitive impairment and AD dementia, indicating its

276   strong association with cognitive impairment. Model 2 focused on non-verbal measures and

277   demonstrated a better fit, explaining 32% of the variance (Log-likelihood: -100.99, AIC: 228). In

278   this model, auditory memory for amplitude modulation rate had the largest effect size,

279   significantly associated with both mild cognitively impaired people and people with AD

280   dementia. The comparison of AIC values suggests that the non-verbal measures model (Model

281   2) provided a statistically better fit than the verbal measures model (Model 1).

282

283   To further assess the discriminative power of the verbal and non-verbal auditory measures,

284   ROC curve analysis was performed, and the Area Under the Curve (AUC) values were

285   calculated for each model (Figure 1). The verbal measures model produced AUCs of 0.85 for

286   cognitively healthy, 0.78 for mild cognitively impaired people, and 0.82 for people with AD

287   dementia, indicating a high level of accuracy in distinguishing between the cognitive groups.

288   Similarly, the non-verbal measures model yielded AUCs of 0.83 for cognitively healthy, 0.79 for

289   mild cognitively impaired people, and 0.80 for people with AD dementia, demonstrating that

290   non-verbal measures were equally effective in classifying cognitive status. The comparative

291   analysis of the ROC curves showed no significant difference in the AUC values between the

292   verbal and non-verbal models (p > 0.05), suggesting that non-verbal auditory tests are as

293   effective as verbal tests in identifying cognitive impairment.

294

295

296 *Table 1*

297 **Demographic and Auditory Characteristics**

298

	Cognitively Healthy (n = 158)	Mild Cognitive Impairment (n=26)	Alzheimer's Disease Dementia (n=28)
Demographic			
Age, mean (SD)	67.0 (9.5)	73.2 (6.9)	75.2 (5.1)
Female, n (%)	96 (62)	16 (62)	9 (38)
Advanced education, n (%)	31 (20)	4 (15)	1 (4)
Hearing aid use, n (%)	23 (15)	4 (15)	7 (29)
Cognition			
ACE-III, mean/100 (SD)	96 (3)	84 (6)	73 (9)
Hearing measures			
Adjusted PTA threshold, mean, dB HL (SD)	44.8 (20)	46.6 (17)	40.6 (16)
DIN threshold, dB (SD)	-8.9 (4.1)	-7.5 (3.6)	-4.2 (2.9)
SIB threshold, dB (SD)	-6.9 (3.4)	-3.4 (6.9)	-0.5 (7.9)
AuMF, au (SD)	0.29 (0.2)	0.13 (0.1)	0.09 (0.1)
AuMA, au (SD)	0.08 (0.03)	0.05 (0.03)	0.04 (0.02)

