



**EVALUATING LITERATURE ON SOUND-FIELD
AMPLIFICATION SYSTEMS FOR THE UK SCHOOL
ENVIRONMENT**

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BACKGROUND

In 2006 the Royal National Institute for Deaf and Hard of Hearing People (RNID) published a report outlining their findings that 1 in 5 of the 2,000 10-14 year olds that took part in the RNID telephone hearing check could not perceive speech in noise at the level that would be expected by an adult listener. They did not attribute this difficulty to poorer hearing thresholds but to less well developed cognitive abilities to decipher sounds in the presence of noise.

It has been previously reported that children are not able to make use of the redundant acoustic cues in speech in the same way that adults are able to (Stelmachowicz et al., 2000). Soli and Sullivan (1997) reported that a child's ability to understand speech in background noise is not fully developed until adolescence. This would suggest that for children younger than those taking part in the RNID survey, whose cognitive abilities are even less well developed, the problem is potentially even greater. Blandy and Lutman (2005) demonstrated a similar trend with 7 year-old children listening to Bamford-Kowal-Bench (BKB) sentences in a task where the noise level was adaptively adjusted to obtain a 71% score. They found that the 7 year olds required a 2dB higher signal-to-noise ratio (SNR) than the normally-hearing adult population (-4dB SNR for children and -6dB SNR for adults) to understand speech at the same performance level.

Finitzo-Hieber and Tillman (1978) tested speech perception in 12 normal-hearing and 12 mild-moderate hearing-impaired school aged (8 to 13 years) children in either an anechoic or a reverberation chamber with a range of reverberation times and signal-to-noise ratios that simulated typical listening conditions in a school classroom. The average scores for the normal hearing children fell from 95% when tested in quiet with a RT^{60} (time taken for reflections to decay by 60dB) of 0 seconds, to 30% when RT^{60} was 1.2 seconds and the SNR was 0dB (the longest RT^{60} and most difficult SNR). For the hearing-impaired children listening through hearing aids the scores fell

from 83 to 11.5% for the same two conditions. The conditions tested by Finitzo-Hieber and Tillman are equivalent to those observed in classroom listening environments and these results demonstrate rather dramatically how big an impact on speech perception a classroom with poor acoustics might have both for normally-hearing and hearing-impaired children.

The impact of noise does not only affect speech understanding - it also has an impact on other educational activities. In a recent UK study (Dockrell and Shield, 2006) 58 children (average age 8.5 years) were assessed in 4 London schools. The schools were matched for external noise, Standard Assessment Test (SAT) results and proportion of children receiving free school meals (a measure of social disadvantage). The population contained 35% of children with English as an additional language and 24% with Special Educational Needs (predominantly literacy based), a typical distribution for an urban classroom in the UK. They compared 3 different listening conditions: quiet classroom, babble noise present and babble and environmental noise present and the groups of children were given a range of tests to perform (Reading, Spelling, Non-verbal information processing test (British Abilities Scales II (Elliott et al., 1996), and a written arithmetic test). The biggest impact was seen on the non-verbal tests (children concentrating on reading the information), both babble and babble and environmental noise were significantly poorer than quiet listening, and this was particularly apparent for number of items missed. Babble and environmental noise was the poorest scoring condition. For the verbal reading and spelling and also the arithmetic tests the results were not so straightforward; the babble condition was always significantly poorer than the quiet control condition, however the babble and environmental sounds condition produced significantly higher scores than babble or quiet. This suggests that noise differentially affects different tasks. They found that the children with English as an additional language were not differentially affected by the noise but children with special educational needs (SEN) scored significantly more poorly than the other children.

The RNID (2006) stressed that schools should provide the optimal acoustic environment to ensure that all children could adequately access the

curriculum. Crandell and Smaldino (2000) in a review of the literature on classroom acoustics determined that the signal-to-noise ratio (SNR) found in school classrooms ranged from +5 to -7dB. If this is considered in light of the Blandy and Lutman (2005) study, described above, where the normal-hearing children achieved 71% correct perception of sentences at a SNR of -4dB one can conclude that in some of the acoustically poorer classrooms much of the speech information would be missed by the children. Bradley (2005) reported similar findings in Canada, stating that the average Grade 1 pupil will not understand 1 in 6 words in a typical classroom setting.

