

Cognition Influencing Auditory Perception in SLD Children: Revisiting the Models of Auditory Processing

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Abstract

The study assessed the auditory processing abilities and the cognitive skills in children with specific learning disability. It investigates the top-down or bottom-up influence on auditory processing. Using a test battery approach, the association between cognitive skills (verbal working memory and attention) and auditory processing abilities (auditory closure, binaural integration and temporal processing skills) has been measured. The results revealed that cognitive processes significantly affect the bottom-up auditory perception. The effect of cognition was more evident in speech processing than non-speech signal processing. These findings may be useful in designing appropriate therapeutic protocol for children with specific learning disability.

Keywords: dyslexia; learning disability; psychoacoustics; speech perception.

Introduction

Auditory processing involves the ability of the auditory system to localize and lateralize sounds, discriminate and recognize auditory patterns, temporal aspects of signal, and understanding the auditory information in degraded listening environments (ASHA, 1996; Bellis, 2003; Chermak & Musiek, 1997), efficiently and effectively. Any disturbance in perceptual processing of the auditory information is referred to as auditory processing disorders (ASHA, 1996).

Auditory processing is affected in individuals with peripheral hearing loss (Neijenhuis, Tschur, & Snik, 2004), elderly population (Atcherson, Nagaraj, Kennett, & Levisse, 2015), with certain neurological disorders (Klein et al., 1995), psychological disorders (Iliadou et al., 2013), developmental disabilities like attention deficit hyperactive disorders (Chermak, Somers, & Seikel, 1998), dyslexia (Hugdahl et al., 1998), learning disability (Kraus et al., 1996), specific language impairment (Cohen, Campbell, & Yaghamai, 1989), and others. Studies have indicated that children with learning disability show inability in processing complex auditory information (Merzenich et al., 1996). This processing problems have been attributed to the neurophysiological encoding of the speech stimuli and higher level processing deficits (Studdert-Kennedy & Mody, 1995). Lui et al. (2009) have suggested top-down processing deficit of semantic tasks in auditory modality in children with

reading disability. Verbal working memory, which is the ability to store acoustic information for a short period and plays important role in speech perception (Ingvalson, Dhar, Wong, & Liu, 2015), is affected in LD children (Alloway & Alloway, 2010; Wiguna, Wr, Kaligis, & Belfer, 2012).

Attention deficits have also been found to be prominent in children with learning disability (Finneran, Francis, & Leonard, 2009). Pinheiro et al. (2010) have reported that LD children have displayed poor divided attention abilities in dichotic listening tasks. In auditory stroop task, selective attention, i.e., the ability to focus on relevant auditory information while ignoring the irrelevant information, has been found to be affected in these children (Faccioli, Peru, Rubini, & Tassinari, 2008).

Researchers have reported that deficits in the cognitive abilities in the form of verbal working memory and auditory attention have been found in case of LD children. Therefore, it was hypothesized that the cognitive abilities may be associated with auditory processing disorders in LD children. Hence, in the present study, some auditory processing abilities and cognitive skills were assessed in children with specific learning disability.

Methodology

Participants

A standard group comparison research design was adapted. 31 children (17 males and 14 females) diagnoses as specific learning disability (SLD) by qualified speech language pathologist as per DSM-5 criterion (American Psychiatric Association, 2013) were included. Equal number of typically developing children (TD) were also selected (n=31). The children in both SLD and TD group were native Kannada speakers and belonged to similar socio-economic and cultural background. All the children were within the age range of 8-10 years and were having normal hearing sensitivity ($PTA \leq 15$ dBHL; $SRT \pm 10$ dB of PTA; $SIS > 90\%$). All children had average or above average intelligence ($I.Q. \geq 90$) as assessed by the school psychologist. None of the child had any associated speech, language, otological, psychological and/or neurological problems. The study adhered to the rules of the institutional ethical board and approved to test human

subjects. An informed written consents were obtained from either parents or teachers of all the participant before commencing the tests.

