Investigating the effects of age and hearing loss on speech intelligibility and amplitude modulation frequency selectivity

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Abstract

The perception of amplitude modulation (AM), characterized by a frequency-selective process in the modulation domain, is considered critical for speech intelligibility. Previous literature has provided evidence of an age-related decline in AM frequency selectivity. Additionally, a notable sharpening of AM tuning with hearing loss has been observed, which was proposed to be related to a perceptual advantage resulting from peripheral compression loss. This study explores whether such changes in AM tuning with age and hearing loss contribute to the speech intelligibility challenges that older listeners often face in noisy environments. Young (n=10, 22-28 years) and older (n=9, 57–77 years) listeners with normal hearing as well as older listeners with hearing impairment (n=9, 64-77 years) participated in the study. All had previously taken part in studies on AM tuning. Speech-reception thresholds (SRTs) were collected in conditions including stationary, fluctuating, and competing-speech maskers. The results revealed an age-related increase in SRTs, with an additional negative impact of

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hearing loss. Beyond age and audibility, a measure of AM tuning significantly contributed to explaining the variance in SRTs across listeners for specific maskers. These findings motivate further exploration of the relationship between AM frequency selectivity and speech intelligibility in noise.

I. INTRODUCTION

Temporal envelope fluctuations (also known as "amplitude modulation" or AM) refer to the slow variations in overall amplitude that characterize most sounds in daily life (e.g., Singh and Theunissen, 2003; Elliott and Theunissen, 2009). The auditory system exhibits remarkable sensitivity to AM, as demonstrated by physiological studies (see Joris *et al.*, 2004 for a review) and behavioral investigations of AM detection (e.g., Viemeister, 1979; Kohlrausch *et al.*, 2000). Similar to masking effects in the audio-frequency domain, the detectability of a target AM is disrupted by the presence of distinct masking AM components. AM masking has been extensively studied in behavioral investigations (e.g., Bacon and Grantham, 1989; Houtgast, 1989; Dau *et al.*, 1997; Verhey *et al.*, 2003) as well as through recent neurophysiological research (Viswanathan *et al.*, 2021). Behavioral studies of AM masking have provided evidence of a frequency-selective process in the modulation domain, often conceptualized as a series of bandpass modulation filters known as the modulation filterbank (e.g., Dau *et al.*, 1997, 1999; Ewert and Dau, 2000; Ewert *et al.*, 2002). Computational modelling studies have shown that this concept significantly contributes to quantitatively predicting experimental data from various psychoacoustic tasks (e.g., Dau *et al.*, 1997, 1999; Jepsen *et al.*, 2008; Jepsen and Dau, 2011; McDermott and Simoncelli, 2011; McWalter and Dau, 2017), underscoring the importance of AM in auditory processing and perception.

Beyond its role in 'simple' listening tasks, AM has been argued to be crucial for accurate speech intelligibility (Houtgast and Steeneken, 1985; Drullman *et al.*, 1994; Smith *et al.*, 2002; Elliott and Theunissen, 2009). The significance of AM in speech was highlighted by vocoding studies, which demonstrated that intact envelope information conveyed through a few broad spectral bands was sufficient for precise speech recognition in quiet, even when spectral cues were greatly reduced (e.g., Shannon *et al.*, 1995; Dorman *et al.*, 1997; Xu *et al.*, 2005). Based on this, AM masking has been proposed as the primary mechanism underlying speech intelligibility in noise, whereby speech-

reception thresholds (SRTs) - reflecting the signal-to-noise ratio required for 50% speech recognition - are related to the modulation-domain signal-to-noise ratio (SNR_{env}) between the speech and masker (e.g., Dubbelboer and Houtgast, 2008; Jørgensen and Dau, 2011).

The crucial role of AM masking in speech intelligibility in noise was also emphasized by studies using maskers designed to contain AM components or to have maximally flat envelopes, which suggested that so-called stationary maskers, usually associated with energetic masking (EM) in the audio-frequency domain, effectively function as AM maskers due to their inherent envelope fluctuations (Stone *et al.*, 2012; Stone and Moore, 2014). Computational auditory modeling studies have successfully incorporated these concepts by employing the SNR_{env} (Jørgensen and Dau, 2011; Jørgensen *et al.*, 2013; Chabot-Leclerc *et al.*, 2014) or correlation-based measures (Relaño-Iborra *et al.*, 2016, 2019; Steinmetzger *et al.*, 2019) at the output of the modulation filterbank as decision metrics. Based on these modeling studies, the spectral decomposition of the stimulus envelope carried out by the modulation filterbank, i.e., AM frequency selectivity, has been suggested as an important factor for accurately predicting SRTs (see Relaño-Iborra and Dau, 2022 for a review of different speech intelligibility models using modulation filtering).

Regev *et al.* (2023, 2024a) investigated the effects of age and hearing loss on the selectivity of hypothetical modulation filters using a perceptual AM masking task. Regev *et al.* (2023) found a general reduction in AM frequency selectivity associated with age, resulting in broader masking patterns among older compared to young listeners with normal hearing (referred to as hereafter as NH listeners). Conversely, Regev *et al.* (2024a) demonstrated a general sharpening of masking patterns among young and older listeners with hearing impairment (referred to as hereafter as HI listeners) compared to NH listeners of similar age. This finding suggested that sensorineural hearing loss was accompanied by a perceptual benefit that partially offset the detrimental effects of age, possibly due to the HI listeners' ability to exploit an increased internal representation of AM depth resulting from

reduced peripheral compression when "listening in the dips" of the masker. Hence, Regev *et al.* (2024a) proposed that the sharpening of the masking patterns found in HI listeners was an "apparent" effect, reflecting the loss of peripheral compression rather than an actual greater selectivity of the hypothetical modulation filters. Such changes in the sharpness of the hypothetical modulation filters due to age and hearing loss may affect speech intelligibility in noise by altering the amount of AM masking at the output of the modulation filters.

The effects of age and hearing loss on speech intelligibility have received significant attention in the literature. Hearing loss is known to cause a decline in speech intelligibility in both quiet and noisy environments (e.g., Glasberg and Moore, 1989; Humes and Christopherson, 1991; Frisina and Frisina, 1997; see Humes and Dubno, 2010 for a review). In addition to audibility loss, speech intelligibility challenges associated with hearing loss have been linked to various supra-threshold deficits, including reduced frequency selectivity, poorer temporal fine structure processing, reduced recovery from forward masking, poorer AM depth discrimination, and loudness recruitment (Glasberg and Moore, 1986, 1989; Oxenham and Moore, 1997; Moore and Oxenham, 1998; Moore, 2003; Lorenzi *et al.*, 2006; Strelcyk and Dau, 2009; Schlittenlacher and Moore, 2016). Aided speech intelligibility performance has also been shown to be strongly correlated with deficits in spectro-temporal modulation detection in HI listeners (e.g., Bernstein *et al.*, 2016; Zaar *et al.*, 2023, 2024). Recent neurophysiological studies suggested that poorer speech intelligibility in HI listeners may be related to increased neural coding of the envelope (Millman *et al.*, 2017; Goossens *et al.*, 2018; Decruy *et al.*, 2020). This effect may be partly attributed to an increased internal representation of the AM depth resulting from the loss of cochlear compression commonly associated with sensorineural hearing loss (Moore *et al.*, 1996; Jennings *et al.*, 2018). In addition to the effects of hearing loss itself, age and reduced cognitive function have been found to contribute to the decline in speech intelligibility observed in older HI listeners (e.g., Dubno *et al.*, 1984; Humes and Christopherson, 1991; Frisina and Frisina,

1997; Humes, 2002, 2007; Humes *et al.*, 2006). This suggests that cognitive and age-related perception deficits may also play a role in speech intelligibility challenges.

