DOI: 10.61782/fa.2025.0319

EEG INSIGHTS INTO THE IMPACT OF NOISE AND DYSPHONIC SPEECH ON CHILDREN'S LISTENING EFFORT AND SENTENCE COMPREHENSION

Silvia Murgia[1*] **Mary M. Flaherty**[2] **Pasquale Bottalico**[2]

[1] Department of Psychology, University of Illinois at Urbana-Champaign, United States of America
[2] Department of Speech and Hearing Science, University of Illinois at Urbana-Champaign, United States of America

ABSTRACT

This research investigates the effects of background noise, dysphonic speech on children's sentence comprehension and listening effort, using electroencephalography (EEG). Inhibitory control (IC) and working memory (WM) were assessed to account for individual variability. Twenty-four children (ages 8-12) completed the Test for Reception of Grammar under two signal-to-noise ratios (0 dB and 6 dB) and two voice qualities (typical and dysphonic). EEG analyses focused on theta and alpha frequency bands to examine neural dynamics of listening effort. Findings revealed that sentence comprehension decreased under noisier and dysphonic conditions, particularly for children with higher WM. EEG results showed heightened theta power and reduced alpha power during dysphonic speech, indicating increased cognitive demands, with a positive relationship to WM and IC, respectively. This suggests that children had to recruit additional cognitive resources to process degraded auditory input. These findings demonstrate that noise and dysphonic speech place distinct demands on cognitive resources, hindering comprehension and increasing listening effort, while relying on executive function to adapt to difficult acoustic environments.

*_**Corresponding author**: smurgia2@illinois.edu._

Keywords: _electroencephalography, speech comprehension, noise, dysphonia, children_

1. INTRODUCTION

Listening comprehension plays a central role in children's academic development, enabling them to follow instructions, engage in discussions, and acquire knowledge through spoken language [1, 2]. Yet, this skill can be disrupted by external and internal factors—particularly poor acoustic environments, degraded speech input, and individual differences in cognitive abilities such as working memory (WM) and inhibitory control (IC) [3, 4]. Many classrooms present acoustical challenges that fall short of recommended standards. Although guidelines suggest that classrooms maintain a signal-to-noise ratio (SNR) of at least +15 dB for optimal learning [5], actual measurements often range much lower, from -7 to +6 dB [6, 7]. These conditions obscure speech cues and demand more cognitive resources for accurate processing, especially for younger children whose executive function skills are still developing [8–12].

Compounding the effects of background noise is the issue of poor voice quality, particularly dysphonia, which is common among teachers due to prolonged voice use in noisy environments [13, 14]. Dysphonic speech, characterized by hoarseness, breathiness, or strain, degrades intelligibility and requires additional mental effort to interpret [15–17]. This may reduce children's ability to sustain attention and negatively impact their learning experience [18, 19]. While some studies indicate that dysphonic voices may not always reduce comprehension accuracy, they still pose processing challenges for children—particularly when paired with noise [20, 21]. Standard comprehension assessments often overlook the added mental effort required under these challenging auditory conditions [22, 23].

Executive functions like WM and IC may help buffer against these challenges. WM supports the retention and manipulation of verbal input, while IC enables selective attention to target speech in the presence of distractions [24–26]. Research suggests that children with stronger executive function may show improved comprehension in difficult listening environments [27–29].

Physiological techniques such as electroencephalography (EEG) offer promising tools for examining the neural mechanisms that support listening under strain. EEG captures brain responses in real time and provides insight into how children process auditory information under varying levels of acoustic and vocal degradation [30]. Two key frequency bands—alpha and theta—have emerged as indicators of neural effort during auditory tasks. Alpha oscillations are associated with attentional filtering and inhibition of irrelevant input, whereas theta oscillations relate to memory load and speech processing under increased task demands [31–33]. Studies in adults show that adverse auditory environments lead to decreased alpha and increased theta activity, reflecting the recruitment of additional cognitive resources [34, 35]. Although EEG research in children is more limited, early evidence supports its potential for detecting changes in neural effort in response to difficult speech conditions [36].