Assessment of Auditory Processing Abilities

Tests to assess auditory closure, binaural integration, temporal resolution, temporal pattern recognition and temporal masking were selected. Auditory closure is the ability to fill-in the missing auditory information when the external redundancy in the acoustic signal is reduced. Time compressed speech test (TCST) and word recognition in noise test (WRS) were used to assess auditory closure abilities. TCST comprised of 40 standardized Kannada sentences (a Dravidian language) with 3-4 words. These sentences were divided into 2 sets by randomly assigning the sentences into sets, i.e. 20 sentences per set. The sentences were processed to have 50%, 60%, 70% and 80% of temporal compression. The participants were expected to repeat the complete sentence as the compressed sentences were presented.

WRS consisted of five lists with 30 standard Kannada words per list. Each list was processed with steady-state noise to obtain a SNR of -9, -6, -3, 0 and +3 dB. The participants were expected to repeat the words as they heard. A detailed description of the stimulus parameter is available elsewhere (Jain, Vasudevamurthy, & Raghavendra, 2015).

Auditory fusion test was used to measure binaural integration skills. The test comprised of standardized Kannada bisyllabic words, where first syllable of the word was presented in to one ear and the corresponding second syllable was presented in other ear, simultaneously. The participants were expected to say the whole word. Two lists of 30 words each, were presented randomly. The lists were constructed in such a way that a syllable which was in the initial position in one word would also occur in the final position of any other word. This reduced the syllabic position effect.

Temporal resolution abilities were measured using temporal modulation transfer function (TMTF) at 8, 60 and 200 Hz modulation frequencies. The stimulus was a 500 ms Gaussian noise that was modulated at specific frequency. Using a two alternative force choice method, the participants were asked to identify the interval containing a modulated noise. 90 sound sequences were presented by adapting the maximum likelihood procedure which was implemented using Matlab (Grassi & Soranzo, 2009).

Temporal pattern recognition was measured using duration pattern test. The test stimuli, as suggested by Musiek (1994), consisted of a 1000 Hz pure tone generated using audacity software (ver. 1.3.14 beta). Two tones, one with 500 ms and another with 250 ms, were used. The tones were patterned in six different combinations such that one tone was presented once while other tone was presented twice, with an inter-tone interval of 300 ms. The participants were asked to repeat the

sequence in which tones were presented. Each tone sequence was presented at least five times.

Temporal masking skills were measured using backward masking test by following the maximum likelihood procedure implemented using Matlab (Grassi & Soranzo, 2009). The test stimulus was a 1000 Hz tone of 20 ms duration which was presented immediately before a 300 ms band pass noise (400-1600 Hz). The participants were asked, using a two alternative force choice method, to identify the noise interval which had a tone. 90 pair of sounds were presented.

Assessment of Cognitive Skills

The cognitive skills were assessed in terms of verbal working memory, divided attention and selective attention. Auditory digit span test (Blackburn, 2011) and operation span test (Kane et al., 2004) were used to assess verbal working memory. In digit span test, sequence of digits were presented binaurally and participants were asked to repeat the sequence in either the same order (forward digit span) or in the reverse order (backward digit span) of presentation. The stimuli were presented in the increasing order of the number of digits. The testing started from two digits level and moved up to ten digit level. Three trials at each level were given and when the participant responded 2/3 trials correctly, the next level of test was administered. The maximum number of digits repeated correctly were considered as the thresholds.

The operation span test based on the study of Kane et al. (2004), has been standardized in Kannada by Jain and Kumar (2016). In this test, the target stimuli (phrases varying from two to five bi-syllabic words) were presented along with a secondary task (a mathematical operation). Participant's task was to solve the mathematical problem and label it as correct and incorrect and subsequently say the word in the order of presentation. For two word sentences, each correct word repeated was given a score of 0.5; for three word sentence, each correct word repeated was given a score of 0.33; and so on, till five word sentence where each correctly repeated word was given a score of 0.2. In total, 12 such sentences were presented (three in each phrase length) and the scores were given out of 12 (each sentence carried a total score of one, when all the words were correctly repeated).

The attention skills were measured for divided attention and selective attention task using dichotic digit test (Musiek, 1983). The test comprised of pair of digits presented binaurally. In the divided attention task (free recall), the participants were expected to repeat all the digits presented to them. In selective attention tasks (force recall), the participants focused their attention to one ear only and repeated the digits presented to that ear while ignoring the digits being presented to other ear. Total 30 pair of digits were presented randomly for each task.