299

300 Abbreviations: ACE-III, Addenbrooke's Cognitive Examination (3rd Edition); au, arbitrary units; AuMA,

301 Auditory Memory for Amplitude Modulation rate; AuMF, Auditory Memory for Frequency; DIN, Digits-in-

302 Noise test; SIB, Speech-in-Babble test; PTA, Pure Tone Audiometry.

303

304
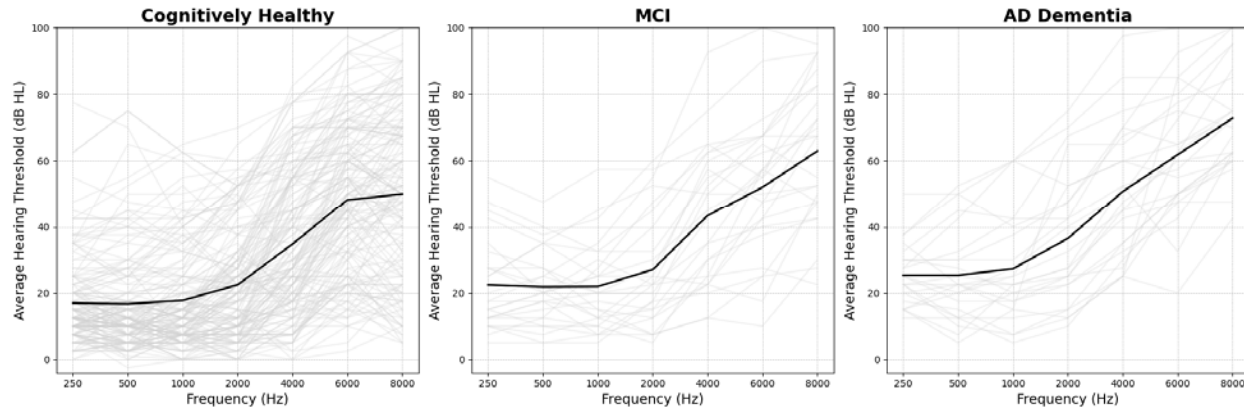
305 **Figure 1.** *Pure-tone audiogram results for cognitively healthy, Mild Cognitive Impairment (MCI) and*

306 *Alzheimer's Disease (AD) dementia groups.* The figure presents the unadjusted averaged hearing

307 thresholds (dB HL) across frequencies (250–8000 Hz) for three cognitive groups: Cognitively Healthy,

308 MCI, and AD Dementia. Individual participants' audiograms are shown as translucent grey lines, while the

309 group average for each frequency is represented by a solid black line. Hearing thresholds are averaged

310 between the left and right ears for each participant. This figure illustrates a general trend of increasing

311 hearing impairment with higher frequencies across all groups.

312

313
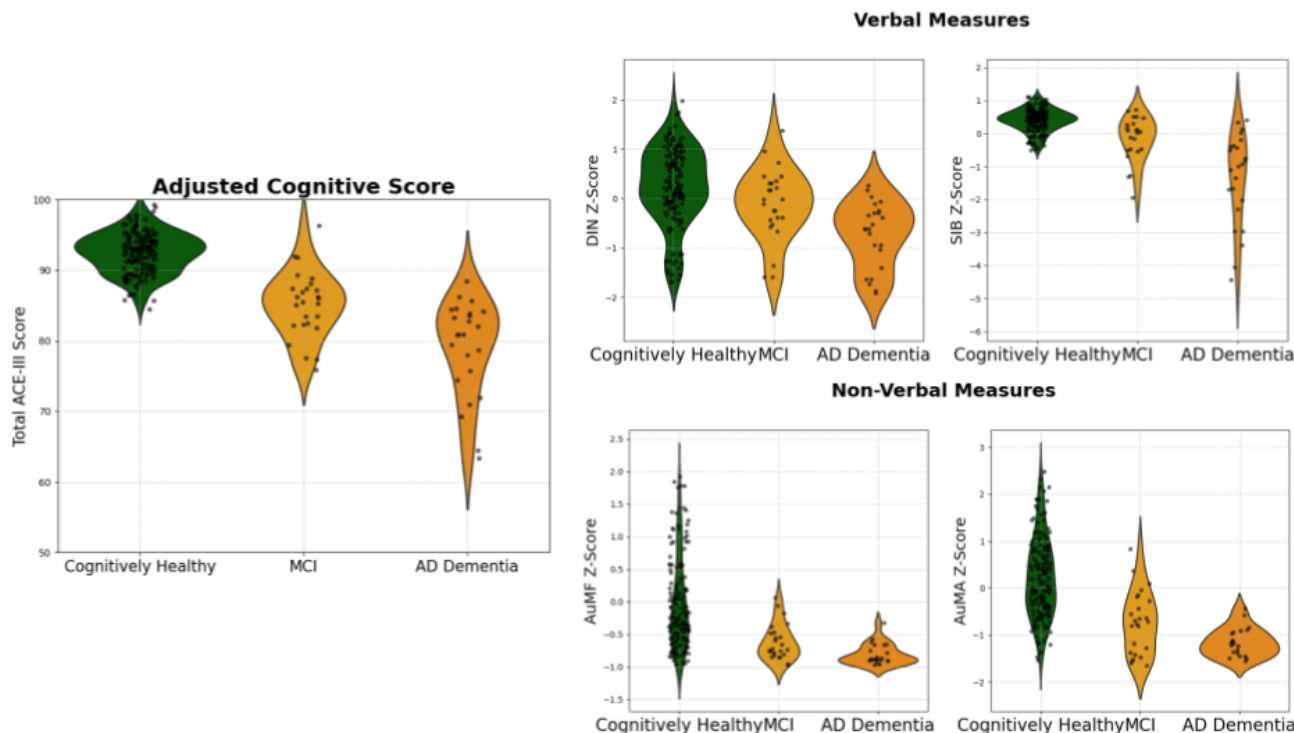
Figure 2. *Cognitive and auditory measure distributions by participant group.* The left panel shows the

