The effects of classroom noise on the reading comprehension of adolescents

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ABSTRACT

An investigation has been carried out to examine the impact of different levels of classroom noise on adolescents' performance on reading and vocabulary-learning tasks. A total of 976 English high school pupils (564 aged 11 to 13 years and 412 aged 14 to 16 years) completed reading tasks on laptop computers while exposed to different levels of classroom noise played through headphones. The tasks consisted of reading science texts, which were followed by multiple-choice questions probing comprehension and word learning. Number of questions attempted, times taken to read the texts and to answer questions were recorded, as well as correct answers to different types of question. The study consisted of two similar experiments, the first comparing performance in classroom noise at levels of 50 dB L_{Aeq} and 70 dB L_{Aeq}; and the second at levels of 50 dB L_{Aeq} and 64 dB L_{Aeq}. The results showed that the performance of all pupils was significantly negatively affected in the 70 dB L_{Aeq} condition, for the number of questions attempted and the accuracy of answers to factual and word learning questions. It was harder to discern effects at 64 dB L_{Aeq}, this level of noise having a detrimental effect upon the older pupils only.

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I INTRODUCTION

The detrimental effects on pupils of noise and poor acoustic design in schools have been of concern for many years. In an attempt to mitigate these effects guidelines and regulations governing the acoustic design of schools have been introduced in many countries. The most comprehensive of these are those introduced in the USA (American National Standards Institute, 2010) and UK (Department for Education, 2015), both of which specify suitable background noise levels for classrooms of different sizes and types. The guidelines also include criteria for sound insulation and reverberation time, with the aim of reducing noise in the classroom to a minimum.

Despite the introduction of standards, surveys have shown that noise levels in classrooms can still be high, the main sources of noise being pupils themselves. An extensive noise survey of secondary schools in England also showed that the level of noise in occupied classrooms was related to the unoccupied background level (Shield *et al*, 2015). Many studies have shown that excessive noise causes annoyance to pupils and that high noise levels affect performance (Shield and Dockrell, 2010). However, it is not known at what level detrimental effects of noise on performance start to occur.

By the time, pupils enter high school, much of teaching and learning occurs through written text in the form of books, worksheets, online material or instructions. Understanding the factors that negatively impact on pupils' speed and accuracy of accessing written materials is an important prerequisite to enhance attainment. The current study examines the effects of internal classroom noise, primarily classroom chatter, at different levels on high school pupils' ability to comprehend and learn from written texts.

II. BACKGROUND

A. Impact of noise on teaching and learning

Despite the widespread introduction of acoustical guidelines for schools, acoustical surveys of high schools show that they are often very noisy places. A recent comprehensive study of English high school classrooms found that occupied noise levels varied between 45 dB and 77 dB L_{Aeq}, depending on the age and number of pupils and the classroom activity, with an average lesson noise level of 64 dB L_{Aeq} (Shield *et al*, 2015). Pupils are sensitive to the disruptive effects of classroom noise: high levels of disturbance and annoyance are reported by pupils in schools with high outdoor and indoor noise levels (Avsar and Gonullu, 2010; Skarlatos and Manatakis, 2003), other students talking being cited as particularly disturbing (Connolly *et al*, 2013; Astolfi and Pellerey, 2008).

In addition to causing annoyance, noise in the classroom can affect teaching and learning. Teaching time is often lost due to interruption, and excessive noise levels interfere with the transmission of the teacher’s voice (Crook and Langdon, 1974; Bronzaft and McCarthy, 1975; Astolfi and Pellerey, 2008). Younger learners, between the ages of six and 12, are more severely affected by adverse listening conditions and require more favorable speech-to-noise ratios than adults in order to accurately identify speech in noisy conditions, especially when room reverberation times are long (Neuman *et al*, 2010). The sound of other learners’ chatter and noise coming into the classroom from corridors and nearby classrooms are identified as a major determinant of classroom noise by pupils in elementary schools (Dockrell and Shield, 2004) and high schools (Enmarker and Boman, 2004; Astolfi and Pellerey, 2008; Connolly *et al*, 2013), and by university students (Kennedy *et al*, 2006). In addition to creating adverse listening conditions, noise can disrupt pupils’ ability to learn from written texts.

B. Impact of noise on reading comprehension

Laboratory studies have shown that processes involved in serial recall of word lists are disrupted by unattended speech and speech-like sounds, a phenomenon known as the irrelevant sound effect (ISE) (Jones *et al*, 1992; Macken *et al*, 1999; Salamé and Baddeley, 1987; Beaman, 2005). Two mechanisms have been posited to explain noise interference with short-term memory (Hughes, Vachon and Cowan, 2007): the deviation effect and interference by process. In the first instance poorer recall in noise is explained by unexpected changes in the irrelevant speech which divert attention away from the task, such as remembering a list of words, resulting in poorer performance. Alternatively, it is suggested that changes in the irrelevant speech are processed automatically, before being subjected to attentional processes, and in this way interfere with the rehearsal of the to-be-remembered items, which in turn negatively impacts on recall. Developmental investigations of the ISE have found that children are more susceptible to auditory distraction than adults (Elliott 2002; Meinhardt-Injac *et al*, 2015; Klatte *et al*, 2010) and that these effects are largest when the noise stream contains unexpected items compared to predictable sound sources, suggesting that children are more susceptible to the ISE because of their immature attentional abilities (Joseph *et al*, 2018).

