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Out of the noise: Effects of sound environment on maths performance in middle-school students

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ABSTRACT

The main goal of the present research is to gain a better understanding of the consequences of background noise on learning, with a specific focus on how noise may impair maths achievement. A mental calculation task was administered in the classroom to 162 middle-school students (11–13 years old). The listening conditions were manipulated, choosing three different conditions - quiet, traffic and classroom noise - to reflect realistic noise exposure experienced in urban classrooms. A differential negative effect of listening condition on maths performance emerged in relation to task difficulty and children's age. The youngest children performed better in the quiet and traffic noise conditions than in the classroom noise condition, while in the older children these differences gradually disappeared. The detrimental effect of classroom noise was most evident when the maths task was moderately difficult. With increasing task complexity, the difference between listening conditions faded.These data support the idea that younger children are more susceptible to the detrimental effects of noise in school classrooms than older children, and that their academic attainments are affected. Our findings have implications for classroom learning because different types of environmental noise affected children's performance differently, depending on the complexity of the task in hand.

1. Introduction

Mathematics is universally acknowledged as one of the core subjects in education. It is also known to be less immediately appealing than other school subjects, and a frequent cause of stress in pupils and teachers alike (Dowker, 2019). A very large amount of literature in the spheres of psychology and education, albeit with different aims, has tried to account for the differences often encountered in pupils' maths achievement. There are many, multi-layered potential sources of diversity, including both cognitive and environmental factors (Ngan Ng & Rao, 2010). Among the latter, noisy classrooms are known to strongly affect students' academic attainments (Dockrell & Shield, 2006; Rudner et al., 2018; Shield & Dockrell, 2003), and the present study focuses on this particular aspect. Taking a multidisciplinary approach, we examine to what extent different noisy classroom conditions interfere with performance in arithmetic, and how their influence might change with students' age and maths task complexity.

1.1. Mathematical skills

Research has shown that children develop an impressive set of mathematical skills during their schooling, demonstrating that maths ability is far from unitary (Cowan et al., 2011; Dowker, 2019; LeFevre et al., 2010). The task of solving an arithmetical problem or algebraic equation consists of sequences of steps involving different domain-specific skills, such as counting, fact retrieval, understanding of arithmetical, conceptual and procedural principles (Kroesbergen, Van Luit, & Aunio, 2012; Passolunghi, Mammarella, & Altoè, 2008), and domain-general skills or cognitive components, such as working memory and attentional resources (Caviola, Mammarella, Lucangeli, & Cornoldi, 2014; Friso-Van

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Den Bos, Van der Ven, Kroesbergen, & Van Luit, 2013; LeFevre et al., 2013).

As in other educational domains, several aspects of maths learning also change with age (especially in children). A few basic skills seem to be linked to processes of maturation/development (Ansari, Holloway, Price, & van Eimeren, 2008), but more complex abilities depend on learning and education, and usually benefit from expertise gained with age (Caviola, Gerotto, & Mammarella, 2016). The acquisition and mastery of arithmetical skills begins with formal schooling (Jordan, Mulhern, & Wylie, 2009; Rittle-Johnson & Schneider, 2015, pp. 1118–1134). In particular, the acquisition of procedural knowledge (i.e., the sequential steps needed to solve calculation problems), and conceptual knowledge (i.e., a deeper understanding of all the underlying principles and concepts) contributes to the development of arithmetical skills, and this helps to explain age-related differences. All these elements of knowledge trigger potentially different development trajectories across pupils, and these dissimilarities can presumably be explained by differences in their cognitive capacities, learning stage and background (Dowker, 2019). For example, research on this learning phase has shown that a gradually increasing use of efficient calculation procedures leads to a more expert use of memory-based strategies (Jordan, Hanich, & Kaplan, 2003). As children grow older, these strategies come to replace less efficient options, such as counting (Caviola, Mammarella, Pastore, & LeFevre, 2018).

Arithmetical tasks can vary considerably in complexity (Holmes, Adams, & Hamilton, 2008; Caviola, Mammarella, Lucangeli, & Cornoldi, 2012). One of the easiest ways to increase a task's complexity is to increase the size of the problem. Individuals perform worse on double-digit than on single-digit problems, possibly because of differences in the procedural or conceptual knowledge required, but also because more complex tasks demand more cognitive capacity (LeFevre et al., 2010; Sowinski et al., 2015). There are several ways to make a problem more or less difficult (e.g., depending on whether it includes a carrying over procedure, on the type of algorithm chosen, etc.) resulting in different cognitive demands (Imbo & LeFevre, 2010). Thus, a problem's greater complexity can also act as a stressor, further modulating task performance. Problem-solving efficiency usually decreases when carrying or borrowing are involved due to the added burden on cognitive resources (Caviola, Mammarella, Cornoldi, & Lucangeli, 2012; Imbo, Vandierendonck, & De Rammelaere, 2007; Noël, Désert, Aubrun, & Seron, 2001).

As regards learning background, children's different experiences at home and at school can account for a part of their different levels of achievement (Ngan Ng & Rao, 2010; Weiss, Carolan, & Baker-Smith, 2010; Barger, Kim, Kuncel, & Pomerantz, 2019, for a recent review). When education systems are analyzed on the strength of a wealth of contextual data collected on an international scale, as for the TIMSS and PISA assessments, the findings suggest that contextual elements - or home/school environments – can have an impact on achievement (Hooper, Mullis & Martin, 2013; Kuger, Klieme, Jude, & Kaplan, 2016). As concerns maths achievement and school settings, students seem to do better in maths if they attend schools with a more positive educational climate (Hwang, Runnalls, Bhansali, Navaandamba, & Choi, 2017; OECD, 2016). The factors contributing to a positive school climate (see Wang & Degol, 2016, for a recent review) include every aspect of the school experience, from the quality of teaching and learning (e.g., teachers' training, experience, and salaries) to structural features (e.g. class size, teaching facilities, and consumables), and the quality of the school environment (e.g., heating, lighting, acoustics, cleanliness) (Bear et al., 2018; Gustafsson, Nilsen, & Hansen, 2018; Maxwell, Reynolds, Lee, Subasic, & Bromhead, 2017). The present study focuses on one of these latter factors –acoustics – in an effort to gain a better understanding of the influence of background noise in the classroom on maths learning at different ages.

1.2. Impact of classroom noise on children's performance in listening tasks

Noisy classrooms are generally acknowledged as having a negative impact on students' academic attainment, at any age (Dockrell & Shield, 2006; Rudner et al., 2018; Shield & Dockrell, 2003). There is growing evidence of poor classroom acoustics giving rise to a learning environment that is unfavorable for many students (Bronzaft & McCarthy, 1975; Bronzaft, 1981; Connolly et al., 2019; Shield et al., 2015; Shield & Dockrell, 2003; Klatte, Bergström, & Lachmann, 2013 for a review), especially those with learning difficulties (Bradlow, Kraus, & Hayes, 2003; Dockrell & Shield, 2006). In this research field, particular attention has been devoted to listening tasks (presented verbally), which are typical of teachers interacting with their class during lessons. It has been well documented that background noise impairs children's performance in the basic task of recognizing an isolated word or whole sentence (Klatte, Lachman & Meis, 2010; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012; Mealings, Demuth, Buchholz, & Dillon, 2015; McCreery, Spratford, Kirby, & Brennan, 2017). While speech processing is largely automatic in ideal listening conditions (e.g., with no background noise), in the presence of noise it becomes much more effortful. Children then have to rely more heavily on cognitive processing to parse and decode the degraded speech signal (Rönnberg et al., 2013). As well as in speech recognition, noise has proved detrimental to performance in several complex tasks resembling activities that children engage in during daily lessons, including discourse comprehension (Valente, Plevinsky, Franco, Heinrichs-Graham, & Lewis, 2012), passage comprehension (von Lochow, Lyberg-Åhlander, Sahlén, Kastberg, & Brännström, 2018), sentence comprehension (Prodi, Visentin, Borella, Mammarella & Di Domenico, 2019(Prodi, Visentin, Borella, Mammarella, & Di Domenico, 2019)), word recall (Hurtig et al., 2016), and execution of complex instructions (Klatte, Lachmann, & Meis, 2010). A noisy environment increases the demand on available resources because, in the case of verbally-presented tasks, speech processing has to compete with the actual performance of the task (Kahneman, 1973).