adjusted ACE-III total scores for three cognitive groups: Cognitively Healthy (CN), Mild Cognitive

Impairment (MCI), and Alzheimer's Dementia (AD). The right panel is split into two sections: Verbal

Measures (top) and Non-Verbal Measures (bottom). The Verbal Measures display violin plots for the

Digits in Noise (DIN) and Speech in Babble (SIB) z-scores, while the Non-Verbal Measures show

distributions for Auditory Memory for Frequency (AuMF) and Auditory Memory for Amplitude Modulation

(AuMA) z-scores. Each plot visualises the distribution of individual scores within each cognitive group,

with individual data points overlaid in black.
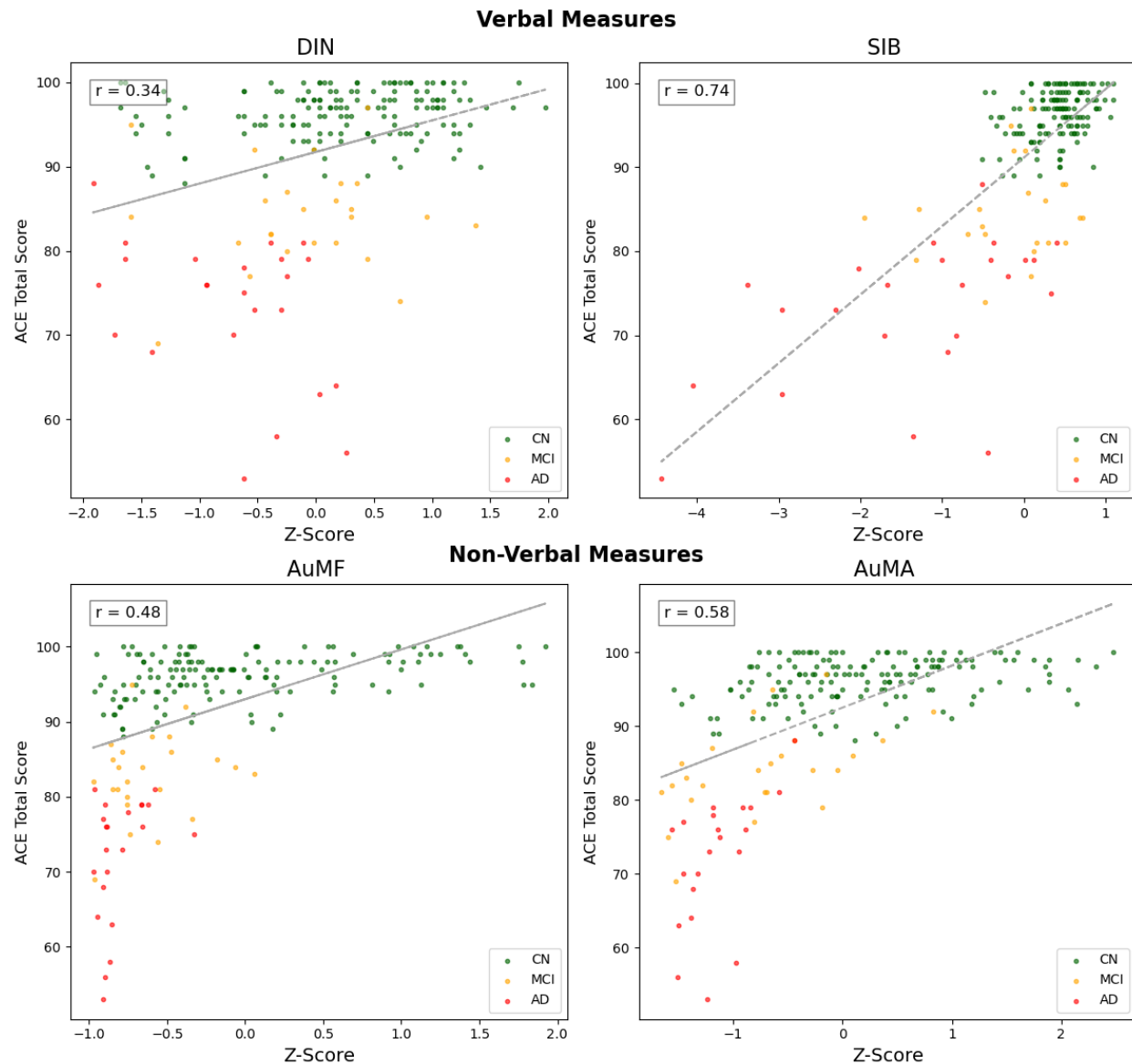
Figure 3. *Correlations between cognitive and auditory measures and ACE-III total score.* This figure