This study examines how background noise and dysphonic voice affect speech comprehension in children aged 8 to 12, and how EEG signals reflect these challenges. It also investigates whether individual differences in WM and IC influence children's ability to cope with degraded auditory input. We hypothesize that noisy and dysphonic speech will lead to reduced comprehension accuracy and increased neural activity in theta and alpha bands. We further expect that children with stronger executive functions will show different EEG patterns, reflecting more efficient processing.

2. METHODS

2.1 Participants

Twenty-four children aged 8–12 years (M = 10.6, SD = 1.4), evenly split by gender, participated. All were native American English speakers with normal hearing and no reported speech, language, or hearing disorders. Informed consent and child assent were obtained in compliance with the University of Illinois IRB (Protocol No. 24087).

2.2 Speech Material

Stimuli were selected from six blocks of the TROG-2 test to assess grammar comprehension. Sentences were recorded in both typical and simulated dysphonic voices by a female speaker. A certified pathologist verified the voice qualities using the GRBAS scale. Classroom noise at two intensity levels (60 and 66 dB(A)) was added to the recordings. Each block's sentences were distributed evenly across four conditions (2 voice qualities × 2 noise levels).

2.3 Setup of the Room and Equipment

Testing occurred in a sound-treated booth. Speech stimuli were delivered via a front-facing TalkBox speaker (66 dB(A)), while ambient noise was played from two rear speakers set at SNRs of 6 dB and 0 dB. Children sat at a desk facing a screen, interacting only via mouse. EEG data were collected using the Emotiv Epoc X system, which includes 14 scalp electrodes and two references, sampled at 128 Hz. Impedance was visually verified. PsychoPy software was used for stimulus presentation and data collection.

2.4 Procedure

Children participated in the experiment in a sound-treated booth while wearing an EEG cap. After a short baseline recording, they listened to pre-recorded sentences presented under varying voice and noise conditions. Following each sentence, children selected the corresponding image from four options displayed on a screen. Two practice trials preceded the test. The entire listening task lasted approximately 10–15 minutes and was conducted using PsychoPy software.

2.5 Signal Processing and Statistical Analysis

The final 3 seconds of each sentence were used for EEG analysis, capturing semantic content. EEG data were processed using EEGLAB in MATLAB. Data were filtered (1 Hz high-pass), baseline-corrected, and segmented from -2.75 to 3.75 seconds around stimulus onset. Bad channels were interpolated, and ICA was used to remove blink artifacts. Only participants with at least 75% usable epochs were retained for EEG analysis (n = 15). ERSPs were computed using Morlet wavelet transformations. Frontal theta (4–8 Hz) and parietal alpha (8–12 Hz) power were extracted. Baseline correction used a gain model over a -600 to -200 ms window. Data analysis was conducted using R and the lme4 package. Listening comprehension (binary), perceived effort (scaled), and EEG power (continuous) were analyzed using GLMs and linear models. Independent variables included voice quality, SNR.

3. RESULTS

3.1 Listening Comprehension

Children's speech comprehension was significantly reduced by both background noise and voice quality (Fig. 1). At 0 dB SNR, the probability of correct comprehension dropped by 70% compared to 6 dB SNR (*p* ¡ .001). Similarly, dysphonic voice led to a 42% decrease in comprehension accuracy compared to typical voice quality ($p = .006$). There was no significant influence of working memory (WM; $p = .800$) or inhibitory control (IC; $p = .284$) on comprehension scores, indicating that challenging listening environments equally affected all participants regardless of cognitive ability.

