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Verification of an automated headphone-based test of spatial release from masking

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Currently there are many different laboratory-based tests of spatial release from masking (SRM) that use speech materials, however there is still disagreement as to the impacts of age and hearing loss on SRM. It is time, then, to take these tests out of the laboratory and begin testing larger numbers of listeners varying in age and hearing ability in order to provide the statistical power needed to answer the questions currently being asked. Unfortunately, most of the tests that have been developed are either open set, and thus require a tester to administer them, or require complex soundfield speaker arrays. Our laboratory has recently developed and verified an automated headphone-based test that can be presented in only five to ten minutes and that provides results that are predictive of results obtained in an anechoic chamber.

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1. SPATIAL RELEASE FROM MASKING

Despite a long history of the development and exploration of paradigms designed to examine spatial release from masking (SRM; for a review see Bronkhorst, 2015) there is still disagreement as to the impacts of age and hearing loss on SRM. One of the serious difficulties for untangling these issues lies in the strong correlation between age and hearing loss in the general population. The best way to solve these issues lies in the use of large samples and modern statistical techniques. Unfortunately, most of the existing paradigms are either open set, and thus cannot be easily administered in an automated fashion, or require the use of multichannel soundfield speaker arrays.

The goal of the current analysis is to verify the ability of a rapid, automated, headphone-based method to reveal relationships between age and hearing loss in a test of spatial release from masking. The task of the listener is to identify speech in the presence of competing speech. By comparing performance when target and maskers are colocated (identical spatial locations of all talkers) with when the target and maskers are spatially separated, it is possible to determine the benefit of spatial cues. In addition, Bayesian hierarchical regression was used to model the data in order to demonstrate the ability of modern statistical techniques to break through some of the difficulties inherent in the techniques more frequently employed.

Experiment One presents a data set collected in an anechoic chamber and analyzed using multiple linear regression. Experiment Two presents a data set collected over headphones and analyzed with Bayesian hierarchical logistical regression. Similarities between the two data sets and analyses reveal the promise of a rapid headphone-based test. Differences between the results of the two analyses shed light on the promise of Bayesian statistical techniques.

2. EXPERIMENT ONE: ANECHOIC CHAMBER

A. PARTICIPANTS

Thirty-six listeners, aged 18-78 years, participated in the testing. The pure-tone averages (PTAs) for these listeners was calculated based on the audiogram by averaging the thresholds in dB HL for the frequencies .5, 1, 2, 4, and 6 kHz. Values varied between -2 and 38 and are plotted as a function of age in Figure 1.

B. METHODS

Using three loudspeakers, target and maskers were presented either from the same loudspeaker, located directly in front of the listener (0 degrees) or each from a different loudspeaker (see Figure 2). The target was always presented from the loudspeaker at 0 degrees. The masking talkers were presented from 45 degrees to the left and right in the spatially separated condition.

All stimuli were drawn from the Coordinate Response Measure (CRM; Bolia et al., 2000) corpus and all talkers were male (talkers 0, 1, and 2 from the corpus). Each CRM sentence contains a callsign (e.g., Charlie, Baron, Hopper, etc.) and two keywords, a color and a number. Participants responded using a custom graphical touch interface to indicate the color/number combination associated with the callsign “Charlie”. Responses were scored correct only if the color and number were both correctly identified.

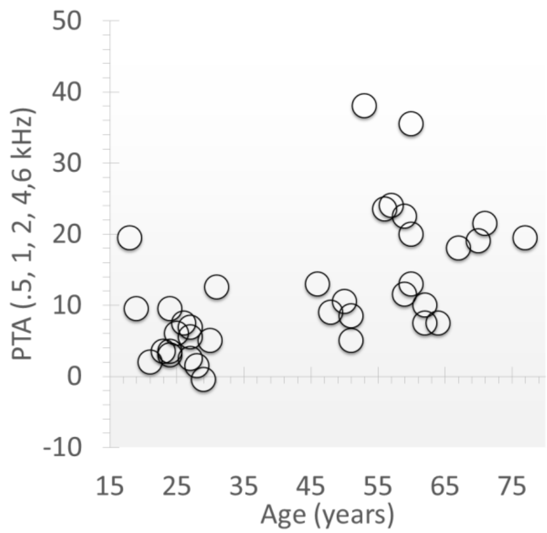

Figure 1. The relationship between age and PTA for the 36 listeners in Experiment One

