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Speech-Language & Audiology Canada
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SAC Position Paper on

Classroom Acoustics

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A position paper represents the direction SAC has taken on a particular topic or provides guidelines for particular areas of practice. These positions are time-bound, representing the thinking at a particular point in time.

Position

It is the position of Speech-Language & Audiology Canada (SAC) that Canada and its provinces and territories must adopt changes to their respective building codes to include standards for classroom acoustics. These standards are essential to optimize learning, teaching, overall health and quality of life. SAC recognises the detrimental impact of poor classroom acoustics on student learning as well as the negative health effects on **educators** and students in early childhood and **school settings**.

Background

The ability to hear, listen and process auditory information effectively is crucial to learning for all students. Although classroom configurations and teaching styles have changed throughout the years, the issue of background noise in classrooms has remained a consistent challenge (Crandall and Smaldino, 2000; Shield, Greenland, & Dockrell, 2010). Many studies have suggested that recommended acoustical standards for noise levels are not achieved in a majority of classrooms (Crandell & Smaldino, 2000; Rubin, Flagg-Williams, Aquino-Russell & Lushington, 2011). Children often work in classrooms with noise levels equal to or higher than the level of the educator's voice, which leaves students listening in a "sea of noise" (Anderson, 2004; Hodgson & Nosol, 2002; Bradley, 2002b). It has been shown that the average level of background noise in a classroom can range from 32 to 67 **decibels** (dB), where 60 dB is equivalent to the sound of a small hair dryer operating (Knecht et al., 2002). A degraded acoustic signal increases cognitive demand and results in mishearing and misunderstanding as well as issues with language processing, memory, attention, stress and fatigue (Peelle, 2018).

Classroom noise has the potential to disrupt educational activities and disturb students' perception of speech (Peelle, 2018; Sato & Bradley, 2008a, b; Hodgson & Nosol, 2002; Shield & Dockrell, 2003). Common sources of noise in classrooms include heating, ventilating and air-conditioning equipment, exterior noise leaking through windows and doors, as well as noise from adjacent rooms and hallways coming through walls and doors (Nelson, 2010).

Reverberation, the persistence of sound reflections from hard walls, floors and ceilings, also creates unwanted noise and contributes to poor classroom acoustics (ANSI, 2010; Bradley 2002a; Yang & Bradley, 2009).

Research has shown that noise and poor reverberation adversely affect typical young children more than typical adults. These factors, in addition to the inherent high demands on listening and auditory processing in classrooms and the immature listening skills of children due to neuromaturation, create barriers to learning that place all children at educational risk. (Millett, 2010; Bradley, 2002b; Sato & Bradley, 2008(a/b); Crandell, C. & Bess, F. 1986).

Specifically there are a number of individuals within the classroom setting who are particularly affected by poor classroom acoustics.

These groups include children with:

- Fluctuating hearing loss from temporary recurring ear infections (Bess, 1998; Niskar et al., 2000; Crandell, 1993; ASA, 2003)
- Permanent hearing loss (Crandell, 1993; ASA, 2003; Bess et al., 1998)
- Learning disabilities (Cunningham et al., 2001, Bradlow, Kraus, & Hayes, 2003)
- Auditory processing disorders (Cunningham et al., 2001)
- An English as a second language background (Crandell & Smaldino, 1994; Mayo & Florentine, 1997; Gelnett et al., 1994) or a language background other than the language of instruction
- Speech and language disorders (Klatte, Bergström, & Lachmann, 2013)
- Emotional and behavioral difficulties (Seltz, 2001; Maag & Anderson, 2006)

Furthermore, poor classroom acoustics can have significant psychological and physical impacts on students and educators (Hétu et al., 1990; Picard & Bradley, 2001; Bradley, 2002b; Sato & Bradley, 2008b, Tiesler et al., 2015).