While the existence of the ISE is well-established, demonstrations of irrelevant sound disrupting reading comprehension have been less consistent. In laboratory studies with adults, some studies have found reading comprehension is negatively affected by background noise, with irrelevant speech causing the greatest disruption (Banbury and Berry, 1998; Martin *et al*, 1988; Oswald *et al*, 2000; Sorqvist *et al*, 2010). Others have found no evidence of irrelevant speech negatively impacting on adults' reading comprehension compared to silence (Boyle and Coltheart, 1996). However, outside of the laboratory, chronic exposure to aircraft noise at school has been shown to be associated with impaired reading comprehension in elementary school children (Bronzaft and McCarthy, 1975; Clark *et al*, 2005; Stansfeld *et al*, 2005; Clark *et al*, 2013; Klatte *et al*, 2017), indicating that environmental noise has a serious, negative impact on the processes involved in reading. In order to further examine the effects of different types of noise and the types of task upon which they have most impact, several studies have investigated the effects of noise from different sources on reading in schools using exposure to simulated noise sources in classrooms. Shield and Dockrell, (2008) found that primary school children's reading and mathematics were impaired by classroom babble compared to quiet conditions, and studies with high school pupils have found negative effects of speech-like noise and road traffic noise on recall of text (Hygge *et al*, 2003; Sörqvist, 2010). However, other studies have failed to find an effect of noise exposure in the classroom on adolescents' performance on reading tasks (Hygge, 2003; Ljung *et al*, 2009).

Reading comprehension is a multi-component skill, which draws upon a range of cognitive resources (Hannon and Daneman, 2001; Oakhill *et al*, 2003). Accurate reading of individual words involves both word decoding and retrieval of their meaning from the mental lexicon. Building a coherent representation of the meaning of a text requires integration of information between sentences and the generation of inferences about states of affairs that are not explicitly detailed in the text (Cain et al, 2001; Graesser *et al*, 1994). Irrelevant sound may disrupt the short-term memory processes involved in reading (Hughes and Jones, 2001; Tremblay *et al*, 2000), and irrelevant speech has been shown to cause semantic interference resulting in poorer reading comprehension in adolescents (Sörqvist, 2010). However, little is known about the ways in which realistic classroom noise impacts aspects of reading comprehension in adolescents, such as inference or the ability to learn from text.

High school students are required to access progressively more complex reading materials and encounter words that are increasingly abstract and low in frequency of occurrence with non-literal meanings (Nagy *et al*, 1993; Nippold *et al*, 1988). By the time students are in high school vocabulary development is primarily supported by reading. Whilst there is evidence that noise interferes with oral vocabulary acquisition in toddlers (Capone and McGregor, 2005), on older students' listening comprehension (Bradlow *et al*, 2003; Klatte *et al*, 2010) and the ability to identify words correctly (Elliott, 1979; Elliott *et al*, 1979; Neuman *et al*, 2010), there have been no investigations of adolescents' word learning in noisy classrooms. Given the demands placed on working memory in developing new vocabulary it is predicted that poor classroom acoustics will reduce the acquisition of new vocabulary from written texts.

III. THE CURRENT STUDY

The aim of the current study was to examine the impact of typical levels of classroom noise on the reading performance of high school pupils aged between 11 and 16 years, and thereby to investigate at what level of noise a negative impact on reading might occur; in what ways the processes involved in reading are affected; and whether noise has a differential impact upon pupils of different ages. Previous studies have found that younger children are more susceptible to the negative effects of noise than older pupils (Elliott and Briganti, 2012; Klatte *et al*, 2010; Meinhardt-Injac *et al*, 2015).

The reading test was part of a test battery that also included tests of numeracy, speed of processing and short-term memory. The tests were programmed using E-Prime version 2.0.8.9 software. For the reading tests, bespoke science texts were created from science news articles and read silently by pupils on individual laptop computers, while classroom noise was presented over headphones at levels that reflected the typical range of noise levels measured in English high school classrooms. Comprehension and word learning were assessed by multiple-choice questions.

As well as accuracy in answering questions, it is possible that the time taken to read each text and the time taken to respond to each question (the ‘response latency’) may be affected by noise. Typically, readers are able to re-read sections of text they did not understand on first reading or to vary their speed when reading passages that are difficult to process (Cain, 2010). Hence, the ability to reread and alter reading speed may reduce the impact of noise on the processing of written text. Reading speed and response latency may therefore offer a valid way to measure the effects of noise in cases where accuracy measures may not be sufficiently sensitive to identify changes (Jackson and McClelland, 1975). These measures also permit discrimination between the ways in which background noise might affect reading. Unfavorable noise levels might produce a speed-accuracy trade off, such that reduced accuracy is reflected in shorter reading times and response latencies. Alternatively, noise might affect reading comprehension because screening out the noise places an additional load on cognitive processes, resulting in slower reading, longer response latencies and poorer accuracy (Sweller, 1988). Therefore, reading and response times were measured as described in Section IV.

The experimental methods and procedures, which are described in Section IV, were approved by the Psychology Ethics Committee of the Institute of Education, London. Approval for pupils to participate in the study was given by the head teachers of all participating schools, and by parents/guardians of individual pupils. In addition, all participating pupils were offered the opportunity to withdraw at any point during the testing.

