SOUND FIELD AMPLIFICATION RESEARCH SUMMARY

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Purpose and methodology

This paper is a summary of research studies investigating efficacy of sound field amplification for children and adults. Reviews of issues in classroom listening and learning environments, and the contributions of sound field amplification have been published in books, book chapters and journals (Crandell, Flexer & Smaldino, 2004; Crandell, Smaldino & Flexer, 1999; Sockalingham, Pinard, Cassie & Green, 2007); however, this paper is intended to be an updated review of research studies categorized with respect to populations in which the use of sound field amplification has been studied, for use by consumers of research in education.

Database searches were conducted to identify research studies; these included Medline, ERIC, Web of Science, Scholars Portal Search, Education Index, PsycINFO, Applied Science and Technology Index, Proquest Digital Dissertations and Theses, and the Native Health Database, in the areas of natural sciences, social sciences, medicine and nursing, technology, and education. The majority of research studies included in this paper were published in peer-reviewed journals or presented at refereed conferences. Internet searches were also used to identify additional research. Publications from newsletters, newspaper articles, promotional materials and other un-reviewed sources were not included in this summary. A number of school districts have conducted independent research projects; however, unless published results detailing methodology were available for review, such projects have not been included here. Unpublished Masters and PhD theses and dissertations have been included.

Sound field amplification in regular classrooms

While original sound field amplification research focused on children with auditory and language learning challenges, positive results of these studies and anecdotal reports from classroom teachers prompted expansion of research into efficacy of sound field amplification in regular classrooms. The rationale for the use of sound field amplification in regular classes is based on an extensive body of literature documenting a higher incidence of ear infections (and related hearing loss) in young children, greater difficulty understanding speech in the presence of noise, and immature listening skills related to neuromaturation of the auditory system well into adolescence (Bluestone, 2004; Moore, 2002; Nelson & Soli, 2000; Gil-Loyzaga, 2005; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). As well, studies have found that recommended acoustical standards for noise levels and reverberation times are not achieved in the majority of classrooms (Bess, Sinclair & Riggs, 1984; Crandell & Smaldino, 1994; Crandell & Smaldino, 1995; Crandell, Smaldino & Flexer, 1999; Pekkarinen & Viljanen, 1991).

Researchers have argued that the intersection of often poor classroom acoustics, 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 (Anderson, 2004; Flexer, 2004, Millett, 2009). Signal to noise ratios (ie. the level of the teacher's voice compared to the level of the background noise) can be improved through the use of sound field amplification, resulting in clearer speech signals (Larsen & Blair, 2008). Millett (2009) argued that the installation of sound field systems in every classroom should be considered an important part of universal design.

Research with hearing children indicates better ability to discriminate words and spoken language more accurately with the use of a sound field amplification system than without (Arnold & Canning, 1999; Prendergast, 2005). Vickers et al (2013) used an innovative group administered speech perception test and found significant improvements in students' abilities to discriminate all phonetic aspects of consonants (manner, place and voicing). Sound field amplification was particularly beneficial in improving speech perception for children with lower expressive vocabulary scores. Studies have found improved scores in dictated spelling tests (Burgener & Deichmann, 1982; Zabel & Taylor, 1993). Chelius (2004) reported that students in grades 1, 3, 4 and 5 in amplified classrooms achieved better standardized test scores in early literacy, on the Developmental Reading Assessment and in reading fluency than did students in unamplified classrooms. Millett & Purcell (2010) also compared results on the Developmental Reading Assessment for 486 students in unamplified and amplified grade one classrooms. They found that for the group of students identified as being at risk for reading difficulties and who were receiving reading intervention, the percentage of students reading at grade level increased by 5.3% in the amplified classrooms, while for the unamplified classrooms, the percentage of students reading at grade level had decreased by 6.7%. A longitudinal study by Gertel, McCarty & Schoff (2004) found that students in amplified classrooms scored 10% better on a standardized achievement test than students in unamplified classrooms. Dairi (2000) found first grade students in amplified classrooms to show greater literacy gains as measured by a reading inventory. Long term outcome measures from the Mainstream Amplification Resource Room Study Project (MARRS) indicated better scores on standardized tests of listening and language skills for kindergarten students, and better scores in the areas of math concepts, math computation and reading for grade 2 and 3 students (Flexer, 1989; Ray, 1992).