Classroom noise, in particular, has been shown to interfere with children's academic performance. Its negative effects have been seen on both verbal (i.e., reading, spelling) and non-verbal (i.e. arithmetic, speed of processing) tasks (Dockrell & Shield, 2006; Shield & Dockrell, 2008), and more generally on any task demanding high levels of cognitive processing, and involving attention and/or working memory (Shield & Dockrell, 2003). The impact of classroom noise (intended as a combination of non-intelligible speech and non-verbal, isolated sound events) also depends on the specific characteristics of the task in hand, however. It has been suggested in the literature that this derives from a duplex mechanism (Hughes, 2014). The first mechanism, "interference by process" (Hughes, Vachon, & Jones, 2007; Marsh, Hughes, & Jones, 2009; Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013), would involve noise having a direct impact on cognitive resources by competing with the target material to be processed. In other words, similar cognitive processes are involved in unwittingly analyzing the background noise while wittingly dealing with a task, thus generating conflict and a consequently impaired performance (Macken, 2014). To give an example, the semantic content of background speech has been shown to impair performance on tasks that rely on semantic processing (e.g., reading comprehension, writing; Sörqvist, Nöstl, &

Halin, 2012). The second mechanism, "attentional capture", means that noise interferes with an individual's attention and attentional control. The reason why performance in a given task is impaired by background noise lies in that the focus of attention is distracted by the noise, and completion of the main task (a maths problem in our case) is disrupted as a result (Sörqvist, 2010; Bell, Röer, Dentale, & Buchner, 2012). This latter mechanism has been shown to depend on the acoustic characteristics (e.g., spectrum, temporal envelope, saliency, and predictability) of the noise, the listener's age, and the degree of engagement in the task. It does not appear to be sensitive to the specific processes involved in the task, or to the task administration modality. As long as a task is attention-demanding, the presence of a background noise is enough to divert our attention from it. For instance, Meinhardt-Injac et al. (2015) showed that irrelevant speech impaired performance in a mathematical equation task administered to 8-year-old children.

Children are more susceptible to the resource-consuming, detrimental effects of noise than adults due to the greater demands on their still-developing cognitive and linguistic skills (Johnson, 2000; Wightman & Kistler, 2005; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Children are also more susceptible than adults to auditory distractions, as their attention is more prone to being diverted (Elliott et al., 2016). In the case of verbal tasks, younger children are usually expected to perform less well than older children (McCreery & Stelmachowicz; 2013), but the reverse might also be the case, depending on the type of task (Connolly et al., 2019), and whether the exposure to noise is chronic or acute (Shield & Dockrell, 2008). The age at which an adult-like performance in speech perception is reached is generally placed around 13 years old, though this depends on the listening conditions, i.e., the type of noise (Leibold, 2017).

1.3. Impact of classroom noise on children's performance in maths tasks

To the best of our knowledge, only a few studies have considered academic maths tasks when assessing the impact of environmental noise on students' performance (Cohen, Krantz, Evans, Stokols, & Kelly, 1981; Dockrell & Shield, 2006), and little attention has been paid to verbally-presented maths tasks (i.e., maths tasks in which the problems are presented in the auditory modality). The first studies of this kind were conducted almost fifty years ago (Kassinove, 1972; Johansson, 1983; Zentall & Shaw, 1980), and the results indicated that noise had no effect on children's performance in mentally solving written additions, subtractions, multiplications and divisions, whatever their type or level of difficulty. Then the topic was ignored for more than 20 years, until Dockrell and Shield (2006) investigated the impact of noise on reading, spelling and arithmetical tasks in a classroom experiment with 8-year-old children. Three noise conditions were tested (silence, babble noise, and babble plus environmental noise). Unlike the earlier studies, their results indicated that children performed better in silence than in babble or babble plus environmental noise (and, presented at the same overall sound level, the latter two noise conditions did not affect performance differently).

Later on, more complex arithmetical tasks were administered in similar investigations. Ljung, Sörqvist, and Hygge (2009) administered basic arithmetical, geometrical problems, and a mathematical reasoning test to pupils 12–13 years old. Like Dockrell and Shield (2006), they found that noise had a significant effect on basic mathematics performance (which was better in quiet than in traffic noise), but no such effect was found on performance in the more complex maths reasoning task. This latter finding was unexpected, contrasting with the Authors' hypothesis that a task involving more complex processing would elicit a greater noise-related reduction of performance. Similar basic arithmetical and numerical reasoning tasks were then used by Connolly et al. (2016) with older children (11–16 years old), with classroom noise (children's babble plus sound events) played back on three different sound levels: 50 (baseline), 64 and 70 dB(A). Both accuracy and response latencies were analyzed, and the effect of noise on task performance was found to depend on its sound level. To be specific, a sound level of 70 dB(A) significantly reduced the children's accuracy (but did not affect their response times) in both arithmetical and numerical reasoning tasks, whereas a more moderate sound level of 64 dB(A) did not impair their accuracy (but did significantly slowed down their response times in the basic arithmetical task).

As concerns learning maths, it is worth noting that studies published so far have limited their analysis to samples of children of much the same age, without investigating the influence of age on children's ability to cope with background noise. On the other hand, the effect of age on tasks that involve language comprehension is well documented (Klatte et al., 2010; Prodi et al., 2019(Prodi, Visentin, Borella, Mammarella, & Di Domenico, 2019); Connolly et al., 2019). The paucity of findings on the effect of age on maths task performance is hardly surprising for two reasons: because maths learning is sensitive to age-related changes due to cognitive development; and because that it is not easy to select a task capable of taking into account how children's levels of expertise interact with the task's cognitive load. Very often a task may be rather complex and demanding for younger children, but very easy for older (and more skilled) students ((Blayney et al., 2015)Blayney, Kalyuga, & Sweller, 2010; Caviola, Gerotto, & Mammarella, 2016; Lee & Kalyuga, 2014). We can see an example of this in the only study on how age-related differences influence the effect of background noise on performance in a mathematical task conducted by Meinhardt-Injac et al. (2015). They administered an arithmetical verification task (asking children to judge whether a simple addition or subtraction was correct or not) to 8- and 12-year-old children in three listening conditions: pink noise (baseline condition); speech in a foreign language; and classroom noise (only sound events, without any speech). The results provided no evidence of any influence of developmental stage on accuracy, although the older pupils' response times were significantly faster than the younger children's. On the other hand, while the older children were unaffected by any background sounds, a detrimental effect of speech in a foreign language was seen in the younger children's accuracy and response times. These results might mean that the effect of noise on task performance might be modulated by a child's age in terms of a different allocation of resources being associated with different levels of maths ability between children in 2nd and 6th grade. For the present study, we consequently chose a task consistent with, and appropriate for the maths abilities already acquired in previous school years, that could be presented to the children verbally. During their formal education, children gradually learn procedures for solving multi-digit problems. The maths curricula in many countries conventionally distinguish between three main arithmetical approaches: written standard algorithms (procedural knowledge, also called the routine approach), written informal algorithms (making notes or using equations), and mental arithmetic, or the strategic approach (that involves individuals applying strategies drawn from their own repertoire) (Heinze et al., 2009; Selter, 2001). The former two are taught mainly with paper-and-pencil standard algorithms (Selter, Prediger, Nührenbörger, & Hussmann, 2012), while the latter focus principally on verbally-taught strategies (Caviola et al., 2018).

1.4. The present study

The overall goal of this study was to investigate the effect of noise on mental calculation ability in a school setting. We were particularly interested in examining whether background noise affects mental calculation performance in children in grades six to eight in terms of: i) whether it has a different impact at different ages; ii) whether it depends on the type of noise; and iii) whether its effect is modulated by the maths task's difficulty. The mental calculation task was verbally administered to the children as would be done normally in the classroom. We manipulated both the task's complexity (i.e., presence/absence of borrowing and carrying procedures) and the listening conditions, mimicking the classroom sound environment (i.e., quiet, traffic noise, or classroom noise [speech-like fluctuating noise plus typical classroom sound events]). As the sound environment depends on both the sound sources and the acoustic properties of a space (Reinten, Braat-Eggen, Hornikx, Kort, & Kohlrausch; 2017), the task was presented in real-life reverberating classrooms.

Older children were expected to be more accurate and respond faster than younger children in the mental calculation task, in line with previous research (Thevenot & Barrouillet, 2010bib_Thevenot_and_Barrouillet_2010). Likewise, as regards task complexity, older children were expected to perform better than younger ones (Caviola et al., 2018). As for the impact of noise, we predicted a worse performance and slower response times in noisy than in quiet conditions, in line with previous research (i.e. Dockrell & Shield, 2006; Ljung et al., 2009). Younger children were also expected to be more susceptible to the negative effect of noise than older children (i.e. Meinhardt-Injac et al., 2015; Prodi et al., 2019(Prodi, Visentin, Borella, Mammarella, & Di Domenico, 2019)). In agreement with Klatte et al. (2013), and Prodi et al. (2019), we predicted that different types of background noise would affect children's performance differently, and that the effects of the listening conditions would change depending on the task's difficulty (Sahlén et al., 2017).