Using the "progressive" tracking method of Gallun et al. (2013), target level was fixed at 30 dB above the speech reception threshold measured in quiet for the CRM corpus used and masker levels were progressively increased across trials. The target-to-masker ratio (TMR) started at 10 dB and progressively decreased by 2 dB after every two trials, eventually stopping after 20 trials with the presentation of two trials at -8 dB. Threshold was estimated by subtracting the number of incorrect responses from the starting TMR (10 dB). Gallun et al. (2013) showed that this method underestimates threshold relative to an adaptive tracking method, but the correlation with adaptive threshold was high and there was no evidence that the underestimate produced a bias in the predicted thresholds. Thresholds were estimated based on the average of four tracks collected in each spatial condition.

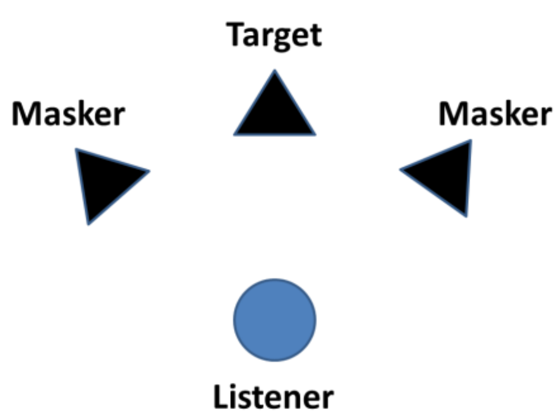

Figure 2. Target and masking positions in the spatially separated condition in the anechoic chamber.

C. RESULTS

TMR threshold estimates in the colocated condition varied between 0 and 4 dB, while TMR threshold estimates in the spatially separated condition varied between -8.75 and -2.5 dB. The relationships between PTA and TMR are shown in Figure 3, panels A and B, and those between age and TMR are shown in panels C and D. In both figures, the colocated data are plotted in the left panels (A and C) and the spatially separated in the right panels (B and D). A stepwise multiple linear regression model revealed that while age accounted for 14.8% of the variance in TMR for the colocated condition, adding PTA only increased the variance accounted for by .4%. The initial model was statistically significantly different from a "null" model containing no predictors (p = .02) but the difference between the age alone and PTA plus age model was not significant (p = .713). Applying the same two factors to the spatially separated condition produced the opposite results, however. The model based on age alone accounted for 9.6% of the variance, which was not statistically different from the null model (p = .07), but the model including age and PTA accounted for 33% of the variance, which was statistically significantly different from the age alone model (p = .002).

D. DISCUSSION

Figure 3 demonstrates that while age and hearing loss are both predictors of performance, accounting for between 9 and 34% of the variance in TMR across conditions, the relative influence of each factor and the interaction of the two factors is still difficult to assess from this analysis. This conclusion mirrors a general lack of consensus in the literature as to the relative importance of age and hearing loss on spatial hearing (e.g., Gallun et al., 2013; Glyde et al., 2013; Fullgrabe et al., 2015)