Massie & Dillon (2006b) reported statistically significant improvement in ratings of attention, communication and classroom behaviour in amplified vs unamplified classrooms, and noted that teachers considered that "sound-field amplification facilitated peer interaction, increased verbal involvement in classroom discussion, and promoted a more proactive and confident role in classroom discussion" (p. 89). Wilson (1989) compared classroom amplification and teacher training in language development with respect to changes in language skills for children enrolled in Head Start programs, and found that while neither sound field amplification nor teacher training alone resulted in measurable changes in language scores for these children, the combination of amplification and training did.

Allcock (1999) reported improvement in scores on standardized tests of phonological processing, with 74% of children in amplified classrooms achieving an improvement of 1 stanine or more, versus 46% in unamplified classrooms. There are two studies examining the effects of sound field amplification vs targeted phonological awareness interventions, by Good & Gillon (2014) and by Flexer, Biley, Hinkley, Harkema,& Holcomb (2002). However methodological considerations related to lack of control groups to control for maturation/learning effects and, in the case of the Flexer et al study, unequal sample sizes in the two conditions, make it difficult to tease out the differential effects of sound field amplification.

Rubin, Flagg-Williams, Aquino-Russell & Lushington (2011) studied 60 New Brunswick classrooms, grades 1 through 3, in which 31 classrooms received sound field amplification systems, and 29 served as a control group. Using the Revised Environmental Communication Profile (as described in Massie, Theodoros, McPherson, & Smaldino, 2004), they found statistically significant increases in student responses to teacher statements, decreases in the number of teacher repetitions, and fewer student initiated communications with peers during instruction (ie. fewer instances of students speaking amongst themselves during teacher instruction) in the amplified classrooms. The findings that teachers needed less time to direct and maintain attention was particularly strong for kindergarten children. Teachers commented that sound field amplification helped make classrooms more inclusive because all students were more engaged, and that use of the passaround microphone increased student participation, confidence, and empowerment.

Dickinson & Asiasiga (2011) also described anecdotal teacher and student comments on the benefits of sound field amplification. However, they also discussed challenges in implementing sound field amplification as a large scale, “universal” project, an important issue which has not been widely addressed in the literature. These challenges included providing appropriate and adequate hands-on teacher training, ensuring correct system installation, and addressing issues of ensuring a process for ongoing troubleshooting and system maintenance. Lafargue & Lafargue (2012) noted that the effectiveness of sound field systems used in regular classrooms can be in fact diminished without a system-level plan for ongoing support and maintenance.

Dockrell, & Shield, (2012) used a combination of teacher and student questionnaires, and standardized tests of reading, spelling, mathematics, academic and non-verbal processing skills to assess the effects of sound field amplification, factoring in acoustic variables in each classroom. They saw positive teacher and student reports; differences between students in amplified and unamplified classrooms were seen only in listening comprehension measures and not in academic measures. Greater changes were seen in classrooms with poorer acoustics. Interestingly, similar to Millett & Purcell (2010), overall improvements in academic skills were seen in vulnerable learners which were not seen in students with typical academic achievement.

Wilson, Marinac, Pitty, & Burrows (2011) used a comprehensive battery of listening comprehension, reading and phonological awareness measures to compare the performance of 147 students in 4 schools, where each school had one amplified classroom and one unamplified classroom (assigned randomly). They found statistically significant changes in listening comprehension and auditory analysis for only one school. They suggested that a possible contributing factor was the differences in the acoustical properties of the schools, where classrooms in the three schools which did not show significant changes were either open concept in design, or portable classrooms. The issue of the intersection between sound field amplification systems and the acoustical properties of individual classrooms is one which has not been addressed extensively in the literature; Lafargue & Lafargue (2012) have been one of the few research teams to discuss the potential disadvantage of amplification if sufficient attention to correct installation and placement of systems in classrooms is not paid.