2. Material and methods

2.1. Participants

A total of 182 children from 11 to 13 years old (grades 6 to 8) took part in the study. The children were from two schools in [location masked for blind review]; three classes were chosen for each grade. The children and their parents came from working-class and middle-class families. Six children were excluded from our data analysis due to intellectual disabilities or already-diagnosed hearing impairments. Another 14 children were excluded in the light of their maths fluency assessment (12 children did not complete the assessment, and two scored lower than the threshold). Table 1 shows details of the final sample of 162 children.

The study was approved by the Ethics Committee on Psychology Research at the University of [location masked for blind review]. After the approval of the school administrations, written informed parental consent was obtained before testing.

Table 1
Characteristics of the students participating in the experiment.

Age group	School grade	Sample size	% females	Age [M; SD]	Age range
11 years	grade 6	50	50	11.0; 0.32	10–12
12 years	grade 7	55	47	12.0; 0.30	11–13
13 years	grade 8	57	44	12.9; 0.32	12–14

2.2. Maths performance

2.2.1. Maths fluency test

Children were administered the Maths Fluency Test (Caviola, Gerotto, Lucangeli, & Mammarella, 2016), a standardized assessment consisting of 24 multi-digit written additions, 24 written subtractions, and 24 written multiplications. Two minutes were allowed to complete each set of calculations. The total score was the sum of all correct answers. The test was administered collectively to the students in their classrooms, in a quiet condition, nearly one week after the experimental task.[1] It was used as a preliminary data-screening measure: participants obtaining a standardized score lower than −3 in this test were excluded from the data analysis (n = 2).

2.2.2. Mental calculation task

Materials derived from Caviola et al. (2012) were used for the mental calculation task, consisting of three sets of 28 two-digit additions and subtractions (14 of each). The difficulty of the problems was manipulated by means of the presence or absence of borrowing and carrying procedures, obtaining two levels of difficulty (low for additions or subtractions without carrying/borrowing, or high for additions or subtractions with carrying/borrowing). In each set, there were 14 problems for each level of difficulty. For each problem, there were multiple-choice answers with three options (the correct answer, the correct answer plus or minus two, and the correct answer plus or minus 10). Sets of problems were counterbalanced by type and difficulty, and their order of presentation within each set was randomized. For each question, participants listened to the playback of a voice posing the problem, then the three possible answers appeared on their tablets and they were asked to select the right answer by tapping on the screen. They were given a maximum of 20 s to choose their answer. Accuracy and response times (RTs) were recorded for each problem. RTs were defined as the time elapsing between the end of the audio playback and the moment an answer was selected. The proportions of correct answers and RTs were used as measures of mental calculation performance.

The problems were recorded in a silent room by a native Italian, female, adult speaker. Each problem was preceded by a carrier phrase (e.g., "*Ora risolvi 87-62*" [Now solve 87-62]). All signals were recorded with a B&K Type 4189 ½ inch microphone placed about 20 cm from the speaker's mouth and connected to a B&K Type 5935 signal conditioner. The recordings had a 44.1 kHz sampling rate and a 16-bit resolution, and were normalized to the same average root-mean-square value.

2.3. Listening conditions

2.3.1. Background noises

Three noise conditions typical of occupied classrooms were included in the study: quiet, traffic noise, and classroom noise. The quiet condition is typical of classroom life when the teacher is speaking and the students are sitting at their desks and not talking. To reproduce this condition, no additional background noise was played

[2] A one-way ANOVA was conducted to compare the effect of classroom on the maths fluency score for each age group. Normality checks (Shapiro-Wilk test) and Levene's test were carried out and the assumptions were met. For all age groups, there was a significant effect of the classroom on the maths fluency score (11 years: $F[2,47] = 6.09$, $p = 0.004$; 12 years: $F[2,52] = 3.30$, $p = 0.045$; 13 years: $F[2,54] = 4.88$, $p = 0.011$). Each child's score in the test was included in the data analysis as a covariate.

back but our mental calculation task was administered in the actual ambient noise of the classroom, including the noises coming from nearby classrooms where other students were engaging in similarly quiet activities. The traffic noise condition was created by obtaining recordings alongside a road in conditions of busy traffic, with cars and trucks passing by, then applying a spectral filtering procedure to the recordings to correct for the sound insulation properties of a typical building façade. The classroom noise condition was obtained by digitally mixing sound events typical of a working classroom (e.g., chairs scraping, pages being turned in a book) with a standard noise signal, which is the fluctuating ICRA noise (Dreschler, Verschuure, Ludvigsen, & Westermann, 2001) constructed from Italian phrases spoken by a native female speaker. This latter type of noise reflects the long-term average spectrum as well as the temporal envelope fluctuations of a speech signal, but it is not intelligible.

2.3.2. Classroom acoustic set-up

One classroom in each of the two schools was used for the experiments. The two classrooms had a similar volume (152 and 155 m^3) and size (7.3 × 7.0 x 3.1 and 8.3 × 6.0 × 3.1 m), and a similar reverberation time (after temporarily installing sound-absorbing polyester fiber blankets in one of them).

The speech signal was played back through a Gras 44AB mouth simulator positioned in front of the teacher's desk at a height of 1.50 m, while the background noises (traffic noise, classroom noise) were played back with a Look Line D303 omnidirectional source placed on the floor near a corner of the classroom. The audio playback, the presentation of the possible answers in the mental calculation task, and data collection were all managed by a laptop PC running a wireless test bench (Prodi, Visentin, & Feletti, 2013). For all conditions, the level of the speech signal was set to 63 dB(A), measured at 1 m in front of the speech source. This sound level corresponds to a speaker making a vocal effort midway between "normal" and "raised" (International Organization for Standardization, 2003). In the traffic noise and classroom noise conditions, these background noises were played back at a level of 60 dB(A), measured as the spatial average of four receivers. This coincides with the level of background noise in typical classrooms where pupils are working, with some talking and fidgeting (Shield et al., 2015).

2.3.3. Acoustic measurements

Acoustic measurements of the reverberation time (T_{20}; the time it takes the sound to decrease by 60 dB after a sound source has stopped in an enclosure) and A-weighted equivalent sound pressure levels ($L_{A,eq}$) were obtained in the classrooms when they were occupied by the children (International Organization for Standardization, 2008), using an omnidirectional B&K4189 ½ inch microphone (height: 1.20 m) placed in four different positions in the part of the room where the children were seated. The acoustic measurements showed: (i) a spatial uniformity of the acoustic parameters due to the classrooms' small size and the distance between the speech source and the listeners, which ensured equivalent listening conditions for the various seating positions (see Prodi, Visentin, Borella, Mammarella, & Di Domenico, 2019; Author, 2019 for more details); and (ii) that any differences between the objective acoustic parameters in the two classrooms were below the minimum perceivable threshold. For the purpose of our study, the two classrooms were thus considered equivalent in terms of acoustic perception. Table 2 shows the listening conditions in the classrooms during the experiments. For more details on the listening conditions, see Prodi, Visentin, Borella, Mammarella, & Di Domenico, 2019; Author, 2019.

Table 2
Listening conditions in the classrooms during the experiments, in terms of reverberation times ($T_{20,mid}$, averaged over the 0.5–2 kHz frequency bands) and sound pressure levels ($L_{A,eq}$). All measurements were obtained when the classrooms were occupied by the children.

Acoustic parameter	Listening condition		
	Quiet	Traffic noise	Classroom noise
$T_{20,mid}$ [s]	0.69	0.69	0.69
$L_{A,eq}$ - speech dB(A)	60.0	60.0	60.0
$L_{A,eq}$ - noise dB(A)	41.9	60.4	60.3

2.4. Study design and general procedures

2.4.1. Study design

A within-subject design was used, with all children performing the mental calculation task in the three listening conditions. The order of the listening conditions was balanced across the classes for each age group, following a Latin square design.

2.4.2. Procedure

The experiment took place in the first half of the school year, during morning school hours. Children participated in the experiment as a whole class and completed the mental calculation task in a session, lasting just under 1 h, and the maths fluency test in a second session lasting about 15 min.

At the beginning of the first session, the children were randomly assigned to a seat, given a tablet and given instructions about the task. They practiced with a set of three problems in quiet conditions. Then they performed three test comprising 28 problems each, one for each listening condition. To avoid fatigue, a 5-min break was allowed after they had completed each test.

During the tests, the background noises started approximately 1 s before the speech signal and ended simultaneously with it. In the quiet condition, an acoustic signal (a brief pure tone at 500 Hz) was played back 1 s before the spoken sentence. The next problem was automatically played back only after all participants had answered or run out of time. Participants were instructed to pay attention to the task, and to respond as accurately as possible.

2.5. Data analysis

All analyses were conducted with the *R* software (R Core Team, 2017), setting a statistical significance threshold of 0.05. The effect of listening condition, task difficulty, and age on performance in the mental calculation task was examined using generalized linear mixed-effect models (GLMM), and the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015). One model was set up for each dependent variable (i.e., accuracy and RT). In the GLMMs, a binomial distribution was adopted for the statistical analysis of the accuracy data (which could only take a value of 0 or 1), and a Gamma distribution with a logarithmic link function was used for the raw RT data (Lo & Andrews, 2015). Only response latencies for correct responses were included on the analysis.

