The impact of sound field systems on learning and attention in elementary school classrooms[1]

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Abstract

Purpose: An evaluation of the installation and use of sound field systems (SFS) was carried out to investigate their impact on teaching and learning in elementary school classrooms.

Methods: The evaluation included acoustic surveys of classrooms, questionnaire surveys of students and teachers and experimental testing of students with and without the use of SFS. Students' perceptions of classroom environments and objective data evaluating change in performance on cognitive and academic assessments with amplification over a six month period are reported.

Results: Teachers were positive about the use of SFS in improving children's listening and attention to verbal instructions. Over time students in amplified classrooms did not differ from those in nonamplified classrooms in their reports of listening conditions, nor did their performance differ in measures of numeracy, reading or spelling. Use of SFS in the classrooms resulted in significantly larger gains in performance in the number of correct items on the nonverbal measure of speed of processing and the measure of listening comprehension. Analysis controlling for classroom acoustics indicated that students' listening comprehension scores improved significantly in amplified classrooms with poorer acoustics but not in amplified classrooms with better acoustics.

Conclusions: Both teacher ratings and pupil performance on standardized tests indicated that SFS improved performance on children's understanding of spoken language. However, academic attainments showed no benefits from the use of SFS. Classroom acoustics were a significant factor influencing the efficacy of SFS; children in classes with poorer acoustics benefited in listening comprehension while there was no additional benefit for children in classrooms with better acoustics.

Much of teaching and learning in schools is established through talking and listening. Poor listening environments have detrimental effects on students' ability to attend and process relevant aspects of the acoustical signals in classrooms and compromise learning and achievement (McSporran, 1997; Picard & Bradley, 2001). There is an increasing awareness of the specific ways in which poor classroom acoustics can impact on students' learning and attainment and evidence that particular groups of students are differentially at risk. A wide range of attainments and performance factors have been examined to establish the effects of environmental noise. These include literacy, attention, mathematics and memory (Cohen, 1980; Cohen, Evans, Krantz, & Stokols, 1980; Cohen, Krantz, Evans, Stokols, & Kelly, 1981; Cohen & Weinstein, 1981; Shield & Dockrell, 2008). Tasks that involve language, such as reading and word problems in mathematics, and those that have high cognitive processing demands involving attention, problem solving and memory appear to be particularly vulnerable to exposure to noise (Evans & Lepore, 1993; Shield & Dockrell, 2008) although such effects are not always evident (Cohen, et al., 1980; Cohen, et al., 1981). A significant factor governing the potential impact of noise is the classroom's internal and external acoustic environment (Shield & Dockrell, 2004; Stansfeld et al., 2005). A number of attempts have been made to address these negative acoustic factors including more stringent government standards such as those in the USA and UK (ANSI/ASA 2009; Department for Education and Skills, 2003). However, regulations are difficult to introduce retrospectively and are not necessarily adhered to. Hence alternative methods of modifying the acoustic environment, for example the installation of sound amplification, or sound field systems (SFS), are an appealing alternative. Establishing the efficacy of such modifications for different pupil groups and different classroom conditions is an essential step in developing evidence based practice.

Sound field systems

Sound amplification offers the possibility of immediately minimizing the impact of poor classroom acoustics on students' learning. Sound field systems work by projecting the teacher's voice so that children are predicted to have a better opportunity to hear clearly the teacher's instructions. These systems do not reduce exposure to external sound sources but importantly, by raising the level of the teacher's voice, they can increase the level of the speech signal relative to levels of external and internal sound sources. Initially SFS were used to support students with hearing problems; however the technology is now promoted widely for use in mainstream classrooms. Many claims about the wide ranging positive impacts of these systems have been made in the media and in recommendations for practice. For example McSporran (1997:16) argues that "possibly the most cost-effective, appropriate and acceptable way of maximizing the classroom acoustic environment is through the use of signal-to-noise enhancing technology". By hearing what is being taught, every child benefits and enjoys a higher degree of achievement (Flexer, Biley, Hinckley, Harkema, & Holcomb, 2002: 38). Sound field systems have the added benefit of reducing the strain on teachers' voices (Jónsdottir, Laukkanen, & Siikki, 2003). To identify specific effects on learning environments and students' attainments it is necessary to devise complex studies. Reports of the benefits of SFS need to control for the initial levels of performance of pupils in the target classrooms and relate changes to those typically experienced by students in matched classrooms who do not have the benefit of these systems. Without comparison groups and baseline measures on target skills it is not possible to attribute any changes to the system per se, since teachers and classes that use the system may not be representative and simply introducing something different to the classroom can produce a novelty effect for pupils and teachers alike. It is, therefore, also useful to include measures of academic and cognitive performance which are independent of teacher assessment and to carry out studies which examine the effects of SFS at different ages since the younger the child the greater the detrimental effect of noise and reverberation (Bradley & Sato, 2008). Robust evaluations should include information about the acoustics of the classrooms to identify specifications for beneficial use of the systems (Rosenberg et al., 1999).

The evidence base

We first consider studies which evaluate the impact of amplification on teachers' and pupils' voices, we then consider teachers' and pupils' ratings of listening behavior and finally examine studies which have extended our understanding of the impact of amplification on academic performance.

Amplification of the teacher's (and pupil's) voice is the main purpose of SFS. As such SFS should create a more favorable signal to noise ratio (SNR) than is generally available in the classroom. Changes in mean speech recognition performance in amplified classrooms have been reported and these improvements are consistent across different positions in the classroom, maintaining a level which is optimal for speech recognition even in noisy conditions (Larsen & Blair, 2008). Larsen and Blair (2008) also noted the additional SNR advantage for students when a hand held microphone was used during class discussions or for oral reading. The extent to which improved SNR provides wider benefits in the classroom has been the focus of a number of research studies. Decreased vocal strain is one of the greatest benefits recorded for SFS by teachers (Rosenberg, et al., 1999). Teachers are at high risk of vocal abuse and voice problems compared with non teaching professions (Jónsdottir, 2010). The use of SFS has consistently been shown to reduce voice level (Sapienza, Crandell, & Curtis, 1999) and reduces the amount of managerial time in physical education settings, at least in the short term (Ryan, 2009). However, such results are only obtained in classrooms with short reverberation times (Shield & Carey, 2007) indicating that establishing classroom parameters for acoustic measurements is necessary in any classroom prior to installing SFS.