To investigate these potential mechanisms, cross-sectional studies focusing on age-related effects have been conducted, often involving listeners with no or mild hearing loss. These studies have consistently shown a detrimental effect of age on speech intelligibility in the presence of competing speech maskers (Rajan and Cainer, 2008; Helfer and Vargo, 2009; Schoof and Rosen, 2014; Füllgrabe *et al.*, 2015; Gordon-Salant and Cole, 2016; Goossens *et al.*, 2017; Decruy *et al.*, 2019; Sobon *et al.*, 2019). However, the effects of age in stationary and fluctuating noise have been less consistent. Some studies found differences between young and older listeners (e.g., Goossens *et al.*, 2017; Decruy *et al.*, 2019; Sobon *et al.*, 2019), while others did not (Rajan and Cainer, 2008; Helfer and Vargo, 2009; Schoof and Rosen, 2014). Overall, the age-related increase in SRTs has been more pronounced for speech maskers than for stationary or fluctuating noises (e.g., Goossens *et al.*, 2017; Decruy *et al.*, 2019; Sobon *et al.*, 2019). The observed age-related decline in speech intelligibility has been suggested to be mediated by deficits in temporal processing (e.g., Gordon-Salant *et al.*, 2006; Anderson *et al.*, 2012; Füllgrabe *et al.*, 2015; Goossens *et al.*, 2016; Decruy *et al.*, 2019) and by reduced cognitive abilities (Humes *et al.*, 2012; Füllgrabe *et al.*, 2015; Gordon-Salant and Cole, 2016).

Since AM frequency selectivity has been identified as a significant factor contributing to accurate speech intelligibility, it is reasonable to suggest that the age-related decline in AM selectivity reported by Regev *et al.* (2023) may contribute to the aforementioned challenges in speech intelligibility. A reduction in AM tuning would likely result in increased AM masking, thus disrupting the intelligibility of the target speech. Conversely, while the increased AM frequency selectivity found in older HI listeners compared to older NH listeners (Regev *et al.*, 2024a) may suggest a decrease in AM masking with hearing loss, it is hypothesized that this would not directly translate into improved speech intelligibility. Regev *et al.* (2024a) proposed that the greater AM frequency selectivity in HI listeners,

97 rather than reflecting a sharpening of the hypothetical modulation filter, is linked to reduced cochlear
98 compression. Reduced cochlear compression is associated with various supra-threshold deficits that
99 impair speech intelligibility (e.g., Glasberg and Moore, 1989; Oxenham and Moore, 1997; Moore and
100 Oxenham, 1998; Moore, 2003). This assumption is consistent with previous studies showing that HI
101 listeners exhibit higher SRTs than age-matched NH listeners (Goossens *et al.*, 2017).

102 The present study explored whether the results of speech intelligibility tests align with the
103 assumption that an age-related decline in AM frequency selectivity would negatively impact speech
104 intelligibility, while an apparent sharpening of AM tuning with hearing loss would not be beneficial
105 for speech intelligibility. SRTs were collected for speech in noise, building upon the previous studies
106 on AM frequency selectivity (Regev *et al.*, 2023, 2024a), using a subset of the participants. Young NH,
107 older NH, and older HI listeners were tested on sentence recognition in various maskers, including
108 speech-shaped noise, fluctuating noise, and competing talkers. It was hypothesized that changes in
109 AM frequency selectivity with age and hearing loss would be linked to increases in SRTs for the older
110 NH and HI listeners.

111 II. METHODS

112 A. Listeners and previously published data

113 Ten young NH listeners, aged 22-28 years (mean age = 24.7 years, eight female), nine older NH
114 listeners, aged 57–77 years (mean age = 66.9 years, six female), and nine older HI listeners, aged 64-
115 77 years (mean age = 71.2 years, 2 female), participated in the study. All listeners were native Danish
116 speakers. The experiment was conducted monaurally. Figure 1 shows the audiograms in the
117 participants' test ears. All young NH listeners had audiometric pure-tone thresholds (PTTs) ≤ 20 dB
118 HL at frequencies ranging from 125 Hz to 8 kHz. All older NH listeners had PTTs ≤ 20 dB HL at
119 frequencies ranging from 125 Hz to 4 kHz, PTTs ≤ 25 dB HL at 6 kHz, and PTTs ≤ 45 dB HL at 8

120 kHz. The older HI listeners exhibited a high-frequency sloping hearing loss, classified as an N2 or N3
121 standard audiogram (Bisgaard *et al.*, 2010).[1] All HI listeners had a sensorineural hearing loss, with air-
122 bone gaps ≤ 15 dB at 1, 2, 3, and 4 kHz.[2]
123 Prior to this study, all listeners took part in the AM frequency selectivity studies conducted by Regev
124 *et al.* (2023, 2024a). The corresponding datasets are publicly available from Regev *et al.* (2024c, 2024b).
125 In those studies, masked-threshold patterns (MTPs) were used to assess the masked detection
126 threshold of a target AM across different masker center frequencies, providing an indication of AM
127 frequency selectivity. Figure 2 indicates an example of the MTPs for a 4-Hz target modulation
128 frequency, where the age-related reduction of AM selectivity is evident on both skirts and the
129 sharpening of the MTP with hearing loss is evident on the low-frequency skirt (see Regev *et al.*, 2023,
130 and 2024a for a detailed discussion of the possible origins of these effects.). A measure of AM
131 frequency selectivity at the individual level can be derived from the MTPs by computing the average
132 range spanned by the MTP (i.e., the MTP's average dynamic range; DR_{MTP}), where a larger dynamic
133 range is indicative of greater AM selectivity. This is done by identifying the highest masked threshold
134 as the peak of the MTP, computing the difference between the peak and the lowest masked threshold
135 on each side of the peak, and averaging the resulting dynamic range across both sides. If the peak of
136 the MTP is on either extreme, the DR_{MTP} is taken as the dynamic range across the whole MTP. An
137 illustration of this derivation is provided in supplementary Figure 1. This measure was derived for the
138 4-Hz MTP of each listener (with the exception of one older HI listener for whom a MTP at 4 Hz
139 could not be obtained by Regev *et al.*, 2024a), since the 4-Hz modulation frequency has been suggested
140 to be particularly important for speech perception (e.g., Drullman *et al.*, 1994; Arai *et al.*, 1999;
141 Greenberg *et al.*, 2003; Elliott and Theunissen, 2009; Varnet *et al.*, 2017) and showed the largest effect

[1] The classification of the audiograms was performed using the lowest mean squared error between the standard audiograms and the collected audiometric thresholds at frequencies from 1 to 8 kHz.
[2] Except for one listener who showed a gap of 20 dB at 1 kHz.

sizes across listener groups in Regev *et al.* (2023, 2024a). The resulting individual quantifications of AM frequency selectivity are shown in Figure 3 for each listener group. As reported by Regev *et al.* (2023, 2024a), the MTPs and corresponding dynamic ranges indicate a general decline in AM frequency selectivity with age, which is partially "compensated" by the presence of hearing loss.

Regev *et al.* (2023, 2024a) also evaluated working-memory capacity using a reverse digit span (RDS) test, which was administered binaurally following the procedure described in Fuglsang *et al.* (2020). For the HI listeners, a linear gain was applied based on the Cambridge formula (CamEq; Moore and Glasberg, 1998), with a maximum gain of 30 dB at any frequency. The older NH listeners exhibited significantly lower average RDS scores (0.40 on a normalized scale) compared to the young NH and older HI listeners (0.60 and 0.52, respectively).[3]

All participants provided written informed consent and were offered financial compensation for their participation. The study received ethical approval from the Science Ethics Committee of the Capital Region of Denmark (reference H-16036391).