The following fixed effects were included in each model: listening condition (quiet, traffic noise, classroom noise), task difficulty (low, high), age group (11, 12, 13 years). All possible two- and three-way interactions were assessed for each model. The individual standardized score in the maths fluency test was also included as a covariate. The following random effects were included in the models: participant (random intercept), listening condition (random slope) and difficulty (random slope).

Values for the GLMMs were obtained using likelihood ratios. The normality of the random effects and residuals in each model was assessed to identify potential violations of statistical assumptions (Everitt & Hothorn, 2010). Post-hoc pairwise comparisons and the calculation of the standardized effect sizes (corresponding to Cohen's *d*) were performed using the *emmeans* package (Lenth, 2019). To control for Type I errors in the case of multiple comparisons, the p-values were adjusted using the False Discovery Rate procedure (Benjamini & Hochberg, 1995).

3. Results

3.1. Accuracy

The analysis revealed a significant main effect of listening condition ($\chi^2(2) = 11.51$, $p = 0.003$), a main effect of age ($\chi^2(2) = 22.15$, $p < 0.001$), a main effect of difficulty level ($\chi^2(1) = 297.50$, $p < 0.001$), and a main effect of maths fluency score ($\chi^2(1) = 68.03$, $p < 0.001$). The interactions between listening condition and age ($\chi^2(4) = 16.96$, $p = 0.002$), and between listening condition and difficulty level ($\chi^2(2) = 16.02$, $p < 0.001$) were also significant. The main effect of the maths fluency score was significant as well ($\chi^2(1) = 68.03$, $p < 0.001$), indicating that children with higher scores were significantly more accurate in the mental calculation task than children with lower scores. The age x difficulty level interaction ($p = 0.21$) and the three-way interaction ($p = 0.46$) were non-significant.

The significant interaction between listening condition and age was considered first, collapsing the data across levels of difficulty (Fig. 1A). When the effect of listening condition was analyzed by age group, pairwise comparisons revealed that the effect depends on the children's age. Eleven-year-olds were significantly more accurate in quiet and traffic noise than in classroom noise (quiet > classroom noise: $p = 0.005$, $\Delta = 6.5\%$, $d = 0.32$; traffic noise > classroom noise: $p = 0.021$, $\Delta = 4.1\%$, $d = 0.28$; quiet *vs* traffic noise: $p = 0.70$). For 12-year-olds, on the other hand, a significant difference in accuracy was only found when comparing quiet and classroom noise (quiet > classroom noise: $p < 0.001$, $\Delta = 6.9\%$, $d = 0.42$; traffic noise *vs* classroom noise: $p = 0.09$; quiet *vs* traffic noise: $p = 0.15$). No difference between listening conditions emerged for 13-year-olds (all *ps* > 0.14). When the effect of age was analyzed for each listening condition, pairwise comparisons showed that: the youngest students were the least accurate in quiet conditions (11 < 12: $p = 0.01$, $\Delta = 6.3\%$, $d = 0.46$; 11 < 13: $p = 0.008$, $\Delta = 6.1\%$, $d = 0.47$; 12 *vs* 13: $p = 0.99$); in traffic noise, 11-year-olds only performed significantly worse than 13-year-olds (11 < 13: $p < 0.001$, $\Delta = 11.3\%$, $d = 0.37$; 11 *vs* 12: $p = 0.08$; 12 *vs* 13: $p = 0.07$); and there were significant differences between all three age groups in classroom noise (11 < 12: $p = 0.041$, $\Delta = 5.9\%$, $d = 0.37$; 12 < 13: $p = 0.003$, $\Delta = 7.9\%$, $d = 0.54$).

Then the interaction between listening condition and level of difficulty was considered, collapsing the data across ages (Fig. 1B). Pairwise comparisons indicated that the children performed significantly better on the less difficult problems than on the more difficult ones whatever the listening condition ($p < 0.001$ for all conditions; quiet: $\Delta = 23.5\%$, $d = 1.10$; traffic noise: $\Delta = 16.9\%$, $d = 1.16$; classroom noise: $\Delta = 10.7\%$, $d = 0.73$). When the effect of listening condition was analyzed by level of difficulty of the problems to solve, pairwise comparisons indicated a better performance in quiet and traffic noise than in classroom noise for the less difficult problems (quiet > classroom noise; traffic noise > classroom noise; $p < 0.001$, $\Delta = 5.8\%$ and $d = 0.39$ for both comparisons; quiet *vs* traffic noise: $p = 0.90$), while there was no difference between listening conditions for the more difficult problems (all *ps* > 0.83).

3.2. Response times

The analysis revealed a significant main effect of the level of difficulty of the problem ($\chi^2(1) = 924.10$, $p < 0.001$), and significant interactions between listening condition and level of difficulty ($\chi^2(4) = 11.27$, $p = 0.004$), between and age and level of difficulty ($\chi^2(2) = 25.73$, $p < 0.001$). The main effect of maths fluency score ($\chi^2(1) = 13.63$, $p < 0.001$) was also significant, indicating that children with higher maths fluency scores had significantly faster RT than children with lower scores. The main effects of listening condition ($p = 0.15$), age ($p = 0.36$), and the three-way interaction ($p = 0.38$) were nonsignificant.

The significant interaction between listening condition and level of difficulty was considered first, collapsing the data across ages (Fig. 2A). Pairwise comparisons indicated that children had significantly faster RTs for the easier problems than for the harder ones in all listening conditions ($p < 0.001$ for all conditions; quiet: $\Delta RT = 2.75$ s, $d = 0.80$; traffic noise: $\Delta RT = 2.63$ s, $d = 0.76$; classroom noise: $\Delta RT = 2.19$ s, $d = 0.61$). When the effect of listening condition was analyzed for each level of difficulty of the problems, pairwise comparisons indicated faster RTs in quiet and traffic noise than in classroom noise for the easier problems (quiet < classroom noise: $p = 0.022$, $\Delta RT = 0.76$ s, $d = 0.19$; traffic noise < classroom noise: $p = 0.034$, $\Delta RT = 1.00$ s, $d = 0.13$; quiet *vs* traffic noise: $p = 0.36$) and no difference between listening conditions for the harder problems (all *ps* > 0.84).

Then the interaction between age and level of difficulty was considered, collapsing the data across listening conditions (Fig. 2B). Pairwise comparisons indicated that there was no difference in RTs between the age groups whatever the difficulty of the problem to solve (all *ps* > 0.054). For each age group, the RTs were significantly slower for the more difficult problems than for the easier ones (all *ps* < 0.001), but this difference depended on the children's age (11 years: $\Delta RT = 2.14$ s, $d = 0.55$; 12 years: $\Delta RT = 2.75$ s, $d = 0.75$; 13 years: $\Delta RT = 2.95$ s, $d = 0.88$).

4. Discussion

This study assessed the impact of realistic listening conditions in classrooms on the ability to perform mental calculations, focusing on 11- to 13-year-old children. In particular, we investigated whether, and to what extent, different noisy conditions interfered with maths performance of students of different age, and at different points in their school careers. We wanted to consider task complexity as well, since a key issue in maths achievement concerns the intrinsic difficulty of the topic. No published studies to date (to our knowledge at least) have examined the influence of noise exposure on verbally-presented maths tasks in a large sample of school children.

A different effect of listening condition on maths performance was observed, depending on the difficulty of the problem to solve and the children's age. Performance (both accuracy and RTs) was negatively affected by classroom noise but only for easier maths problems, whereas this was no longer the case for more difficult problems, for which there was no difference in performance between quiet and noisy conditions. A detrimental effect of classroom noise on accuracy was seen for the youngest students, but the influence of listening condition gradually disappeared in the older children. Going against our initial hypotheses, older children did not solve problems faster, despite their greater expertise as a result of more schooling and more refined capacity for allocating their cognitive resources. All pupils' RTs were slower for the harder problems whatever their age, though the difference in RTs between the easier and harder problems was greatest for the 13-year-olds. It is worth noting that the negative effect of classroom noise compared with the quiet