These impacts include:

- Elevated levels of stress, high anxiety, increased annoyance, sleep disruption, depression, fatigue and increased risk of cardiovascular disease (Doherty, 1999; Evans & Johnson, 2000; Glass and Singer, 1972; Kalveram, 2000; Kryter, 1994; Kersten, 2015; Swinburn et al., 2015).
- Compromised physical and mental function, including chronic psychological distress and a decline in cognitive processes (Hughes & Jones, 2003; Banbury et al., 2001; Sandrock et al., 2009; Grebennikov and Wiggins, 2006; Kristiansen et al., 2014; Kjellberg et al., 2008; Ljung et al., 2009).
- Elevated **vocal load**, which increases proportionally with levels of background noise. The **Lombard effect** predicts that educators speak louder in noise. (Sato & Bradley, 2008a; Whitlock et al., 2006; Calosso et al., 2017; Kristiansen et al., 2014; Guidini et al., 2012; Sodersten et al., 2002).
- A high prevalence of **occupational voice disorders** among educators often resulting in missed teaching days. Common symptoms include: vocal hoarseness, vocal strain and vocal fatigue (Gotaas & Starr, 1993; Titze, Lemke & Montequin, 1997; Smith, Gray, Dove, Kirchner & Heras, 1997; Russell, Oates & Greenswood, 1998; Mattiske, Oates & Greenwood, 1998; Smith, Lemke, Taylor, Kirchner and Hoffman, 1998; Rantala, Vilkman & Bloigu, 2002; Roy et al, 2004; Laukkanen et al, 2008; Guidini et al, 2012; Kristiansen et al, 2014; Remacle, Morsomme and Finck, 2014; Rantala & Sala, 2015; Calosso et al, 2017).

Rationale

There continues to be a need to advocate for improved classroom acoustics in Canada along with the development and adoption of acoustic standards specifically for classroom environments. Designing listener-friendly classrooms requires the expertise of architects, acoustical engineers, mechanical consultants and audiologists who understand the importance of classroom acoustics. Many architects and designers are not aware of the detrimental effects of poor acoustical conditions in schools. It is crucial that those involved in designing or constructing educational facilities are aware of the impact that poor acoustics may have on both educators and students.

Canada's National Building Code (NBC) does not explicitly include acoustical standards for classrooms. Building codes are legislated at the provincial and territorial levels, however most provinces and territories rely on the NBC as a guideline in the development and adaptation of their own codes. Research into the building process suggests that building costs to implement acoustic improvements during construction can be significantly lower than the cost of implementing such improvements after construction (James, Stead, Clifton-Brown, & Scott, 2012; Lubman & Sutherland, 2001; Mealings, 2016; "Counting the costs of noisy vs. quiet classrooms", 2003).

Despite documented evidence of the detrimental impact of noise in the classroom, acoustic conditions in many Canadian schools remains poor. (Sato & Bradley, 2008a; Bradley, 2002b; Hétu, Truchon-Gagnon & Bilodeau, 1990; Yang & Hodgson, 2005). Children's speech comprehension can be reduced when the educator has a vocal impairment (Rogerson & Dodd, 2005). Educator absences due to occupational voice disorders disrupt instructional continuity. Furthermore, extensive use of sick leave benefits, workers' compensation claims and employment of substitute educators result in increased costs to the education system.

Recommendations

1. Ensure new and renovated schools in Canada are built with acoustical features that are consistent with current evidence-informed acoustic standards for classrooms. Examples of standards that could be adopted or adapted include:
    - The American National Standards Institute (ANSI) standards which provide design criteria and guidelines for new and refurbished classrooms and other learning spaces. ANSI recommends that unoccupied classroom levels must not exceed 35 dBA, the **signal-to-noise ratio (SNR)** should be at least +15 dB, and reverberation time (RT) should not exceed 0.6-0.7 seconds (ANSI, 2010).
    - The World Health Organization (1999) standards which recommend that the ambient noise level in an empty classroom be no greater than 35 dB and the noise level in an occupied classroom should not exceed 40-50 dBA.