Procedure

The testing was carried out in a sound treated room. The stimuli were presented binaurally at the participant's comfortable loudness level which varied from 65 dB to 80 dB HL, using TDH-39 headphones connected to computer based audiometer (Interacoustics AD-629). The testing took at least 2-2.5 hours for each participant and was conducted in two sitting for the consecutive days. Using this procedure, participants of both the groups were tested and data was collected.

Data Analysis

Logistic regression with linear or non-linear interpolation was used to measure SNR-50 (SNR level at which participants responded correctly, at least for 50% stimuli) for word recognition scores in noise and compression-50 (compression level at which 50% correct identification of sentences was obtained) for time compressed speech test. The data was normally distributed across groups as per Shapiro-Wilk test for normalcy ($p > 0.05$) and hence parametric statistics was used. One way analysis of variance was used to estimate the significance of differences of scores for auditory processing and cognitive tests between SLD and TD children. The test scores were dependent variables whereas group distribution was independent variable. The partial least square regression-structured equation modeling was used to note the relationship between the test carried out for cognitive skills and auditory processes. Further, it was also used to find out the correlation between cognitive abilities and auditory processes in SLD children.

Results

The data obtained from descriptive statistical analysis for auditory processing tests and cognitive tests are presented in Figure 1 and 2, respectively as box plots. The mean scores for all the tests (except DPT) were better for TD children in comparison to SLD children. The results of one way ANOVA are shown in Table 1. Statistically significant differences, between TD and SLD groups were found in all the tests of auditory processing and cognitive skills, except for DPT. It was also specific learning disability accounted for more than 50% variance in the test scores (partial eta square was greater than 0.5). An exception to this was word recognition in noise scores and forward digit recall scores, where the effect size was greater than 0.3 only.

The correlation between cognitive skills and auditory processing abilities were measured using partial least square regression. A formative model was created where working memory and attention were considered as latent variables and the measures to assess working memory (digit and operation span) and attention skills (dichotic digit test scores) as observed variables. The effect was seen on three measures of auditory processing i.e., auditory closure, binaural integration and temporal processing. The model had good fit with

standardized root mean residual of 0.036 (Hu & Bentler, 1998).

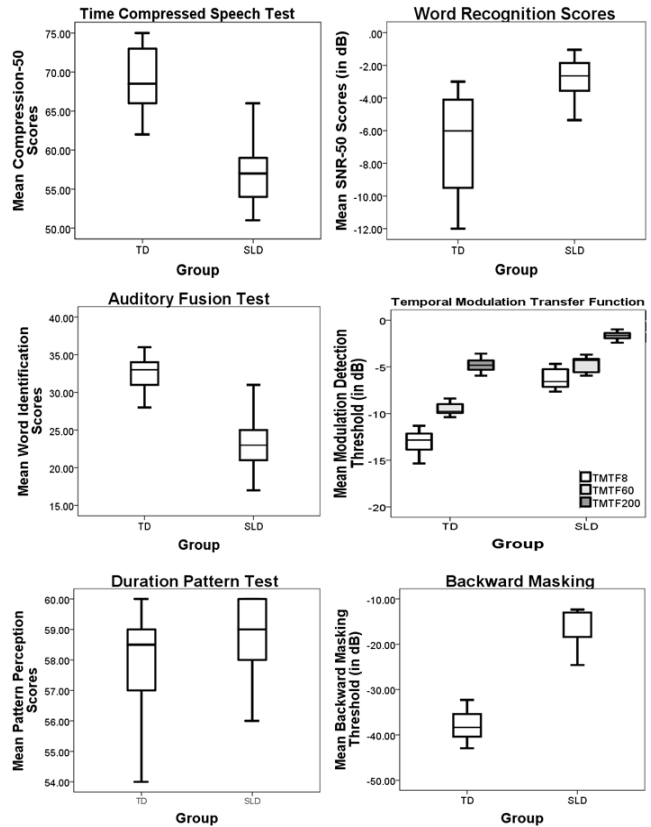


Figure 1: Box plots are representing the scores obtained for tests to assess auditory processing abilities.