Nelson et al. (2005) in a report prepared for the Acoustical Society of America outlining the ANSI classroom noise recommendations (ANSI S12.60-2002. Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools) stated that the SNR in a classroom should be +15 dB for optimal speech understanding for young children, the background noise level in the unoccupied room should be 35 dBA and the RT^{60} should be less than 0.6 seconds. In the UK, school building and extension work should conform with the building guidelines "Building Bulletin 93" published in 2003. The goal of the guidance is to produce school environments that are acoustically optimised removing the acoustic barriers to learning within the classroom. They recommend ambient noise requirements for a variety of different settings and provide suggestions for achieving the standards. They recommended that the unoccupied ambient noise level measured in primary and secondary school classrooms should not exceed 35dBA (L_{Aeq} 30 min). Shield and Dockrell (2004) surveyed the noise levels in 16 London schools and found that the average ambient noise level was 47 dBA (L_{Aeq} 30 min) - far higher than the recommendations. To acoustically optimize the classroom many noise sources need to be addressed such as: reverberation time of the room, equipment noise from air conditioning units and projectors, speech from pupils in the room and external noises from outside and children in the corridors. Siebein et al. (2000) proposed design approaches to combat some of these issues and also identified the main noise problems as being associated with poorly selected air conditioning systems and tall ceilings that create highly reverberant rooms.

The targets for optimal classroom acoustics are extremely difficult to achieve, and to optimise speech perception it may be necessary to overcome some of the acoustical restrictions of the room with the assistance of Sound Field Amplification (SFA). The goal of such an approach is to distribute the teacher's voice around the room ensuring that the teacher's voice is equally accessible to all children. The teacher uses a wireless microphone system that is amplified and sent to speakers located at different positions throughout the room.

Palmer (1997), in an article reporting ways to enhance listening and hearing in a classroom, suggested that the cost of a sound amplification system is relatively low and could ultimately save money due to those children that may struggle in noisy environments no longer requiring one-to-one tutoring. This view was echoed by DiSarno et al. (2002) in a report of a study they conducted on changes in listening behaviour in a group of 9 children with learning difficulties. Two teachers monitored behaviour pre-SFA and post-SFA and observed improvements in both listening and academic performance.

AIM

The goal of this review is to evaluate some of the key literature on SFA systems and determine if the technology could be of benefit within the UK school environment. The literature search specifically looked into performance of children with normal hearing in classrooms where SFAs were utilised. Only peer reviewed papers were considered for review.

An evidence based medicine approach was utilised to devise the questions for the review and construct the analysis. Specifically the "PICO" (**P**opulation, **P**atient or **P**roblem, **I**ntervention, **C**omparison, **O**utcome) approach was used (see <http://www.cebm.net/index.aspx?o=1036> PICO link from the centre for evidence based medicine, Oxford, UK). The question asked in this review was:

What is the impact of sound field amplification in the classroom on the performance and behaviour of normally-hearing children? See table 1 for the PICO grid that was used.

Population	Intervention	Comparison	Outcome
Children	Sound Field Amplification	No Amplification	Educational Attainment Spelling SATs scores Speech Perception
		Acoustic Treatment	

Table 1. PICO grid to define the areas for observation in the research question.

METHOD

Literature sources used for the review were: University College London Catalogue, Web of Science, SCOPUS, JSTOR and UCL Eprints, PCWerth literature resource. Date of the search was limited to papers after 1990. The Key words used in the search combinations were: Sound Field, Amplif? (? ensures that all endings are found), classroom, teacher, FM Amplif?. The search was refined to exclude papers relating to special educational needs, hearing impairment, auditory processing problems, dyslexia, adults and English as an additional language, because this is not within the scope of the current report. However if these groups were incorporated in any of the normal hearing papers the information was reviewed.