SFS are often regarded positively by students and teachers and changes in teachers' subjective ratings of pupil listening behavior have been noted. Rosenberg et al. (1999) carried out two extensive studies in Florida examining the impact of SFS installation. In study 1 the impact of amplification was investigated with 1,139 kindergarten, grade 1 and grade 2 school students in comparison and amplified classrooms over a period of 12 weeks. Students in amplified classrooms demonstrated significantly greater improvement in listening and learning behaviors, as rated by their teachers, than students in unamplified classrooms. Study 2, which included pre and posttest assessments, involved 431 students studied over a four week period and again indicated that there were significant improvements for the students, as rated by the teachers, after amplification.

Massie and Dillon (2006 a, b) reported the results of an Australian study which compared the views of students and teachers from 12 primary classrooms when amplification was on and when it was absent. In addition to academic gains, which are reported later, teachers completed a rating scale of the students' attention, communication and classroom behavior following use of the SFS. Teachers reported significant improvements in pupil behavior with the use of SFS. Similar improvements in behavior have been reported in other studies (e.g. Mulder, 2011) but often there were no comparison/control classrooms so it is not possible to distinguish the impact of the amplification system from other factors such as the passage of time, familiarity with the classroom or students' development.

Students' ratings of SFS are also positive. Students in the Massie and Dillon (2006 b) study reported that they were 'happier' when the microphone was used with many students identifying that they could hear better when the systems were in use. Similarly Rosenberg et al. (1999) reported that students' ratings to five statements identifying the positive effects of the systems were uniformly high, with 95 per cent or more affirmative responses about the value of the systems. These data indicate generally positive views about the use of SFS, however, it is not possible to establish whether there are specific tasks such as spoken language or particular listening situations where amplification may be differentially beneficial (Shield & Dockrell, 2004).

Purdy and colleagues examined the impact of a personal FM system in a sample of 23 students aged between 7 and 11 years who were experiencing reading difficulties (Purdy, Smart, Baily & Sharma, 2009). Personal FM systems provide each child with an individual amplification system and may, therefore, be more effective than classroom systems. Ratings of ability to hear in difficult classroom situations, e.g. hearing a teacher when another teacher was talking, improved with the use of personal amplification and decreased when the amplification systems were removed. Ratings of the students' ability to hear did not differ in other classroom situations. These data point to the potential effectiveness of amplification in specific classroom listening conditions and by implication the need for studies to examine ratings over different classroom listening conditions, which may be more likely to be improved by the use of SFS.

There are fewer studies reporting objective gains in achievement for academic subjects or for specific skills related to academic achievements following the extended use of SFS. Some of the reported work comes from unpublished studies, studies without detailed methodologies or outputs which are not subject to peer review. For example, an often cited study is the ‘Trost study’ (see Millet, 2008) where reports on a range of literacy measures for students in the amplified classrooms and a group in a nonamplified classroom are described. However, the lack of data prior to the installation of the amplification systems in the study means that these results may reflect differences in the populations studied rather than the effect of the SFS per se. The majority of systematic experimental work has been with children in the initial stages of formal education (Flexer, et al., 2002; Palmer, 1997). We focus on four experimental studies which have investigated impacts on academic achievement and reported detailed outcome data.

Darai (2000) reports greater literacy gains for first grade children in four classes with amplification as compared to controls over a five month period; increases were reported to be greatest for bilingual children and children with additional learning needs, who may be more adversely affected by noise and poor classroom acoustics (Dockrell & Shield, 2006). Darai (2000) notes that teachers suggested that the students were more attentive to the teacher’s voice. However, no data were presented about either the numbers of participants with additional learning needs or the pupils’ actual baseline performance and follow-up performance. The failure to present baseline performance for the evaluation means that the results need to be regarded cautiously, but suggest that SFS may improve reading performance in children at the initial stages of learning to read.

Objective achievement data to support this conclusion have been collected by Massie and Dillon (2006 a). They used a cross over design with a sample of 242 grade 2 students, of whom a large proportion were English language learners. Acoustic measurements were available for all classrooms. Staff were trained and the benefits of the system were explained. During the first semester half the classes had the SFS on and the other half had the SFS off. This was reversed in the second semester. By using a cross over design this study had the benefit of controlling for the effect of passage of time on pupils' performance. Teachers rated the students' skills using the Queensland education monitoring system which examined reading, writing and numeracy. The SFS provided positive effects in each semester, as rated by the teachers on the outcome measure, and the effect was strongest when averaged across the three skill areas tests. Flexer et al. (2002) focussed on the potential added benefit of SFS to a preschool phonological training program. A strength of this pilot study was the focus on the development of a specific skill, phonology, which underpins single word decoding. Research has consistently shown the benefits of phonological training in relation to reading and this study compared typical classroom teaching, a phonological intervention and a phonological intervention supported by the use of a SFS. Although there were indicators that the SFS provided added benefit there were no statistically significant differences relative to the phonological training program alone. Sample sizes were small making significance difficult to detect. However, given the reported significant changes in the teacher's voice noted above, this is one skill which ought to benefit from amplification and, as the authors suggest, further studies of this kind would be beneficial. This is important as not all studies have found beneficial effects for the systems. Purdy et al. (2009) measured improvement in reading for students who had use of a personal FM in comparison to controls but found no differential benefit of amplification. All students improved over time, with greater improvement when English was spoken at home.

In many cases the acoustic conditions of rooms in which SFS are to be installed have not been considered. The intelligibility of speech in an enclosed space is related to both the speech to noise ratio, which is the difference in decibels between the levels of the received speech signal and the background noise, and the acoustic characteristics of the space. If a room is too reverberant and/or the background noise levels are too high then the ability of students to hear and understand the teacher will be compromised, whether the speech is natural or amplified. Early reflections of the speech from nearby room surfaces which arrive at the listener's ear within 50 ms of the direct speech reinforce the speech signal thereby enhancing speech intelligibility (Department for Education and Skills, 2003). However if the room is too reverberant the speech may be masked by later arriving reflections and speech intelligibility reduced; in addition the background noise level will increase. It is therefore important that SFS are installed in rooms where the acoustic conditions are suitable for both natural and amplified speech.

The amount of reverberation in a room can be described by the reverberation time RT, that is the length of time it takes for the sound level to drop by 60 decibels (dB) once the source of the sound has ceased. Current regulations regarding the acoustic design of new schools in England and Wales (Department for Education and Skills, 2003) specify that, for unoccupied primary school classrooms, the midfrequency RT (average of RTs at 500, 1000 and 2000 Hz) should not exceed 0.6 seconds. This is the value also specified in the current US guidelines (ANSI/ASA, 2009) for unoccupied classrooms not exceeding 283 m^3 in volume. (All classrooms used in this study had volumes less than this limit.)

