Adaptive Control for Gap Detection across the Lifespan

Kenneth I. Vaden Jr., Mark A. Eckert, Judy R. Dubno, Kelly C. Harris

Department of Otolaryngology-Head and Neck Surgery
Medical University of South Carolina, Charleston, SC

Introduction

Elevated task-focused attention can benefit performance in challenging perceptual tasks (Carter et al., 2000; Kerns et al., 2004), including speech recognition in noise (Vaden et al., 2013). Attention declines can contribute to age-related differences in gap detection (Alain et al., 2004; Harris et al., 2010, 2012; He et al., 1999).

Cingulo-opercular (CO) regions in frontal cortex are hypothesized to facilitate *adaptive control* to optimize task performance by adjusting attention and monitoring outcomes (Eckert et al., 2016; Vaden et al., 2013).

CO activity increases prior to the detection of target sounds (*adjusting attention*; Sadaghiani et al., 2009; Coste & Kleinschmidt, 2016) and during difficult task conditions, response errors, and response uncertainty (*outcome monitoring*; Dosenbach et al., 2006).

Does CO activity enhance detection of gaps in noise for younger and older adults, when age-related perceptual differences are experimentally controlled?

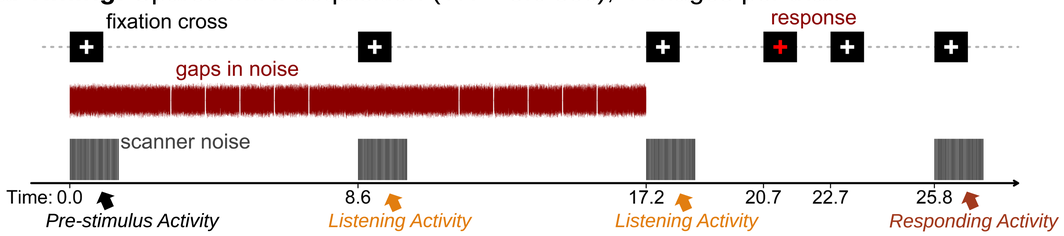
Method

Participants: Younger adults (N = 15; 11 female; m ± sd age = 24 ± 3 years) and older adults (N = 15; 10 female; age = 68 ± 8 years) performed a gap detection in noise task during an fMRI experiment. Each participant had mean pure-tone thresholds < 25 dB HL from 500 to 4000 Hz in the right ear (test ear).

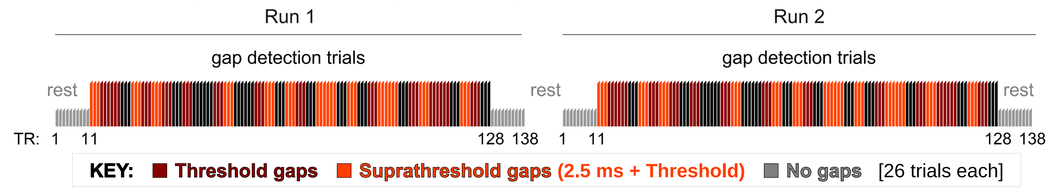
Gap-detection thresholds (in ms) were calculated for each participant prior to the fMRI visit.

Task: Listen to a noise recording and indicate whether it contained a gap (yes/no button).

Trial Timing: Sparse fMRI acquisition (TR = 8.6 sec); 4 images per trial.



Mixed Block Design: 138 T2*-weighted images (3 mm^3 voxels) ×2 runs (19 m 47 s each).



Structural MRI: T1-weighted images (1 mm^3 voxels).

Analysis

Preprocessing for the fMRI dataset: 1) motion correction, 2) co-registration to structural images, 3) spatial warping to the average brain space (ANTS; Avants and Gee, 2004), and 4) smoothing (8mm FWHM).

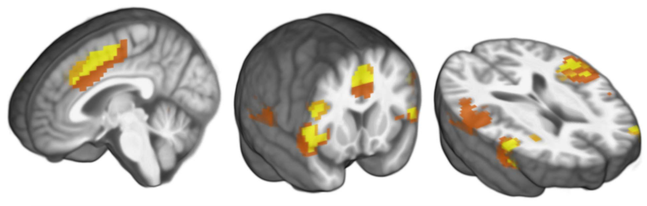
Significant group-level BOLD contrast effects were defined with a combined voxel threshold: Z = 4.26, p_{UNC} = 0.00001 and permutation-based cluster threshold p_{FWE} = 0.05; Ecklund et al., 2014.

A logistic mixed effect model was used to determine whether elevated pre-stimulus BOLD contrast in CO regions of interest predicted a higher likelihood of correct responses, and to estimate subject-level effects.

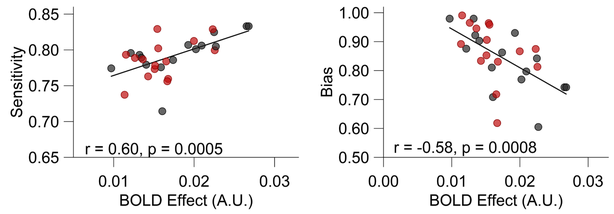
Results

Gap thresholds obtained outside of the scanner were longer for older adults [5.34 ms] than younger adults [4.19 ms; t(28) = 5.15, p < 0.001]. Presenting gaps at or above detection thresholds in the scanner limited age-related differences in gap sensitivity [p = 0.42] or response bias [p = 0.33], based on button responses.