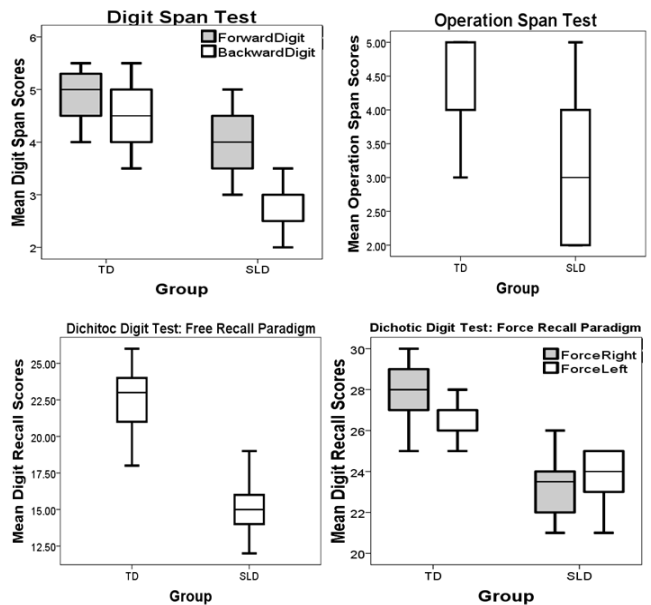


Figure 2: Box plots are representing the scores obtained for tests to assess cognitive skills.

Table 1: The F-values and significance of difference (p-values) for tests to assess auditory processing abilities and cognitive skills, between SLD and TD children.

Test Procedures	df	F-value	p-value
Tests to assess auditory processing abilities			
Time Compressed Speech Test	1	126.34	0.000
Word recognition Scores (in noise)	1	51.13	0.000
Auditory Fusion Test	1	160.75	0.000
TMTF (8 Hz)	1	579.00	0.000
TMTF (60 Hz)	1	753.11	0.000
TMTF (200 Hz)	1	446.50	0.000
Duration Pattern Test	1	1.87	0.176
Backward Masking Test	1	579.55	0.000
Tests to assess cognitive skills			
Digit Span Test (Forward)	1	27.79	0.000
Digit Span Test (Backward)	1	166.70	0.000
Operation Span Test	1	57.64	0.000
Dichotic Digit Test (Free Recall)	1	256.47	0.000
Dichotic Digit Test (Force Right)	1	149.95	0.000
Dichotic Digit Test (Force Left)	1	94.89	0.000

The regression model is presented in Figure 3. It was noted from the figure that the adjusted R^2 indicated 71.6% of variance in the auditory closure abilities were associated with attention skills and working memory. Similarly, 67.5% variance in binaural integration abilities, and 91% variance in temporal processing abilities were attributed to cognitive skills. It was also noted that attention was highly correlated to auditory processing than with working memory. Among the working memory tests, backward digit recall represented the working memory skills maximally. Attention skills were better represented in terms of divided attention. Similarly, TCST was found to be a more reliable measure to assess auditory closure. The temporal processing abilities were better represented by backward masking test.

Discussion

The present study measured the association between cognitive skills and auditory processing in SLD children. The results of ANOVA revealed significant differences on all the measures of auditory processing and cognition between SLD and TD children (except DPT). Many researchers have reported disorders of auditory processing in LD children (Cohen et al., 1989; Dawes & Bishop, 2010; Kraus et al., 1996). Therefore the assessment of SLD, using series of tests of auditory processes, like in the present study may provide better information about SLD. Further, cognitive abilities have also being examined previously in such children (Alloway & Alloway, 2010; Faccioli et al., 2008; Finneran et al., 2009; Pinheiro et al., 2010; Wiguna et al., 2012), but the relationship between cognition and auditory processing has not been investigated intensively. Such investigations, like in the present study, would lead to better understanding of the

relative contribution of top-down or bottom-up processes involved in auditory perception.