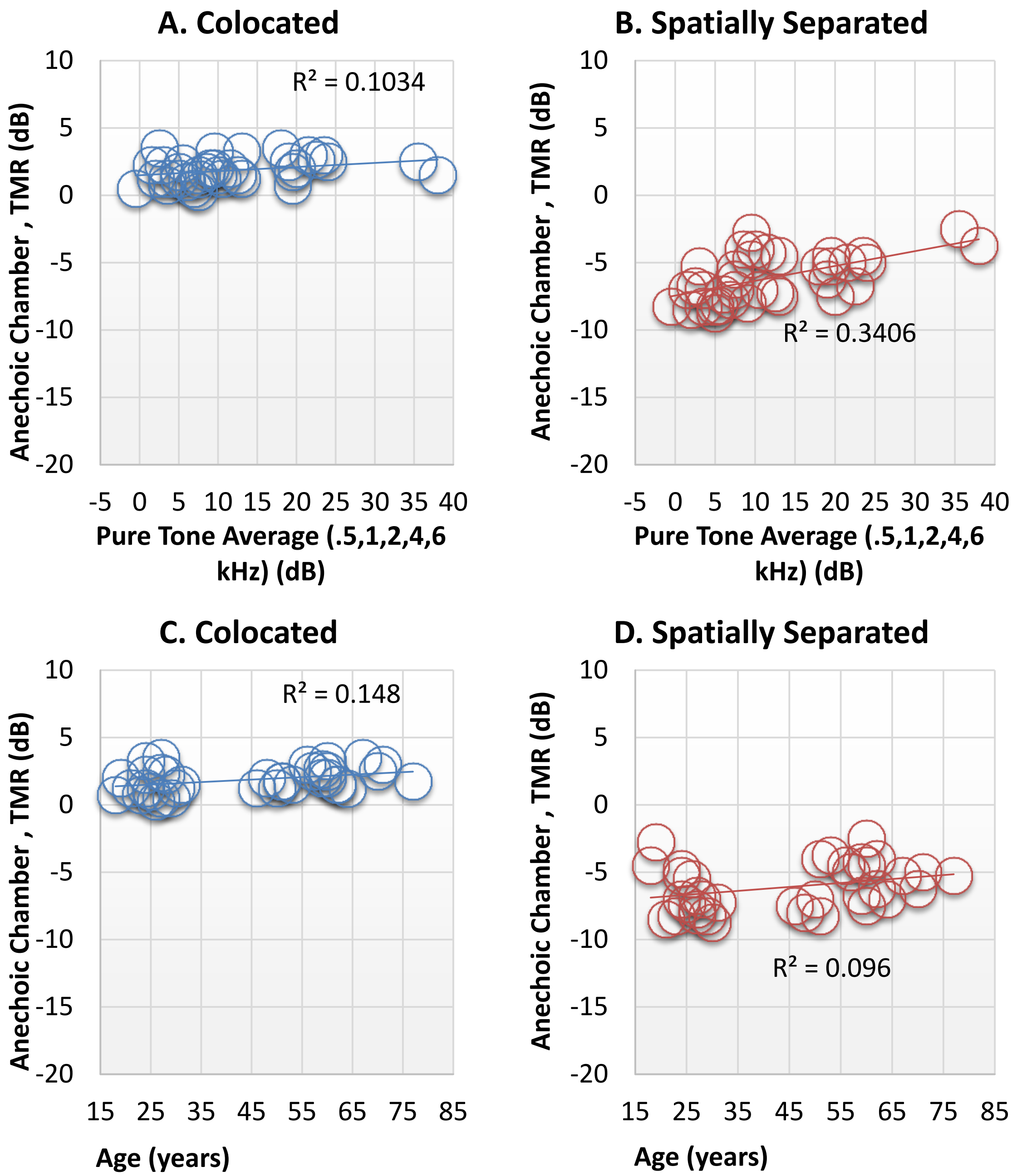

Figure 3. The relationships between PTA and TMR (Panels A and B) and age and TMR (Panels C and D) for the 36 listeners in Experiment One.

3. ALTERNATIVE APPROACHES TO DATA ANALYSIS.

Conventional statistical analyses rely heavily on p-values to identify the presence or absence of a relationship between causes (e.g. age or hearing) and effects (e.g. SRM). This reliance is highly sensitive to the accuracy of the p-value, which can be difficult to verify. Furthermore, we find the statistical 'null hypothesis' to be almost universally specious: under no circumstances would a reasonable scientist suggest that the quantitative association between hearing or age and an auditory task is exactly equal to zero. Any investigation into the association among variables implies belief that there is some relationship. Accordingly, we prefer a Bayesian approach that offers much greater flexibility and facilitates interpretation of results. A multi-level approach (Gelman et al., 2012) is especially useful for identifying potential interactions among predictors.