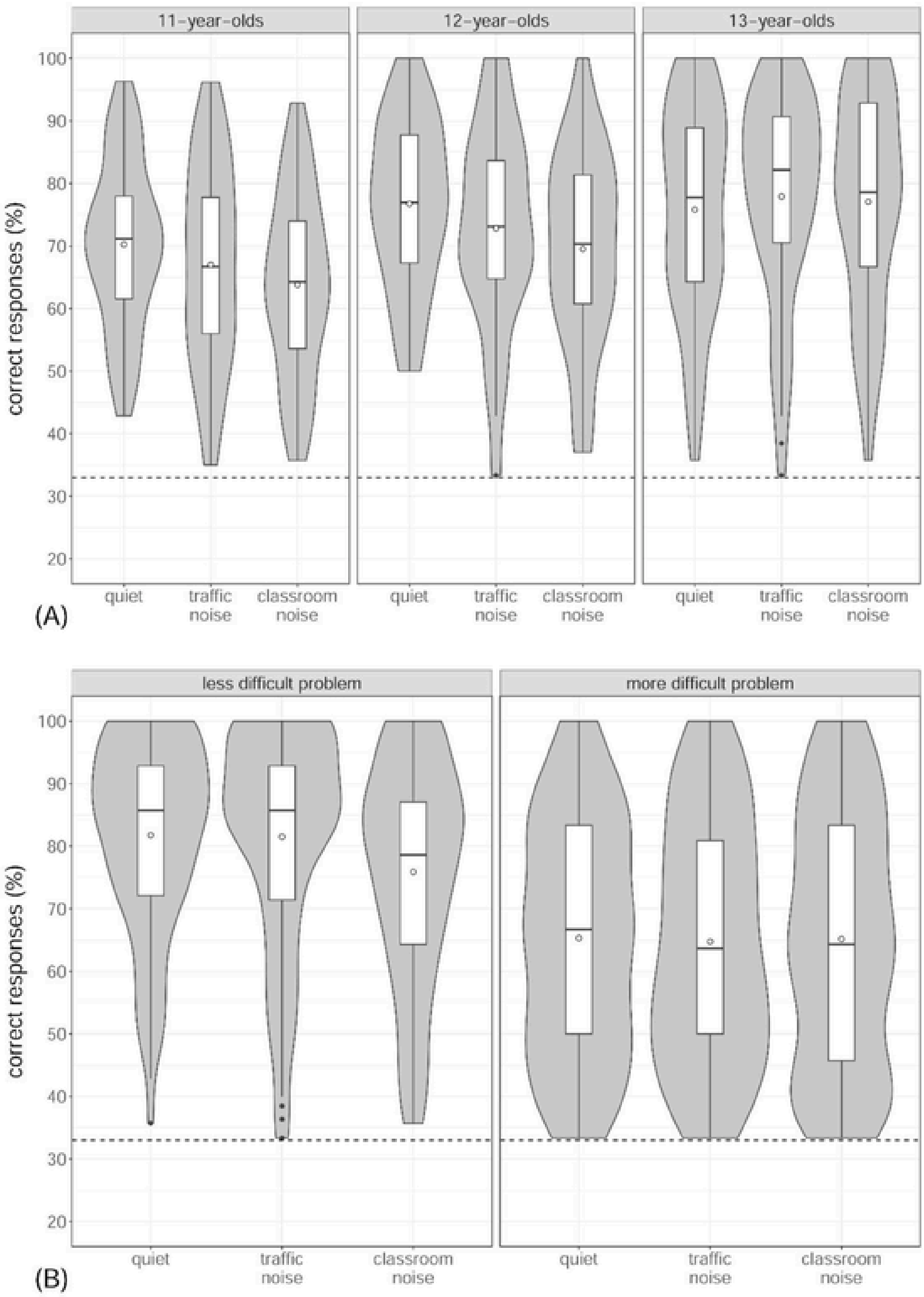

Fig. 1. Accuracy in the mental calculation task: (A) by age and listening condition, with data averaged over level of difficulty of the problem; (B) by listening condition and level of difficulty, with data averaged over age. Box plots show the median (middle line), mean (white circle) and interquartile range of the data distributions; outliers are shown as black circles outside the whiskers. The regions around each boxplot are symmetrical representations of the data distribution. The dashed horizontal line represents the chance threshold of 33% for the three-option, forced-choice paradigm.

condition caused a general worsening in performance, affecting both accuracy and RTs, with no sign of any trade-off between speed and accuracy.

It might be argued that these effects of background noise on maths task performance could be at least partly influenced by the verbal presentation of the problems, since background noise interferes with the peripheral auditory processing of a verbal signal, making it less intelligible. The SNR of 0 dB used in the experiment was carefully chosen to minimize this possibility, however, and ensure a near-ceiling intelligibility. Published studies on the identification of digits in noise have shown that, with such a SNR, 100% of correct responses are achieved by both adults (Houben, van Doorn-Bier-

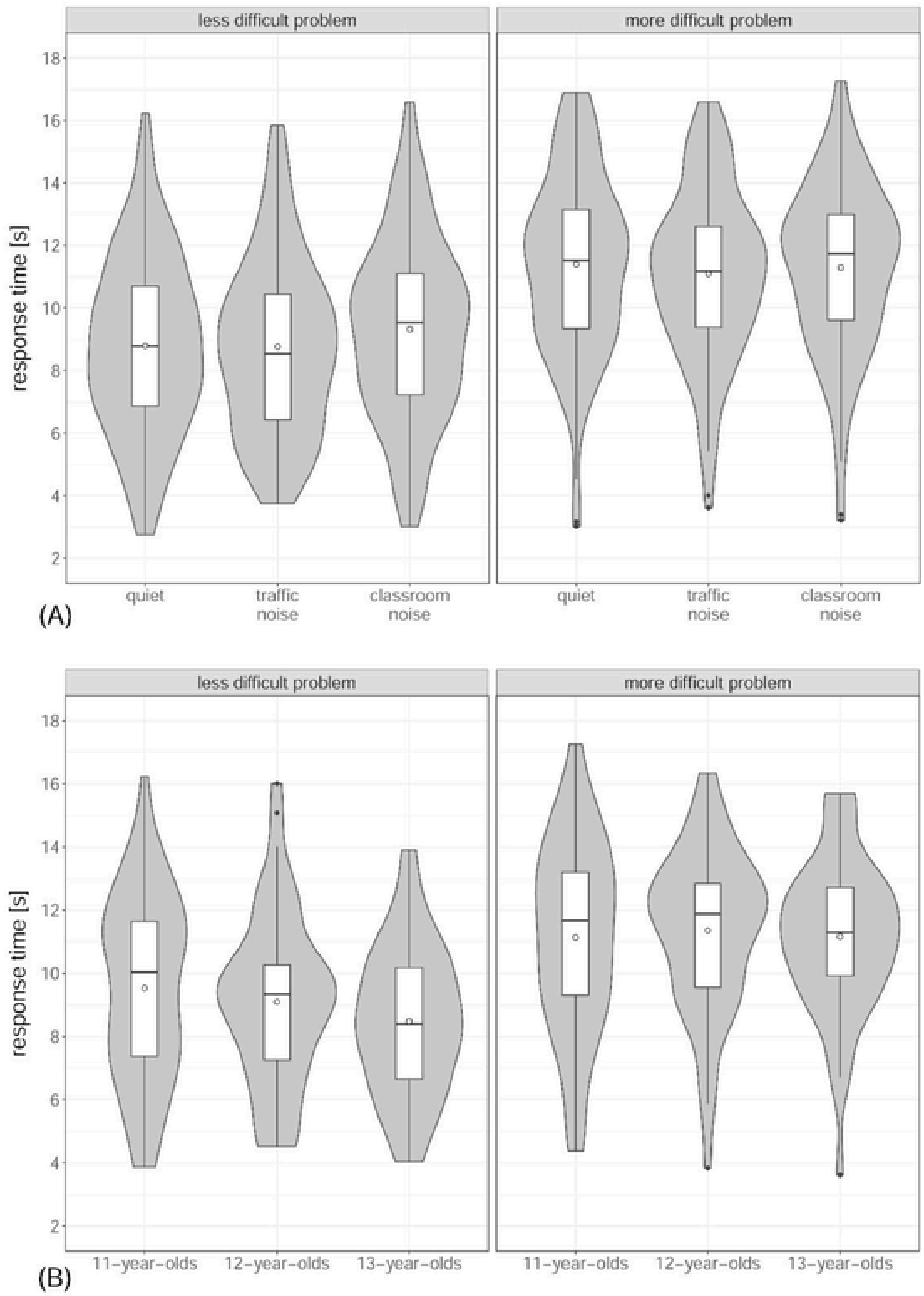

Fig. 2. Response times (in s) for correct answers: (A) by listening condition and level of difficulty of the problem, with data averaged across ages; and (B) by age and level of difficulty, with data averaged across listening conditions. Box plots represent the median (middle line), mean (white circle) and interquartile range of the data distribution; outliers are shown as black circles outside the whiskers. The regions around each boxplot are symmetrical representations of the data distribution.

man, & Dreschler, 2013) and children 10–12 years old (Koopmans, Goverts, & Smits, 2018) in stationary and fluctuating background noise.