Rationale for the current study

Sound field systems have the potential to mitigate the effects of poor classroom acoustics. The current review has demonstrated that there are a small number of rigorous studies which provide empirical evidence to support the use of SFS and these studies are beginning to capture the potential loci of the effects of SFS. These studies generally report positive results for behavior, achievement and views of usage but typically data have been collected from children in the early stages of elementary school. This study aims to extend previous work by a) focusing on an older elementary school group b) sampling performance on academic and nonacademic tasks which were administered and coded by researchers, not teachers and c) attempting to differentiate classroom conditions where amplification may be particularly valuable. In addition the study collects teachers' views of the impact of amplification and acoustic data of the classrooms.

Use of SFS might enhance learning in a number of ways. Listening in classrooms could be improved and, as such, it would be predicted that classes using amplification would see gains across academic subjects reflecting enhanced access to classroom teaching. Alternatively improved SNR could enhance auditory processing and improved achievements would be expected on verbal but not nonverbal tasks. Finally, amplification may serve to support classroom management and as a result affect behavior and attention resulting in general improvements across classroom performance.

The achievements of elementary school students in amplified and unamplified classrooms over a six month period were examined. Acoustic surveys of a sample of classrooms were also conducted. Matched comparison classes with and without installed SFS were identified. Students' perceptions of amplification and their performance on academic tests (reading, spelling and numeracy), nonverbal tasks (speed of information processing) and listening comprehension (spoken language processing) were assessed prior to the installation of the SFS and after six months of use in the target and comparison classrooms. Testing occurred with SFS off to evaluate differential improvement in learning and attention over time.

METHODS

The study involved questionnaire surveys and experimental testing of students in classrooms with and without SFS, and questionnaires completed by teachers. The sample of students who participated in the study was taken from one county in southeast England which had 458 elementary schools. The local authority had decided to install SFS in every elementary school classroom (ages 5 to 11 years) which at that point included or was expected to include a child with a hearing problem. The questionnaire surveys and experimental testing of students were carried out before installation of the SFS in target and comparison classrooms (baseline) and six months later (post testing). The project met the ethical guidelines set by the British Psychological Society and ethical approval was sanctioned by the Institute of Education, London.

School selection

Head teachers in all schools where systems were to be installed in classes of eight year olds or above were invited to participate in the study. To participate schools needed to agree to baseline and follow-up measures six months later in amplified and comparison classrooms, and acoustic surveys of the classrooms. Originally ten schools agreed to participate in the completion of the questionnaires and six schools agreed to participate in the experimental phase of the study, although valid data from all schools were not available for final analysis. Participating schools were within the average range for national school statistics, including achievement, numbers of students with additional learning needs and students receiving free school meals. They were in the bottom decile for students learning English as an additional language, as is typical for schools outside major cities in England. Participating classrooms reflected the local authority statistics for both numbers of pupils learning English as an additional language and pupils with additional learning needs.

Table 1 shows the eight schools that took part in the study and provided valid questionnaire and experimental data (listed as schools 1, 2 etc) and the classes in each school (listed as A, B etc). The average ages and types of class (that is, with SFS or comparison classes) are also indicated. The table also shows the measured and estimated reverberation times, where available, as discussed below.

INSERT TABLE 1 ABOUT HERE

Participants

Questionnaire study

Students completed a questionnaire before and six months after installation of SFS in their home classrooms. Other students in classrooms without SFS also completed questionnaires at the same time to provide comparison data. In total 740 students completed baseline questionnaires and 478 completed questionnaires at follow-up. Data from classes where SFS had been installed but did not work or were not used were excluded from the analyses. Pupil data available for analysis were from 19 classrooms in seven schools; as shown in Table 1 14 were rooms which had SFS installed and five were comparison classrooms. The total number of students for whom baseline and follow-up installation questionnaires were available was 393. These participants were included in the analyses examining the impact of classroom amplification. Teachers in classrooms with SFS were also asked to complete a questionnaire about the systems when students were completing the follow-up questionnaires.

Experimental study

For the experimental study, 186 students aged 8 to11 years participated; of these 15 per cent (*N* = 28) had special educational needs which had been identified and documented by professionals and 13 per cent (*N* = 25) had English as an additional language. Four students were identified with both special educational needs and English as an additional language. The students were from eight classrooms in five schools, five classrooms (*N* = 114) with amplification and three comparison classrooms (*N* = 72), as shown in Table 1. Comparison and SFS classrooms did not differ in numbers of students with special educational needs (χ^2 (1, *N* = 186) = .13, *p* = .72) or numbers of students learning English as an additional language χ^2 (1, *N* = 186) = 1.74, *p* = .42). Of the five classes where systems were installed three classes included students with a hearing problem. In contrast, none of the three comparison classrooms included a child with a hearing problem. Data from students with hearing impairments are not included in the sample and were not analyzed due to the small number (*N* = 4). Students were assessed in their classrooms by a qualified psychologist. Order of presentation of the assessments was randomized. Participants were free to opt out of assessments if they wished.

Assessments

Questionnaires. Students' awareness of 11 environmental noises typically heard in classrooms (see Table 2) and their perceptions of teacher and peer audibility in eight different classroom contexts (see Table 3) were examined using a revised version of a previously used classroom listening questionnaire (Dockrell & Shield, 2004). A smiley face Likert scale was used where a rating of 1 indicated the child could hear very well in the condition and a rating of 5 indicated that it was very difficult to hear.

Teachers in classrooms where SFS had been installed were asked to complete a questionnaire examining their use of the systems, the classroom activities where amplification was used, and their rating of the impact of the system on the students' understanding of spoken language, attentiveness in the classroom and changes in behavior and rate of learning. For the impact items a Likert scale was used where a rating with 1 indicated that the teacher strongly disagreed that there was a change and a rating of 5 indicated that the teacher strongly agreed that there was a positive change.

Academic and cognitive skills. We identified measures which have been standardized on UK population samples, report reliability and validity measures in their respective manuals and are used within the UK to assess the relevant academic and cognitive domains. Tests were scored by a trained psychologist who did not know whether pupils were in amplified or comparison classrooms.