124 papers were found to be relevant in the initial search. The quality of evidence was reviewed in the selected list. If the papers were not published in a peer reviewed journal they were excluded. The papers were also reviewed to locate those that made use of a relevant outcome measure and contained control conditions to be used within the PICO analysis. Papers were not excluded due to small number of subjects if it involved a rigorous analysis with those subjects.

RESULTS

Only six of the papers from the search fitted within the criteria. Table 2 shows the completed PICO grids for the study together with information on the design and the results. The original intention was to perform a meta-analysis on the combined data from different papers but unfortunately the number of appropriate papers was very low and the outcome measures were not the same to permit pooling of results. The results are a critical appraisal of the summaries in the individual papers.

Table 2. Completed PICO grid for 6 papers that fitted the criterion of the search

Arnold and Canning (1999)					
Population	Intervention	Comparison	Outcome	Design	Results
49 Primary School Children in 2 UK Schools (23 girls and 26 boys) mean age 9.92 years (range 8.58-11.42 years)	FM Sound Field Amplification (SFA).	No Amplification	Neale (1988) Analysis of Reading Comprehension Non-standardized questionnaire	Randomised Crossover Trial with comprehension test conducted in both conditions	<ul style="list-style-type: none"> -Significantly better (ANOVA) comprehension scores with FM compared to Non-FM system - No correlation between scores and classroom location, age and intelligence - Note age range fairly narrow so the lack of correlation may have been different if a larger range had been included - 54% reported an improvement in hearing and 71% stated that noise was a problem in their school - Note there were two hearing-impaired children with moderate losses in the group and when their results were removed the significant differences were no longer apparent
Long (2007)					
Population	Intervention	Comparison	Outcome	Design	Results
16 first grade pupils from rural school in Georgia, U.S.	SFA	No Amplification	Phonic and Phonemic Awareness assessments Developed at University of Oregon "Dynamic Indicators of Basic Early Literacy Skills"	Assessments at pre- and post-intervention only considered. For phoneme segmentation and nonsense word stimuli. Children received 20 minute lesson on reading daily for 15 days over amplification system.	<ul style="list-style-type: none"> -No statistics performed - Reported scores showed a 4.12% increase in performance for phoneme segmentation and a 30.4% increase in nonsense word fluency. - Note standard deviations are reported so statistics could have been performed. - Note Author reports some limitations of the study – namely the short intervention period and that different people could have delivered the tests.

McSporrán (1997)					
Population	Intervention	Comparison	Outcome	Design	Results
<p>2 UK classrooms of children.</p> <p>Class A consisted of 35 children aged between 7.3 and 8.2 years speaking English as a first language. The room had a RT⁶⁰ of 1.6-1.7. Class B consisted of 30 children of which 12 had EAL. The RT⁶⁰ was 0.79. 10 children in class A and 15 in class B were identified as at risk for academic achievement and assessed in the study</p>	Sound Field Amplification (SFA)	Pre and Post Installation. Impact of EAL.	<p>Children's Auditory Processing Performance Scale (CHAPPS) (Smoski <i>et al.</i>, 1992).</p> <p>Student and Teacher Questionnaire developed by the Educational Audiology Association (1994)</p>	<p>CHAPPS completed for each child prior to the start of the amplifier trial and following the 5 month trial period.</p> <p>Student and teacher Questionnaire elicited at the end of the trial period</p>	<p>-Questionnaire results from 5 teachers were very positive and all wished to keep their systems and felt that the SFA improved listening abilities.</p> <p>- Significant Improvement in CHAPPS score for entire group and for children in Class A (both at $p < .005$). For children in Class B there was not a significant improvement, irrespective of whether they spoke English as first or second language. Wilcoxon was used to assess significance.</p> <p>- Note Teachers were given thorough training</p>