At times, it seems that the structured equation modeling used in the present study is under powered, as the sample size is small. However, the power analysis run with effect size of 0.5 and the power coefficient of 0.95, for five predictor variables (the variables assessed the cognitive skills) indicated that total sample size should be 42. In the present study, although the sample size for SLD children is 31 only, it is not much lesser than the suggested sample size. Thus, it was considered that SEM should be a reasonable tool to assess the association between auditory processing abilities and cognitive skills.

The association between cognitive skills and auditory processing are highly significant. Both attention and working memory seems to be influencing auditory processing, and the contribution of attention seems to be more than working memory, especially for temporal processing. Therefore, the findings of the present study may be considered as suggesting the influence of cognitive skills on auditory processing. Similar findings have been reported by other researchers (Moossavi et al., 2014; Murphy et al., 2013) in normal children. Based on the present results, it may be extended to SLD children also.

In the present study, most of the tests used speech stimuli, and the results suggest that the cognition was influencing the auditory processing of speech than auditory processing of tonal/noise perception.speech test and cognition (correlation) Similar findings have been investigated by several other investigator (Fedorenko, 2014; Hällgren, Larsby, Lyxell, & Arlinger, 2001; Larsby, Hällgren, Lyxell, & Arlinger, 2005). Word recognition in noise required the processing of both speech and non-speech stimuli, showed the path coefficient of WRS (in noise) was 0.379. This also suggest the contribution of cognition in auditory processing of speech more than for non-speech stimuli. This further strengthen the conclusion that the cognition has greater influence on auditory processing of speech.

Conclusion

The present study examined the association between cognitive abilities and auditory processing, and highlights the cognitive influence on auditory processing. The findings of the study indicate that the cognitive abilities are associated with auditory processing in SLD children also like in normal. It has also been found that the cognition is associated with auditory processing of speech more than non-speech signal. These findings may be useful in understanding speech perception in SLD children and may be used in designing appropriate speech and language intervention techniques.