Modified versions of standardized tests (British Ability Scales II (Elliott, Smith, & McCulloch, 1997) for spelling, numeracy and speed and accuracy of nonverbal processing (Dockrell & Shield, 2006) and the Suffolk Reading Scale (Hagley, 2002) and listening comprehension test (Hagues, Sissiqui, & Merwood, 1999) were used. A and B versions were available for each measure and use of the versions was balanced across classrooms and time of testing.

Reading. Suffolk Reading Scale (Hagley, 2002) is a standardized reading assessment. Participants are presented with paper booklet comprising 86 items. Each item is a sentence containing a missing word. Children identify a word to complete the sentence in a semantically correct form from a choice of 5. For example – ‘In hockey we have two types of players __and defenders’. The options for this question include – attackers, attenders, antagonists, assassins, and assessors. The child silently reads each incomplete sentence and identifies which word out of 5 should be inserted in the sentence.

Spelling. British Ability Scales II; Spelling Scale (Elliott *et al.*, 1997) provides a number of phonetically regular and irregular words to assess the child’s ability to produce correct spellings. There were 25 items in the scale and each item is first presented in isolation, then within the context of a sentence, and finally in isolation. The child has to respond by writing the word.

Numeracy. British Ability Scales II (Elliott *et al.*, 1997); Numeracy scale is a test of basic computation. Students are presented with a sheet of 25 computations starting with single digit addition and subtraction and increasing to multiplication, division and fractions.

Non-verbal processing. The speed of information processing test was developed from the British Ability Scales II (Elliott et al., 1997). The scale assesses how quickly the pupil can perform simple mental operations. Students needed to process a sequence of circles containing small squares, and decide which circle had the most squares. Each item of the scale consisted of a row of circles (3, 4 or 5) each of which contained a number (1 to 4) of small squares. There were two versions, each one with 15 pages, with 5 items in each page; a total of 75 items. The test was time limited to 2 minutes. Students recorded their responses by ticking the circle with the most squares in it. Scores were computed for both the number of correct responses and the number of pages completed. An error analysis was derived to examine missed items and incorrect items.

Listening comprehension. The Listening Comprehension Test Series (Hagues et al., 1999) is a standardized test that assesses the communication skills that enable a child to listen, understand and respond appropriately to information. It includes a section of true/false statements to assess comprehension of passages read orally to the students. It is standardized for students aged 6 years and above. Participants completed two scales comprising a total of 20 items.

Acoustics survey

The acoustics survey consisted of two parts. Firstly, measurements were made of room acoustics parameters in 20 typical classrooms in which SFS were to be installed in 10 schools across the county. These gave an indication of the variation in acoustic conditions in rooms where SFS were to be fitted. Secondly, where possible acoustic surveys of the classrooms included in the questionnaire survey and experimental testing were carried out.

Each room was unoccupied at the time of the survey, Measurements were carried out in accordance with BS EN ISO 3382:2000 (British Standards Institution, 2000) using an omni-directional source and maximum length sequence (MLS) procedures to excite the room. In each room measurements were made at six receiver positions using two source positions, chosen where possible to reflect the typical use of the classroom by the teacher. Reverberation time (RT) was measured across the octave bands. The values for 500 Hz, 1000Hz and 2000 Hz were averaged to give the mid-frequency reverberation time, T_{mf}, in accordance with the current acoustic design standards for schools in England and Wales (Department for Educational and Skills, 2003). The measurements at each receiver position were spatially averaged to give a single figure for T_{mf} for each room.

Typical classrooms

A histogram showing the distribution of mid-frequency reverberation times, T_{mf}, in the 20 typical classrooms is shown in Figure 1. It can be seen that the SFS were installed in rooms with a wide range of acoustic conditions including some with a long RT (over 1 second in one case). Other rooms had very short RTs of less than 0.4 seconds, where it could be argued that SFS were not necessary as the listening conditions were already very good in those spaces.

Classrooms used in study

The reverberation times of the study classrooms are shown in Table 1. For various practical reasons (for example, not being able to gain access to certain classrooms or noise from construction work taking place in the school out of school hours) acoustic data was measured in only seven of the study classrooms. However, some of the classrooms used were of similar dimensions, volume, construction, design, layout and surface finishes (for example plaster, wood or glass) to ones that were measured in both parts of the acoustic survey. Where a room was identical or near identical to a measured classroom in terms of size, design and finishes it was assumed that the RT would be approximately the same as that of the measured room. In this way it was possible to estimate the RT of six additional classrooms, as indicated in Table 1. It can be seen that the RTs of the 13 rooms for which data were available varied from 0.38 seconds to 0.9 seconds.

INSERT FIGURE 1 ABOUT HERE

RESULTS

Results of teachers questionnaire following SFS installation

Sixteen teachers from classrooms where SFS had been installed 6 months previously completed the questionnaire. The majority (*n* = 15) had never used SFS previously and fewer than half (*n* = 7) received training in their use. Only two had been consulted prior to installation about the position of the system. At the time of questionnaire completion 11 were still using the system and we report descriptive data from these respondents in terms of their use, benefits of the system and the changes they have noted in their pupils over the 6 month period. Of the five who stopped using the system three reported that it was uncomfortable to use and the remaining two reported technical problems with the systems.

Of the 11 teachers still using the system all reported using it daily for at least 40% of the day. Whole class teaching was a primary determinant of use (*n* = 6). Seven used the systems for all academic lessons with the remaining four noting that they used it for literacy lessons. Teachers were positive about the effect of the systems in supporting pupils' ability to understand spoken instructions (*n* = 9), their ability to produce more appropriate answers to questions (*n* = 8) and in terms of the reduced need for the teachers to raise their voice (*n* = 6). Improved levels of attention were also noted with nine teachers noting improved attention spans. In addition nine teachers noted better attention when there were increased levels of noise. In contrast there was much more variability in teachers' reports of the impact of the system on the students' academic attainments with eight teachers noting no changes in the pupils' rate of learning and nine teachers noting no differences in on-task behavior.

Results of pupil questionnaire survey

Overall the classrooms were rated positively for listening conditions at baseline (mean rating ranges from 1.3 for no noise outside or inside the classroom to 2.9 for students making noise outside the classroom). As predicted and shown in Table 2 the installation of SFS had no significant impact on the students' reported awareness of external sound sources, reinforcing the view that the presence of the SFS did not lead to more positive responding across all questions relating to noise in the classroom environment.