The interfering effect of noise in the classroom on performance was predicted in the light of previous studies tackling noise, academic proficiency (e.g., Dockrell & Shield, 2006), and cognitive processes. Based on the assumption of the duplex mechanism (Hughes, 2014), a background noise may evoke the interference by process or the attentional capture mechanism of auditory distraction, or even a combination of the two, depending on its characteristics (i.e., temporal envelope, spectrum, presence/absence of semantic content), and on the type of focal task (Klatte et al., 2010). In the present study, it was only in classroom noise that children performed less well than in quiet. Unlike traffic noise (which has a stationary temporal envelope), classroom noise has temporal fluctuations that reflect the flow of amplitude modulations of speech, while also including salient events typical of a working classroom. Assuming an interference by process mechanism, the deterioration in mental calculation performance could be explained by the changing state of the classroom noise, yielding an irrelevant sound effect (ISE). Even though the ISE is typically seen in tasks using serial recall, evidence of its effects in adults has also been found for mental arithmetic problems involving the retention and retrieval of running totals in the correct order (Banbury & Berry, 1998; Perham, Hodgetts, & Banbury, 2013). The interference by process mechanism does not explain the significant effects of both age and task difficulty on children's performance, however. The attentional capture mechanism might be better to enlighten the pattern of our results.

The negative effect of noisy conditions was modulated by our participants' age (though only for accuracy, not for RTs), with younger children more affected by a noisy environment than older children. The (developmental) age differences were especially evident in the classroom noise condition, given its attentional capture potential. Previous studies showed that younger children have a greater tendency than older children or adults to disengage from a task in the presence of background noise, regardless of the nature of the task itself (Klatte et al., 2013). The review by Klatte et al. (2013) clearly showed that children are more vulnerable to environmental noise than adults, as their cognitive functions are still developing and consequently more prone to disruption. Based on previous findings, we could thus attribute the better performance of older students to a greater capacity to allocate their cognitive resources or direct attentional control (Elliott, 2002; Klatte et al., 2013). Unfortunately, these are only speculations as the present study did not include any cognitive measures. Although several studies have demonstrated that attention, working memory and executive functions relate to complex aspects of learning, such as reading comprehension (Borella & De Ribaupierre, 2014bib_Borella_and_De_Ribaupierre_2014; Butterfuss & Kendeou, 2018), or mathematics (see Peng, Namkung, Barnes, & Sun, 2016, for a meta-analysis), the extent to which these cognitive functions are variously engaged in complex tasks performed in noisy conditions still remains to be clarified.

As for task difficulty, we found that noise had a detrimental effect on performance in solving the easier problems (it was associated with a lower accuracy and longer RTs), but no such effect on performance in solving the more difficult ones. As Dockrell and Shield (2006) suggested, a possible explanation for this unexpected result lies in that a more complex maths task implicitly encourages children of any age to actively focus their attention on the task in hand. The difficulty of a task, time constraints, motivation and individual capacity all influence how much we concentrate, and higher levels of concentration have been shown to protect against the negative impact of noise on task performance (Sörqvist & Marsh, 2015). In our study, the more difficult maths problems, which were already associated with a worse performance, masked the detrimental effects of noise. In other words, when a task is difficult, the presence or absence of noise does not seem to affect accuracy or RTs, because the task absorbs all the available cognitive resources. Based on the attentional capture mechanism, a greater engagement in the task (obtained by making the problems more difficult) had the effect of shielding the children's performance against external auditory distractions (Hughes, 2014). This explains why there was no effect of classroom noise for more difficult problems, when performance was much the same as in the quiet condition. More specifically, a higher working memory capacity gives rise to a more steadfast locus of attention, coinciding with a substantial attenuation of background environment processing, when a task is more difficult (see Sörqvist & Rönnberg, 2014; Sörqvist, Stenfelt, & Rönnberg, 2012). Such a shielding effect would stem from a more limited processing of unwanted, task-irrelevant background sounds (Sörqvist et al., 2012; Marsh, Sörqvist, & Hughes, 2015; Marsh et al., 2018), and a more persistent attention (i.e., the attentional focus on the task is less easily diverted by the noise; Hughes et al., 2013). In the studies cited, the demands of a task were raised by increasing either the cognitive load (e.g. greater memory load) or the perceptual load (e.g. greater difficulty in perceiving the stimulus) of the task. Studies with adults indicate that higher task demands shield recall of written prose and text memory against background noise (Halin, Marsh, Hellman, Hellström, & Sörqvist, 2014; Halin, 2016). In other words, a harder task prevents adults from being distracted by background noise. The present findings extend this pattern of results to children and to mental calculation tasks.

4.1. Limitations, future directions and conclusions

Although the present research offers new insight, some limitations need to be acknowledged. As stated previously, children's learning experiences also depend on their cognitive development. When specifically considering maths learning, a large body of literature has confirmed the constant, moderate effect of working memory components (Caviola, Colling, Mammarella, & Szűcs, 2020; Friso-Van Den Bos, Van der Ven, Kroesbergen, & Van Luit, 2013bib_Friso_Van_Den_Bos_et_al_2013; Peng et al., 2016). Further research should replicate our findings with a study design including cognitive measures as we did not directly assess students' cognitive resources. It would be reasonable to wonder whether our findings simply reflect a general trend towards the differentiation of children's cognitive skills as they grow older - as suggested by Klatte et al. (2013) - or whether other competences come into play, such as metacognition or motivation. Future studies might therefore include a comparison with young adults.

Another limitation of the present study lies in that the types of background noise considered did not include informational masking. This type of masking occurs when a speech signal cannot be separated from a noise due to the similarity of their characteristics (von Lochow et al., 2018). It interferes with the signal "inside the perceiver, in the perceptual process" (Lidestam, Holgersson, & Moradi, 2014). To give an example, it happens when the noise is (partly) intelligible speech coming from two or more concurrent talkers, a common condition in the classroom setting. As shown in the report by Meinhardt-Injac et al. (2015), a noise with informational components may have a greater attentional capture potential for children solving a maths task than background noises including a more "energetic" masking, such as those considered in the present study. It may be that noise generating informational masking would have a negative impact on children's performance when they are solving more difficult problems too. This hypothesis warrants further, dedicated studies, possibly also exploring how the number of competing talkers influences children's performance in a verbally-presented mental calculation task.

Alongside such theoretical implications, our results points to some issues that might be further explored. For example, the interaction between the difficulty of a maths task and the individual's age. Maths is a multifaceted domain, and a whole host of cognitive resources contribute to performance. Young children's maths competence is measured in terms of proficiency in counting or basic arithmetical skills, whereas high-school students must be able to solve problems involving complex functions and integral equations, for instance. In manipulating task complexity, future studies should therefore make an effort to consider the developmental trajectory of both conceptual/procedural knowledge and cognitive resources.

Another aspect that may inspire future studies concerns the choice of how a task is presented. We opted for a verbally-presented mental calculation task in order to maintain a strong adherence to typical classroom activities (e.g., teachers usually assess this ability by saying problems aloud and waiting for children's verbal answers). Future studies could nonetheless explore the interaction between background noise, children's age and task difficulty in the event of a visually-presented mental calculation task.

In conclusion, our findings suggest a different theoretical framework in which to consider the relationship between background noise and maths skills. Our data seem to illustrate a chain of relations between background noise and educational achievement - in maths, at least – in schoolchildren in grades 6 to 8. Different types of noise seem to affect learning performance differently at different ages and depending on the difficulty of the task in hand. This finding warrants further investigation to see if the same applies to other areas of learning too. While more work on this topic is needed before we can claim to have a thorough understanding of the dynamics between noise and performance in solving maths problems, pooling the multidisciplinary competences of acoustical engineering and psychology could contribute to promoting the academic success of students with and without maths learning difficulties.

CRediT authorship contribution statement

Sara Caviola: Conceptualization, Resources, Methodology, Validation, Writing - original draft, Writing - review & editing. **Chiara Visentin:** Conceptualization, Investigation, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Erika Borella:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Irene Mammarella:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Nicola Prodi:** Conceptualization, Methodology, Investigation, Project administration, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101552.

Uncited references

Blayney, Kalyuga, & Sweller, 2015; Caviola, Colling, Mammarella, & Szűcs, 2020; Hughes & Jones, 2001; Sahlén et al., 2018.

References

Ansari, D., Holloway, I.D., Price, G.R., & van Eimeren, L. (2008). Toward a developmental cognitive neuroscience approach to the study of typical and atypical number development. Mathematical difficulties (pp. 13–43). Academic Press. doi:10.1016/B978-012373629-1.50004-6.

Author (2019). ([Title omitted for blind review]. Published manuscript).

Banbury, S., & Berry, D.C. (1998). Disruption of office-related tasks by speech and office noise. British Journal of Psychology, 89(3), 499–517. doi:10.1111/j.2044-8295.1998.tb02699.x.