IV. METHODOLOGY

A. Overall design

Two experiments were carried out with two different groups of pupils. In each experiment one group of participants completed tasks in two different noise conditions. Experiment 1 compared pupils' performance in noise levels of 50 dB L_{Aeq} and 70 dB L_{Aeq} and Experiment 2 compared pupils' performance in noise levels of 50 dB L_{Aeq} and 64 dB L_{Aeq}. The noise levels were chosen to represent typical levels measured during an extensive noise survey of occupied classrooms in English secondary schools (Shield *et al*, 2015), which found 64 dB L_{Aeq} to be the average level measured across all lessons, while 50 dB L_{Aeq} and 70 dB L_{Aeq} represent the lower and upper ranges of levels measured in lessons.

The materials and test procedure for each experiment, as described in sections IVC to IVE, were the same. In each experiment, participants completed two different test sessions separated by two academic school weeks, experiencing one noise condition in the first test and a different noise condition in the second test. The order of the noise conditions was counterbalanced across the group, with half of the participants in each year group receiving the 50 dB L_{Aeq} condition first and half receiving the louder (64 dB L_{Aeq} or 70 dB L_{Aeq}) condition first, to allow for learning effects in the second test. In addition, two sets of reading materials were counterbalanced across conditions to avoid familiarity with the texts.

B. Participants

A total of 976 pupils aged 11 to 16 years of age (Year 8 to Year 11) , from seven schools, participated in the study, 669 from seven schools in Experiment 1 and 307 different pupils from four of those schools in Experiment 2. The schools reflected the national intake of high school pupils in England. Pupil roll numbers were slightly larger than the national averages (mean = 1052; national mean = 910). Numbers of pupils with a statement of special educational needs (mean = 4.3; national mean = 4.1), and eligible for free school meals (an index of poverty) (mean = 27.4; national mean = 29.1) were all commensurate with national data. Numbers of pupils reporting English as an additional language (mean = 11.66) was below the national average (16.1) reflecting the school catchment areas.

In the UK children enter school at the age of five and continue with their peer group until school leaving age (16 at the time of the study). For the purposes of statistical analysis, and to examine the impact of noise on different age groups, the participants were divided into two age groups, 11 to 13 years (Year 8 to Year 9) and 14 to 16 years (Year 10 to Year 11), reflecting UK national school age groupings. A breakdown of the age groups in the two experiments is shown in Table I.

C. Noise stimuli

The noise stimulus was constructed from recordings of the activity noise during science and history lessons in cellular classrooms, with pupils aged 12 to 13 years. The recordings consisted of unidentifiable speech (babble) and sound events (e.g. chair scrapes, pencil drops, movement). Eight unique but acoustically identical segments of recording were combined to create a noise stimulus with a total duration of 4 minutes 40 seconds. Filters were applied to the signal to correct for the frequency response of the headphones and ensure that calibrated dB levels were reproduced faithfully.

To determine the frequency response of the Beyerdynamic DT100 headphones, they were placed onto a B&K 4100 Head And Torso Simulator (HATS). A three minute white noise signal was fed to the headphones from one of the task laptops to ensure that the entire reproduction system was measured. This white noise signal was recorded 16 times with the headphones placed on the HATS in different positions to simulate real life headphone placement variation between subjects. This process was repeated for 4 headsets to account for headphone hardware variations. These 64 recorded white noise signals were averaged and the differences between the average and the input white noise signal was calculated. From this a filter bank was created to compensate for the headphones' frequency response at each ear. A combination of free-field and diffuse-field corrections were further applied to the filter bank to account for the head and ear effects at different frequencies on measured sound pressure levels at the ear.

To calibrate the HATS for level, an 84 dBA white noise signal was measured at 3 m from a Genelec 8030A loudspeaker using a calibrated type 1 Svantek 959 sound level meter (SLM) in a regular classroom setting. The SLM was replaced with the HATS, whose microphone output was adjusted to also read 84 dBA. The filter bank was then applied to the test signals. These filtered test signals were played back through the headphones placed on the HATS. The L_{Aeq} over 5 minutes was measured for each test signal and the gains adjusted to meet the required level of 70 dBA. The gain was reduced by 20 dB to create the 50 dBA test signals.

D. Reading task

The reading task was an adaptation of a self-paced reading paradigm (O'Brien *et al*, 1985). Two sets of materials were developed, each consisting of four articles adapted from science news stories on children's science education websites. All articles were adapted to be 160 words in length and contain an average of 1.2 polysyllabic words per sentence. The average reading age of the articles was established as being between 11 and 12 years using three established techniques of calculating reading age. Five multiple-choice questions accompanied each article, assessing factual information contained explicitly in the text (two questions); ability to infer information not explicitly stated in the text (two questions); and learning of a single polysyllabic word contained in the title page of each text (one question). An example of a text and questions is shown in the Appendix.

E. Test procedure

Test sessions took place in the pupils' usual science room under the supervision of a teacher and two experimenters. An experimenter gave verbal introductions about the task and then instructed participants to enter their names and ages onto the laptops. Responses were anonymized once data from the two test sessions had been combined. Before starting the task, participants completed an animated tutorial installed on the laptop that demonstrated the procedure, and were given an opportunity to ask any questions about the test before the task began.

All students completed the articles in a fixed order, starting with the easiest (average reading age 11) and progressing to the most difficult (average reading age 12). Each article was divided into three sections of text, of approximately equal length. At the start of each article, participants read a title page featuring a polysyllabic word describing the subject matter of the article, along with an explanation of its meaning. For example, ‘Selenology: The Study of the Moon’. Each section of text was followed by one or two questions that had to be answered before proceeding to the next section (see the Appendix). Five multiple-choice response options were presented on the screen below each question. Questions 1 and 2 were factual questions, questions 3 and 4 were inferential and question 5 assessed understanding of the novel word. The position of correct responses was randomized. In summary, each article was presented in the following sequence: Title page (containing science word tested subsequently); Text section 1, Question 1 (factual); Text section 2, Question 2 (factual), Question 3 (inferential); Text section 3, Question 4 (inferential), Question 5 (word learning). Progress through the test was achieved by pressing the space bar to advance to the next item.