Mendel (2003)					
Population	Intervention	Comparison	Outcome	Design	Results
95 kindergarten children in the U.S. followed for two years so were in 1 st grade at end of study.	Sound Field Amplification (SFA)	No SFA between groups and within groups (i.e. control group and also with the SFA switched on and switched off within the test group and also within the control group)	Phonetically Balanced Kindergarten (PB-K) word lists (Haskins, 1949) and the Word Intelligibility by Picture Identification (WIPI) test (Ross & Lerman, 1979). Presented in noise (recorded from classroom) at +6dB SNR.	3 kindergarten classes received SFA (test) and 3 did not have SFA (control). When children moved to 1 st grade they remained in the same test and control groups but were separated into 4 classes for each group. Children tested with speech assessments at start of the study in autumn of kindergarten, in spring of kindergarten and in 1 st grade.	<ul style="list-style-type: none"> -No significant differences in WIPI scores between groups - ANOVA demonstrated a significant improvement across test sessions (as would be expected due to increase in age) and a significant improvement with SFA switched on compared to being being switched off ($p < .001$) - Significant difference between groups when test group tested with SFA and control tested without SFA ($p = .002$) - Similar results observed for PB-Ks in that significant improvement across test sessions but no significant difference between groups - Subjective teacher responses were extremely positive and they used the systems between 2 and 6 hours per day - Note other educational measures were not incorporated into the test battery. Although the speech perception measures did not discriminate between the groups it does highlight that in noise speech perception is better with the SFA and this could potentially impact on other areas. - Note this was a well controlled study in which children and classroom acoustics were well matched at the beginning

Palmer (1998)					
Population	Intervention	Comparison	Outcome	Design	Results
8 children randomly selected across 4 classes with believed attention difficulties. 2 were in kindergarten, 4 in 1 st grade and 2 in 2 nd grade.	Sound Field Amplification (SFA)	SFA switched off	Behaviour changes recorded by observers using the Code for Instructional Structure and Student Academic Response (CISSAR; Greenwood, Schulte, Kohler, Dinwiddie, & Carta, 1986) a measure for eco-behavioural interaction. Observation programme was controlled as much as possible by using a computer programme to direct the observer. 2 observers were present at each data collection to ensure validity of data collection.	Teachers were blind to which children were being observed. Observations occurred over a 2-year period.	<ul style="list-style-type: none"> -At worse the reliability between observers was 80% - With SFA significant decrease in competing/inappropriate behaviours compared to SFA switched on. Did not carry over when SFA switched off again. - There was a significant increase in task management activities that did carry over when SFA was switched off. - Teacher behaviours did not change, so this was not the cause for the change in pupils behaviours - Teachers reported that they would like to continue using the soundfield systems because of reduced fatigue, reduced instruction repetition, increased control, and increased attention. - Note the study would have been improved with video recording, however it is not always practical to do this and it would need to be wide angle to avoid the teacher becoming un-blinded.

Zabel and Tabor (1993)					
Population	Intervention	Comparison	Outcome	Design	Results
145 students in 3 rd , 4 th and 5 th grade classes in the U.S. (aged between 8.8 and 12.5 years).	Sound Field Amplification (SFA)	Testing in at two levels. 53 dBA and 66 dBA (higher level distributed through the soundfield system. Also distance from sound source	Iowa Spelling Scale (Green, 1954). Pre-recorded lists presented.	Random order of spelling lists presented in classroom either from a tape recorder only at 53 dBA or distributed through SFA at 66dBA	-In all year grades there was a significant improvement in score with amplification system – all at p<.001 level. -Significant effect of location on the impact of the amplification. Scores were lower for children more distant from teacher without SFA but with SFA the scores for the close and distant locations became equivalent. However, significance values were not reported in the paper.

SUMMARY OF RESULTS AND DISCUSSION

Table 2 contains the tabulated summaries of the papers used for the evaluation. As only 6 papers fulfilled the criteria for analysis a full statistical meta-analysis was not possible.

These six papers cover a range of outcomes and different areas of interest were covered. Four of the studies were conducted in U.S. and two in U.K. classrooms. The primary results are summarised below.