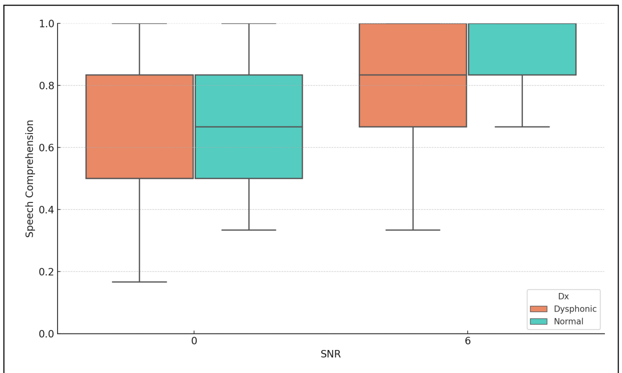

Figure 1. Average speech comprehension scores across different SNRs, grouped by voice quality. Each box represents the distribution of average comprehension scores per participant (ID) for a given SNR and Dx condition.

3.2 Relative Alpha Power

Alpha power, associated with attentional processes, significantly decreased (desynchronized) when children listened to dysphonic speech ($p = .041$), reflecting increased cognitive load. No significant effect was found for SNR ($p = .541$). Children with higher IC scores showed lower alpha power ($p = .013$). WM did not significantly influence alpha activity ($p = .111$).

3.3 Relative Theta Power

Theta power, linked to memory demands, significantly increased (synchronized) during listening to dysphonic voice ($p = .041$), indicating greater effort. SNR again showed no significant effect ($p = .541$). Higher WM was associated with greater theta power ($p = .013$). IC had no significant effect on theta activity ($p = .235$).

4. DISCUSSION AND CONCLUSION

This study demonstrates that both background noise and dysphonic voice significantly impair children's listening comprehension. Comprehension accuracy declined in degraded conditions, with a notable 70% drop at 0 dB SNR and a 42% decrease for dysphonic speech—findings consistent with previous work showing that noise and reduced vocal clarity hinder speech perception and cognitive processing in children [17, 37, 38].

EEG analyses revealed that dysphonic voice, more than background noise, induced marked changes in brain activity. Decreased alpha power indicated heightened attentional demands, particularly in children with stronger inhibitory control, supporting the role of alpha oscillations in attentional modulation [31, 35]. Increased theta activity was observed in response to dysphonic input, especially among children with higher working memory capacity, reflecting greater memory-related processing load [33].

Interestingly, the relatively small difference in SNR (6 dB vs. 0 dB) may have limited the ability to detect distinct EEG responses to noise alone. Dysphonia, however, consistently elicited both alpha and theta modulations, underlining its disruptive effect on neural processing.

These findings suggest that adverse acoustic conditions increase cognitive demands even when comprehension remains superficially intact. Although children with stronger executive function appear better equipped to manage moderate challenges, their advantage diminishes under more severe degradation. Improving classroom acoustics and supporting teacher vocal health are therefore essential to minimize cognitive strain and optimize learning conditions [18, 20].

5. REFERENCES

[1] Y. S. G. Kim and H. Pilcher, "What is listening comprehension and what does it take to improve listening comprehension?," *Interventions in Learning Disabilities*, vol. 13, pp. 159–173, 2016.

[2] P. Backlund, "Essential speaking and listening skills for elementary school students," *Communication Education*, vol. 34, no. 3, pp. 185–195, 1985.

[3] S. L. Mattys, M. H. Davis, A. R. Bradlow, and S. K. Scott, "Speech recognition in adverse conditions: A review," *Language and Cognitive Processes*, vol. 27, no. 7–8, pp. 953–978, 2012.

[4] D. J. Plebanek and V. M. Sloutsky, "Selective attention, filtering, and the development of working memory," *Developmental Science*, vol. 22, no. 1, p. e12727, 2019.

[5] A. N. S. Institute, "Ansi/asa s12.60: Acoustical performance criteria, design requirements, and guidelines for schools," *ANSI Standards*, 2010.

[6] C. C. Crandell and J. J. Smaldino, "Classroom acoustics for children with normal hearing and with hearing impairment," *Language, Speech, and Hearing Services in Schools*, vol. 31, no. 4, pp. 362–370, 2000.