Barger, M.M., Kim, E.M., Kuncel, N.R., & Pomerantz, E.M. (2019). The relation between parents' involvement in children's schooling and children's adjustment: A meta-analysis. Psychological Bulletin, 145(9), 855. doi:10.1037/bul0000201.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67(1), 1–48. doi:10.18637/jss.v067.i01.

Bear, G.G., Yang, C., Chen, D., He, X., Xie, J.S., & Huang, X. (2018). Differences in school climate and student engagement in China and the United States. School Psychology Quarterly, 33(2), 323. doi:10.1037/spq0000247.

Bell, R., Röer, J.P., Dentale, S., & Buchner, A. (2012). Habituation of the irrelevant sound effect: Evidence for an attentional theory of short-term memory disruption. Journal of Experimental Psychology: Learning, Memory, and Cognition, 38(6), 1542–1557. doi:10.1037/a0028459.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. Journal of the Royal Statistical Society: Series B (Methodological), 57(1), 289–300.

Blayney, P., Kalyuga, S., & Sweller, J. (2015). Using cognitive load theory to tailor instruction to levels of accounting students' expertise. Journal of Educational Technology & Society, 18(4), 199–210.

Borella, E., & De Ribaupierre, A. (2014). The role of working memory, inhibition, and processing speed in text comprehension in children. Learning and Individual Differences, 34, 86–92. doi:10.1016/j.lindif.2014.05.001.

Bradlow, A.R., Kraus, N., & Hayes, E. (2003). Speaking clearly for children with learning disabilities. Journal of Speech, Language, and Hearing Research, 46(1), 80–97. doi:10.1044/1092-4388(2003/007.

Bronzaft, A.L. (1981). The effect of a noise abatement program on reading ability. Journal of Environmental Psychology, 1(3), 215–222. doi:10.1177/001391657500700406.

Bronzaft, A.L., & McCarthy, D.P. (1975). The effect of elevated train noise on reading ability. Environment and Behavior, 7(4), 517–528. doi:10.1016/S0272-4944(81)80040-0.

Butterfuss, R., & Kendeou, P. (2018). The role of executive functions in reading comprehension. Educational Psychology Review, 30(3), 801–826. doi:10.1007/s10648-017-9422-6.

Caviola, S., Colling, L.J., Mammarella, I.C., & Szűcs, D. (2020). Predictors of mathematics in primary school: Magnitude comparison, verbal and spatial working memory measures. Developmental Science, e12957. doi:10.1111/desc.12957.

Caviola, S., Gerotto, G., Lucangeli, D., & Mammarella, I.C. (2016). Test AC-FL: Prove di fluenza per le abilità di calcolo [AC-FL Test: Math Fluency abilities test]. (Erickson).

Caviola, S., Gerotto, G., & Mammarella, I.C. (2016). Computer-based training for improving mental calculation in third- and fifth-graders. Acta Psychologica, 171, 118–127. doi:10.1016/j.actpsy.2016.10.005.

Caviola, S., Mammarella, I.C., Cornoldi, C., & Lucangeli, D. (2012). The involvement of working memory in children's exact and approximate mental addition. Journal of Experimental Child Psychology, 112(2), 141–160. doi:10.1016/j.jecp.2012.02.005.

Caviola, S., Mammarella, I.C., Lucangeli, D., & Cornoldi, C. (2014). Working memory and domain-specific precursors predicting success in learning written subtraction problems. Learning and Individual Differences, 36, 92–100. doi:10.1016/j.lindif.2014.10.010.

Caviola, S., Mammarella, I.C., Pastore, M., & LeFevre, J.A. (2018). Children's strategy choices on complex subtraction problems: Individual differences and developmental changes. Frontiers in Psychology, 9, 1209. doi:10.3389/fpsyg.2018.01209.

Cohen, S., Krantz, D.S., Evans, G.W., Stokols, D., & Kelly, S. (1981). Aircraft noise and children: Longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement. Journal of Personality and Social Psychology, 40(2), 331–345. doi:10.1037/0022-3514.40.2.331.

September Connolly, D., Dockrell, J.E., Mydlarz, C., Shield, B., Conetta, R., & Cox, T. (2016). A quasi-experimental field study of the impact of classroom noise on adolescents' mathematical performance. Paper presented at ICA2016 – 22nd international congress on acoustics. http://ica2016.org.ar/website/proceedings/.

Connolly, D., Dockrell, J., Shield, B., Conetta, R., Mydlarz, C., & Cox, T. (2019). The effects of classroom noise on the reading comprehension of adolescents. Journal of the Acoustical Society of America, 145(1), 372–381. doi:10.1121/1.5087126.

Cowan, R., Donlan, C., Shepherd, D.L., Cole-Fletcher, R., Saxton, M., & Hurry, J. (2011). Basic calculation proficiency and mathematics achievement in elementary school children. Journal of Educational Psychology, 103, 786–803. doi:10.1037/a0024556.

Dockrell, J.E., & Shield, B.M. (2006). Acoustical barriers in classrooms: The impact of noise on performance in the classroom. British Educational Research Journal, 32(3), 509–525. doi:10.1080/01411920600635494.

Dowker, A. (2019). Individual differences in arithmetic: Implications for psychology, neuroscience and education. New York, NY, US: Routledge; Psychology Press.

Dreschler, W.A., Verschuure, H., Ludvigsen, C., & Westermann, S. (2001). ICRA noises: Artificial noise signals with speech-like spectral and temporal properties for hearing instrument assessment. Ruidos ICRA: Señates de ruido artificial con espectro similar al habla y propiedades temporales para pruebas de instrumentos auditivos. Audiology, 40(3), 148–157.

Elliott, E.M. (2002). The irrelevant-speech effect and children: Theoretical implications of developmental change. Memory & Cognition, 30(3), 478–487. doi:10.3758/BF03194948.

Elliott, E.M., Hughes, R.W., Briganti, A., Joseph, T.N., Marsh, J.E., & Macken, B. (2016). Distraction in verbal short-term memory: Insights from developmental differences. Journal of Memory and Language, 88, 39–50. doi:10.1016/j.jml.2015.12.008.

Everitt, B.S., & Hothorn, T. (2010). A handbook of statistical analyses using R. Chapman and Hall/CRC.