When the three text sections and questions from each article had been completed, participants progressed onto the next article. The reading task was time-limited to four minutes in total, timed from initiation of the first title page. If the time limit was reached when participants were halfway through a section of text, they were permitted to complete that section and its associated questions and these responses were included in the analysis. After reaching the time limit and completing the last question for that section, participants were presented with a screen containing the comment ‘That’s it, all done’.

Response latencies for all questions and the reading time for each section of text were recorded automatically by the E-prime software. Timing for each item was commenced when the spacebar was pressed to advance to that item and terminated when it was pressed to advance to the next item.

F. Data analysis

The number of correct responses for each question type was calculated for each pupil. Performance for all questions was assessed using the number of correct responses for each question type, averaged across all pupils. Mean article reading times were calculated by averaging participants’ time to read the ~50 word sections of text in milliseconds, each section of text being timed from the point at which participants cued the presentation of the text to the point at which they cued the presentation of the subsequent questions; this provided a measure of reading speed. The total number of sections to be averaged depended on the speed with which individual pupils progressed through the task, such that pupils who read the text more quickly completed more sections of the task. To control for unexplained erroneous responses, response latencies for correct answers only were analyzed (Fazio, 1990). To prevent data attrition, randomly missing data points were replaced with the mean of the nearest two data points (Graham, 2009). Mean latencies for each type of question and article reading times were logarithmically transformed to correct for violations of assumptions of normality in the analysis.

Multivariate analysis of variance (MANOVA) using Pillai’s trace was used to investigate the effect of classroom noise level on the number of questions attempted, the number of correct responses (response accuracy) and the log-transformed reading times and response latencies. Both age group and noise conditions were examined as between group variables to investigate possibly different impacts of the two noise levels on the two age groups. Analysis of variance (ANOVA) was used to further analyse effects of noise condition on the recorded response data. A second MANOVA was used to examine whether order of noise conditions might have affected the results.

V. RESULTS

A. Effects of noise level on performance

1. Experiment 1: performance in 50 dB and 70 dB

The results of Experiment 1 are shown in Table II. Students attempted an average of 11.85 questions (*SD* 2.45) in the 50 dB condition and 11.31 questions (*SD* 3.28) in the 70 dB condition, out of a possible maximum of 20 questions. As Table II shows, in general, there were more correct answers to all question types and longer reading times and latencies in the 50 dB condition than in 70 dB L_{Aeq}. Overall, older pupils provided more correct answers, with faster response times, as would be expected.

The effect of both noise level and age was examined. A MANOVA revealed statistically significant main effects of noise level (V = 0.08, F (8, 642) = 6.53, p < 0.001, Pη2 = 0.08), and of age group (V = 0.12, F (8, 642) = 11.37, p < 0.001, Pη2 = 0.12), indicating differences in performance in the two noise conditions, and between the two age groups. There was also a statistically significant interaction between noise level and age group (V = 0.04, F (8, 642) = 3.41, p < 0.001, Pη2 = 0.04), showing that noise had differing impacts on the two age groups. Follow up ANOVAs revealed statistically significant effects of noise level on the number of questions attempted (F (1, 649) = 4.08, p = 0.044, $P\eta^2$ = 0.01); correct responses to the factual questions (F (1, 649) = 6.53, p = 0.01, $P\eta^2$ = 0.01); and correct responses to the word learning question (F (1, 649) = 3.94, p = 0.048, $P\eta^2$ = 0.01), with, overall, more correct responses to both types of question in the 50 dB condition. There was also a statistically significant effect of noise level on latency for the word learning question (F (1, 649) = 7.98, p = 0.005, $P\eta^2$ = 0.01), with longer latencies in the lower noise condition of 50 dB L_{Aeq}. The difference in article reading times between the two conditions approached significance (F (1, 649) = 3.69, p = 0.055, $P\eta^2$ = 0.01), with longer reading times in the lower, 50 dB L_{Aeq}, condition. There were no statistically significant effects of noise level on correct responses to inferential questions, or response latencies for factual or inferential questions ($F < .84$, $p > 0.163$ in all cases). Thus, in sum pupils were significantly more accurate for responses to factual and word learning questions, spent more time reading and were slower to respond in the quieter condition.

Performance of the two different age groups was examined using follow up ANOVAs and yielded statistically significant effects of age for the number of questions attempted (F (1, 649) = 6.43, $p = 0.010$, Pη2 = 0.01), where the older group provided more correct answers to both factual (F (1, 649) = 26.20, $p < 0.001$, Pη2 = 0.04) and inferential (F (1, 649) = 24.45, $p < 0.001$, Pη2 = 0.04) questions, and word learning (F (1, 649) = 21.83, $p < 0.001$, Pη2 = 0.03). There was also a statistically significant effect of age on response latencies to factual questions (F (1, 649) = 24.56, $p = 0.030$, Pη2 = 0.01) and word learning (F (1, 649) = 48.45, $p < 0.001$, Pη2 = 0.01) with the latencies being longer in the younger age group. There were no effects of age on article reading times or latencies for inferential questions ($F < .81$ and p >. 0.25 in both cases). Overall, older pupils attempted more questions and answered more questions correctly than the younger ones, and their response latencies to factual and word learning questions were shorter than those of the younger age group.