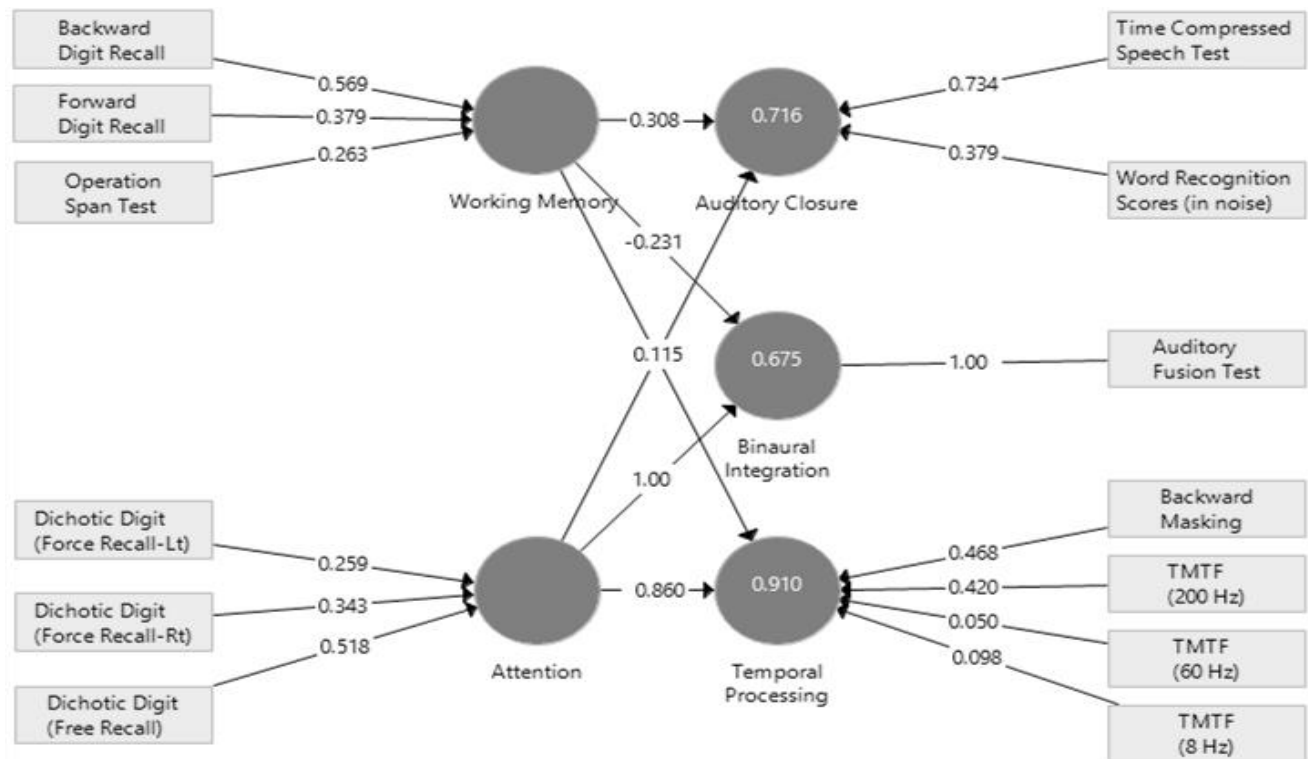


Figure 3: The structure equation model showing the association of cognitive skills (in terms of working memory and attention skills) with auditory processing (in terms of auditory closure, binaural integration and temporal processing). The eclipse and rectangle are used to represent latent and observed variables, respectively. In the eclipse, adjusted R² values are given, and those between the arrow bars are path coefficients of the model.

References

- Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, 106(1), 20–29.
- American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition). American Psychiatric Association. Retrieved from <http://psychiatryonline.org/doi/book/10.1176/appi.books.9780890425596>
- ASHA. (1996). Central Auditory Processing: Current Status of Research and Implications for Clinical Practice. *American Journal of Audiology*, 5(2), 41.
- Atcherson, S., Nagaraj, N., Kennett, S., & Levisse, M. (2015). Overview of Central Auditory Processing Deficits in Older Adults. *Seminars in Hearing*, 36(03), 150–161.
- Bellis, T. J. (2003). *Assessment and management of central auditory processing disorders in the educational setting: from science to practice* (2nd ed). Clifton Park, NY: Delmar Learning.
- Blackburn, J. (2011). Digit Span Tester (Version 2.1.3) [Windows]. Retrieved from <https://sourceforge.net/projects/digitspantester>
- Chermak, G. D., & Musiek, F. E. (1997). *Central auditory processing disorders: new perspectives*. San Diego: Singular Pub. Group.
- Chermak, G. D., Somers, E. K., & Seikel, J. A. (1998). Behavioral signs of central auditory processing disorder and attention deficit hyperactivity disorder. *Journal of the American Academy of Audiology*, 9(1), 78–84; quiz 85.
- Cohen, M., Campbell, R., & Yaghamai, F. (1989). Neuropathological abnormalities in developmental dysphasia. *Annals of Neurology*, 25(6), 567–570.
- Dawes, P., & Bishop, D. V. M. (2010). Psychometric profile of children with auditory processing disorder and children with dyslexia. *Archives of Disease in Childhood*, 95(6), 432–436.
- Faccioli, C., Peru, A., Rubini, E., & Tassinari, G. (2008). Poor readers but compelled to read: Stroop effects in developmental dyslexia. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, 14(3), 277–283.
- Fedorenko, E. (2014). The role of domain-general cognitive control in language comprehension. *Frontiers in Psychology*, 5.
- Finneran, D. A., Francis, A. L., & Leonard, L. B. (2009). Sustained attention in children with specific language