INSERT TABLE 2 ABOUT HERE

Means and standard deviations across conditions and time for students' ratings of the classroom listening conditions are presented in Table 3. Independent samples t- tests indicated that the students in the amplified and comparison classrooms did not differ statistically significantly at baseline in their ratings of classroom listening conditions (all *ts* < 1.40 and *ns*). However there were significant differences in ratings across listening conditions (F (7, 2519) = 159.95, $p < .001$, $\eta p^2 = .29$, corrected for sphericity with Greenhouse-Geisser). For students in both amplified and comparison classrooms ratings for the quiet classroom (Item 8) were significantly better than for all the other conditions (Bonferonni post hocs *p*s < .001) while ratings for students making noise outside (Item 5) were significantly worse than for all other conditions (Bonferonni post hocs *p*s < .001).

We expected that the SFS would be of benefit in hearing the teacher in poorer listening conditions (Items 1, 2, 3, 5 and 7) but effects would be less likely with other situations (Items 4, 6 and 8). We computed two new variables from the mean scores for items on the questionnaire data presented in Table 3: a predicted change variable (Items 1, 2, 3, 5 and 7) and a no change predicted variable (Items 4, 6 and 8).

A repeated measures ANOVA for the new ratings (change predicted, no change predicted) examined effects of time (baseline and follow-up) and interactions by condition (SFS and comparison). There were significant improvements in ratings of classroom listening for both the change predicted (baseline $M = 2.29$, $SD = .69$; follow-up $M = 2.11$, $SD = .72$, F (1, 389) = 435.90, $p < .001$, $\eta p^2 = .53$) and no change predicted variables (baseline $M = 1.73$, $SD = .60$; follow-up $M = 1.63$, $SD = .58$, F (1, 389) = 4.42, $p < .001$, $\eta p^2 = .04$). There were no significant two-way interactions by condition, indicating that ratings of classroom listening conditions over time did not differ between students in amplified classrooms and those in comparison classrooms. In sum students' ratings of their classroom listening environments improved over time but this was not differentially affected by the use of SFS.

INSERT TABLE 3 ABOUT HERE

Results of experimental tasks

Students' scores on the experimental tasks at baseline and follow-up are presented in Table 4. Students in the comparison classrooms were significantly younger than the students in the SFS classrooms (Comparison *M* = 9;5 years, *SD* = 8 months; SFS *M* = 9;8 years, *SD* = 13 months, *t* = 2.04, *df* = 131.04, *p* = .04, Cohen's *d* = .28). Therefore, the subsequent analyses control for the age difference between the comparison and amplified classes. A series of ANOVAs controlling for age showed that there were no significant differences for any measures (spelling, numeracy, speed of information processing, accuracy of information processing, reading accuracy and listening comprehension) between pupils in the comparison and amplified classrooms at baseline (All F values < 2.00 and *ns*).

INSERT TABLE 4 ABOUT HERE

We first considered the impact of SFS on the accuracy of pupils' performance on the non-verbal processing test and the verbal listening comprehension measure. Two mixed-design ANOVAs were conducted with time (baseline and follow-up) as the within subjects factor and amplification (SFS or control) and special educational needs (present or absent) as between subject factors with age as a covariate. Where interactions with classroom SFS are non-significant we present *p* levels for a guide in interpreting the effect and the likelihood of significant results if the sample size were larger. For the non-verbal processing task there were a significant main effect of time, *F* (1, 112) = 4.82, *p* = .03, ηp^2 = .04, a significant interaction with age, *F* (1, 112) = 8.34, *p* = .005, ηp^2 =.07 and a significant interaction between time and condition, *F* (1, 112) = 9.48, *p* = .003, ηp^2 = .08 but there was no three way interaction with special educational needs, time and condition, *F* (1, 112) = 3.00, *p* = .86. All other effects were not statistically significant. Figure 2 shows the average number of items correct in the speed of processing task before and after installation of SFS for students in the SFS classrooms and the comparison classrooms. As Figure 2 shows students in classes where SFS were installed showed a greater improvement in performance on the non verbal processing task than students in the comparison classes.

INSERT FIGURE 2 ABOUT HERE

In contrast the ANOVA for listening comprehension revealed no significant main effect of time, *F* (1,139) = .01, *ns* and no interaction with age, *F* (1, 139) = .04, *ns*, but a statistically significant interaction between time and condition, *F* (1, 139) = 6.51, *p* = .012, ηp^2 =.05 with no three way interaction between special educational needs, time and condition, *F* (1, 139) = .44, *p* = .51. All other effects were not statistically significant. Figure 3 shows the mean scores for the two groups of students before and after installation of the SFS systems. It can be seen that students in the classrooms with SFS demonstrated an improvement in their listening comprehension score while those in the nonamplified classrooms did not.

INSERT FIGURE 3 ABOUT HERE

Finally we considered the impact of amplification on students' academic performance. A mixed-design ANOVA was conducted with time (baseline and follow-up) and academic test (reading, spelling and numeracy) as the within subjects factors and amplification (SFS or control) and special educational needs (present or absent) as between subject factors and age as a covariate. As before where interactions with classroom SFS are nonsignificant we present p levels for a guide in interpreting the effect and the likelihood of significant results if the sample size were larger. There was a main effect of time of testing, F (1, 151) = 4.80, p = .03, ηp^2 =.03, and a main effect of academic test, F (2, 302) = 4.20, p = .02, ηp^2 =.03. There was also a significant interaction with age and test, F (2, 302) = 27.52, p < .001, ηp^2 =. 15, but not of time of testing with age, F (1, 151) = .23, *ns*. In relation to our predictions there was no interaction between time of testing and condition, F (1, 151) = .12, p = .77, or test and condition, F (2, 302) = .17, p = .17. However, there was a trend indicating a three way interaction between time, condition and special educational needs, F (1, 153) = 3.18, p = .07, ηp^2 =.02. Pupils with special educational needs in the SFS classes made an average gain of 4.1 points (*SE* = 1.79) on academic tests across the six months whereas those in the comparison classrooms made an average gain of 0.02 points (*SE* = 2.41). All other effects were statistically nonsignificant. In summary, as expected, performance on the achievement measures improved over time but contrary to our predictions this improvement was not affected by the use of SFS; however, there was a trend for those students with special educational needs to benefit differentially from the use of SFS.