shows scatterplots of four cognitive and auditory measures, grouped by cognitive status (Cognitively

Healthy (CN), Mild Cognitive Impairment (MCI), Alzheimer's Disease (AD) dementia) and their

relationship with the ACE-III total score. The upper row (Verbal Measures) presents the associations for

the Digits in Noise (DIN) and Speech in Babble (SIB) z-scores, while the lower row (Non-Verbal

Measures) presents the associations for Auditory Memory for Frequency (AuMF) and Auditory Memory

for Amplitude Modulation (AuMA) z-scores. Trendlines (dark grey) highlight the correlations, with

corresponding r-values displayed in each subplot. All correlations were statistically significant with $p <$

0.001.

350

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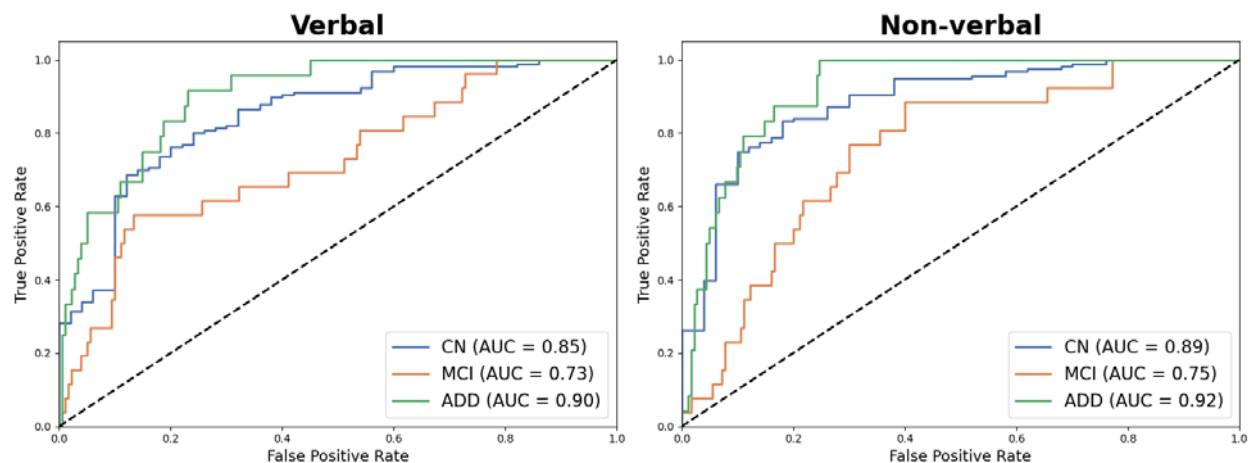
352 **Figure 4.** *Receiver Operating Characteristic (ROC) Curves for Verbal and Non-Verbal Auditory Measures*