2. Take steps to minimize noise within the classroom:
    - Walls between classrooms, hallways and outdoors should be properly acoustically sealed and there should be no gaps between the walls and ceiling and floor. Open concept classrooms are not acceptable. Speech from other classrooms should not be intelligible and noise from the hallway and outdoors should be minimized.
    - Noise from tables, chairs, and children's feet should be reduced by using noise reduction devices such as felt pads or specialty products that cover the bottom of tables, desks and chairs. Minimize other sources of noise in the classroom, which may come from activities aimed at stimulating learning such as aquariums, or activity centres.
    - Mechanical noise should be kept to the lowest level possible within classrooms including sounds from heating, ventilating and air-conditioning (HVAC) systems, which can be primary sources of internal classroom noise. Ducting or noisy equipment should be located in hallways and away from the classrooms. Where possible, low noise equipment should be chosen.

3. Adopt measures to optimize the signal-to-noise ratio:
    - **Classroom audio distribution systems (CADS)**, formerly known as sound field amplification systems, should be used, when appropriate, to achieve clearer speech signals (Larsen & Blair, 2008). With these systems, the signal level is greatly improved since only the voice at the microphone is amplified, not the background noise.
    - In situations where room design results in poor acoustics, reverberation and noise reduction must be addressed before CADS are added to a classroom. This ensures that each child has full access to an optimum signal and improves learning conditions.
    - Research supports signal-to-noise ratios that ensure a educator's voice is at least 20 decibels louder than the background noise (Bradley, 2002b; Sato & Bradley, 2008 a/b).

4. Optimize reverberation characteristics:
    - Reverberation time should be minimized as much as possible to optimize learning (ANSI, 2010). This can be achieved by installing sound absorbing material (acoustical wall panelling or treated ceiling tiles, soft seats, carpets, drapes, etc.) that significantly reduces unwanted reverberation. Material with good absorption coefficient should be chosen. Hypoallergenic materials should be used where possible.
    - Lower ceilings reduce the volume of the room thereby reducing reverberation.

5. Consult with audiologists and other key stakeholders such as speech-language pathologists in the planning and remodeling of schools to ensure that optimal conditions are met for children's developmental and learning needs and educators' vocal health. Furthermore, audiologists and speech-

language pathologists should be involved in interprofessional efforts to mitigate the effects of poor classroom acoustics on students and educators.

Definitions

Classroom Audio Distribution Systems (CADS): formerly referred to as sound field amplification systems. CADS are designed to address poor classroom acoustics, thereby benefiting students and educators. The educator wears a small microphone and his or her voice is broadcast to loudspeakers placed strategically throughout the classroom. This creates a uniform distribution of the sound of interest across the classroom and provides a modest improvement in the signal-to-noise ratio (educator's voice compared to background noise). Thus, students in the back of the room can hear as clearly as those in the front.

Decibel (dB): The decibel is a degree of loudness or is a unit used to measure how powerful or loud a sound or signal is using a logarithmic formula. A-weighted decibels (dBA) are used to account for the relative loudness of the human ear, with less emphasis on very low and very high frequency sounds.

Educator: a person who provides instruction or education in the classroom environment. Most research in classroom acoustics has been focused on the classroom teacher.

Lombard effect: Tendency for people to raise their voices and/or increase vocal effort in noisy environments (Lane & Tranel, 1971; Van Heusden, Plomp & Pols, 1979; Calas, Verhulst, Lecoq, Dalleas & Seilhean, 1989; Junqua, 1993; Summers, Pisoni, Bernacki, Pedlow & Stokes, 1998).

Occupational Voice Disorder: A voice problem experienced by individuals who rely heavily on speech/voice production to engage in their occupation. The voice problem may be characterized by symptoms such as vocal hoarseness/strain/fatigue, which are exacerbated by vocal use in the workplace. Approximately 13% of the population has a profession that relies on voice as a primary tool. Such professions include educators, sales personnel, actors and singers, and TV and radio reporters. Educators especially, suffer from voice-related medical problems.