Special education referral rates

Data showing decreases in special education referral rates following installation of sound field systems across school districts has been reported in several studies. Of course, special education referral rates encompass a range of students with learning challenges, and many factors may be at play; however, the magnitude of these decreases in referral rates is very interesting. For example, in the Oconto Falls School District in Wisconsin, special education referral rates fell from an average of 7.72% in the years 1989-1998 to 4.6% from 1998 to 2000, where sound field amplification systems were installed in every classroom in the district from kindergarten to grade 5 (Flexer & Long, 2004). Long term data from the MARRS project described previously indicated special education referral rates fell almost 40% after 5 years of sound field use in classroom across the school district (Ray, 1992).

Studies of Aboriginal and First Nations students

There is ample evidence to suggest that Aboriginal and First Nations children experience a higher incidence of recurrent otitis media and related conductive hearing loss. In fact, the highest rates of chronic otitis media in the world are found in Inuit, First Nations and Metis populations of Canada, Alaska and Greenland, with incidence rates as high as 40 times those of southern communities (Bluestone, 1998; Bowd, 2005, see review by Baxter, 1999). Aboriginal children in Australia and New Zealand similarly demonstrate a very high incidence of otitis media (McPherson, 1990; Nienhuys, Boswell, & McDonnell, 1994; Massie, Theordoros, McPherson & Smaldino, 2004); Nienhuys (1994) reported that 50 to 80% of Aboriginal children have sufficient middle ear related hearing loss to have an adverse effect on learning. American Indian children show incidence rates of otitis media of 3 times that of other populations (Hunter, Davey, Kohtz, & Daley (2007). Eriks-Brophy & Ayukawa (2000) suggest that complicating the fact that otitis media is extremely common in Aboriginal children is the fact that traditional amplification for hearing aids is typically not used consistently due to problems with acceptance and with maintaining and repairing working hearing aids in extremely isolated communities with limited resources.

Sound field amplification is a classroom intervention which may help to address this high incidence of hearing loss. Two Canadian studies have investigated the use of this technology with Aboriginal children. Eriks-Brophy & Ayukawa (2000) found an improvement of 16.2% in speech discrimination scores for children with hearing loss when sound field amplification was used, and an improvement of 9.7% for children with normal hearing. Teachers also reported measurable improvements in on-task behaviors for children with hearing loss with the use of sound field amplification, and anecdotally, described increased attention in large group activities, more rapid student response times, less need for repetition, improved listening skills and decreased teacher fatigue at day’s end. Pinard (2006) studied efficacy of sound field amplification for First Nations children in Nova Scotia, Canada and found hearing loss incidence to range from 12 to 25% of students screened, from mild to moderate hearing loss levels. Implementation of sound field amplification resulted in significant increases in teacher reported scores on the Screening Instrument for Targeting Educational Risk (SIFTER), with the greatest changes seen for children with hearing loss compared to normal hearing classmates (although lack of a comparison unamplified control group was a limitation of this study). This researcher also noted that greater improvements in student performance were associated with number of hours the systems were used per day.

A study in New Zealand of schools with overall a 35% Maori population indicated significant improvement in standardized test scores of listening comprehension, reading comprehension, and reading vocabulary following one year of sound field use in the classrooms (Heeley, 2004). A particular focus of this study was changes in phonological awareness skills, which showed statistically significant improvement in ten subskills of phonological awareness for children in amplified classrooms vs control groups in unamplified classrooms. Anecdotal teacher comments in amplified classrooms included lower noise levels in the classroom, increased on-task behaviour, reduced disruptive behavior, improved understanding of instruction and student cooperation, and reduced vocal strain. As New Zealand school districts categorize schools on a socioeconomic status (SES) scale, this data was available for analysis; results show that, although not statistically significant, overall student score improvements in low SES schools were greater than for those in higher SES schools.