4. EXPERIMENT TWO: HEADPHONES

The second experiment was designed to verify the combination of headphone testing using a Virtual Auditory Space (VAS) with the rapid progressive testing method described in Gallun et al. (2013) and used in Experiment One. Initial data from this approach were presented in Gallun et al. (2013), but only two tracks were collected in each condition and the range of PTAs was purposely limited to allow the effects of age to be more clearly revealed.

A. PARTICIPANTS

Eighty-three listeners participated, ranging in age from 18 to 78 years. PTAs varied between -2 and 45 dB. The relationship between age and PTA is shown in Figure 4.

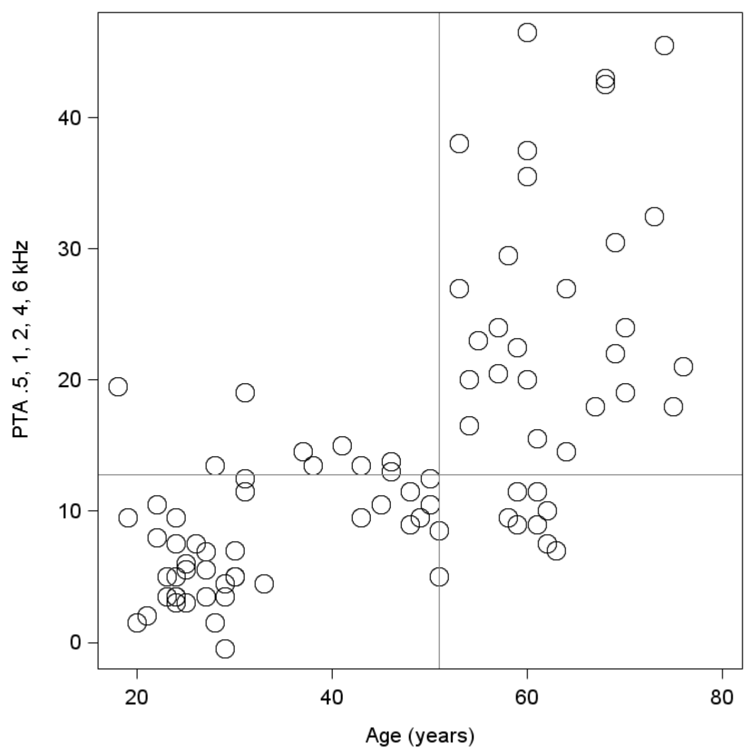

Figure 4. The relationship between age and PTA for the 83 listeners in Experiment Two.

B. METHODS

As detailed in Gallun et al. (2013) head-related impulse responses (HRIRs) associated with the appropriate spatial locations were convolved with the CRM stimuli prior to presentation over headphones. Otherwise, the conditions were matched precisely to those used in Experiment One, with progressive tracks that were presented in colocated and spatially separated conditions. Each participant completed between two and eight tracks per condition, with sets of two tracks collected on successive test sessions. Sessions occurred across three years of testing, with the time between sessions ranging from as little as an hour to as long as two years.

A Bayesian hierarchical logistic regression model was fit to the data, using diffuse priors on the intercepts and slopes of the psychometric functions. Individual performance, age, and PTA were all used to fit the model to the data. Examples of potential psychometric functions drawn from the prior and posterior distributions are shown in Figure 5. Functions relating probability of a correct response to TMR for the colocated condition are shown in the panels on the left and the psychometric functions for the spatially separated condition are shown on the right.