Reverberation (Echo): the persistence of sound in a room, after the source has stopped generating energy, is what we call reverberation. It is the phenomenon of overlapping of sound caused by multiple reflections. Energy is lost at each reflection and the sound eventually becomes inaudible. It is measured in terms of Reverberation Time (RT). It is defined as the time it takes for sound to decay 60 dB or 1 millionth of its original sound level. RT depends on the physical volume and surface materials of a room. Large spaces, such as cathedrals and gym, usually have longer reverberation times and sound "lively" or sometimes "boomy." Small rooms, such as bedrooms and recording studios, are usually less reverberant and sound "dry" or "dead." Therefore acoustical needs in a classroom vary greatly from the acoustical needs in a cafeteria or gym.

School setting: refers to all learning environments and classrooms, including early childhood, elementary, secondary and post-secondary settings.

Signal-to-noise ratio (SNR): the relationship between the primary or desired auditory signal (e.g. educator's voice) and all other unwanted background sounds. With respect to classroom acoustics, SNR can be considered as the relative intensity of the information carrying the components of the speech signal versus unwanted noise. The more favorable the signal-to-noise ratio (SNR), the more intelligible the spoken message. A SNR of +15/20 dB or better is recognized as being necessary in the classroom.

Vocal load: Amount of vocal work over time, determined by vocal duration, intensity and frequency over time. (Titze, Svec & Popolo, 2003)

Voice loading: Stress exerted on vocal folds and the laryngeal mechanism due to sustained voice. Loading is exacerbated namely by variables such as ambient noise, level of vocal projection, dynamic and emotional extents, social context as well as acoustic environment. Similarly to repetitive strain injuries, voice loading may lead to vocal fatigue and/or mechanical or functional laryngeal injuries.

References

Anderson, K. (2004). The problem of classroom acoustics: the typical classroom soundscape is a barrier to learning. *Seminars in Hearing, 24*(5), 117-130.

Acoustical Society of America (2003). *Classroom Acoustics I - a resource for creating listening environments with desirable listening conditions*. Melville, NY.

American National Standards Institute (2010). *S12.60–2010, Acoustical performance criteria, design requirements, and guidelines for schools.* Melville, NY.

Banbury S. P., Macken W. J., Tremblay, S. & Jones, D. M. (2001). Auditory distraction and short-term memory: phenomena and practical implications. *Human Factors 43*(1), 12-29.

Bess, F. H., Dodd-Murphy, J. & Parker, R. A. (1998). Children with minimal sensorineural hearing loss. *Ear and Hearing*, *19*, 339-354.

Bradley, J.S. (2002a). *Acoustical designs of rooms for speech*. Retrieved from https://www.nrc-cnrc.gc.ca/ctu-sc/en/ctu_sc_n51/

Bradley, J.S. (2002b). *Optimising sound quality for classrooms*. Retrieved from https://nparc.nrc-cnrc.gc.ca/eng/view/object/?id=cb8703be-2eb7-45d8-a769-84d69261fd3a

Calas, M., Verhulst, J., Lecoq, M., Dalleas, B. & Seilhean, M. (1989). Vocal pathology of teachers. *Revue de larygologie, otologie, rhinologie. 110*(4), 397-406.

Calosso, G., Puglisi, G. E., Astolfi, A., Castellana, A. C. & Pellerey, F. (2017). A one-year longitudinal study of secondary teachers' voice parameters and the influence of classroom acoustics. *Journal of the Acoustical Society of America, 142*(2), 1055-1066.

Counting the costs of noisy vs. quiet classrooms (2003, October). Retrieved from https://www.acousticalsurfaces.com/soundproofing_tips/html/classroom_acoustics3.htm

Crandell, C. (1993). Speech recognition in noise by children with minimal degrees of sensorineural hearing loss. *Ear and Hearing, 14,* 210-216.

Crandell, C. & Bess, F. (1986) Speech recognition of children in a 'typical' classroom setting. *ASHA*, *29*, 82.

Crandell, C., & Smaldino, J. (1994). An update of classroom acoustics for children with hearing impairment. *The Volta Review, 96*, 291-306.