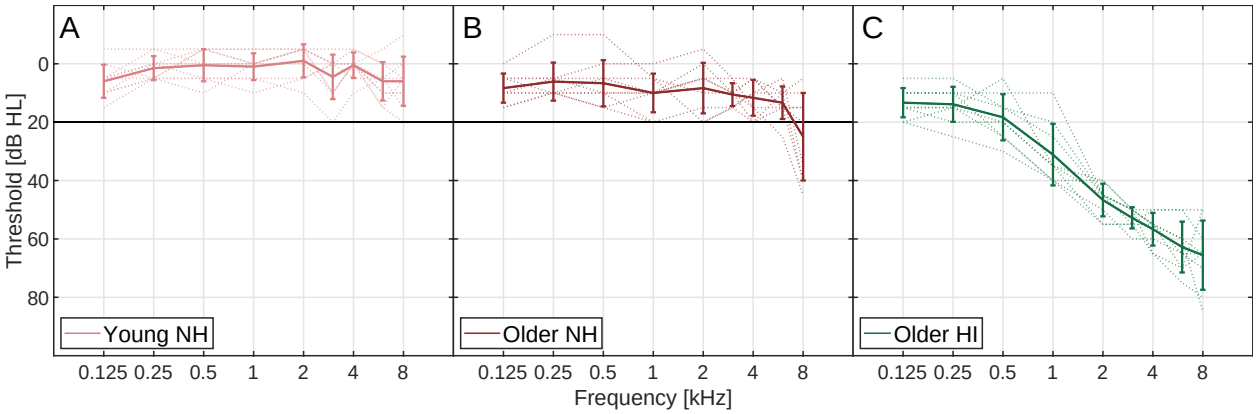


Figure 1 (Color online): Individual and average audiograms of the test ear for each listener group. The thin dashed lines show the individual audiograms, while the dark solid lines represent the average and

[3] This was shown by the post-hoc analysis run on a linear model ANOVA using estimated marginal means. The older NH listeners had significantly lower RDS scores than the young NH and older HI listeners [M = 0.21, SE = 0.05 dB; M = 0.13, SE = 0.05 dB, respectively].

standard deviation across listeners. Panel A shows the audiograms for the young NH listeners, with the black horizontal line indicating the 20 dB HL normal-hearing criterion. Panel B displays the audiograms for the older NH listeners, also with the black horizontal line denoting the 20 dB HL normal-hearing criterion. Panel C presents the audiograms for the older HI listeners.

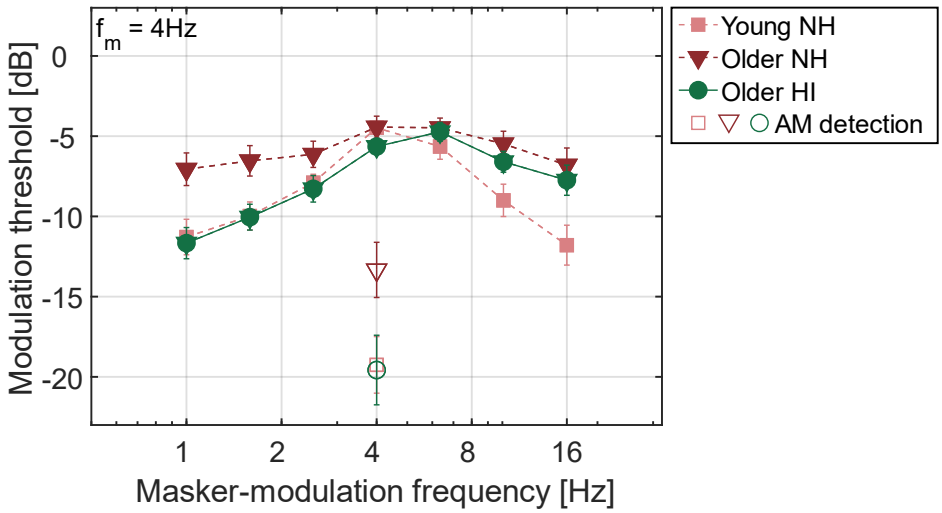


Figure 2 (Color online): Average MTPs and AM detection thresholds for a 4-Hz target modulation frequency. The results for the young NH group are presented as dashed lines and squares, the older NH group as dashed lines and triangles, and the older HI group as continuous lines and circles. The bottom open symbols represent the average AM detection threshold for each group. The means and standard errors are shown. Data adapted from Regev *et al.* (2023, 2024a).

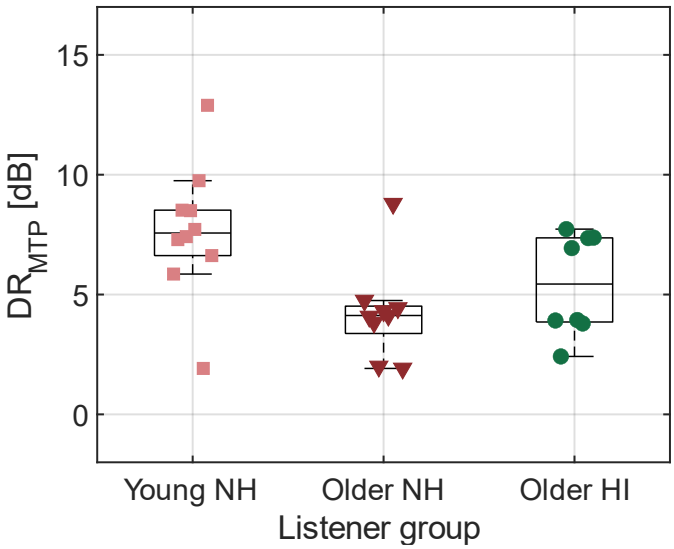


Figure 3 (Color online): Boxplots displaying the average dynamic range of the 4-Hz MTP (DR_{MTP}) for all listeners. The data for the young NH listeners are represented by squares, older NH by triangles, and older HI by circles. Data derived from Regev *et al.* (2023, 2024a).

B. Apparatus

The listening test was conducted in a single-walled soundproof booth. The experiment was conducted using MATLAB (The Mathworks Inc., 2015). The stimuli were digitally played using SoundMexPro (HörTech, Oldenburg, Germany), converted to analog using an RME Fireface soundcard (Haimhausen, Germany), and played monaurally through Sennheiser HDA200 headphones (Wedemark, Germany). The output level was calibrated using a GRAS RA0039 ear simulator (Holte, Denmark) and the frequency response of the headphones was compensated using an inverse digital filter. The listeners received no feedback during the test.

186 **C. Procedure and stimuli**

187 Speech intelligibility in noise was assessed using the Danish Hearing in Noise Test (HINT; Nielsen
188 and Dau, 2011). The HINT speech material consists of 10 test lists and 3 training lists, each containing
189 20 five-word sentences. The sentences were spoken by a male speaker with an estimated average
190 fundamental frequency (F_0) of 123 Hz. The speech signals were combined with five different masking
191 noises: i) a stationary speech-shaped noise (SSN); ii) a fluctuating ICRA-5 noise (Dreschler *et al.*, 2001)
192 resembling a single male talker in terms of spectral and temporal characteristics; iii) a single male
193 competing talker reading a news piece (F_0 = 118 Hz); iv) a single female competing talker reading a
194 news piece (F_0 = 173 Hz); and v) a 'cocktail party' condition. The recordings of the competing talkers
195 had previously been edited to reduce long pauses to 65 ms. The cocktail-party noise was generated by
196 combining a relatively dry recording from a cafeteria with the recordings of the male and female
197 competing talkers mentioned earlier. The levels of the competing talkers were each 3 dB higher than
198 that of the cafeteria noise. Prior to mixing, each recording was convolved with an impulse response
199 from the Aachen Impulse Response database (office setting with dummy head at 1m distance from
200 the loudspeaker; Jeub *et al.*, 2009) to introduce reverberation to the original recordings (T_{60} = 0.37 s).
201 The spectra of all recordings (prior to mixing the cocktail-party noise) had been pre-processed to
202 match the long-term average spectrum of the HINT speech material as closely as possible. The long-
203 term average spectra and modulation spectra of the Danish HINT speech material and of all the
204 maskers are presented in Figure 4.

205 The SRT for each masking noise was determined by conducting two separate measurements using
206 different lists. The final SRT was obtained by averaging the SRTs obtained from the two
207 measurements. The order of masker presentation and the lists used for each masker were randomized

208 across the listeners. Both repetitions for each masker were always conducted consecutively.[4] The SRTs
209 were estimated at the 50%-correct point using an adaptive 1-up 1-down sentence-based scoring rule.
210 A response was considered correct if all five words of the sentence were repeated accurately. The step
211 size in SNR was set at 4 dB for the first four sentences and reduced to 2 dB afterwards. To refine the
212 tracking procedure, a special rule was implemented for the 5th sentence: The change in SNR was
213 computed as the average of the preceding four SNRs and the predicted following SNR, minus the
214 immediately preceding SNR. The first sentence was repeated until the listener could accurately repeat
215 the entire sentence. If the sentence had to be repeated more than four times, the run was terminated,
216 and the starting SNR was increased by 2 dB before starting again. The SRT of a run was calculated as
217 the average SNR across sentences 5 to 20 plus the SNR required for a fictitious 21st sentence,
218 determined by scoring the 20th sentence (Soli and Wong, 2008). The scoring was performed by a
219 trained native Danish speaker.