Massie, Theodoros, McPherson & Smaldino (2004) found increases in classroom communicative interactions, increases in number of child initiated interactions, and statistically significant changes in teacher evaluations of attention and class participation. Massie & Dylan (2006) in a study of 12 classrooms with a majority of students from Aboriginal heritage or learning English as a Second Language, found increases in numbers of skills mastered over a term in the areas of reading, writing and numeracy associated with sound field amplification use.

Page (1995) also reported positive teacher reports related to implementation of sound field amplification in 4 schools in Aboriginal communities and in schools with high proportions of Aboriginal students; similar positive anecdotal reports were found for Aboriginal kindergarten students by Dowell (1995). Flexer (2000) studied sound field amplification in first grade classrooms in Utah with 85% of its student population from Native American heritage. In five years prior to sound field use, only 44 to 48% of students scored at the “basic” level of a standardized reading test; following implementation of sound field amplification for 7 months, 74% of children scored at the basic level.

English Language Learners

A variety of studies have indicated that adults and children learning English as a Second Language demonstrate more difficulty in discriminating words accurately when there is background noise (Crandell, 1990; Crandell & Smaldino, 1995; Crandell, Smaldino & Flexer, 1995; Mayo & Florentine, 1997; Nabelek & Nabelek, 1994). Mayo & Florentine (1997) further found that children who acquired English at an earlier age had less difficulty with speech discrimination in noise than did children learning English at an older age.

Sound field amplification has been shown to produce improvements in speech perception scores of up to 30% for children learning English as a Second Language when noise is present

(Crandell, 1994; Crandell, 1996). Vincenty-Luyando (2000) compared monolingual school children (English speaking) and bilingual children (Spanish speaking) in their speech perception accuracy in a real classroom with typical classroom noise levels introduced, with and without sound field amplification. Bilingual students demonstrated significantly poorer phoneme discrimination abilities in the presence of noise (63% vs 76% for monolingual children). Under the highest noise conditions, all children's scores combined improved by 19% with the introduction of sound field amplification. Differences in phoneme identification scores with and without sound field amplification were statistically significant, although monolingual and bilingual children did not differ in the amount of improvement seen.

Millett (2010) interviewed teachers using sound field amplification in a low income urban school with a very high population of families who were new immigrants to Canada. This study investigated benefits beyond improved speech perception from the perspective of classroom teachers. Unstructured interviews were conducted with 11 teachers who used sound field amplification and SMART Board technology in a high needs urban school with a high percentage of English Language Learners for 2 years. This study showed benefits of sound systems in enhancing English and French language learning, expanding teacher effectiveness, and particularly, enhancing student engagement. Teachers reported innovative uses of the technology to create more dynamic, engaging classrooms, and described particular advantages of the technology for English Language Learners to provide better English language models, improve student discrimination of unfamiliar English phonemes and to highlight morphological marker and other aspects of English grammar which differ from students' first languages.

Students with hearing and learning challenges

McSporran , Butterworth & Rowson (1997) reported a significant increase in scores on the Children's Auditory Processing Scale (CHAPPS) (Smoski, Brunt & Tannahill, 1992) for children identified as being at educational risk, following 5 months' use of sound field amplification in two classrooms, and in fact suggested that the greater the initial difficulties reported, the greater the improvement tended to be.

Research has shown sound field amplification to have positive effects on classroom behaviour for students with Attention Deficit Hyperactivity Disorder (ADHD); a small study by Maag & Anderson (2007) found decreases in the time it took their subjects to respond to teacher instructions to levels approximating those of average students. A similar study by these authors of children identified with emotional and behavior disorders (with Individual Education Plans) also indicated faster responses to instructions when sound field amplification was present versus unamplified conditions. Studies have also shown positive changes in listening behaviour of students with learning disabilities (DiSarno, Schowalter & Grassa, 2002)

The fact that children with Down Syndrome and other developmental disabilities have a higher incidence of temporary and permanent hearing loss is well-documented (see review by Bluestone, 2004). While it might be hypothesized that self-contained classrooms for children with special needs might represent more favourable listening environments, Leung & McPherson's (2006) study of 8 classrooms for children with developmental disabilities showed that classroom acoustics were no better than what is consistently reported in the literature for typical classrooms, and that sound field amplification provided a signal to noise ratio which met recommended guidelines. Research shows improved speech perception abilities for children with Downs Syndrome with sound field amplification (Bennetts & Flynn, 2002; Flexer, Millin & Brown, 1990). McPherson, Lai, Leung, & Ng (2007) in fact recommended the routine use of sound field amplification systems in classrooms based on their findings on previously undiagnosed hearing loss in older children with Down Syndrome in Chinese schools.