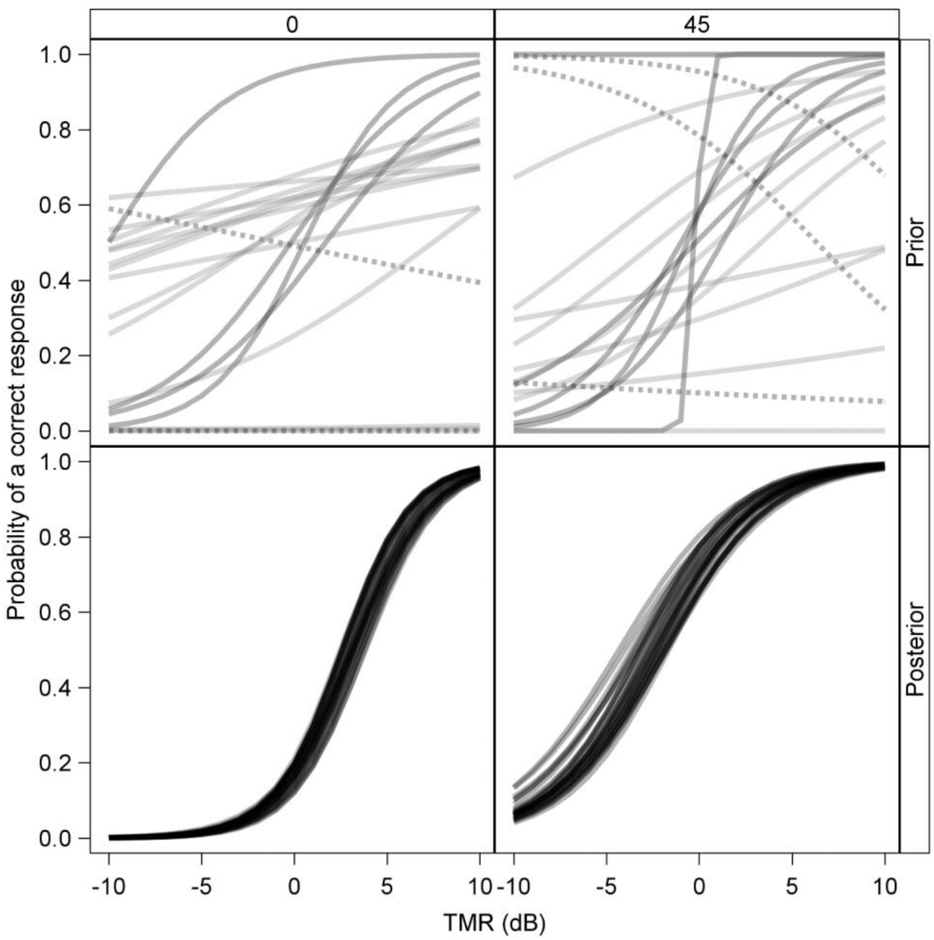

Figure 5. Example functions drawn at random from the prior and posterior distributions of functions relating TMR and probability of a correct response in Experiment Two.

C. RESULTS

The resulting posterior distribution of functions, examples of which are shown in Figure 5, was very regular and fit the theoretical expectations. Specifically, the probability of a correct response was monotonically increasing with TMR and the range of thresholds (TMR at which there was a 50% chance of a correct response; TMR50) was very similar to the range found in Experiment One. As shown in Figure 6, the relationship between the predicted and observed probability of a correct response was very strong. Analysis of the repeated testing across sessions revealed that TMR50 estimated from the first session differed by less than 1 dB from TMR50 values estimated from the later sessions.

The model was able to provide a clear demonstration of the impact of age and PTA on performance. Thresholds below the lowest TMRs presented were able to be estimated from the data. As in the anechoic chamber, PTA had a more consistent effect on performance than age at the 45 degree separation, but both effects were present and interacted in predicting thresholds for both spatial conditions. Thresholds predicted by the model (TMR50) are shown as a function of PTA and age in Figures 7 and 8, respectively. The other parameter (PTA or age) is indicated by the darkness of the filled symbols.

The effects of PTA and age shown in Figures 7 and 8 were calculated by the model to be non-linear, as was the interaction. That is, the change in TMR50 with each year of age depends on the starting age. For a model in which the PTA is fixed at 10 dB, a value of 20 years gives a mean TMR of 2.25 dB in the colocated condition and predicts a TMR50 of -5.37 in the spatially-separated condition. The same model predicts for a value of 60 years (and a PTA of 10 dB) that TMR 50 in the colocated condition will be 3.16 dB and TMR50 will be -2.53 dB in the spatially-separated condition.