- impairment (SLI). *Journal of Speech Language and Hearing Research*, 52(4), 915.
- Grassi, M., & Soranzo, A. (2009). MLP: a MATLAB toolbox for rapid and reliable auditory threshold estimation. *Behavior Research Methods*, 41(1), 20–28.
- Hällgren, M., Larsby, B., Lyxell, B., & Arlinger, S. (2001). Cognitive effects in dichotic speech testing in elderly persons. *Ear and Hearing*, 22(2), 120–129.
- Hu, L., & Bentler, P. M. (1998). Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological Methods*, 3(4), 424–453.
- Hugdahl, K., Heiervang, E., Nordby, H., Smievoll, A. I., Steinmetz, H., Stevenson, J., & Lund, A. (1998). Central auditory processing, MRI morphometry and brain laterality: applications to dyslexia. *Scandinavian Audiology. Supplementum*, 49, 26–34.
- Iliadou, V. V., Apalla, K., Kaprinis, S., Nimatoudis, I., Kaprinis, G., & Iacovides, A. (2013). Is central auditory processing disorder present in psychosis? *American Journal of Audiology*, 22(2), 201–208.
- Ingvalson, E. M., Dhar, S., Wong, P. C. M., & Liu, H. (2015). Working memory training to improve speech perception in noise across languages. *The Journal of the Acoustical Society of America*, 137(6), 3477–3486.
- Jain, C., & Kumar, A. U. (2016). *Relationship among Psychophysical abilities, Speech Perception in Noise and Working memory in Individuals with Normal hearing sensitivity across different age groups* (PhD in Audiology). University of Mysore, Mysore, India.
- Jain, S., Vasudevamurthy, & Raghavendra, A. P. (2015). Maturation of temporal processing in children: measurements using speech and non-speech stimuli. *Journal of Hearing Science*, (2), 23–35.
- Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology. General*, 133(2), 189–217.
- Klein, S. K., Kurtzberg, D., Brattson, A., Kreuzer, J. A., Stapells, D. R., Dunn, M. A., ... Vaughan, H. G. (1995). Electrophysiologic manifestations of impaired temporal lobe auditory processing in verbal auditory agnosia. *Brain and Language*, 51(3), 383–405.
- Kraus, N., McGee, T. J., Carrell, T. D., Zecker, S. G., Nicol, T. G., & Koch, D. B. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science (New York, N.Y.)*, 273(5277), 971–973.
- Larsby, B., Hällgren, M., Lyxell, B., & Arlinger, S. (2005). Cognitive performance and perceived effort in speech processing tasks: effects of different noise backgrounds in normal-hearing and hearing-impaired subjects. *International Journal of Audiology*, 44(3), 131–143.
- Liu, L., Friedman, E., Bolger, D., Bitan, T., & Booth, J. (2009). Children with reading disability show deficits in top-down and bottom-up processing during semantic tasks in both visual and auditory modalities. *NeuroImage*, 47, S165.
- Merzenich, M. M., Jenkins, W. M., Johnston, P., Schreiner, C., Miller, S. L., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science (New York, N.Y.)*, 271(5245), 77–81.
- Moossavi, A., Mehrkian, S., Lotfi, Y., Faghihzadeh, S., & Sajedi, H. (2014). The relation between working memory capacity and auditory lateralization in children with auditory processing disorders. *International Journal of Pediatric Otorhinolaryngology*, 78(11), 1981–1986.
- Murphy, C. F. B., La Torre, R., & Schochat, E. (2013). Association between top-down skills and auditory processing tests. *Brazilian Journal of Otorhinolaryngology*, 79(6), 753–759.
- Musiek, F. E. (1994). Frequency (pitch) and duration pattern tests. *Journal of the American Academy of Audiology*, 5(4), 265–268.
- Neijenhuis, K., Tschur, H., & Snik, A. (2004). The effect of mild hearing impairment on auditory processing tests. *Journal of the American Academy of Audiology*, 15(1), 6–16.
- Pinheiro, F. H., Oliveira, A. M. de, Cardoso, A. C. V., & Capellini, S. A. (2010). Dichotic listening tests in students with learning disabilities. *Brazilian Journal of Otorhinolaryngology*, 76(2), 257–262.
- Smith, S. L., & Pichora-Fuller, M. K. (2015). Associations between speech understanding and auditory and visual tests of verbal working memory: effects of linguistic complexity, task, age, and hearing loss. *Frontiers in Psychology*, 6.
- Studdert-Kennedy, M., & Mody, M. (1995). Auditory temporal perception deficits in the reading-impaired: A critical review of the evidence. *Psychonomic Bulletin & Review*, 2(4), 508–514.
- Wiguna, T., Wt, N. S., Kaligis, F., & Belfer, M. L. (2012). Learning Difficulties and Working Memory Deficits among Primary School Students in Jakarta, Indonesia. *Clinical Psychopharmacology and Neuroscience*, 10(2), 105–109.