[7] P. Arnold and D. Canning, "Does classroom amplification aid comprehension?," *British Journal of Audiology*, vol. 33, no. 3, pp. 171–178, 1999.

[8] M. Klatte, K. Bergström, and T. Lachmann, "Does noise affect learning? a short review on noise effects on cognitive performance in children," *Frontiers in Psychology*, vol. 4, p. 578, 2013.

[9] F. Gheller, E. Lovo, A. Arsie, and R. Bovo, "Classroom acoustics: Listening problems in children," *Building Acoustics*, vol. 27, no. 1, pp. 47–59, 2020.

[10] J. R. Sullivan, H. Osman, and E. C. Schafer, "The effect of noise on the relationship between auditory working memory and comprehension in school-age children," *Journal of Speech, Language, and Hearing Research*, vol. 58, no. 3, pp. 1043–1051, 2015.

[11] J. Leon-Carrion, J. García-Orza, and F. Pérez-Santamaría, "Development of the inhibitory component of the executive functions in children and adolescents," *International Journal of Neuroscience*, vol. 114, no. 10, pp. 1291–1311, 2004.

[12] L. J. Leibold and E. Buss, "Masked speech recognition in school-age children," *Frontiers in Psychology*, vol. 10, p. 1981, 2019.

[13] L. C. C. Cutiva, I. Vogel, and A. Burdorf, "Voice disorders in teachers and their associations with work-related factors: A systematic review," *Journal of Communication Disorders*, vol. 46, no. 2, pp. 143–155, 2013.

[14] L. C. C. Cutiva and A. Burdorf, "Effects of noise and acoustics in schools on vocal health in teachers," *Noise and Health*, vol. 17, no. 74, pp. 17–22, 2015.

[15] R. T. Sataloff, A. K. Lalwani, M. P. Fried, A. Tabaee, M. S. Benninger, and C. J. Hartnick, "Sataloff's comprehensive textbook of otolaryngology: Head and neck surgery," *JP Medical Ltd.*, 2015.

[16] P. Bottalico, S. Murgia, T. Mekus, and M. M. Flaherty, "Classroom acoustics for enhancing students' understanding when a teacher suffers from a dysphonic voice," *Language, Speech, and Hearing Services in Schools*, vol. 54, no. 4, pp. 1195–1207, 2023.

[17] I. S. Schiller, D. Morsomme, M. Kob, and A. Remacle, "Listening to a dysphonic speaker in noise may impede children's spoken language processing in a realistic classroom setting," *Language, Speech, and Hearing Services in Schools*, vol. 52, no. 1, pp. 396–408, 2021.

[18] A. S.-L.-H. Association, "Voice disorders: Overview," *ASHA.org*, 2009.

[19] C. K. Porcaro, P. M. Evitts, and N. K. et al., "Effect of dysphonia and cognitive-perceptual listener strategies on speech intelligibility," *Journal of Voice*, vol. 34, no. 5, pp. 806.e7–806.e18, 2020.

[20] M. Rudner, V. Lyberg-Åhlander, and J. B. et al., "Listening comprehension and listening effort in the primary school classroom," *Frontiers in Psychology*, vol. 9, p. 1193, 2018.

[21] K. J. Brännström, V. Lyberg-Åhlander, and B. Sahlén, "Perceived listening effort in children with hearing loss: listening to a dysphonic voice in quiet and in noise," *Logopedics Phoniatrics Vocology*, vol. 47, no. 1, pp. 1–9, 2022.

[22] M. B. Winn and K. H. Teece, "Listening effort is not the same as speech intelligibility score," *Trends in Hearing*, vol. 25, p. 23312165211027690, 2021.

[23] S. Alhanbali, P. Dawes, R. E. Millman, and K. J. Munro, "Measures of listening effort are multidimensional," *Ear and Hearing*, vol. 40, no. 5, pp. 1084–1097, 2019.