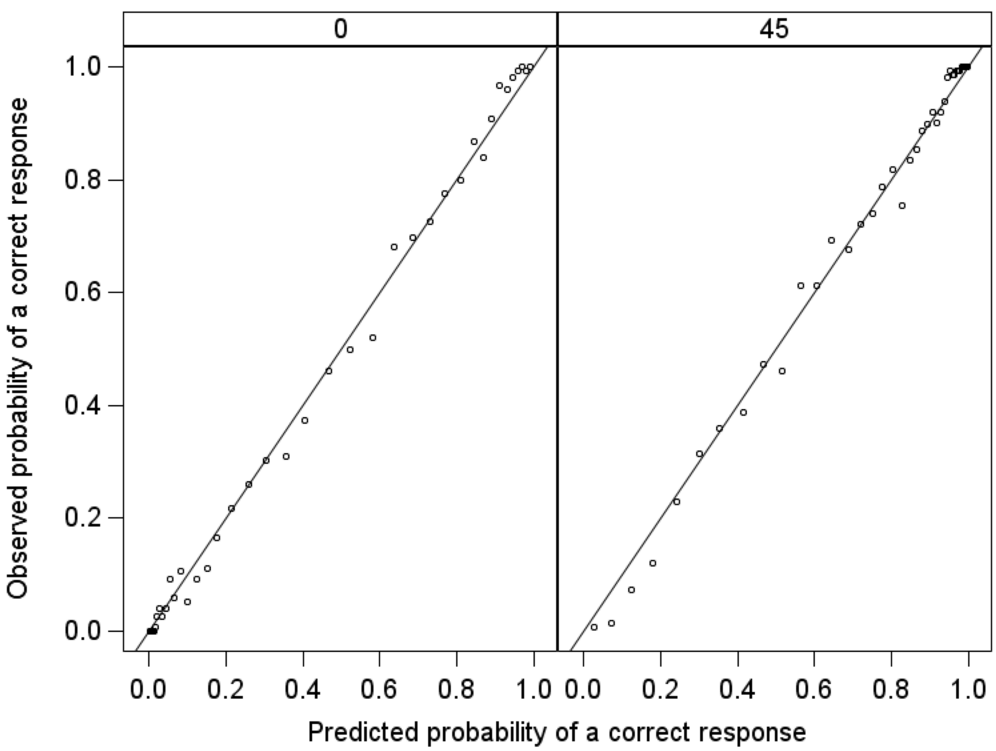

Figure 6. Observed and predicted probability of a correct response for the colocated condition (left panel) and the spatially separated condition (right panel).