We had established that three of the five classrooms where SFS were installed had good acoustics for speech (RT ≤. 52). We therefore repeated the ANOVAs comparing the gains made in the amplified classrooms between students across time in classrooms with good acoustics and those in classrooms with poorer acoustics (RT ≥ 0.83), controlling for age. Three mixed-design ANOVAs were conducted with time (baseline and follow-up) and speed of processing as the within subjects factor for the first ANOVA, listening comprehension as the within subjects factor for the second ANOVA and academic test (reading, spelling and numeracy) as the within subjects factor for the third ANOVA. As the focus of interest is the differential effect of classroom acoustics we only report results for the interaction between good and poor acoustics. There was no interaction with classroom acoustics with the speed of processing measure, *F* (1, 75) = 2.77, *p* = .10. In contrast for listening comprehension there was a significant effect by classroom acoustics, *F* (1, 107) = 7.73, *p* = .006, ηp^2 =.07. Students in the classrooms with poorer acoustics made an average gain of 2.44 (*SE* = .47) correct answers while those in the classrooms with good acoustics made an average gain of 0.86 (*SE* = .40) correct answers. There was no interaction between academic test scores and classroom acoustics, *F* (2, 230) = .04, *p* = .33.

Discussion

The current study aimed to evaluate the use of SFS in elementary schools in one English local authority. Data were available to examine teachers' views of the systems, compare pupils' evaluation of classroom listening conditions over time in classes with and without SFS installed and evaluate changes in cognitive skills and academic performance over time. Together these measures tap the range of factors reported to be improved when classroom amplification is used.

The listening conditions questionnaire used is a subjective measure that is sensitive to different acoustic conditions (Dockrell & Shield, 2004). Overall students had rated their classrooms as good listening environments and these ratings improved over time. We had predicted no differences between the amplified and comparison classrooms in the environmental noises students reported hearing, as amplification does not affect external noise. There were no significant differences between students in amplified classrooms and those without SFS, so this prediction was upheld. In contrast we had predicted that students in amplified classrooms would produce better ratings for teacher audibility but this prediction was not upheld. There was no evidence to support improved ratings of teacher audibility, that is there were no differential effects over time for those in amplified and nonamplified classrooms, although there were increases in students' perceptions of audibility over time. The inclusion of appropriate comparison groups is crucial to understanding these patterns of responses. If we had omitted the comparison group increased ratings of classroom listening over time would have erroneously been attributed to a specific effect of SFS. Students' improved ratings of the listening features of their classrooms over time may reflect increased familiarity with the classrooms and their teachers' voices. In addition students may have developed strategies to minimize difficulties they had in listening in their classrooms (Dockrell & Shield, 2004).

We had predicted that if SFS improved the academic achievement of students in the classrooms we would expect greater improvement across all academic subjects, that is reading, spelling and numeracy in classes with SFS compared to comparison classrooms. Students' performance did improve over time indicating that they had been learning during the interim six months, but there was no evidence to support a differential effect for students in amplified classrooms. Neither was there evidence to support the view that all tasks which are verbally mediated (listening comprehension, spelling and reading) were improved in comparison to nonverbal tasks (numeracy and speed of processing). Finally we had predicted that, if the use of these systems improved the learning environment, attention and the processing of spoken language would show differential improvements along with the academic tasks. This did not occur. Thus overall, there was no evidence to support the specific hypotheses that were made about the ways in which amplification could improve the learning environments in these classrooms.

We did find significant benefits in the amplified classrooms for the listening comprehension task and the nonverbal speed of information processing task, accounting for five per cent and seven per centof the variance, respectively. Overall performance on the listening comprehension measure did not improve significantly over the six month period. There was, however, a differential effect where improvement was evident only for pupils in the amplified classrooms. The listening comprehension differential gain may, therefore, reflect either improved listening in difficult situations or the strategies implemented by the teacher. The fact that this improvement was specific to classrooms with poorer acoustics suggests that the impact of SFS was moderated by the specific classrooms - for students in classrooms with excellent speech intelligibility there was little to gain. This effect was not expected (see Shield & Carey, 2007). It is possible that improving aspects of speech intelligibility (possibly improved speech to noise ratio) in the classrooms with poorer acoustics led to relative improved performance on this spoken task. Alternatively, as suggested by Darai (2000) and reported by the teachers in this study pupils may be more attentive to the teacher's voice and this strategy may be particularily beneficial in classrooms with poorer acoustics.

This does not explain the differential improvement in speed of information processing between amplified and comparison classrooms. It is possible that SFS helped the teacher maintain the students' attention and that over time their approach to work had improved and this was evident on a task which required speed and attention to detail. These are performance factors that are reported to be specifically vulnerable to exposure to noise (Evans & Lepore, 1993; Shield & Dockrell, 2008)**.** However, performance on this speeded task did not differ between amplified classrooms with good and poorer acoustics supporting the view that changes in teacher (or pupil) behavior are a more likely explanation. Teachers who chose to use SFS may have been more aware of the need to monitor the attention and listening of their students. It is also possible that schools with SFS were less exposed to the types of noises that interfere with speeded nonverbal tasks (Dockrell & Shield, 2006), although this was not evident in the students' ratings.

Our sample included students with certified special educational needs in experimental and comparison classrooms. We examined the extent to which their performance differed from mainstream peers without documented learning difficulties. It is known that students with special educational needs are often vulnerable in the area of processing verbal material and this is frequently evidenced in terms of poor phonological skills (Bradlow, Krauss & Hayes, 2003; Dellatolas, Kremin, De Agostini, Martin, & Dupuis, 2002). Previous work has shown that this vulnerability is exacerbated in acoustically marginal classrooms. As expected we found no differential performance for students with special educational needs on the nonverbal processing measure. Contrary to predictions we also found no differential effect for listening comprehension; however our sample of students with special educational needs was small. Despite the small sample size differential performance in academic attainments was evident. The current results indicate that the use of SFS may serve to minimize the impact of poorer acoustics on the academic attainments of vulnerable learners. The students with special educational needs in the current study made virtually no progress on our academic measures over the six month period when SFS were not in use. In contrast gains were noted when SFS were used. This trend in differential improvement for students with special educational needs warrants further systematic research and points to the ways in which modifications of the acoustic environment might support learning and attainments.