Examining the differential impact of noise on the two age groups, there was a statistically significant interaction between noise level and age group for correct answers to factual questions (F (1, 649) = 14.63, $p < 0.001$, Pη2 = 0.01). As can be seen in Table II performance on factual questions by the older age group was better than that of the younger age group in both noise conditions; however, the older pupils were less accurate in the 70 dB L_{Aeq} than in the 50 dB L_{Aeq} condition, whereas younger pupils were more accurate at 70 dB L_{Aeq}. Separate analyses for each age group revealed a significant effect of noise condition for the older pupils on factual questions (*F* (1, 307) = 19.73, $p < 0.001$, Pη2 = 0.06), but a non significant effect of noise condition on factual questions in the younger pupils (*F* (1, 347) = .666, *ns*) ,There were no other significant noise/age group interactions ($F < 3.00$ and $p > 0.25$ in all other noise condition/age group ANOVAs.

In sum, there were statistically significant effects of classroom noise level on reading comprehension. Overall, performance was less accurate in the 70 dB condition compared to the 50 dB condition, and this difference was statistically significant for the number of correct responses to factual questions and word learning questions. Time taken to read and process the information was also affected by classroom noise level: there was a trend for response latencies to be longer in the 50 dB condition, especially for the younger pupils, and this effect was statistically significant for response latencies to word learning questions. There was also a differential impact of condition on each of the age groups: accurate responding in the older age group was more negatively impacted in the louder condition compared to the younger age group, whereas reading times and response latencies were longer in the quiet condition for the younger but not the older age group.

2. Experiment 2: performance in 50 dB and 64 dB

Table III presents the results of the students' performance in the 50 dB L_{Aeq} condition and the 64 L_{Aeq} dB conditions. MANOVA revealed statistically significant main effects of noise level (V = 0.08, F (8, 290) = 3.02, p = 0.003, Pη^2= 0.08), and of age group (V = 0.09, F (18, 290) = 2.42, p = 0.005, Pη^2 = 0.09). There was also a statistically significant interaction between noise level and age group (V = 0.08, F (12, 290) = 2.05, p = 0.021, Pη^2 = 0.08). Follow up ANOVAs revealed a statistically significant effect of noise condition on the number of questions attempted (*F* (1, 301) = 4.09, *p* = 0.044, Pη^2 = 0.01), with more questions attempted in the 50 dB condition. There were no significant effects of noise condition on any other measure (*F* < 3.00 and p > 0.15 in each case).

By contrast, overall, there was a significant effect of age on the following measures, where performance by the older age group was better than that of the younger age group; number of questions attempted F (1, 301) = 11.407, p < 0.001, Pη^2 = 0.04, factual questions F (1, 301) = 5.43, p = .02, Pη^2 = 0.02, inferential questions F (1, 301) = 12.64, p < 0.001 Pη^2 = 0.04, word learning F (1, 301) = 4.24 p = .04, Pη^2 = 0.01, reading time F (1, 301) = 10.787, p < 0.001 Pη^2 = 0.04, response latency to factual (F (1, 301) = 9.555, p = 0.002 Pη^2 = 0.03), inferential (F (1, 301) = 14.147, p < 0.001 Pη^2 = 0.05) and word learning (F (1, 301) = 10.290, p < 0.001 Pη^2 = 0.03) questions.

There was also a significant noise level/age group interaction for the number of questions attempted (*F* (1, 301) = 7.70, *p* = 0.006, Pη^2 = 0.03), correct responses to the factual questions (*F* (1, 301) = 5.76, *p* = 0.02, Pη^2 = 0.02), inferential questions (*F* (1, 301) = 4.43, *p* = 0.036, Pη^2 = 0.01) and word learning questions (*F* (1, 301) = 12.38, *p* = 0.001, Pη^2 = 0.04) ANOVAs for each age group indicated that for the younger group there were no significant differences for inferential questions or total attempts between the two noise conditions (*F* < 2.5 and p > 0.11 in each case), while they performed significantly better at 64 dB L$_{Aeq}$ in both the factual (*F* (1, 201) = 7.54, *p* = 0.007, Pη^2 = .04) and word learning tasks (*F* (1, 201) = 7.00, *p* = 0.009, Pη^2 = .03) For the older group there were no significant differences for factual or inferential questions (*F* < 2.0 and p > 0.15 in each case), whereas total number of attempts (*F*(1, 103) = 5.51, *p* = 0.02, Pη^2 = .06), and word learning (*F*(1, 103) = 6.10, *p* = 0.015, Pη^2 = .04), were significantly better in the 50 dB L$_{Aeq}$ condition.

There was also a statistically significant noise level/age group interaction for article reading times (*F* (1, 301) = 9.64, *p* = 0.002, $P\eta^2$ = 0.03). Pupils in the younger group read significantly faster in the 64 dB L_{Aeq} condition (*F* (1, 201) = 7.78, *p* = 0.006, $P\eta^2$ = .04) whereas older pupils read significantly slower at 64 dB L_{Aeq} (*F*(1, 103) = 4.60, *p* = 0.034, $P\eta^2$ = .04), Overall, the noise level/age interactions reveal that the older age group's performance was negatively impacted by the 64 dB $L_{Aeq,}$ noise condition, compared with 50 dB L_{Aeq} but the younger age group performed better at 64 dB L_{Aeq} .To summarise, over all pupils more questions were attempted in the 50 dB L_{Aeq} condition, however, the follow up ANOVAs revealed no statistically significant differences in overall performance between the 50 dB L_{Aeq} and 64 dB L_{Aeq} conditions. As expected, there were statistically significant differences between age groups on all measures. Where differences by age group between the noise conditions were found the 64 dB L_{Aeq} condition reduced performance for the older group and increased performance for the younger group. In general, response latencies decreased in the higher noise level, apart from responses to factual questions for the older age group.