Task-Related BOLD Effects



Individual Differences



Cingulo-opercular BOLD contrast increased during listening and responding, relative to the resting baseline.

Correct responses were significantly more likely on trials with relatively higher pre-stimulus CO BOLD contrast [Z = 2.62, p = 0.009]. Effects of CO activity on trial-level gap detection were larger for participants with better sensitivity and less response bias [p's < 0.001] and did not differ between age groups [p = 0.21].

Conclusions

Elevated cingulo-opercular activity predicted correct gap detection responses, consistent with activity changes during auditory target detection tasks (Sadaghiani et al., 2009; Coste and Kleinschmidt, 2016).

Only pre-stimulus CO activity from the onset of each trial was significantly related to task performance, despite robust activation throughout listen and response portions of the task.

Participants with better gap detection demonstrated the largest benefit from cingulo-opercular activity, consistent with previously observed effects on speech recognition in noise (Vaden et al., 2015). However, these effects did not vary systematically with age (or age-related differences in task difficulty).

Gap detection is sensitive to CO activity and attention engaged prior to task trials, irrespective of age.

Acknowledgements. This work was supported (in part) by the NIH/NIDCD (P50 DC 000422, R01 DC014467, K23 DC008787), MUSC Center for Biomedical Imaging, South Carolina Clinical and Translational Research (SCTR) Institute, NIH/NCRR UL1 RR029882. This investigation was conducted in a facility constructed with support from the NIH/NCRR Research Facilities Improvement Program (C06 RR014516). We thank the study participants.

Download PDF

REFERENCES

Alain, C., McDonald, K.L., Ostroff, J.M., Schneider, B., 2004. Aging: a switch from automatic to controlled processing of sounds? Psychol. Aging 19, 125–133.

Avants, B.B., Gee, J.C., 2004. Geodesic estimation for large deformation anatomical shape averaging and interpolation. Neuroimage 23 Suppl 1, S139–S150.

Carter, C.S., Macdonald, A.M., Botvinick, M., Ross, L.L., Stenger, V.A., Noll, D., Cohen, J.D., 2000. Parsing executive processes: Strategic versus evaluative functions of the anterior cingulate cortex. Proc Natl Acad Sci USA 97, 1944–1948.

Coste, C.P., Kleinschmidt, A., 2016. Cingulo-opercular network activity maintains alertness. Neuroimage 128, 264–272.

Dosenbach, N.U.F., Visscher, K.M., Palmer, E.D., Miezin, F.M., Wenger, K.K., Kang, H.C., Burgund, E.D., Grimes, A.L., Schlaggar, B.L., Petersen, S.E., 2006. A core system for the implementation of task sets. Neuron 50, 799–812.

Eckert, M., Teubner-Rhodes, S., Vaden, K., 2016. Is listening in noise worth it? The neurobiology of speech recognition in challenging listening conditions. Ear Hear. 37, 101S–110S.

Eklund, A., Dufort, P., Villani, M., Laconte, S., Cheng, X., Ben-Shalom, R., 2014. BROCCOLI: Software for fast fMRI analysis on many-core CPUs and GPUs. Front Neuroinf 8.

Harris, K.C., Eckert, M.A., Ahlstrom, J.B., Dubno, J.R., 2010. Age-related differences in gap detection: Effects of task difficulty and cognitive ability. Hear. Res. 264, 21–29.

Harris, K.C., Wilson, S., Eckert, M.A., Dubno, J.R., 2012. Human Evoked Cortical Activity to Silent Gaps in Noise: Effects of Age, Attention, and Cortical Processing Speed. Ear Hear. 33, 330–339.

He, N.J., Horwitz, A.R., Dubno, J.R., Mills, J.H., 1999. Psychometric functions for gap detection in noise measured from young and aged subjects. J Acoust Soc Am 106, 966–978.

Kerns, J.G., Cohen, J.D., MacDonald, A.W., Cho, R.Y., Stenger, V.A., Carter, C.S., 2004. Anterior cingulate conflict monitoring and adjustments in control. Sci. 303, 1023–6.

Sadaghiani, S., Hesselmann, G., Kleinschmidt, A., 2009. Distributed and antagonistic contributions of ongoing activity fluctuations to auditory stimulus detection. J Neurosci 29, 13410–7.

Vaden, K.I., Kuchinsky, S.E., Ahlstrom, J.B., Dubno, J.R., Eckert, M.A., 2015. Cortical activity predicts which older adults recognize speech in noise and when. J. Neurosci. 35, 3929–3937.

Vaden, K.I., Kuchinsky, S.E., Cute, S.L., Ahlstrom, J.B., Dubno, J.R., Eckert, M.A., 2013. The cingulo-opercular network provides word-recognition benefit. J. Neurosci. 33, 18979–86.