Study limitations

Examining students' performance in classroom settings over time raises a number of methodological challenges, including assumptions about causal mechanisms of change, ensuring a sufficiently large sample is recruited and problems with implementation. The use of SFS was not continued in some of the experimental classrooms in this study and teachers of some comparison classrooms were not willing to be involved in the repeat assessments six months later. Thus, class and subject attrition reduces the power of the samples and is a potential bias in the results. Moreover, despite the local authority providing training some teachers reported not being sufficiently trained in the use of the systems, thereby reducing the potential efficacy of SFS. Further larger studies will need to consider these factors in the design. Practical limitations in the school environment also meant that it was not possible to obtain all the acoustic measurements we would have wished from target classrooms. It is possible that improvements to the acoustic conditions of classrooms with poor acoustics, for example by the installation of acoustically absorbent materials to reduce reverberation time, rather than the use of SFS would have similar beneficial effect by improving speech intelligibility. A further study is required in which the two approaches to mitigating the effects of poor classroom acoustics are compared. Finally study of the impact of SFS needs to systematically address students with special educational needs with a larger sample size and a more detailed profile of the difficulties the students experience to confirm the benefits we have identified for this group of students.

Conclusions

The current study found specific effects in classrooms where SFS were used but these effects were small and subtle. The gain in the spoken comprehension measure suggests that improved speech to noise ratio in classrooms with poorer acoustics may be responsible for these results but further studies are required to substantiate this effect. Of paramount importance is the need to consider the acoustics of the classrooms. Students in this study rated their classroom acoustic environments positively which is consistent with the relatively low values of RT which were measured. Further work needs to consider the specific acoustic parameters of the classroom as an additional variable in the measurement of the benefits of SFS and link predicted changes in behavior to theoretical models of language processing and learning in classrooms.

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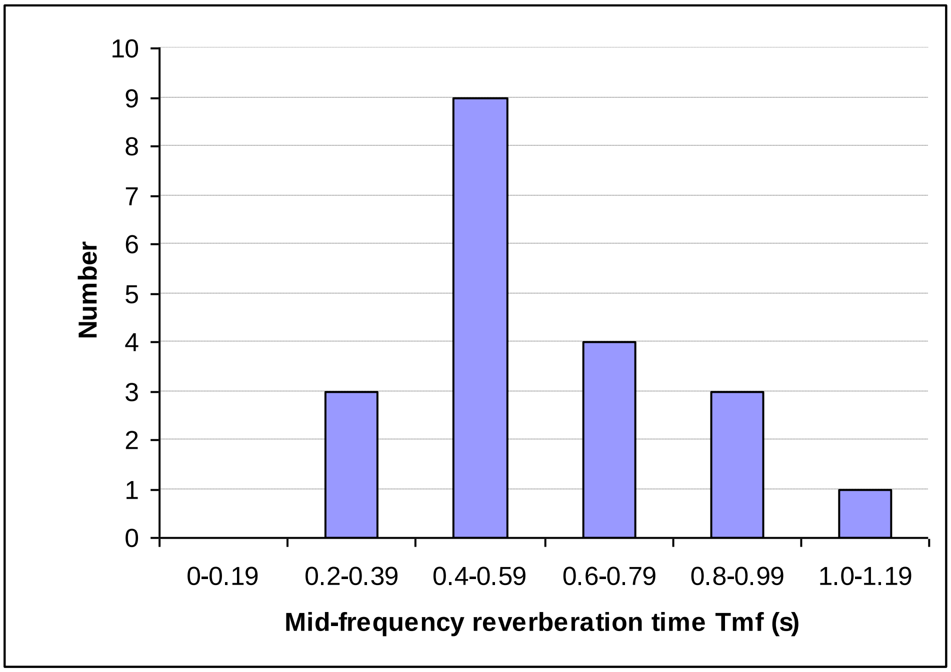

Figure 1. Distribution of mid-frequency (average of 500, 1000 and 2000 Hz) reverberation times in 20 classrooms with amplification.

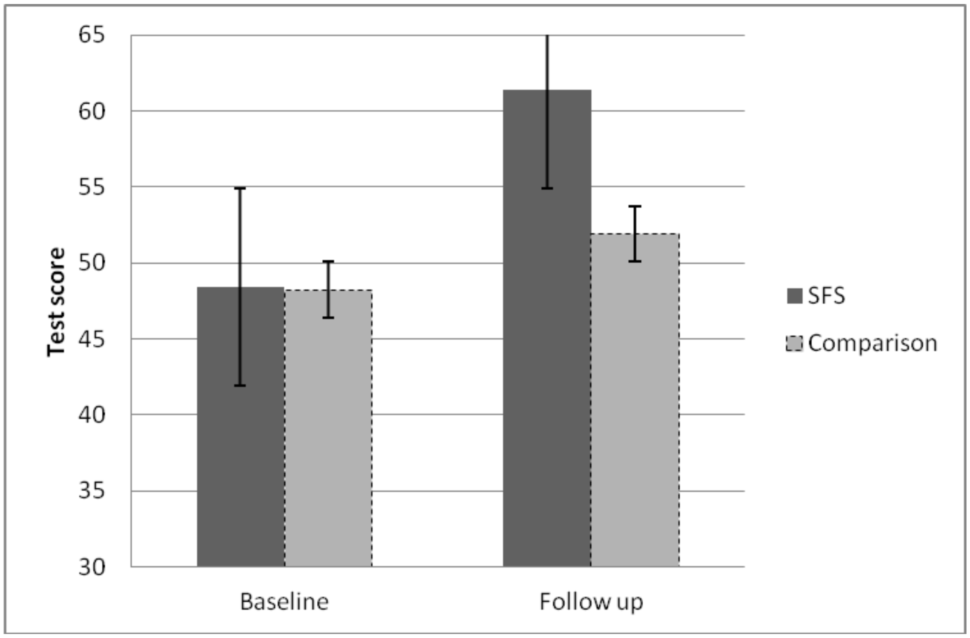

Figure 2. Mean (and standard error of) numbers of items correct in the speed of processing task over 6 months for sound field system (SFS) classrooms and comparison classrooms.