220 The target sentences were played at a fixed level of 60 dB SPL. The masking noise was looped
221 over the recording, played continuously, and adjusted in level to achieve the desired SNR. For the HI
222 listeners, linear amplification was added to both the speech and masking noise according to the
223 Cambridge formula (CamEq; Moore and Glasberg, 1998), with a maximum gain of 30 dB at any
224 frequency. Each participant underwent training using all three training lists with the SSN. The starting
225 SNR for each masker and each run was adjusted to be 6 dB lower than the expected SRTs. The
226 expected SRTs were determined based on a pilot test conducted with young NH listeners and were
227 defined relative to the SRT measured from the final training run. Therefore, the starting SNR was 6
228 dB lower than the SRT of the listener's last training list for the SSN, male competing talker, and

[4] Due to a mistake in the audibility compensation, one of the older HI listeners was tested twice on the entire HINT corpus. However, more than 7 weeks separated the two testing sessions. Nielsen and Dau (2011) reported an average improvement in SRT of only 0.5 dB across two sessions separated by three weeks. Hence, the current case was likely not affected by memorization of the speech material.

cocktail party conditions; 9 dB lower for the ICRA noise; and 15 dB lower for the female competing talker condition.

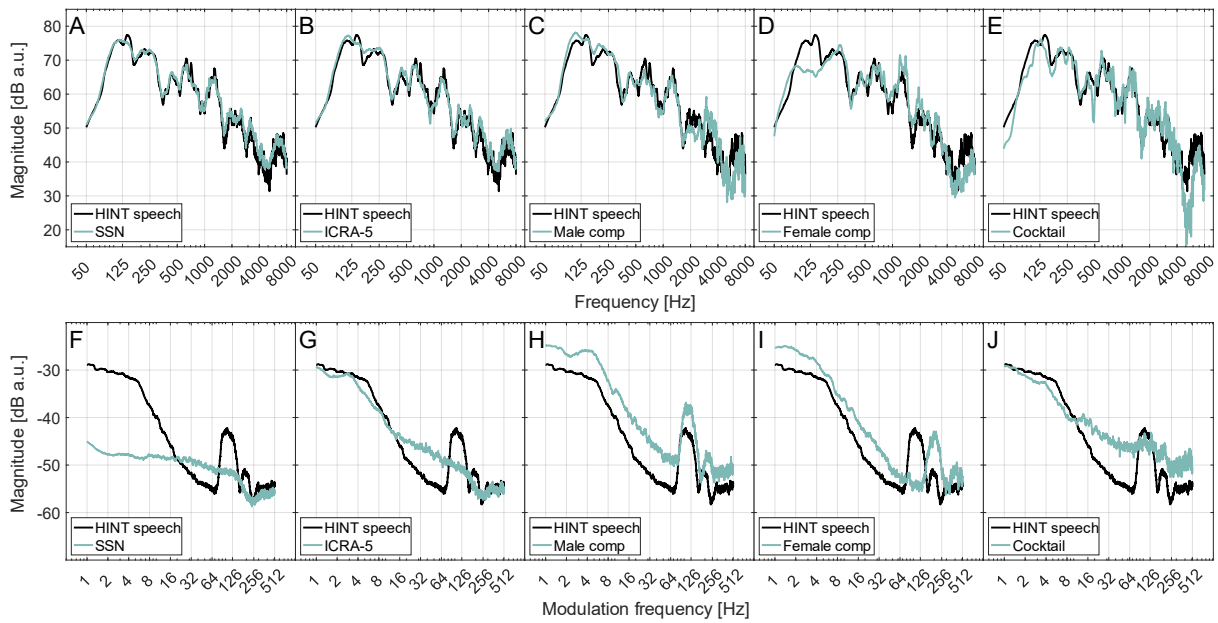


Figure 4 (Color online): Long-term average spectra (top row) and modulation spectra (bottom row) of the speech material and maskers. Each panel shows the spectra for the HINT speech material (black line) and one of the maskers (light blue line). Panels A and F: SSN; Panels B and G: ICRA-5; Panels C and H: Male competing talker; Panels D and I: Female competing talker; Panels E and J: Cocktail-party condition.

D. Statistical analysis

1. Group-level analysis of SRTs

The degree of variability between the two SRT estimates obtained for each masker was assessed by calculating the standard deviation across the absolute differences in SRTs, $\sigma_{\Delta|SRT|}$. Notably, although small, the variability across all maskers was highest for the young NH listeners ($\sigma_{\Delta|SRT|}$ = 2.43 dB) compared to the older NH listeners ($\sigma_{\Delta|SRT|}$= 1.76 dB) and older HI listeners ($\sigma_{\Delta|SRT|}$= 1.49 dB). Nevertheless, the degree of variability between SRT estimates was considered sufficiently small

244 for all statistical analyses to be conducted using the SRTs averaged across both repetitions for each
245 listener and masker. Analyses of variance (ANOVAs) of linear mixed-effects model fittings were
246 performed to examine the differences between the listener groups. Two sets of analysis were
247 conducted: First, the older NH group was compared to the young NH listeners to isolate the effects
248 of age from hearing loss, and second, the older HI group was compared to the older NH listeners to
249 isolate the effects of hearing loss from age-related effects. In both analyses, the listeners were treated
250 as a random effect, while group classification and masker were considered as fixed effects.[5] Post-hoc
251 analyses were carried out using estimated marginal means, and a Holm-Bonferroni correction criterion
252 was applied to account for multiple comparisons. The significance level for all analyses was set at 5%.

253 ***2. Regression analysis***

254 To assess whether a change in AM frequency selectivity contributes to the variance in SRTs, a
255 multilinear regression model was built to relate age, audibility, working memory capacity, and AM
256 frequency to SRTs across listeners. The SRTs from the condition showing the largest effect size across
257 young and older NH listeners were chosen as the model's outcome variable. The measure of age was
258 taken as the listeners' chronological age at the time of testing. The measure of audibility was taken as
259 the 4-frequency pure-tone average threshold (PTA; where the audiometric thresholds at 0.5, 1, 2, and
260 4 kHz are averaged). The measure of working memory capacity was taken as the listeners' RDS score.
261 Finally, the measure of AM frequency selectivity was taken as the listeners' DR_{MTP} at a 4-Hz target
262 modulation frequency, shown in Figure 3. The model included all young and older NH listeners and
263 8 of the 9 older HI listeners, since a 4-Hz MTP could not be obtained by Regev *et al.* (2024a) for one
264 of them. The multilinear regression model was built in steps, starting from a model including only age,

[5] Levene's test was used to assess the homoskedasticity of the residuals and Shapiro-Wilk's test was used to assess the normality of residual's distribution. Shapiro-Wilk's test was not passed for either model, likely due to the relatively small group sizes and to the presence of outliers in the older HI data. However, no other aspect of the data justified the removal of the outliers, and they were therefore kept in the dataset. Furthermore, the average fittings of the models to the experimental data were found to be accurate, and the models were hence considered as appropriate.

265 by assessing whether adding the other predictors and their interactions significantly reduced the
266 model's residual sum of squares, using an F-test. The predictors were added in the above order (PTA,
267 RDS, and DR_{MTP}) and the addition of their interactions was only assessed if the main effect
268 significantly improved the model. The significance level was set at 5%.

269 III. RESULTS

270 A. Speech intelligibility

271 The SRTs for all listeners and groups are shown in Figure 5 for each masker. The young NH
272 listeners are represented by squares, older NH listeners by triangles, and older HI listeners by circles.