SFA Benefits on Language Tasks

Arnold and Canning (1999) demonstrated benefits in verbal story comprehension scores with SFA. It should be noted that the benefit was most probably attributable to the improvements exhibited for moderately hearing-impaired children in the group, because when these data were removed from the analysis the significant differences were no longer apparent. Taking these results in a positive light it would certainly support the use of SFA for hearing-impaired children and given that on any given day approximately one third of primary school children could fail a hearing test at 15dB criterion level (Flexer, et al.1994) it could be beneficial for all children. Long (2007) provided reading tuition verbally over a period of 15 days to 16 students. The children were assessed at the beginning and the end using tests of phoneme segmentation and nonsense word stimuli perception. The study showed trends in improvement in the perception of nonsense word stimuli (30.4%) at the post-testing session compared to the pre-testing session. No statistical analyses were performed and the testing period was extremely short but this results can be seen as a potential trend. Zabel and Tabor (1993) presented an audio spelling test at 53 dBA undistributed or amplified to 66 dBA and distributed through the SFA. There was a significant improvement in spelling score for the SFA condition but this should be treated with some caution because the difference in level between the two conditions is larger than one would expect (DiSarno et al., 2002; reported an example of 66 dBA directly in front (6 inches) of the teacher and 72 dBA from each of the distributed speakers). The paper did highlight the importance of classroom position and

that the distribution of sound around the room allows all children to perform at the same level. The difference in the performance based on location was apparent in the unamplified condition but the location difference was no longer seen in the scores at the higher level distributed presentation (this was reported as significant but the values from the statistics were not quoted). This suggests that children sitting further away from the teacher will not be disadvantaged by the decrease in level of the teachers' voice and the reflections of the teacher's voice should no longer be at a higher level than the direct signal. Berg (1996) pointed out that children towards the back of the classroom could be receiving large levels of interference from the reflections of the teachers' voice.

SFA benefits on childrens' general behaviour in the classroom

Palmer (1998) looked at behaviour patterns in children with learning difficulties. The number of children observed was small (8) but this was a time consuming carefully conducted analysis, in which the teachers were blind to which children in the classes were being monitored. Palmer showed that while the SFA was switched on the number of distractive/inappropriate behaviours was reduced and once switched off the behaviour pattern reverted back to normal and the number of inappropriate behaviours increased again. They also observed task management activities which improved while the SFA was switched on and over time there was carry over such that these activities did not return to the base level once the SFA was switched off. Teachers commonly report that they observe changes in children's attention and listening behaviour with the SFA and this study provides support for these anecdotal reports.

SFA benefits of childrens' listening behaviour in the classroom

McSporran (1997) evaluated the listening and attending behaviour of 25 children who had been identified as being at risk of learning difficulties. The populations were drawn from 2 classrooms from separate schools. In the first classroom all the children in the study group (10) spoke English as their first language and in the second classroom 8 children in the study group spoke English as their first language and 7 spoke English as an additional language.

The test used was the Children's Auditory Processing Performance Scale (CHAPPS) (Smoski *et al.*, 1992). There was a significant benefit of SFA for the children in classroom A (a highly reverberant $RT^{60} = 1.60$ to 1.75 seconds) but not for classroom B ($RT^{60} = .79$ seconds). The numbers in this study are small so there is probably not sufficient power for the measure used to break down the results into the sub groups. This paper could lend further support to the idea that SFA could impact on children's behaviour patterns. It could also highlight the point that the SFA will have more impact when installed in the appropriate classroom setting (although this was not a conclusion of the authors).