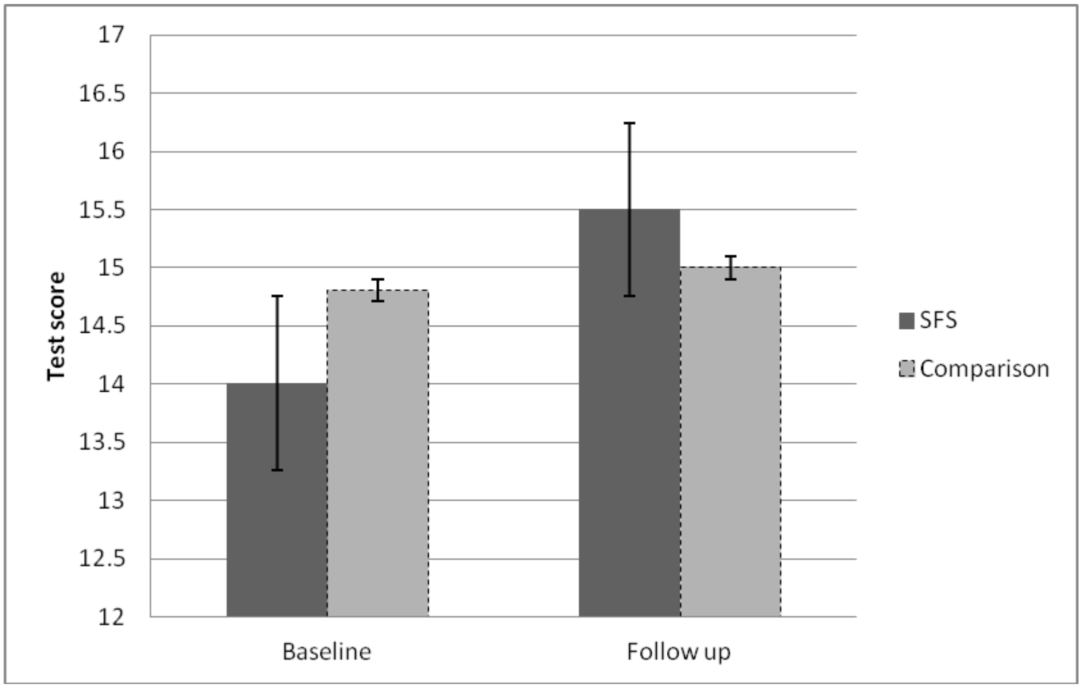

Figure 3. Mean (and standard error of) listening comprehension scores over 6 months for sound field system (SFS) classrooms and comparison classrooms.

Table 1

Classes included in the different phases of the study and class RT measurements

School	Class	Mean Age[3]	Condition	Pupil Questionnaire[4]	Experimental Testing	Mid-frequency RT[5,4] (seconds)
1	A	8	SFS	*		0.52
	B	9	Comparison	*		0.55E
	C	9;5	SFS	*	*	0.52E
	D	9;8	Comparison		*	
2	A	8	SFS	*		
	B	9;9	Comparison		*	
	C	10;5	SFS	*	*	0.48
3	A	9	SFS	*		
	B	9;6	SFS	*	*	0.41E
4	A	8;9	Comparison		*	
5	A	8	Comparison	*		
	B	8;3	SFS	*	*	0.90
	C	9	SFS	*		0.83
	D	10	SFS	*		0.55
	E	10	Comparison			
	F	10;6	SFS	*	*	0.83E
6	A	9	Comparison	*		
	B	10	SFS	*		
7	A	10	Comparison	*		0.38E
8	A	8	SFS	*		0.55
	B	9	SFS	*		0.55E
	C	10	SFS	*		0.55

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[3] Pupils recorded age in years on the questionnaire. Date of birth at time of testing was collected for the experimental tasks and age in years and months calculated

[4] * indicate that data were collected in these classrooms

[5] Mid-frequency RT is average of RTs at 500, 1000 and 2000 Hz

[4] E indicates RT has been estimated from measurements made in similar rooms

Table 2

Percentage of students reporting environmental sounds in amplified classrooms prior to installation of amplification and six months later

Environmental sound	Baseline	Follow-up	Chi Square values[a]
Cars	34	37	(1, *N* = 858) = 0.41
Planes	53	58	(1, *N* = 854) = .1.63
Trains	10	8	(1, *N* = 854) = 0.86
Phones	38	42	(1, *N* = 856) = 1.56
Motorbikes	33	37	(1, *N* = 852) = 1.69
Buses	17	15	(1, *N* = 854) = 0.49
TV	24	28	(1, *N* = 852) = 1.87
Helicopters	51	57	(1, *N* = 854) = 3.21
Lorries	34	31	(1, *N* = 854) = 0.92
Stereos	31	37	(1, *N* = 851) = 3.27
Sirens	56	57	(1, *N* = 856) = 0.94

Table 3

Mean ratings (standard deviations) for the listening environment at baseline and follow-up for students

Listening environment	SFS classrooms		Comparison classrooms	
	Baseline	Follow-up	Baseline	Follow-up
	Mean (SD)	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
1.Teacher is talking but you cannot see the teacher's face	2.21 (.95)	2.00 (.94)	2.36 (1.09)	2.13 (.95)
2.Teacher is writing on the board and talking to the class	1.91 (.92)	1.69 (.83)	1.97 (1.04)	1.91 (.99)
3.Teacher is talking and walking around the classroom	1.80 (.93)	1.69 (.89)	1.91 (.98)	1.84 (.96)
4. You are working in groups	2.41 (1.08)	2.26 (.99)	2.46 (1.21)	2.48 (1.10)
5.Children are making noise outside the classroom	2.87 (1.08)	2.51 (1.08)	2.97 (1.08)	2.87 (1.02)
6.You are doing a test	1.52 (.88)	1.33 (.80)	1.54 (.98)	1.24 (.62)
7.There is no noise outside the classroom but there is some noise in the classroom	2.56 (1.06)	2.45 (1.03)	2.54 (1.10)	2.49 (.99)
8.It is very quiet inside and outside the classroom	1.24 (.65)	1.30 (.82)	1.32 (.88)	1.23 (.64)

Note. Rating 1: hear very well to 5: very difficult to hear

Table 4

Mean scores (standard deviation) for the academic and cognitive assessments at baseline and follow-up for students

Assessment		SFS classrooms		Comparison classrooms	
		Baseline *M* (SD)	Follow-up *M* (SD)	Baseline *M* (SD)	Follow-up *M* (SD)
Cognitive Skills	Listening comprehension	14.01 (3.49)	15.50 (3.21)	14.81 (3.62)	15.00 (3.55)
	Non-verbal processing	48.42 (12.95)	61.42 (16.90)	48.24 (18.74)	51.88 (16.81)
Academic attainment	Reading	55.73 (10.94)	59.06 (11.15)	49.16 (15.84)	54.53 (13.30)
	Spelling	21.77 (4.08)	22.46 (3.66)	18.33 (6.83)	19.77 (6.70)
	Numeracy	18.07 (6.09)	19.36 (5.84)	14.67 (7.05)	17.14 (6.64)