Crandell C. & Smaldino, J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech and Hearing Services in Schools*, *31*, 362-70.

Cunningham, J., Nichol, T., Zecker, S. G., Bradlow, A., and Kraus, N. (2001). Neurobiologic responses to speech in noise in children with learning problems: Deficits and strategies for improvement. *Clinical Neurophysiology*, *112*, 758-767.

Doherty, G. W. (1999). Disaster work and stress. Proceedings of the Rocky Mountain Region Disaster mental health Conference. Laramie, Wyoming, 11-14 February. Retrieved from http://angelfire.com/biz/odoc/disasterstress.html

Evans, G. W. & Johnson, D. (2000). Stress and open office noise. *Journal of Applied Psychology, 85*(5), 779-783.

Gelnett, D., Sumida, A., & Soli, S. D. (1994). *The development of the Hearing in Noise Test for Children (HINT-C)*. Paper presented at the annual convention of the American Academy of Audiology, Richmond, Virginia.

Glass, D. C. & Singer, J. E. (1972). *Urban Stress: Experiments on Noise and Social Stressors*., New York, Academic Press.

Gotaas, C. & Starr, C. D. (1993). Vocal fatigue among teachers. *Folia Phoniatrica, 45*, 20-129.

Grebennikov, L. & Wiggins, M. (2006). University of Western Sydney: Psychological Effects of Classroom Noise on Early Childhood Teachers. *The Australian Educational Researcher*, *33*(3), 35-53.

Guidini, R. F., Bertoncello, F., Zanchetta, S., & Dragone, M. L. S. (2012). Correlations between classroom environmental noise and teachers' voice. *Revista da Sociedade Brasileira de Fonoaudiologia*, *17*(4), 398-404. http://dx.doi.org/10.1590/S1516-80342012000400006

Hétu, R., Truchon-Gagnon, C. & Bilodeau, S. A. (1990). Problems of noise in school settings: a review of literature and results of an exploratory study. *Journal of Speech Language Pathology and Audiology*, *14*(3), 31-39.

Hughes, R. W. & Jones, D. M. (2003). Indispensable benefits and unavoidable costs of unattended sound for cognitive functioning. *Noise Health, 6*(21) 63-76.

Hodgson, M. & Nosol, E. M. (2002). Effect of noise and occupancy on optimal reverberation times for speech intelligibility in classrooms. *Journal of the Acoustical Society of America, 111*(2), 931-939.

James, D., Stead, M., Clifton-Brown, D., & Scott, D. (2012). A cost benefit analysis of providing a 'sound' environment in educational facilities. *Proceedings of Acoustics 2012*, 1-4.

Junqua, J. (1993). The Lombard reflex and its role on human listeners and automatic speech recognizers. *Journal of the Acoustic Society of America, 93*(1), 510-524.

Kalveram, K. T. (2000, June). *How acoustical noise can cause physiological and psychological reactions: Behavioural-ecological considerations on the origin of the capability to experience annoyance*. Paper presented at The Fifth International Symposium on Transport Noise and Vibration, St. Petersburg, Russia.

Kersten, N. & Backé, E. (2015). Occupational noise and myocardial infarction: considerations on the interrelation of noise with job demands. *Noise & Health, 17*(75) 116-122.

Kjellberg, A., Ljung, R. & Hallman, D. (2008). Recall of words heard in noise. *Applied Cognitive Psychology, 22*(8), 1088-1098.

Klatte, M., Bergström, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology, 30*(4), 578.

Knecht, H., Nelson, P., Whitelaw, G., and Feth, L. (2002). Structural variables and their relationship to background noise levels and reverberation times in unoccupied classrooms. American Journal of Audiology, 11, 65-71.

Kristiansen, J., Lund, S. P., Persson, R., Shibuya, H., Nielsen, P. M., & Scholz, M. (2014). A study of classroom acoustics and school teachers' noise exposure, voice load and speaking time during teaching, and the effects on vocal and mental fatigue development. *International Archives of Occupational and Environmental Health*, *87*(8), 851–860.