B. Effects of order of testing on performance

As explained in section IVA, in each experiment half the participants received the quieter noise level first and half were tested first in the louder condition. To examine the stability of the effects of noise exposure, results of each experiment were investigated to see if the order in which the two noise conditions were presented affected performance. For each experiment individual changes in scores between the two test times were examined. For each participant the difference between the number of questions attempted, accuracy, response latency, text reading times and coefficient of variance at the two times of testing were calculated. These difference scores were entered as dependent variables into a MANOVA with condition order and age group as between participant variables.

For Experiment 1 there was no effect of order on accuracy. There was a significant order/age interaction on stability of performance (F (8, 642) = 5.65, p < 0.001, Pη2 = 0.07), indicating that, although pupils in both condition orders attempted more questions on the second time of testing, the older children who received the 50 dB L_{Aeq} condition first attempted significantly more questions in the 70 dB L_{Aeq} condition than those who received the louder condition first (F (1, 649) = 4.84, p = 0.028, Pη2 = 0.07), an average difference of 1.2 questions. Thus, overall, the impact of the noise conditions was independent of the order of testing with an indication that, for older pupils only, completing the task in the quieter condition first resulted in more attempts to answer in the louder condition.

In Experiment 2, the only effects of order were greater increases in reading time (F (1, 297) = 6.39, p = 0.012, $P\eta^2 = 0.02$) and latency for inferential questions (F (1, 297) = 65.82, p = 0.016, $P\eta^2 = 0.02$) for those tested first in the quieter condition. As in experiment 1, there was no effect of order on accuracy.

VI. DISCUSSION

This study has shown that high levels of classroom noise can have disruptive effects upon secondary school pupils' performance on short time limited reading tasks, particularly on reading comprehension and word learning. Negative effects were pronounced at levels of 70 dB L_{Aeq}, when compared with performance at the lower level of 50 dB L_{Aeq}. By contrast results at 64 dB L_{Aeq} in comparison 50 dB $L_{Aeq.}$ were conflicting: the accuracy and processing time of the older pupils were impaired but performance of the younger pupils was not. For some measures younger pupils performed better in the 64 dB L_{Aeq} condition.

Thus there were differences in the ways in which the older and younger age groups were affected by noise. Both experiments showed that the higher levels of noise had a negative impact upon the older (14 to 16 years) compared to the younger (11 to 13 years) pupils. The decrease in numbers of questions attempted and numbers of correct responses was significantly greater for the older age group than the younger when comparing performance in both 70 dB L_{Aeq} and 64 dB L_{Aeq} with 50 dB L_{Aeq}. However, the response latencies for the older group were generally the same in the lower and higher noise levels in both experiments whereas for the younger group they were longer in the lower noise level, possibly reflecting the more efficient reading processes of the older pupils.

When comparing performance in levels of 50 dB L_{Aeq} and 70 dB L_{Aeq} , overall pupils attempted fewer questions, and responses to questions and word learning were less accurate at 70 dB L_{Aeq}. Taking into account reading times and response latencies, the results suggest that better accuracy was underpinned by a speed/accuracy trade-off. Response latencies for word learning questions in the 70 dB L_{Aeq} condition were significantly shorter than in the 50 dB L_{Aeq} condition, and performance was less accurate, while there was also a non-significant tendency towards shorter article reading time in the 70 dB L_{Aeq} condition. Thus the 70 dB L_{Aeq} condition significantly affected processing efficiency, where pupils were less accurate but faster. The finding that lower classroom noise levels tended to produce longer reading times and response latencies suggests that participants were enabled to focus on the task in hand. Such strategies might include reading more slowly and carefully, re-reading difficult passages or unfamiliar words, and pausing to reflect and make appropriate inferences. This is consistent with the view of reading as a complex, multi-component process (Hannon and Daneman, 2001; Oakhill *et al*, 2003; Cain *et al*, 2001; Graesser *et al*, 1994), with different skills being differentially affected by unfavourable levels of noise. The results are also consistent with experimental studies demonstrating the ISE, where processing of the written text was disrupted by the unattended oral stimuli (Elliott, 2002; Joseph *et al*, 2018). Further work needs to establish the impact of extended exposure to high levels of classroom noise, but the current data clearly indicate that such levels impact on reading.

When comparing performance by the two age groups in 50 dB L_{Aeq} and 64 dB L_{Aeq}, that of the older age group was, in general, better in the 50 dB condition, but the size of this advantage was not as large in the 64 dB condition. Older pupils spent significantly more time reading in the 64 dB $L_{Aeq.}$ Overall, their performance in the 50 dB L_{Aeq} condition was better, with significant negative effects at 64 dB L_{Aeq} for the number of questions attempted and numbers of new words learnt. Performance by the younger age group in the 64 dB condition was not negatively affected, and, unexpectedly, in some of the tasks the higher noise level appeared to have a positive effect upon this age group, although results were often not statistically significant. While inconsistent with previous research on listening comprehension (Klatte *et* al, 2010), older pupils' susceptibility to high noise levels is consistent with results of a survey of adolescents' perceptions of school acoustical environments, in which older pupils expressed more sensitivity to noise in school and its negative consequences (Connolly *et al*, 2013) and the greater potential cognitive engagement in the tasks expected for older pupils.