[24] A.-M. Adams and S. E. Gathercole, "Phonological working memory and spoken language development in young children," *Quarterly Journal of Experimental Psychology Section A*, vol. 52, no. 3, pp. 543–560, 1999.

[25] M. K. Pichora-Fuller, S. E. Kramer, M. A. Eckert, B. Edwards, B. W. Y. Hornsby, L. E. Humes, U. Lemke, T. Lunner, M. Matthen, C. L. Mackersie, G. Naylor, N. A. Phillips, M. Richter, M. Rudner, M. S. Sommers, K. L. Tremblay, and A. Wingfield, "Hearing impairment and cognitive energy: The framework for understanding effortful listening (fuel)," *Ear and Hearing*, vol. 37, no. Suppl 1, pp. 5S–27S, 2016.

[26] M. I. Posner and S. E. Petersen, "The attention system of the human brain," *Annual Review of Neuroscience*, vol. 13, pp. 25–42, 1990.

[27] J. Brännström, E. Zunic, A. Borovac, and T. Ibertsson, "Listening effort and speech recognition with hearing aids: Effects of background noise, frequency lowering, and working memory capacity," *Journal of the American Academy of Audiology*, vol. 29, no. 5, pp. 416–427, 2018.

[28] P. Dalton and N. Lavie, "Listening to speech under load: The impact of cognitive load on semantic processing of spoken language," *Cognition*, vol. 111, no. 3, pp. 403–409, 2009.

[29] C. Visentin, A. Astolfi, S. Murgia, E. Pellerey, and N. Prodi, "Children's listening effort and inhibitory control in classrooms with different background noise conditions," *Journal of Speech, Language, and Hearing Research*, vol. 66, no. 2, pp. 329–342, 2023.

[30] K. Miles, C. M. McMahon, I. Boisvert, R. Ibrahim, P. De Lissa, P. Graham, and B. Lyxell, "Objective assessment of listening effort: Coregistration of pupillometry and eeg," *Trends in Hearing*, vol. 21, pp. 1–13, 2017.

[31] A. Dimitrijevic, M. L. Smith, D. S. Kadis, and D. R. Moore, "Cortical alpha oscillations predict speech intelligibility," *Frontiers in Human Neuroscience*, vol. 11, p. 88, 2017.

[32] A. Strauß, M. Wöstmann, and J. Obleser, "Cortical alpha oscillations as a tool for auditory selective inhibition," *Frontiers in Human Neuroscience*, vol. 8, p. 350, 2014.

[33] M. G. Wisniewski, E. R. Thompson, N. Iyer, J. R. Estepp, M. N. Goder-Reiser, and S. C. Sullivan, "Frontal midline theta power as an index of listening effort," *NeuroReport*, vol. 29, no. 9, pp. 705–710, 2018.

[34] E. B. Petersen, M. Wöstmann, J. Obleser, and T. Lunner, "Hearing loss impacts neural alpha oscillations under adverse listening conditions," *Frontiers in Psychology*, vol. 6, p. 177, 2015.

[35] J. Obleser and N. Weisz, "Suppressed alpha oscillations predict intelligibility of speech and its acoustic details," *Cerebral Cortex*, vol. 22, no. 11, pp. 2466–2477, 2012.

[36] P. Marsella, A. Scorpecci, G. Cartocci, S. Giannantonio, A. G. Maglione, I. Venuti, F. Babiloni, I. De Lucia, P. Arpaia, and F. Vozzi, "Eeg and pupil features reveal listening effort during bilateral hearing aid use in children with hearing loss," *Sensors*, vol. 17, no. 12, p. 2765, 2017.

[37] M. Klatte, T. Lachmann, and M. Meis, "Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting," *Noise and Health*, vol. 12, no. 49, pp. 270–282, 2010.

[38] P. Bottalico, S. Murgia, G. E. Puglisi, A. Astolfi, and K. Ishikawa, "Intelligibility of dysphonic speech in auralized classrooms," *The Journal of the Acoustical Society of America*, vol. 150, no. 4, pp. 2912–2920, 2021.