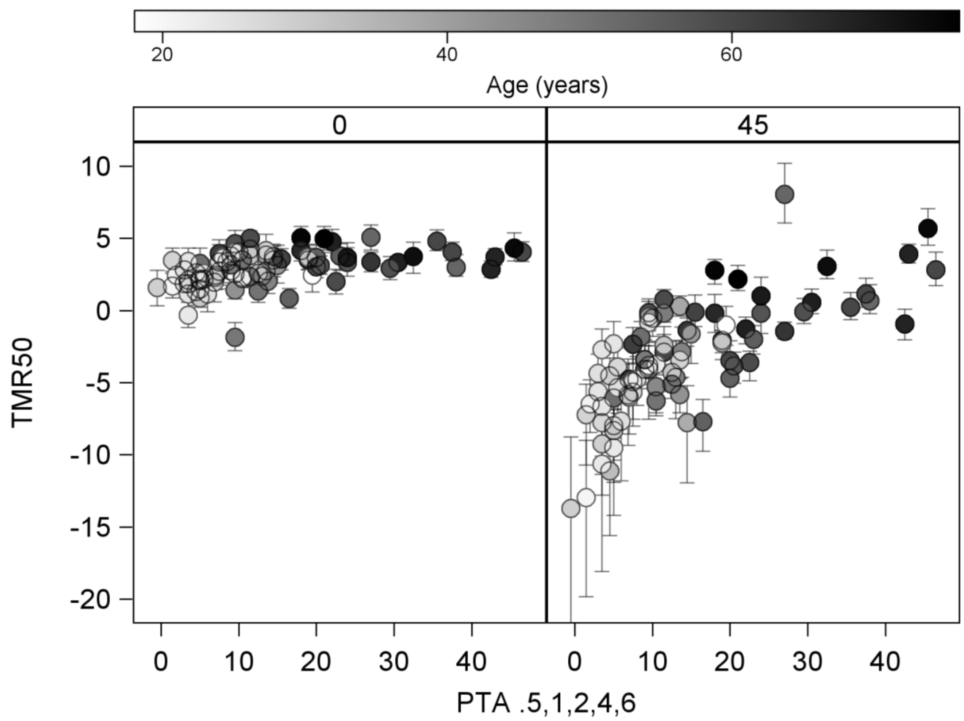

Figure 7. The relationships between PTA and TMR50 for the 83 listeners in Experiment Two. Age is indicated by the darkness of the shading of the symbols.

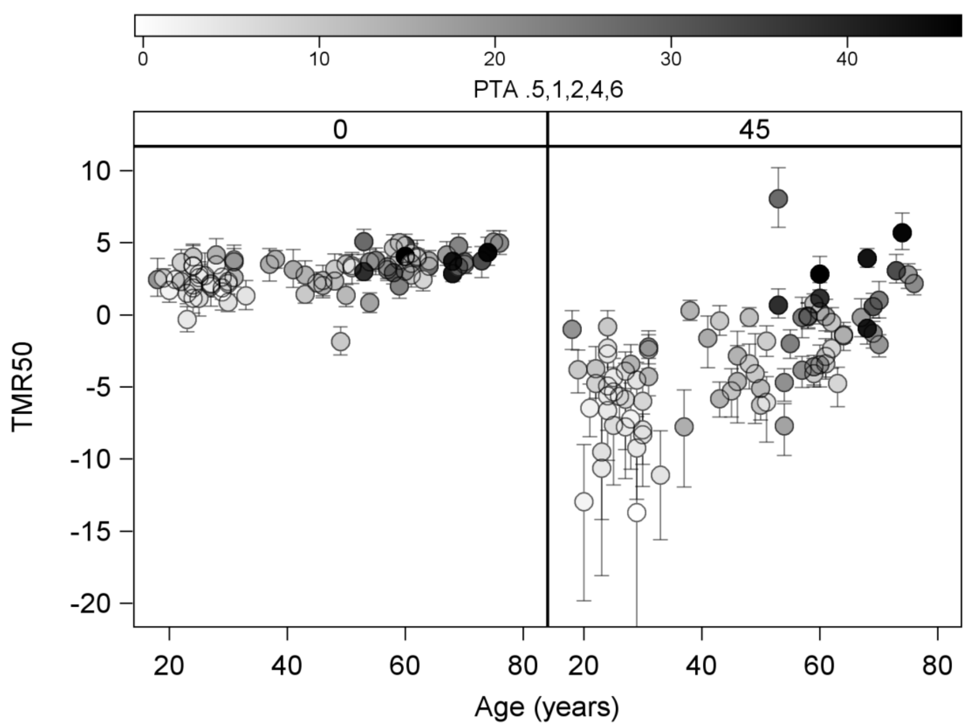

Figure 8. The relationships between age and TMR50 for the 83 listeners in Experiment Two. PTA is indicated by the darkness of the shading of the symbols.

5. CONCLUSION

A rapid, automated test of spatial release can produce data that are reliable across repeated tests, and can be modeled with high accuracy. Bayesian methods allow estimates of effect size in the units of interest, based on models containing multiple predictors. Future work will involve using this test to collect large data sets and to examine multiple potential predictors of performance using hierarchical Bayesian statistical models.

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