Kryter, K. D. (1994). *Handbook of Hearing and the Effects of Noise: Physiology, psychology and Public Health*. San Diego, CA: Academic Press, Inc.

Lane, H. & Tranel, B. (1971). The Lombard Sign and the role of hearing in speech. *Journal of Speech and Hearing Research, 14*, 659-672.

Larsen, J. B., & Blair, J. (2008). The effect of classroom amplification on the signal to noise ratio in classrooms while class is in session. *Language, Speech, and Hearing Services in Schools, 39*(10), 451-460.

Laukkanen, A. M., Ilomaki, I., Leppanen, K. & Vilkman, E. (2008). Acoustic measures and self-reports of vocal fatigue by female teachers. *Journal of Voice, 22*(3), 283-289.

Ljung, R., Sorqvist, P., Kjellberg, A. & Green, A. (2009). Poor listening conditions impair memory for intelligible lectures: implications for acoustic classroom standards. *Building Acoustics, 16*(34), 257-265.

Lubman, D. & Sutherland, L. C. (2001, September). *Good classroom acoustics is a good investment.* Paper presented at 17th International Congress on Acoustics, Rome, Italy.

Maag, J., & Anderson, J. (2006). Effects of sound-field amplification to increase compliance of students with emotional and behavior disorders. *Behavioral Disorders, 31(*4), 378-393.

Mattiske, J. A., Oates, J. M., & Greenwood, K. M. (1998). Vocal problems among teachers: A review of prevalence, cause, prevention, and treatment. *Journal of Voice, 12*, 489-499.

Mayo, L., & Florentine, M. (1997). Age of second-language acquisition and perception of speech in noise. *Journal of Speech and Hearing Research, 40*(3), 686-693.

Mealings, K. (2016, November). *Classroom acoustics conditions: understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements*. Paper presented at ACOUSTICS 2016, Brisbane, Australia.

Millett, P. (2010). Improving student listening and engagement for English Language Learners with sound field amplification. *Proceedings of the Canada International Conference on Education* (590-596). Toronto.

Nelson, P. (2010). Classroom Acoustics. What could possibly be new? *The ASHA Leader*, *15*, 16-19.

Niskar, A. S., Kieszak, S. M., Holmes, A. E., Esteban, E., Ruben, C. & Brody, D. J. (2001). Estimated prevalence of noise-induced hearing thresholds shifts among children 6 to 19 years of age. The third national health and nutrition examination survey, 1998-1994. *Pediatrics, 108*(1), 40-43.

Peelle, J.E. (2018). Listening effort: how the cognitive consequences of acoustic challenge are reflected in brain and behaviour. *Ear and Hearing, 39*(2), 204-214.

Picard, M., & Bradley, J. S. (2001). Revisiting speech interference in classrooms. *Audiology*, *40*(5), 221-44.

Rantala, M. & Sala, E. (2015). Effects of classroom acoustics on teachers' voices. *Building Acoustics, 22*(3-4), 243-258. doi:10.1260/1351-010X.22.3-4.243

Rantala, L., Vilkman, E. & Bloigu, R. (2002). Voice changes during work: Subjective complaints and objective measurements for primary and secondary teachers. *Journal of Voice, 16*(3), 344-355.

Remacle, A., Morsomme, D. & Finck, C. (2014). Comparison of vocal loading parameters in kindergarten and elementary school teachers. *Journal of Speech, Language and Hearing Research*, *57*, 406-415.

Rogerson, J. & Dodd, B. (2005). Is there an effect of dysphonic teachers' voices on childrens' processing of spoken language? *Journal of Voice, 19*(1) 47-60.

Roy, N., Merril, R. M., Thibeault, S., Parsa, R. A., Gray, S. D. & Smith, E. M. (2004). Prevalence of voice disorders in teachers and the general population. *Journal of Speech, Language and Hearing Research, 47*(2), 281-93.