SFA benefits on childrens' speech perception in the classroom

The final paper assessed children's speech perceptual skills with the use of SFA. Mendel (2003) assessed speech perception in noise for 95 children. Half the children were taught in a classroom using a SFA system and half in a classroom without SFA. They were taught in classes for kindergarten and 1st grade school years but each child remained within their environmental (with SFA, without SFA) teaching condition. Speech perception was assessed using the Word Intelligibility by Picture Identification (WIPI) test (Ross & Lerman, 1979) in the sound field and Phonetically Balanced Kindergarten (PB-K) word lists (Haskins, 1949) over headphones at three points over the two years. Results showed a significant improvement in both speech tests over time - as would be expected due to developmental age. Neither test demonstrated a difference in speech perception for the children in the separate groups. However a significant benefit was demonstrated for the WIPI scores when tested with the SFA switched on for children in both groups compared to the SFA being switched off. This suggests that the long-term use of the SFA does not generally impact on speech perception in noise other than would be expected developmentally. It does show that with the SFA switched on there is an immediate effect of improving access to speech, which ultimately is the goal of the SFA.

Of all the papers published on Sound Field Amplification it is striking how many of the studies are not empirically designed; the control conditions are

often inadequate or non-existent and statistical analyses are not conducted. However there is a potential caveat with the current literature evaluation that should be acknowledged. This is that the analysis used an evidence based medicine approach to critically appraise the results reported in the papers. It may not be appropriate to use such a traditional empirical science basis for judging all of the papers within what is often a social science research area. Educational research may, for example, use “Action Research” (see O’Brian, 1998) as an appropriate research method. Such research studies do not use control conditions and would therefore not fit into the PICO model defined here.

A research collaboration between Southbank University and the Institute of Education in London produced a well designed and controlled project conducted on a large scale in the UK. However, the only peer-review publications of the results of the SFA assessments exist as abstracts in the Journal Acoustical Society of America (Carey et al., 2005; Dockrell et al., 2005). These abstracts and other presentations from the group can not be used within the evidence base but it is worth noting anecdotally one of the points that they make. They report the importance that SFA systems should not be installed in small classrooms with low ceilings that do not have acoustic problems or in too large a classroom with an excessively long reverberation time, but if installed appropriately they could be beneficial. .

Although it was not the goal of this review to look at the teachers’ opinions as an outcome it is clear that teachers that use SFAs have a positive opinion of using them (Allen, 1993; McSporrán, 1997; Mendel, 2003; Palmer, 1998). This outcome measure was not used because it could be considered to be biased because the teachers have had to show an interest in SFA to try the system initially. Never-the-less the comments of teachers suggest that they would like to keep their systems, they believe that the listening and attention of many pupils is improved and that there is less strain on their voices.

CONCLUSION

It is clear that poor classroom acoustics will have an impact on speech perception, performance on language tasks, and general behaviour in the classroom, particularly for young children and children with hearing, auditory processing or educational difficulties. Guidelines have been developed (Building Bulletin 93 (2003); ANSI S12.60-2002) to recommend low levels of ambient noise and low reverberation times within the school classroom. It could be a challenge to achieve such acoustic targets without great expenditure and some educational researchers (Palmer, 1997; DiSarno et al., 2002) advocate the use of Sound Field Amplification (SFA) systems as a cost-effective approach to overcoming the problem of poor signal-to-noise ratios within the classroom.

The analysis conducted in this report on the evidence for the use of SFA systems found 6 papers with outcome measures and control conditions that would allow the evidence to be assessed. The original question that was asked was:

What is the impact of sound field amplification in the classroom on the performance and behaviour of normally-hearing children?

Based on the evidence available it would suggest that normally-hearing children might benefit from SFA when fitted in the appropriate classroom. The benefit would be derived because all children would have equal access to the teachers' voice. SFA systems could improve attention and listening abilities of many children. Given that the typical UK classroom is made up of pupils with different abilities, language backgrounds, and hearing abilities, providing speech as clearly as possible should be a target. In some cases clarity may be derived by acoustic design and structure but when this is not possible SFA provides a viable alternative.

Given that there is only a small pool of published research on this important topic, and that these studies indicate a potentially positive benefit to children

from SFA, there is an urgent need to conduct large-scale longitudinal studies within the UK. In this way it will be possible to monitor educational outcomes over time. Comparisons must be made between SFA systems and acoustical treatment to rooms (of equivalent cost). A full understanding of the efficacy of the systems can not be obtained until this has been achieved.

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