353 *in Discriminating Cognitive Status.* The figure displays the ROC curves for two multinomial logistic

354 regression models used to differentiate between cognitively normal (CN), mild cognitive impairment (MCI)

355 and Alzheimer's disease dementia (ADD) groups based on auditory performance. The leftward image

356 represents the model using verbal auditory measures, specifically the digits-in-noise performance and

357 sentence-in-babble threshold. The rightward image shows the model using non-verbal auditory

358 measures, including auditory memory for frequency and auditory memory for amplitude modulation rate.

359 Each ROC curve corresponds to the classification of one cognitive status group (CN, MCI, ADD). The

360 area under the curve (AUC) values are reported for each ROC curve, indicating the model's ability to

361 correctly classify people across cognitive statuses. Both verbal and non-verbal models demonstrate

362 similar AUC values, suggesting that non-verbal auditory measures are as effective as verbal measures in

363 associating with cognitive impairment.

DISCUSSION

We demonstrate that simple non-verbal measures of auditory cognition are significantly

associated with cognitive impairment in AD and can effectively discriminate between individuals

with and without AD dementia. Auditory memory is linked to cognition across the AD spectrum

and, when combined with demographic factors, can classify a clinical diagnosis. These findings

lay the groundwork for future investigations into auditory memory as a potential measure of

brain function, alongside fluid biomarkers that are sensitive and specific to AD, offering a more

inclusive and accessible diagnostic tool.

Previous clinical observations in individuals with AD dementia have highlighted an aversion or

heightened sensitivity to sound processing, particularly in noisy environments. However,

detailed evaluations of these symptoms using non-verbal auditory paradigms are only now

beginning to emerge [18]. Our results align with prior research showing impairments in auditory

scene analysis and spatial processing when using complex sound stimuli [19,20]. Additionally,

this study extends our understanding of non-verbal auditory cognition beyond individuals without

dementia to those experiencing memory and cognitive difficulties due to AD dementia.

Auditory memory is a crucial cognitive ability that supports SIN perception, particularly as one

ages [10,21]. Successful SIN perception requires the listener to attend to the correct auditory

stream, track it and remember it over time despite interference from competing sounds. This

process likely involves several cognitive factors. Previous research suggests that phonological

auditory memory becomes increasingly important as individuals age and experience hearing

loss [21]. While the underlying reasons for this are unclear, they may be related to the increased

working memory resources required to comprehend sentences in noisy environments when

perceptual systems are partially degraded.

390

391 The auditory memory precision measure, which is based on a continuous scale rather than

392 conventional discrete phonological measures, has been shown to reflect the total memory

393 'resource' an individual can allocate to a given task [16]. The specific reasons for the

394 associations between SIN perception and auditory memory for features such as frequency

395 precision and amplitude modulation rates remain uncertain. This may relate to the evolutionary

396 importance of humans tracking the source of a sound object e.g. voices, where frequency is

397 particularly important and the natural modulations that occur in the envelope of speech sounds

398 (which were similar to the rates used as stimuli in this study) [22–24].