The first large sound field amplification study was the Mainstream Amplification Resource Room Study (MARRS), which investigated the benefits of sound field amplification for children with minimal hearing loss. At the end of 3 years, students with minimal hearing loss who received regular classroom instruction in an amplified classroom showed significantly greater improvement in academic achievement than students who received instruction in regular classrooms without amplification, or those who received regular classroom instruction with supplemental resource room instruction (Ray, 1992; Sarff, 1981).

Jones, Berg & Viehweg (1989) found that kindergarten children with minimal hearing loss performed as well as hearing peers in a word discrimination task when words were presented via sound field amplification; discrimination scores for children with minimal hearing loss improved from 81% without amplification, to 98% with amplification. Neuss, Blair & Viehweg (1991) also found improved word recognition in noise for this population of children when sound field amplification was used.

Research on children with permanent hearing loss who use personal amplification indicates that, while sound field amplification provides more benefit than personal hearing aids or cochlear implants alone, personal FM systems are generally preferable to sound field amplification for providing a better auditory signal (Anderson & Goldstein, 2004; Anderson, Goldstein, Colodzin & Inglehart, 2005; Schafer & Thibodeau, Nabelek & Donohue, 1986). Blair, Myrup & Viehweg (1989) found that children with moderate hearing loss showed better speech discrimination abilities with sound field amplification and personal hearing aids, compared to hearing aids alone, and Inglehart (2004) showed similar results for students with cochlear implants. Nelson, Poole & Nunoz (2013) surveyed teachers of preschool deaf and hard of hearing classrooms where sound field systems were used and found that approximately half of their respondents used sound field systems rather than personal FM systems. Teacher perceptions of the benefits of sound field amplification were generally positive, (unsurprisingly, more so for teachers in classrooms using listening and spoken language than for teachers in bilingual-bicultural or total communication classrooms). A number of teachers commented on disadvantages of sound field systems, which included poor sound quality, feedback and discomfort wearing the transmitter. Again, as Lafargue & Lafargue (2012) pointed out, these are entirely preventable or fixable problems generally related to poor installation, poor technical support or insufficient teacher training. These types of complaints very frequently relate to issues of lack of planning or system resources, issues which need to be considered when this technology is used.

Adults and students in postsecondary settings

Studies of postsecondary classroom acoustics have shown similar results to those of elementary classrooms, that reverberation times and noise levels consistently exceed recommended values (Hodgson, 1999; Kelly & Brown, 2002; Woodford, Pritchard & Jones, 1998)

Although most studies have focused on elementary age children, studies have also indicated sound field amplification to be beneficial in postsecondary level classrooms with an improvement in speech recognition scores of up to 37% in classrooms with poor listening conditions (Larsen,Vega, & Ribera, 2008). Crandell, Charlton, Kinder, & Kreisman (2001) found adults to demonstrate better ability to understand sentence material in background noise with sound field amplification than without. Woodword, Prichard & Jones (1998) found statistically significant differences in university students' ratings of speech understanding in amplified vs unamplified classrooms. Prior to sound field installation, all of the instructors predicted that the sound field system would have no significant effect on instruction, however, post-trial, instructor reactions were unanimously favourable.

Teacher vocal problems

Teachers are at increased risk for vocal problems compared to individuals in other professions, a phenomenon which is well documented in the literature (Gotaas & Starr, 1993; Morton & Watson, 1998; Preciado-Lopez, Perez-Fernandez, Calzada-Uriondo, 2008; Smith, Gray, Dove, Kirchner & Heras, 1997; Titze, Lemke & Montequin, 1996; Vilkman, 2004). Gotaas & Starr (1993) in fact, reported that 80% of teachers surveyed reported vocal problems.