273 The statistical analysis comparing young and older NH listeners, focusing on the effects of age,
274 revealed significant main effects of masker [$F_{4,68}$ = 274.2, p < 0.001] and listener group [$F_{1,17}$ = 17.56,
275 p < 0.001], as well as a significant interaction between both factors [$F_{4,68}$ = 9.28, p < 0.001]. In the
276 analysis comparing older NH and older HI listeners, examining the effects of hearing loss, significant
277 main effects of masker [$F_{4,64}$ = 141.6, p < 0.001] and listener group [$F_{1,16}$ = 12.86, p = 0.002], as well
278 as a significant interaction between both factors [$F_{4,64}$ = 5.32, p < 0.001], were observed. Post-hoc
279 analyses revealed that the older NH listeners had significantly higher SRTs than the young NH
280 listeners for the ICRA-5 condition [Effect size (M) = 1.39 dB, standard error (SE) = 0.68 dB], male
281 competing talker [M = 4.53 dB, SE = 0.68 dB], female competing talker [M = 2.70 dB, SE = 0.68
282 dB], and cocktail-party condition [M = 1.53 dB, SE = 0.68 dB]. Additionally, the older NH listeners
283 had significantly lower SRTs than the older HI listeners for the SSN condition [M = 2.36 dB, SE =
284 1.14 dB], ICRA-5 condition [M = 4.30 dB, SE = 1.14 dB], male competing talker [M = 3.60 dB, SE
285 = 1.14 dB], and female competing talker [M = 5.52 dB, SE = 1.14 dB]. The increase in SRT for the
286 older HI listeners in the cocktail-party condition approached, but did not reach, significance [M =
287 2.24 dB, SE = 1.14 dB, p = 0.06]. Furthermore, the post-hoc analyses revealed that the female

competing talker resulted in significantly lower SRTs than all other maskers for all listener groups. The male competing talker yielded significantly higher SRTs than all other maskers for the older NH and older HI listeners (except for the cocktail-party condition in the older NH group), while the cocktail-party condition yielded the highest SRTs for the young NH listeners. Finally, the ICRA-5 noise resulted in significantly lower SRTs than the SSN for the young and older NH listeners, but not for the older HI listeners. Additional details and results from all post-hoc analyses can be found in Appendix A.

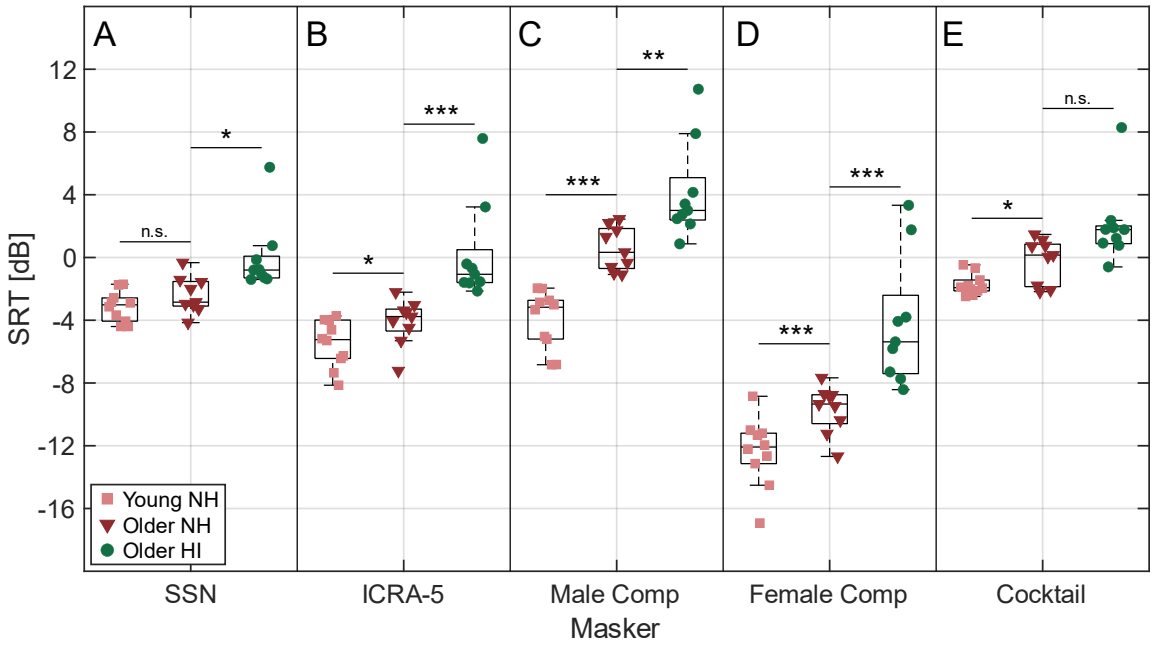


Figure 5 (Color online): Boxplots displaying the SRTs for all listeners. Each panel corresponds to a specific masker: Panel A: Speech-shaped noise (SSN), Panel B: ICRA-5 fluctuating noise, Panel C: Single male competing talker (same sex), Panel D: Single female competing talker (different sex), Panel E: Cocktail-party noise. The SRTs for the young NH listeners are represented by squares, older NH by triangles, and older HI by circles. The stars indicate the level of statistical significance of the differences between the groups separated by the horizontal black lines (* $p < 0.05$, ** $p < 0.01$, *** p

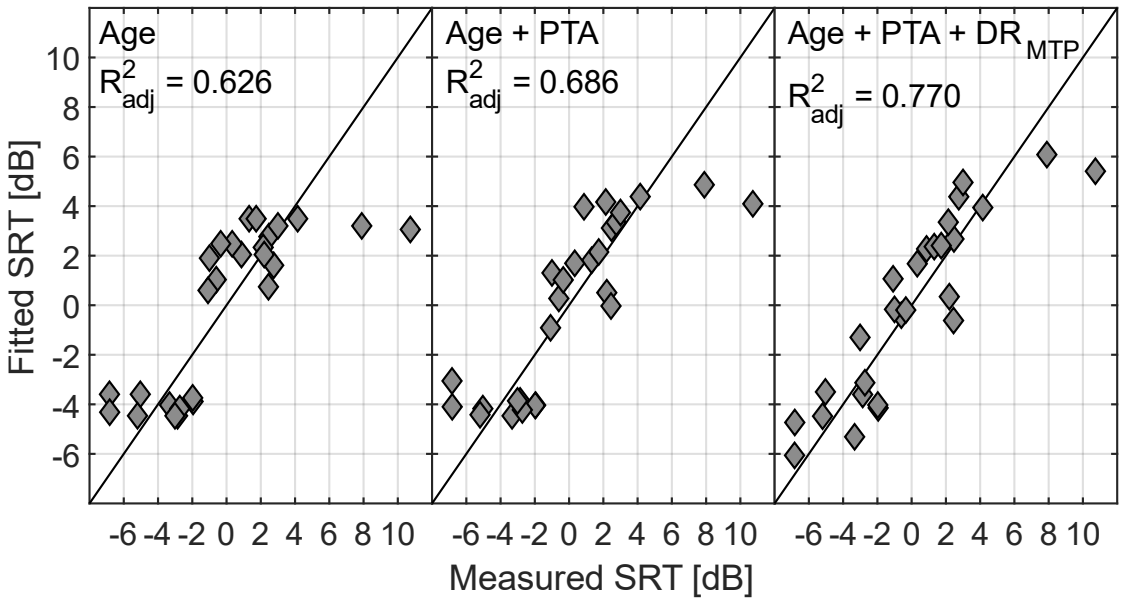
303 < 0.001), while "n.s." denotes non-significant differences. Note that the young NH and older HI
304 groups were not compared in the statistical analysis.