It was found that condition order did not affect accuracy of performance on any measure. The lack of significant order effects speaks to the reliability of the conclusions as they hold across noise levels irrespective of order of testing. This has important implications for the acoustic design of high schools where pupils are likely to move between settings with different noise levels. The current data suggest that noise in the context of a school's acoustical environment will impact on task success and cognitive processing.

In both experiments, the effect sizes for condition were small but statistically significant. These small effect sizes are comparable to those reported in other classroom studies into the effects of noise on pupils' learning with younger pupils (Dockrell and Shield, 2006), and may reflect the heterogeneous nature of pupils in typical school classrooms. In addition, the design of the reading task minimized the amount of time that information had to be held in short-term memory, as questions were presented immediately after each short section of text; this may partially explain the small effect sizes observed. Nonetheless the effect of noise on a short time limited reading task speaks to the pervasiveness of adverse noise conditions on pupil performance.

The research differs from previous studies into the effects of auditory distraction on reading processes, which have focused on the disruptive effects of speech-like distractors on adults' reading comprehension (Martin *et al*, 1988; Oswald *et al*, 2000; Sorqvist *et al*, 2010); or on high school students' comprehension while exposed to variable noise sources (Hygge *et a*l, 2003) and white noise (Soderlund *et al*, 2010). By using real classroom noise stimuli that did not feature identifiable, individual speech signals pupils were provided with a situation which reflected their current classroom environments. In this context, the use of response latencies has shown promise as a tool to investigate the effects of unfavourable noise levels on heterogeneous groups of learners.

The data also contribute to our understanding of the way development moderates the effect of noise. Previous studies have consistently reported that younger pupils are more affected by noise than adults (Elliott and Briganti, 2012; Klatte *et al*, 2010; Meinhardt-Injac *et al,* 2015). However, in the majority of cases these studies have compared performance between elementary school pupils and college students or small groups of elementary school students (Meinhardt-Injac *et al*, 2015). The current study demonstrates that, in a large sample of high school students using realistic and demanding time limited tasks, accuracy and processing were more affected in the older pupils. One possible explanation for this is that older pupils were more engaged with the task and therefore more influenced by the noise distraction. Alternatively, older pupils may be more aware of the need to spend time processing new material and this approach to reading was negatively affected in the noisier conditions. These results suggest that claims of developmental differences require carefully matched samples examining different age bands throughout the years of compulsory schooling using realistic classroom tasks measuring a range of different outcomes.

VII. IMPLICATIONS FOR THE ACOUSTIC DESIGN OF SCHOOLS

The levels at which the noise was presented in the experiments represent the differences between good and poor acoustical conditions observed in high school classrooms. The findings reported provide an insight into the negative impact of poor classroom acoustics on reading comprehension for this age group. Clear detrimental effects were observed in classroom noise levels of 70 dB L_{Aeq}, particularly for the older children aged 14 to 16 years. The older children also demonstrated adverse effects of noise in the lower noise level of 64 dB L_{Aeq}. This is of concern as these levels are typical of the noise levels found during lessons in English high school classrooms (Shield *et al,* 2015) and in other surveys (for example Lundquist *et al*, 2000; Shield and Dockrell, 2004; Avsar and Gonullu, 2010).

It is therefore important to design schools so that classroom noise is kept to a minimum, ideally below 64 dB L_{Aeq}, given the negative impact of the 64 dB L_{Aeq} condition on the older pupils. The secondary school noise survey by Shield *et al* (2015), which measured noise levels during nearly 300 lessons in 80 classrooms, found that there was a significant correlation between lesson noise levels and unoccupied ambient levels. The unoccupied level corresponding to 64 dB L_{Aeq} was found to be 35 L_{Aeq}, which is the maximum level required for unoccupied classrooms under the current UK regulations (Department for Education, 2015). Thus schools must be designed to meet current requirements, to ensure that noise levels do not exceed those known to have a detrimental effect upon pupils' reading comprehension.

VIII. CONCLUSIONS

High school pupils are sensitive judges of the facilitation of teaching and learning that occurs when classroom acoustics are good (Astolfi and Pellerey, 2008; Connolly *et al*, 2013). However, until now there has been a lack of research into the disruption of learning processes caused by poor classroom acoustics in this age group. The present study has produced evidence that adolescent learners' reading comprehension is adversely affected by high levels of classroom noise. Disruption was evident at 70 dB, but the finding that negative effects are also evident at 64 dB for older pupils is a cause for concern, as this represents the average level of noise in secondary school classrooms (Shield *et al*, 2015). One finding in particular went against expectations: pupils in the older age group were more affected by high levels of classroom noise than pupils in the younger age group. Lower noise levels appeared to provide students with the opportunity for longer processing time, which resulted in greater accuracy. This study adds to the body of evidence underlining the importance of good classroom acoustics for learning by demonstrating that adolescents' reading comprehension is vulnerable to the challenges created by unfavorable levels of classroom noise.

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APPENDIX: EXAMPLE OF READING TEST

ENDOCRINOLOGY – THE STUDY OF HORMONES

Scientists have discovered that a weed killer called atrazine can make male frogs act like females. They studied male frogs raised in a tank containing a weak concentration of atrazine. One third of the frogs started sending out chemical signals to attract other males just like females do.