Sapienza, Crandell & Curtis (1999) found that teachers used less vocal effort when they used a sound field amplification system; they were able to speak more softly with the sound field system but still be heard more effectively by their students. A study by Jonsdottir (2002) of teachers and students from elementary school classrooms, and college/university classrooms indicated that without amplification, 70% of teachers reported throat discomfort prior to trial of sound field amplification; this decreased to 27% after sound field installation. Ray et al., (2002) found that teachers using voice amplification reported less voice handicap and voice disorder severity, which was corroborated by objective acoustic analysis following a 6 week trial than teachers in a control group.

Anecdotal comments

Many research studies on sound field amplification report anecdotal comments by teachers and students, or results obtained from informal teacher questionnaires or checklists. While often not included in such studies as formally analyzed data, these comments are both frequent and recurrent in the literature, and have therefore been summarized here. Also included here are such reports noted in studies published in non peer-reviewed sources.

- students hear better (Massie & Dillon, 2006b ; Jonsdottir, 2002)
- less vocal fatigue (Allen, 1995; Dairi, 2000; Edwards, 2005; Jonsdottir, 2002; Page, 1995; Massie et al., 2006)

- less need to repeat instructions (Dairi, 2000; Jonsdottir, 2002; Sarff, 1981)
- better student attention (Berg, Bateman & Viehweg, 1989; Edwards, 2005; Jonsdottir, 2002; Page, 1995; Rosenberg, et al., 1999; Rubin, Aquino-Russell & Flagg-Williams, 2007; Sarff, 1981; Valente, 1998
- increase in on-task behaviors (Allcock, 1999; Allen & Patton, 1990; Cornwell & Evans, 2001; Flexer, 1989; Gilman & Danzer, 1989)
- fewer teacher absences due to vocal problems (Allen, 1995; Boswell, 2006; Flexer, 1989;)
- better listening skills (Dowell, 1995; Edwards, 2005; Rosenberg et al., 1999;)
- positive student reports (Long, 2007; Mendel, Roberts & Walton, 2003; Rubin, Aquino-Russell, & Flagg-Williams, 2007)

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dition for sound amplification in degenerate semiconductors has the form (Vd â€¢q)/q. > Vs in all cases, where q and Vs are respectively the wave vector and the sound velocity, and.Â In the present research, we consider the EA of ultra-sound in a transverse, generally quantized magnetic field both by the drift and the Hall currents and by the "partial" internal currents, which flow in the Hall di-rection with the Hall contacts disconnected. A physical explanation will be given for a number of interesting features of sound amplification associated with the T(â,¬) dependence, and also with the presence of the quantizing magnetic field. 2. In the present work, we shall assume the sound wavelength to be sufficiently large in comparison with. Instead, sound field calibration is only addressed in an Appen-dix, not as part of the official standard . SuggesÂ The lack of standards is of particular con-cern because current research indicates that differences in speaker placement, sound field stimuli, and calibration methods can signifi-cantly affect threshold measurement (Stream and Dirks, 1974 ; Barry and Resnick, 1978 ; Orchik and Rintelmann, 1978 ; Stephens and Rintelmann, 1978 ; Morgan et al, 1979 ; Wilber, 1979, 1985 ; Dillon and Walker, 1980, 1981, 1982 a, b; Walker and.Â Research shows that the position of the loudspeakers, the character-istics of the stimuli used for testing, and the calibration of the sound field signals all affect the measured thresholds of the listener. Sound field amplification systems have been shown to improve time on-task in larger classroom settings, but their potential in small group settings has not yet been established.Â The final chapter, 5, includes a summary of the results, integrates the results with findings in previous research, discusses implications for practice, and provides recommendations for further research. 10. CHAPTER TWO: REVIEW OF THE LITERATURE The ultimate goal of speech therapy in public schools is the same as any educational service.