305

306 The multilinear regression analysis included the SRTs obtained with the male competing talker as
307 the outcome variable, as that condition yielded the largest difference in SRTs between young and older
308 NH listeners, as well as highest SRTs for both the older NH and HI listeners. The results showed that
309 the best-fitting model included the main effects of age, PTA, and DR_{MTP}, while RDS did not contribute
310 to explaining the variance in SRTs. Adding DR_{MTP} to age and PTA [$F_{1,23} = 9.693$, $p = 0.005$]
311 significantly increased the amount of variance in SRT explained by the model (adjusted R^2) by 8.4
312 percentage points to a total of 77%. No interaction term significantly increased the model's R^2. Figure
313 6 shows the scatter plots of the fitted SRTs as a function of the measured SRTs for each one of the
314 models iteratively built (i.e., including age, age + PTA, or age + PTA + DR_{MTP} as predictors) in
315 separate panels. The adjusted R^2 for each model is indicated in each panel. The best-fitting model's
316 regression coefficient (i.e., β weights) was larger for age (0.773) than for PTA and DR_{MTP} (0.303 and
317 0.350, respectively). The structure coefficients, i.e., the correlation of each predictor with the outcome
318 variable estimated from all predictors in the model, showed that both age and PTA were positively
319 correlated with the fitted SRTs, while DR_{MTP} was negatively correlated (0.896, 0.842, and -0.157,
320 respectively).

321 Since all predictors in the best-fitting model (age, PTA, and DR_{MTP}) were likely somewhat collinear,
322 a commonality analysis (Capraro and Capraro, 2001; Ray-Mukherjee *et al.*, 2014) was implemented to
323 assess the R^2 either attributable uniquely to each predictor or shared between them. The outcome
324 showed that age had the greatest unique R^2 (22 %), while PTA and DR_{MTP} had smaller unique R^2 (4.3
325 and 8.3 %, respectively). Furthermore, the commonality analysis revealed that age and PTA were

326 highly collinear whereby they shared a large common R^2 (48.8 %), and that age and DR_{MTP} were also
327 somewhat collinear but shared a negative R^2 (-7.9%). The detailed results of the regression and
328 commonality analyses can be found in Appendix B.



329

330 Figure 6: Scatter plot of the fitted SRTs as a function of the measured SRTs for each one of the
331 regression models assessed. The predictors included in the model as well as the adjusted R^2 are
332 indicated in each panel. The diagonal line indicates identity. The models were iteratively built to include
333 only age (left panel), age and PTA (middle panel), and finally age, PTA, and dynamic range of the 4-
334 Hz MTP (DR_{MTP}; right panel). The last model provided the best fit of the SRTs.

335 IV. DISCUSSION

336 The aim of the present study was to investigate whether the findings from speech intelligibility
337 tests would be consistent with the AM frequency selectivity data collected in previous studies by Regev
338 *et al.* (2023, 2024a). These previous investigations demonstrated an age-related decline in AM
339 frequency selectivity and an effective sharpening of AM tuning with hearing loss (see Figure 2 and
340 Figure 3). A subset of the listener cohort measured by Regev *et al.* (2023, 2024a) was considered here.

It was expected that the age-related reduction in AM frequency selectivity would correspond to poorer speech intelligibility in older compared to young NH listeners. Conversely, the sharper AM tuning observed in older HI listeners, assumed to be an "apparent" effect resulting from the loss of cochlear compression (Regev *et al.*, 2024a), was not anticipated to result in better speech intelligibility compared to the older NH listeners.

The results revealed an overall decline in speech intelligibility with age, which was further exacerbated by the presence of hearing loss. These findings are consistent with previous studies that have shown a deterioration of speech intelligibility with age (e.g., Rajan and Cainer, 2008; Helfer and Vargo, 2009; Schoof and Rosen, 2014; Füllgrabe *et al.*, 2015; Gordon-Salant and Cole, 2016; Goossens *et al.*, 2017; Decruy *et al.*, 2019) and hearing loss (e.g., Glasberg and Moore, 1989; Humes and Christopherson, 1991; Frisina and Frisina, 1997; see Humes and Dubno, 2010 for a review). Additionally, a multilinear regression model relating the SRTs obtained with a male competing talker to age, PTA, and DR_{MTP} (a measure of AM frequency selectivity) showed that DR_{MTP} significantly contributed to explaining the variance in SRTs, increasing the model's R^2 by 8 percentage points.

The observed increase in SRTs with age aligns with the age-related reduction in AM frequency selectivity reported by Regev *et al.* (2023). Broader modulation filters, indicative of reduced AM selectivity, may lead to increased AM masking, resulting in a decrease in the SNR_{env} at the output of these filters and potentially poorer speech intelligibility in noise. However, the lack of a significant age-related increase in SRT for the SSN condition is inconsistent with this notion. Since the SSN contains intrinsic envelope fluctuations that act as a relatively broadband modulation masker (as argued by Stone *et al.*, 2012), one might have expected the broader AM tuning found in older NH listeners to lead to an increase in AM masking. However, the SRTs obtained with the SSN likely reflect aspects of EM rather than AM masking. This is consistent with the extensive overlap observed in the audio spectra of the SSN and HINT speech material (Figure 4, panel A), compared to the highly

365 positive SNR_{env} observed when comparing their modulation spectra at low modulation frequencies
366 (Figure 4, panel F). These findings indicate that the SSN provided more EM than AM masking.
367 Conversely, the differences in modulation spectra between the target speech and masking noise were
368 much smaller for the other maskers, suggesting that AM masking (and thus potentially AM frequency
369 selectivity) may have played a more prominent role in those cases (Figure 4, panels G-J). Notably, the
370 older NH listeners exhibited a reduced release from masking when exposed to the fluctuating ICRA-
371 5 noise compared to the young NH listeners, consistent with previous studies (Dubno *et al.*, 2002,
372 2003; Grose *et al.*, 2009; Goossens *et al.*, 2017). In addition to potentially being the result of an age-
373 related increase in forward masking (e.g., Gifford *et al.*, 2007), the reduced release from masking
374 observed in the older NH listeners may also be attributed to increased AM masking due to the loss of
375 AM frequency selectivity, which may have limited the benefit derived from the slow temporal
376 fluctuations in the ICRA-5 condition.

377 Regarding the effects of hearing loss, the higher SRT's observed in the older HI listeners compared
378 to the older NH group are consistent with the expectation that the increase in AM frequency selectivity
379 observed in HI listeners (as reported in Regev *et al.*, 2024a) would *not* lead to improved speech
380 intelligibility. Regev *et al.* (2024a) argued that the greater AM frequency selectivity with hearing loss
381 was an apparent effect, resulting from improved detection of the AM target during temporal dips in
382 the masker due to the loss of cochlear compression. Since the loss of compression is also associated
383 with other supra-threshold deficits, such as loudness recruitment, poorer recovery from forward
384 masking, and reduced frequency selectivity (Glasberg and Moore, 1986, 1989; Oxenham and Moore,
385 1997; Moore and Oxenham, 1998), it is evident that the process potentially underlying the apparent
386 improved AM frequency selectivity is also linked to the mechanisms underlying poorer speech
387 intelligibility in HI listeners. However, while poorer speech intelligibility was expected in the HI
388 listeners, disentangling the potential impact of the effective sharpening in AM tuning with hearing loss

389 on speech intelligibility is not straightforward. It remains unclear whether the process underlying the
390 apparent sharpening of AM tuning with hearing loss a) improves SRTs but is outweighed by co-
391 occurring supra-threshold deficits typically associated with hearing loss, or b) itself ultimately impairs
392 speech intelligibility.

393 The results of the multilinear regression analysis further supported the existence of a link between
394 alterations in AM frequency selectivity and speech intelligibility challenges in noise for older listeners.
395 The addition of DR_{MTP} to the model significantly increased the amount of variance in SRTs explained
396 by the model. Furthermore, the negative structure coefficient for DR_{MTP} indicated that an increase in
397 the SRTs estimated by the best-fitting model (which included age, PTA, and DR_{MTP}) is linked with a
398 decrease in DR_{MTP}. This finding aligned with the expectation that poorer AM frequency selectivity
399 (quantified by a lower DR_{MTP}) would be linked with higher SRTs.[6] The link between poorer AM
400 frequency selectivity and poorer SRTs across listeners is also broadly consistent with the assumption
401 that the sharper MTPs observed in older HI listeners reflect a perceptual benefit inherited from the
402 loss of cochlear compression (represented by PTA in the regression model), rather than a genuine
403 sharpening of the hypothetical modulation filter (Regev *et al.*, 2024a).