399

400 The reasons for specific associations with auditory memory and cognition in AD have also not

401 yet been thoroughly investigated. Some hypotheses propose that non-verbal measures of

402 auditory memory link speech-in-noise perception ability and cognition in AD due to their

403 neuroanatomical substrates [3]. Performing these tasks is known to activate medial temporal

404 lobe structures, regions implicated in the early stages of AD pathology [25,26]. Degeneration of

405 these structures could impair auditory memory and contribute to cognitive deficits detected by

406 other screening tools. Additionally, damage to these areas, regardless of aetiology, can similarly

407 affect performance in visual cognitive tasks [27,28]. It is also important to recognise that hearing

408 function, age and brain neuropathology independently influence cognition and may collectively

409 contribute to cognitive decline in AD [29].

410

411 This study benefits from incorporating both peripheral and detailed central auditory testing in

412 individuals with and without dementia. Including such comprehensive measures is crucial, as a

413 combination of peripheral and central auditory assessments may provide a more complete

414 understanding of the neurobiological link between hearing and dementia. Previous studies

415 relying solely on pure-tone audiograms or subjective measures have not consistently

416   demonstrated relationships with the underlying neurobiological processes in AD [30,31]. This

417   contrasts with some work using central measures [5]. Central auditory measures may also help

418   clarify whether hearing aids can prevent or delay dementia. The lack of success in trials using

419   hearing aids as an intervention may be due to their limited effectiveness in individuals with

420   central auditory impairments, suggesting that hearing aids might be most beneficial for those

421   without central auditory dysfunction [32].

422

423   Limitations of this study include the relatively small sample size of cognitively impaired

424   individuals, the cross-sectional design and the lack of neurodegenerative biomarkers to

425   characterise the participants. The progression of cognitive impairment in ageing is known to

426   vary based on biomarker status and future work should incorporate these *in-vivo* markers to

427   provide a more comprehensive understanding of the relationship between auditory cognition

428   and AD progression [33]. While participants with normal cognitive function were younger and

429   had higher education levels than other groups, these factors were statistically controlled for in

430   the analyses. Future studies should aim to include more diverse populations, as these auditory

431   measures are applicable across various cultural and linguistic backgrounds. Longitudinal

432   research is also necessary to determine whether auditory cognition measures can predict the

433   onset or progression of AD dementia, particularly in preclinical or mildly impaired individuals.

434

435   This work showcases simple non-verbal auditory stimuli which could potentially be used

436   alongside clinical and neurodegenerative biomarkers for screening and monitoring cognitive

437   impairment due to AD. These measures are potentially less susceptible to confounding factors

438   such as linguistic and cultural differences, offering a broader applicability in diverse populations.

439   Additionally, their suitability for use in remote or resource-limited settings enhances their

440   practical utility [34]. Further work is necessary to see whether these non-verbal auditory tasks,

441   like verbal SIN measures, can predict AD dementia, particularly in individuals with MCI [2].

442   Studying auditory memory alongside highly sensitive and specific fluid biomarkers of AD, such

443   as phosphorylated-Tau, would explain whether poor auditory cognition is a harbinger of

444   dementia [6]. Auditory cognition may also be associated with more general markers of

445   neurodegeneration, such as cortical thinning, detectable through neuroimaging. Urgent work is

446   required to investigate the relationship between auditory cognitive decline and these

447   neuroimaging metrics [35].

448

449   In conclusion, this study demonstrates that non-verbal auditory memory tasks are strongly

450   associated with cognitive impairment in Alzheimer's disease and show potential as early

451   indicators of cognitive decline. These tasks, particularly when combined with demographic

452   factors,could help distinguish AD dementia from normal cognitive ageing. The findings suggest

453   that non-verbal auditory measures tap into neural processes that are particularly vulnerable to

454   early AD pathology, especially in medial temporal lobe structures. Further longitudinal studies

455   incorporating auditory cognition, fluid biomarkers and neuroimaging are essential to clarify the

456   role of auditory memory in predicting dementia and to explore whether these measures could

457   enhance early detection or improve the monitoring of AD progression.

472

473   **Contributors**

474   ML conceived the study. ML collected and analysed the data. ML drafted the initial manuscript.

475   All authors contributed to revision and editing of the manuscript.

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