1. Why did the male frogs in the study send out chemical signals?
    a) To attract females
    b) To act like weed killer
    c) To attract males
    d) To act like male frogs

Scientists also found that some of the frogs actually turned into females. Four out of every hundred frogs had high levels of a female hormone called oestrogen. Some of these frogs were introduced to healthy males. They mated with the males and produced baby frogs.

2. What is oestrogen?
    a) A weed killer

b) A female hormone
c) A male hormone
d) A high level hormone

3. How does atrazine cause some frogs to change sex?
    a) By making them pregnant
    b) By raising their level of oestrogen
    c) By making them mate with males
    d) By raising their levels of male hormone

Farmers use atrazine because it’s an effective weed killer. But it can pollute streams near farms where it is used. In some streams the concentration of atrazine can reach two and a half parts per billion. The government says that up to three parts per billion of atrazine is safe. This is more than the amount that turned some of the males into females in the study.

4. What does this study show about the legal amount of atrazine?
    a) It is too high
    b) It is just right
    c) It is two parts per billion
    d) It is too low

5. What is the study of hormones called?
    a) Haemotology
    b) Oestropology
    c) Endocrinology
    d) Escapology

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TABLE I. Details of pupils in Experiments 1 and 2

Age years	**Experiment 1**		**Experiment 2**	
	N	**%**	**N**	**%**
11	83	12.4	37	12.1
12	145	21.7	133	43.3
13	133	20	33	10.7
14	141	21	70	22.8
15	104	15.5	34	11.1
16	63	9.4	0	0
All	669	100	307	100
	N	**Mean age (sd)**	**N**	**Mean age (sd)**
11 - 13	361	12.14 (0.76)	203	11.98 (0.59)
14 - 16	308	14.75 (0.78)	104	14.33 (0.47)
All	669	13.34 (1.5)	307	12.78 (1.24)

TABLE II: Results of Experiment 1: means and standard deviations of number of questions attempted; correct answers; and time-based measures, showing statistically significant differences between noise levels

	Question type (Maximum score)	Age group	Noise condition			
			50 dB		70 dB	
			Mean	sd	Mean	sd
Number of questions attempted	(20)	11 – 13	11.44	2.25	11.15	3.44
		14 – 16	12.20	2.57	11.55	3.02
		All*	11.85	2.45	11.31	3.28
Accuracy	Factual (8)	11 – 13	2.59	1.26	2.73	1.36
		14-16***	3.52	1.38	2.86	1.18
		All**	3.10	1.40	2.78	1.29
	Inferential (8)	11 – 13	1.84	1.27	1.81	1.34
		14 – 16	2.38	1.31	2.30	1.27
		All	2.13	1.32	2.01	1.33
	Word Learning (4)	11 – 13	0.93	0.78	0.80	0.75
		14 – 16	1.20	0.76	1.09	0.77
		All*	1.08	0.78	0.92	0.77
Article Reading Time (s)		11 – 13	21.9	9.0	20.3	8.9
		14 – 16	21.0	8.2	20.3	7.2
		All	21.4	8.6	20.3	8.2
Response Latencies (s)	Factual	11 – 13	8.1	5.1	7.8	4.2
		14 – 16	6.9	3.5	7.0	3.9
		All	7.5	4.3	7.4	4.1
	Inferential	11 – 13	9.5	5.4	8.9	4.6
		14 – 16	8.9	4.3	9.1	4.6
		All	9.2	4.8	9.0	4.6
	Word Learning	11 – 13	8.7	4.8	7.2	3.1
		14 – 16	6.2	3.5	5.9	3.2
		All***.	7.4	4.3	6.7	3.2

Statistical significance: * $p < 0.05$; ** $p < 0.01$; ***$p < 0.005$

TABLE III: Results of Experiment 2: means and standard deviations of number of questions attempted; correct answers; and time-based measures, showing statistically significant differences between noise levels

	Question type (Maximum score)	Age group	Noise condition			
			50 dB		64 dB	
			Mean	sd	Mean	sd
Number of questions attempted	(20)	11 – 13	11.25	1.94	11.48	2.87
		14 -16*	13.18	3.20	11.67	2.59
		All* .04	11.71	2.43	11.57	2.74
Accuracy	Factual (8)	11 –13$^+$	3.14	1.28	3.64	1.38
		14 – 16	3.95	1.37	3.63	1.49
		All	3.33	1.34	3.64	1.43
	Inferential (8)	11 – 13	2.08	1.06	2.35	1.26
		14 – 16	2.95	1.31	2.56	1.31
		All	2.29	1.17	2.45	1.29
	Word Learning (4)	11 –13$^+$	1.00	0.76	1.30	0.85
		14 - 16**	1.55	0.69	1.16	0.90
		All	1.13	0.78	1.24	0.87
Article Reading Time (s)		11 –13$^+$	22.5	7.0	19.9	6.2
		14 -16*	17.5	6.1	20.0	6.2
		All	21.3	7.1	19.9	6.2
Response Latencies (s)	Factual	11 – 13	7.2	3.9	7.0	3.0
		14 – 16	5.6	1.2	6.3	2.1
		All	6.8	3.5	6.7	2.6
	Inferential	11 – 13	10.4	9..0	9.1	4.0
		14 – 16	7.6	2.4	7.4	2.6
		All	9.7	8.0	8.3	3.5
	Word Learning	11 – 13	7.3	3.8	6.6	4.2
		14 – 16	5.8	2.4	5.5	1.9
		All	6.9	3.6	6.1	3.4

Statistical significance: *$p < 0.05$; **$p < 0.01$

$^+$ performance better at higher noise level, $p < 0.01$