404 To address the likely collinearity across predictors, the commonality analysis revealed that DR_{MTP}
405 acts as a suppressor, as shown by the negative R^2 shared between DR_{MTP} and age (Capraro and
406 Capraro, 2001). As such, the addition of DR_{MTP} to the model helped increase the R^2 uniquely
407 attributable to age, thus increasing the model's total R^2. Within the model, age can be seen as a "noisy
408 term" representing the sum of all factors underlying auditory processing deficits in older listeners that
409 are distinct from the effects of peripheral hearing loss. Such factors, which are likely somewhat
410 collinear, may include cochlear synaptopathy (Parthasarathy *et al.*, 2019a), reduced neural inhibition

[6] Structure coefficients are employed here since they have been suggested to be more robust than regression coefficients in cases involving multicollinearity among predictors (Thompson and Borrello, 1985; Kraha *et al.*, 2012)

411 (Caspary *et al.*, 2008), or poorer temporal envelope processing (Anderson and Karawani, 2020) such
412 as a loss of AM frequency selectivity (Regev *et al.*, 2023). Hence, the greater R^2 resulting from the
413 explicit addition of a measure of AM frequency selectivity to the regression model can reasonably be
414 interpreted as resulting from a "denoising" of the age term, allowing it to more accurately account for
415 the variance in SRTs.

416 However, it should be noted that the significant contribution of DR_{MTP} to the regression model
417 was not found when the model was applied to SRTs for other maskers than the male competing talker,
418 or DR_{MTP} derived from MTPs at other target modulation rates than 4 Hz. While the reasons for this
419 discrepancy remain unclear, the specific choice of the SRTs for the male competing talker and the
420 DR_{MTP} derived for a 4-Hz modulation rate was soundly motivated by the data. Indeed, the male
421 competing talker yielded the largest difference in SRTs between young and older NH listeners, as well
422 as the highest SRTs for both the older NH and HI listeners, compared to all other maskers.
423 Furthermore, the 4-Hz MTP also showed the largest differences in AM selectivity between young and
424 older NH listeners (Regev *et al.*, 2023) and was assumed to reflect the prominent role of the 4-Hz
425 modulation rate in speech perception (e.g., Elliott and Theunissen, 2009; Varnet *et al.*, 2017).

426 Notably, the present findings indicate that declines in speech intelligibility with age and hearing
427 loss are most prominent in contexts that involve high cognitive demand and informational masking
428 (IM), such as in the presence of competing-talker maskers. IM encompasses various factors that
429 complicate the separation of the target and masker speech signals, such as stream segregation
430 (Brungart et al., 2001; Darwin et al., 2003; Schneider et al., 2007; Kidd et al., 2016; see Kidd et al.,
431 2008 for a review). In the groups considered here, the older NH listeners exhibited significantly lower
432 RDS scores compared to the young NH listeners. Such reduced cognitive abilities have been suggested
433 to mediate the age-related increase of SRTs under conditions of IM (Rajan and Cainer, 2008; Gordon-
434 Salant and Cole, 2016; Goossens *et al.*, 2017). Therefore, the poorer speech intelligibility observed in

435 the older NH listeners in the present study may be partly attributed to a reduction in working-memory
436 capacity. However, the older NH listeners also had higher SRTs than the young NH listeners in the
437 ICRA-5 condition, which does not exert large amounts of IM or high cognitive demand. Furthermore,
438 the multilinear regression analysis showed that the RDS scores did not contribute to explaining the
439 variance in SRTs for the male competing talker across all listeners. Theses finding are broadly
440 consistent with studies reporting no significant correlation between reduced cognitive abilities and
441 increased SRTs in babble for older listeners (e.g., Schoof and Rosen, 2014), suggesting that other
442 factors may also contribute to the age-related decline in speech intelligibility. These factors may be
443 associated with age-related temporal processing deficits, as suggested by perceptual (Pichora-Fuller
444 and Souza, 2003; Pichora-Fuller and MacDonald, 2008; Helfer and Vargo, 2009; Füllgrabe et al., 2015;
445 see Fitzgibbons and Gordon-Salant, 2010 for a review) and neurophysiological research (e.g.,
446 Anderson et al., 2012; Decruy et al., 2019; Parthasarathy et al., 2019b; Roque et al., 2019; for reviews
447 see Parthasarathy et al., 2019a and Anderson and Karawani, 2020). The hypothesis that the age-related
448 reduction in AM frequency selectivity (as reported by Regev *et al.*, 2023) may contribute to increased
449 SRTs aligns with the notion that temporal processing deficits underlie the challenges in speech
450 intelligibility associated with age.

451 In the case of hearing loss, the differences in SRTs between older NH and older HI listeners were
452 also largest for the fluctuating and competing-talker maskers. This observation is consistent with the
453 reduced release from masking commonly found in HI listeners (e.g., Bacon *et al.*, 1998; Bernstein and
454 Grant, 2009; Strelcyk and Dau, 2009; Goossens *et al.*, 2017), as well as with the suggestion that the
455 effects of hearing loss on speech intelligibility are most pronounced in cognitively demanding settings
456 (e.g., Schneider *et al.*, 2010; Goossens *et al.*, 2017). Although the older HI listeners showed higher RDS
457 scores than their older NH counterparts, they did exhibit a marginally reduced working-memory
458 capacity compared to the young NH listeners. Hence, the large effect of hearing loss in conditions

459 involving IM may be partly connected to the age-related cognitive decline discussed earlier.
460 Conversely, the older HI listeners also had higher SRTs than their older NH counterparts in the SSN
461 and ICRA-5 conditions, which are commonly assumed not to involve high cognitive demand.

462 Notably, the multilinear regression analysis showed that the RDS scores, when added to age and
463 PTA, did not contribute to explaining the variance in SRTs for the male competing talker across
464 listeners. This suggests that working-memory capacity did not influence the speech intelligibility results
465 obtained in the present study. However, working-memory capacity is only one of several measures of
466 cognitive ability that may be reduced in older listeners, thus contributing to speech intelligibility
467 challenges in noise (e.g., Dryden *et al.*, 2017). Overall, while reduced cognitive ability in older listeners
468 may have partly mediated the observed effects of age and hearing loss on speech intelligibility, the
469 results also indicate that supra-threshold deficits influenced the SRTs, likely related to reduced
470 cochlear compression and temporal envelope processing deficits.

471 Although the data from the present study revealed significant group-level and regression results
472 that support a relationship between changes in AM tuning and speech intelligibility in noise for older
473 listeners, it is important to consider several co-occurring factors that may have influenced the findings.
474 Even though all the older NH listeners exhibited clinically normal hearing up to 4 kHz, their
475 audiometric thresholds were on average 8 dB higher than those of the young NH listeners between
476 125 Hz and 8 kHz, with the greatest differences occurring at 8 kHz. Although these differences in
477 audiometric thresholds are small, previous studies have suggested that they can have a considerable
478 effect on speech intelligibility (Dubno and Ahlstrom, 1997; Dubno *et al.*, 2000), possibly due to related
479 supra-threshold processing deficits (e.g., Léger *et al.*, 2012). Moreover, the older NH listeners included
480 in the present study may have experienced reduced audibility at extended high frequencies (> 8 kHz),
481 which have also been suggested to play a role in speech intelligibility (e.g., Hunter *et al.*, 2020; Polspoel
482 *et al.*, 2022). These aspects may have contributed to the observed age-related increase in SRTs.

483 Concerning the experimental approach, since the tests provided listeners with cues beyond the
484 temporal envelope, factors such as IM, EM, and stream segregation likely interacted with age- and
485 hearing loss-related perception deficits, as well as the age-related reduction in working-memory
486 capacity discussed above. Therefore, the connection between SRTs and AM frequency selectivity
487 suggested by the present results should be investigated further. An experimental paradigm limiting the
488 perceptual cues available in the speech intelligibility test to the temporal envelope may help establish
489 such a link with more certainty.