Rubin, L. R., Aquino-Russell C. E., & Flagg-Williams, J. B., and Lushington, T. (2011). The classroom listening environment in the early grades. *Canadian Journal of Speech-Language Pathology and Audiology, 35*(4) 344-359.

Russell, A., Oates, J. & Greenswood, K. M. (1998). Prevalence of voice problems in teachers. *Journal of Voice, 12*(4), 467-479.

Sandrock, S., Schutte, M. & Griefahn, B. (2009). Impairing effects of noise in high and low noise sensitive persons working on different mental tasks. *International Archives of Occupational and Environmental Health, 82*, 779-785.

Sato, J. & Bradley, J. S. (2008a). Evaluation of acoustical conditions for speech communication in working elementary school classrooms. *Journal of Acoustical Society of America, 123*(4), 2064-2077.

Sato, J. & Bradley, J. S. (2008b). The intelligibility of speech in elementary school classrooms. *The Journal of the Acoustical Society of America, 123*, 2078-2086.

Seltz, A. E. (2001). Let the word be heard. Be an advocate for good classroom acoustics. *The ASHA Leader*, *6*, 4-20.

Shield, B. & Dockrell, J. E. (2003). The effects of noise and poor acoustics on children at school. *Building Acoustics, 10*(2), 97-106.

Shield, B., Greenland, E., & Dockrell, J. (2010). Noise in open plan classrooms in primary schools: a review. Noise and Health, 12(49), 225-234.

Smith, E., Gray, S. D., Dove, H., Kirchner, L., & Heras, H. (1997), Frequency and effects of teachers' voice problems. *Journal of Voice, 11*(1), 81-87.

Smith, E., Lemke, J., Taylor, M., Kirchner, H.L. & Hoffman, H. (1998). Frequency of voice problems among teachers and other occupations. *Journal of Voice*, *12*(4), 480-488.

Sodersten, M., Granqvist, S., Hammarberg, B. & Szabo, A. (2002). Vocal behaviour and vocal loading for preschool teachers studied with binaural DAT recordings. *Journal of Voice*, *16*(3), 356-371.

Summers, W. V., Pisoni, D. B., Bernacki, R. H., Pedlow, R. I., Stokes, M. A. (1998). Effects of noise on speech production: acoustic and perceptual analyses. *Journal of the Acoustical Society of America*, *84*, 917-928.

Swinburn, T. K., Hammer, N. S., & Neitzel, R. L. (2015). Valuing quiet: an economic assessment of U.S. environmental noise as a cardiovascular health hazard. *American Journal of Preventive Medicine, 49*(3), 345-353.

Tiesler, G., Machner, R., Brokmann, H. (2015). Classroom acoustics and impact on health and social behaviour. *Energy Procedia, 78,* 3108 – 3113.

Titze, I. R., Svec, J. G. and Popolo, P. S. (2003). Vocal dose measures: quantifying accumulated vibration exposure in vocal fold tissues. *Journal of Speech, Language and Hearing Research, 46*, 919-932.

Titze, I. R., Lemke, J. & Montequin, D. (1997). Populations in the U.S. workforce who rely on voice as a primary tool of trade: A preliminary report. *Journal of Voice, 11*(3), 254-259.

Van Heusden, E., Plomp, R., & Pols, L. C. W. (1979). Effect of ambient noise on the vocal output and the preferred listening level of conversational speech. *Applied Acoustics, 12*, 31-43.

Whitlock, J. & Dodd, G. (2006). *Classroom acoustics – controlling the café effect … is the Lombard effect the key?* In *Proceedings of Acoustics*, Christchurch, NZ, 20-22: 423-42

World Health Organization. (1999) Guidelines for Community Noise. Retrieved from https://www.who.int/docstore/peh/noise/Commnoise4.htm

Yang W. & Bradley, J. S. (2009). Effects of room acoustics on the intelligibility of speech in classrooms for young children. *Journal of the Acoustical Society of America, 125(*2), 922-33.

Yang, W. & Hodgson, M. (2005). Acoustical evaluation of preschool classrooms. *Noise Control Engineering Journal, 53(2)*, 43-52.