490 V. SUMMARY AND CONCLUSION

491 Speech intelligibility in noise was examined in three groups: young listeners with normal hearing
492 (aged 22-28 years), older listeners with normal hearing (aged 57-77 years), and older listeners with
493 hearing impairment (aged 64 – 77) years. All participants had previously taken part in AM masking
494 studies investigating AM frequency selectivity, which revealed an age-related reduction in AM tuning
495 and an effective sharpening in AM tuning with hearing loss (Regev *et al.*, 2023, 2024a). This study
496 aimed to determine if the effects of age and hearing loss on speech intelligibility in noise support the
497 hypothesis that the age-related reduction in AM tuning negatively impacts speech intelligibility, while
498 the improvement in AM tuning with hearing loss does not provide a benefit.

499 Consistent with the hypothesis, the results showed an age-related decline and an additional
500 negative effect of hearing loss on speech intelligibility, especially for fluctuating maskers. Furthermore,
501 a multilinear regression analysis showed that adding a measure of AM frequency selectivity to a model
502 using age and audibility as predictors significantly increased the amount of variance in SRTs explained.
503 This finding supported the assumption that an age-related loss of AM frequency selectivity is linked
504 to speech intelligibility difficulties in noise, once audibility is accounted for. Moreover, the results
505 broadly aligned with the proposition made by Regev *et al.* (2024a) that the improved AM tuning in
506 listeners with hearing impairment is an "apparent" effect resulting from reduced peripheral

compression, which is known to contribute to other supra-threshold deficits that impair speech intelligibility.

Overall, this study's results support the notion that an age-related reduction in AM frequency selectivity may contribute to speech intelligibility challenges in noise and warrant further investigation into this potential mechanism. To more directly assess the effects of AM tuning, and a loss thereof, on speech intelligibility, future studies may focus on speech-intelligibility testing paradigms that specifically examine envelope-based cues.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflict of interest to report.

Ethics Approval

All participants provided written informed consent and were offered financial compensation for their participation. Ethical approval for the study was provided by the Science Ethics Committee of the Capital Region in Denmark (reference H-16036391).

DATA AVAILABILITY

This manuscript has been submitted to the Journal of the Acoustical Society of America. Once it has been accepted, the data that support the findings of this study will be openly available from Regev, J., Zaar, J., Relaño-Iborra, H., and Dau, T. (2024). "Dataset for: 'Investigating the effects of age and hearing loss on speech intelligibility and amplitude modulation frequency selectivity'", Technical University of Denmark. Dataset. https://doi.org/10.11583/DTU.25771884.

APPENDIX

A. Post-hoc analyses

Table 1 summarizes the results of the post-hoc analyses that compared the SRTs obtained with young and older NH listeners for each masker.

Table 1: Post-hoc analysis of the differences in SRT between young and older NH listeners for each masker. The effect sizes (M), standard errors (SE, and corrected p-values are reported. The significant p-values are highlighted in bold.

Masker	M [dB]	SE [dB]	Corrected p-value
SSN	0.75	0.68	0.279
ICRA-5	1.39		**0.047**
Male competing	4.53		**< 0.001**
Female competing	2.70		**< 0.001**
Cocktail party	1.53		**0.030**

548 Table 2 summarizes the results of the post-hoc analyses that compared the SRTs obtained with
549 older NH and older HI listeners for each masker.
550
551 Table 2: Post-hoc analysis of the differences in SRT between older NH and older HI listeners for each
552 masker. The effect sizes (M), standard errors (SE, and corrected p-values are reported. The significant
553 p-values are highlighted in bold.

Masker	**M [dB]**	**SE [dB]**	**Corrected p-value**
SSN	2.36	1.14	**0.048**
ICRA-5	4.30		**< 0.001**
Male competing	3.60		**0.004**
Female competing	5.52		**< 0.001**
Cocktail party	2.24		0.060

554
555 Table 3 summarizes the results of the post-hoc analyses that compared the SRTs obtained with
556 the different maskers for each of the three listener groups (young NH, older NH, and older HI). Since
557 this post-hoc analysis was run twice for the older NH listeners (once for each statistical model applied),
558 the values reported reflect the most conservative *p*-values and standard errors, obtained from the
559 model fitted to the older NH and older HI listeners. However, the effect sizes and overall statistical
560 outcomes did not differ between the analyses run in the two models.
561
562
563
564

565 Table 3: Post-hoc analysis of the differences in SRT between older the different maskers for each
566 group. The effect sizes (M), standard errors (SE, and corrected p-values are reported. The significant
567 p-values are highlighted in bold.

Listener group	Maskers compared	M [dB]	SE [dB]	Corrected p-value
Young NH	SSN - ICRA-5	2.35	0.48	**< 0.001**
	SSN – Male competing	0.83		0.086
	SSN – Female competing	9.23		**< 0.001**
	SSN – Cocktail party	-1.42		**0.008**
	ICRA-5 – Male competing	-1.52		**0.006**
	ICRA-5 – Female competing	6.88		**< 0.001**
	ICRA-5 – Cocktail party	-3.77		**< 0.001**
	Male competing – Female competing	8.40		**< 0.001**
	Male competing – Cocktail party	-2.25		**< 0.001**
	Female competing – Cocktail party	-10.65		**< 0.001**
Older NH	SSN - ICRA-5	1.71	0.60	**0.011**
	SSN – Male competing	-2.95		**< 0.001**
	SSN – Female competing	7.28		**< 0.001**
	SSN – Cocktail party	-2.20		**0.001**
	ICRA-5 – Male competing	-4.66		**< 0.001**
	ICRA-5 – Female competing	5.57		**< 0.001**
	ICRA-5 – Cocktail party	-3.91		**< 0.001**
	Male competing – Female competing	10.23		**< 0.001**
	Male competing – Cocktail party	0.75		0.212

	Female competing – Cocktail party	-9.48		**< 0.001**
Older HI	SSN - ICRA-5	-0.23	0.60	0.696
	SSN – Male competing	-4.20		**< 0.001**
	SSN – Female competing	4.12		**< 0.001**
	SSN – Cocktail party	-2.09		**0.003**
	ICRA-5 – Male competing	-3.96		**< 0.001**
	ICRA-5 – Female competing	4.35		**< 0.001**
	ICRA-5 – Cocktail party	-1.85		**0.006**
	Male competing – Female competing	8.32		**< 0.001**
	Male competing – Cocktail party	2.11		**0.003**
	Female competing – Cocktail party	-6.20		**< 0.001**

570 **B. Regression analysis**

571 Table 4 summarizes the details of the best-fitting model used in the multilinear regression analysis.

572

573 Table 4: Details of the multilinear regression analysis relating the SRTs obtained for the male
574 competing talker to age, PTA, and DR_{MTP}. For each predictor, the table reports the standardized
575 regression coefficients (β), the 95%-confidence interval for β (lower | upper), as well as the structure
576 coefficients (r_s).

Predictor	**Standardized β**	**95% CI β (lower | upper)**	r_s
Age	0.7726	0.4892 | 1.056	0.8964
PTA	0.3025	0.0452 | 0.5598	0.8422
DR_{MTP}	0.3504	0.111 | 0.5898	-0.1569

577

578 Table 5 summarizes the details of the commonality analysis conducted on the best-fitting model
579 (relating SRTs to age, PTA, and DR_{MTP}), which identifies the R^2 either uniquely attributable to each
580 predictor or shared among them.

581

582 Table 5: Outcome of the commonality analysis applied on the best-fitting model, that related SRTs
583 obtained for a male competing talker to age, PTA, and the 4-Hz MTP's average dynamic range
584 (DR_{MTP}). The table reports the amount of variance in SRTs explained (R^2) either uniquely explained
585 by each predictor (single variables) or commonly shared between predictors (two or more variables).

Predictor	Age	PTA	DR_{MTP}	Age and PTA	Age and DR_{MTP}	PTA and DR_{MTP}	Age, PTA, and DR_{MTP}	**Total**
R^2 [%]	21.96	4.33	8.30	48.78	-7.89	2.49	-1.00	76.97

586

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