Friso-Van Den Bos, I., Van der Ven, S.H., Kroesbergen, E.H., & Van Luit, J.E. (2013). Working memory and mathematics in primary school children: A meta-analysis. Educational Research Review, 10, 29–44. doi:10.1016/j.edurev.2013.05.003.
Gustafsson, J.E., Nilsen, T., & Hansen, K.Y. (2018). School characteristics moderating the relation between student socio-economic status and mathematics achievement in grade 8. Evidence from 50 countries in TIMSS 2011. Studies In Educational Evaluation, 57, 16–30. doi:10.1016/j.stueduc.2016.09.004.
Halin, N. (2016). Distracted while reading? Changing to a hard-to-read font shields against the effects of environmental noise and speech on text memory. Frontiers in Psychology, 7, 1196. doi:10.3389/fpsyg.2016.01196.
Halin, N., Marsh, J.E., Hellman, A., Hellström, I., & Sörqvist, P. (2014). A shield against distraction. Journal of Applied Research in Memory and Cognition, 3(1), 31–36. doi:10.1016/j.jarmac.2014.01.003.
Holmes, J., Adams, J.W., & Hamilton, C.J. (2008). The relationship between visuospatial sketchpad capacity and children's mathematical skills. European Journal of Cognitive Psychology, 20(2), 272–289. doi:10.1080/09541440701612702.
Hooper, M., Arora, A., Martin, M.O., & Mullis, I.V.S. (2013). Examining the behavior of "reverse directional" items in the TIMSS 2011 Context Questionnaire Scales. IEA international research conference.
Houben, R., van Doorn-Bierman, M., & Dreschler, W.A. (2013). Using response time to speech as a measure for listening effort. International Journal of Audiology, 52(11), 753–761. doi:10.3109/14992027.2013.832415.
Hughes, R.W. (2014). Auditory distraction: A duplex-mechanism account. PsyCh Journal, 3(1), 30–41. doi:10.1002/pchj.44.
Hughes, R.W., Hurlstone, M.J., Marsh, J.E., Vachon, F., & Jones, D.M. (2013). Cognitive control of auditory distraction: Impact of task difficulty, foreknowledge, and working memory capacity supports duplex-mechanism account. Journal of Experimental Psychology: Human Perception and Performance, 39(2), 539. doi:10.1037/a0029064.
Hughes, R., & Jones, D.M. (2001). The intrusiveness of sound: Laboratory findings and their implications for noise abatement. Noise and Health, 4, 51–70.
Hughes, R.W., Vachon, F., & Jones, D.M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(6), 1050. doi:10.1037/0278-7393.33.6.1050.
Hurtig, A., Keus van de Poll, M., Pekkola, E.P., Hygge, S., Ljung, R., & Sörqvist, P. (2016). Children's recall of words spoken in their first and second language: Effects of signal-to-noise ratio and reverberation time. Frontiers in Psychology, 6, 2029. doi:10.3389/fpsyg.2015.02029.
Hwang, J., Runnalls, C., Bhansali, S., Navaandamba, K., & Choi, K.M. (2017). "Can I do well in mathematics reasoning?" Comparing US and Finnish students' attitude and reasoning via TIMSS 2011. Educational Research and Evaluation, 23(7–8), 328–348. doi:10.1080/13803611.2018.1500293.
Imbo, I., & LeFevre, J.A. (2010). The role of phonological and visual working memory in complex arithmetic for Chinese- and Canadian-educated adults. Memory & Cognition, 38(2), 176–185. doi:10.3758/MC.38.2.176.
Imbo, I., Vandierendonck, A., & De Rammelaere, S. (2007). The role of working memory in the carry operation of mental arithmetic: Number and value of the carry. The Quarterly Journal of Experimental Psychology, 60(5), 708–731. doi:10.1080/17470210600762447.
International Organization for Standardization. (2003). Ergonomics – assessment of speech communication: ISO9921:2003. Geneva: International Organization of Standardization.
International Organization for Standardization. (2008). Acoustics – measurement of room acoustic parameters. Part 2: Reverberation time in ordinary rooms: ISO3382-2:2008. (Geneva, Switzerland).
Johansson, C.R. (1983). Effects of low-intensity, continuous and intermittent noise on mental performance and writing pressure of children with different intelligence and personality characteristics. Ergonomics, 26(3), 275–288. doi:10.1080/00140138308963341.
Johnson, C.E. (2000). Childrens' phoneme identification in reverberation and noise. Journal of Speech, Language, and Hearing Research, 43(1), 144–157. doi:10.1044/jslhr.4301.144.
Jordan, N.C., Hanich, L.B., & Kaplan, D. (2003). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. Child Development, 74(3), 834–850. doi:10.1111/1467-8624.00571.
Jordan, J.A., Mulhern, G., & Wylie, J. (2009). Individual differences in trajectories of arithmetical development in typically achieving 5- to 7-year-olds. Journal of Experimental Child Psychology, 103(4), 455–468. doi:10.1016/j.jecp.2009.01.011.
Kahneman, D. (1973). Attention and effort. Prentice-Hall.
Kassinove, H. (1972). Effects of meaningful auditory stimulation on children's scholastic performance. Journal of Educational Psychology, 63(6), 526–530. doi:10.1037/h0033747.
Klatte, M., Bergström, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. Frontiers in Psychology, 4, 578. doi:10.3389/fpsyg.2013.00578.
Klatte, M., Lachmann, T., & Meis, M. (2010). Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting. Noise and Health, 12(49), 270–282. doi:10.4103/1463-1741.70506.
Koopmans, W.J., Goverts, S.T., & Smits, C. (2018). Speech recognition abilities in normal-hearing children 4 to 12 years of age in stationary and interrupted noise. Ear and Hearing, 39(6), 1091–1103. doi:10.1097/AUD.0000000000000569.
Kroesbergen, E.H., Van Luit, J.E., & Aunio, P. (2012). Mathematical and cognitive predictors of the development of mathematics. British Journal of Educational Psychology, 82(Pt 1), 24. doi:10.1111/j.2044-8279.2012.02065.x.
Kuger, S., Klieme, E., Jude, N., & Kaplan, D. (2016). Assessing contexts of learning. Springer International Pu.
Lee, C.H., & Kalyuga, S. (2014). Expertise reversal effect and its instructional implications. Applying the Science of Learning in Education: Infusing Psychological Science into the Curriculum, 31–44.
LeFevre, J.A., Berrigan, L., Vendetti, C., Kamawar, D., Bisanz, J., & Skwarchuk, S.L., et al. (2013). The role of executive attention in the acquisition of mathematical skills for children in Grades 2 through 4. Journal of Experimental Child Psychology, 114(2), 243–261. doi:10.1016/j.jecp.2012.10.005.
LeFevre, J.A., Fast, L., Skwarchuk, S.L., Smith-Chant, B.L., Bisanz, J., & Kamawar, D., et al. (2010). Pathways to mathematics: Longitudinal predictors of performance. Child Development, 81(6), 1753–1767. doi:10.1111/j.1467-8624.2010.01508.x.
Leibold, L.J. (2017). Speech perception in complex acoustic environments: Developmental effects. Journal of Speech, Language, and Hearing Research, 60(10), 3001–3008. doi:10.1044/2017_JSLHR-H-17-0070.
Lenth, R. (2019). emmeans: Estimated marginal means, aka least-squares means. R package version 1.3.4. https://CRAN.R-project.org/package=emmeans.
Lidestam, B., Holgersson, J., & Moradi, S. (2014). Comparison of informational vs. energetic masking effects on speech reading performance. Frontiers in Psychology, 5, 639. doi:10.3389/fpsyg.2014.00639.
Ljung, R., Sörqvist, P., & Hygge, S. (2009). Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. Noise and Health, 11(45), 194–198. doi:10.4103/1463-1741.56212.
Lo, S., & Andrews, S. (2015). To transform or not to transform: Using generalized linear mixed models to analyse reaction time data. Frontiers in Psychology, 6, 1171. doi:10.3389/fpsyg.2015.01171.
von Lochow, H., Lyberg-Åhlander, V., Sahlén, B., Kastberg, T., & Brännström, K.J. (2018). The effect of voice quality and competing speakers in a passage comprehension task: Performance in relation to cognitive functioning in children with normal hearing. Logopedics Phoniatrics Vocology, 43(1), 11–19. doi:10.1080/14015439.2017.1298835.
Macken, B. (2014). Auditory distraction and perceptual organization: Streams of unconscious processing. PsyCh Journal, 3(1), 4–16. doi:10.1002/pchj.46.
Marsh, J.E., Hughes, R.W., & Jones, D.M. (2009). Interference by process, not content, determines semantic auditory distraction. Cognition, 110(1), 23–38. doi:10.1016/j.cognition.2008.08.003.
Marsh, J.E., Sörqvist, P., & Hughes, R.W. (2015). Dynamic cognitive control of irrelevant sound: Increased task engagement attenuates semantic auditory distraction. Journal of Experimental Psychology: Human Perception and Performance, 41(5), 1462. doi:10.1037/xhp0000060.
Marsh, J.E., Yang, J., Qualter, P., Richardson, C., Perham, N., & Vachon, F., et al. (2018). Postcategorical auditory distraction in short-term memory: Insights from increased task load and task type. Journal of Experimental Psychology: Learning, Memory, and Cognition, 44(6), 882.
Maxwell, S., Reynolds, K.J., Lee, E., Subasic, E., & Bromhead, D. (2017). The impact of school climate and school identification on academic achievement: Multilevel modeling with student and teacher data. Frontiers in Psychology, 8, 2069. doi:10.3389/fpsyg.2017.02069.
McCreery, R.W., Spratford, M., Kirby, B., & Brennan, M. (2017). Individual differences in language and working memory affect children's speech recognition in noise. International Journal of Audiology, 56(5), 306–315. doi:10.1080/14992027.2016.1266703.
McCreery, R.W., & Stelmachowicz, P.G. (2013). The effects of limited bandwidth and noise on verbal processing time and word recall in normal-hearing children. Ear and Hearing, 34(5), 585–591. doi:10.1097/AUD.0b013e31828576e2.
Mealings, K.T., Demuth, K., Buchholz, J., & Dillon, H. (2015). The development of the Mealings, Demuth, Dillon, and Buchholz classroom speech perception test. Journal of Speech, Language, and Hearing Research, 58(4), 1350–1362. doi:10.1044/2015_JSLHR-H-14-0332.
Meinhardt-Injac, B., Schlittmeier, S., Klatte, M., Otto, A., Persike, M., & Imhof, M. (2015). Auditory distraction by meaningless irrelevant speech: A developmental study. Applied Cognitive Psychology, 29(2), 217–225. doi:10.1002/acp.3098.
Neuman, A.C., Wroblewski, M., Hajicek, J., & Rubinstein, A. (2010). Combined effects of noise and reverberation on speech recognition performance of normal-hearing children and adults. Ear and Hearing, 31(3), 336–344. doi:10.1097/AUD.0b013e3181d3d514.
Ngan Ng, S.S., & Rao, N. (2010). Chinese number words, culture, and mathematics learning. Review of Educational Research, 80(2), 180–206. doi:10.3102/0034654310364764.
Noël, M.P., Désert, M., Aubrun, A., & Seron, X. (2001). Involvement of short-term memory in complex mental calculation. Memory & Cognition, 29(1), 34–42. doi:10.3758/BF03195738.
OECD. (2016). PISA 2015 assessment and analytical framework. Paris: OECD.
Passolunghi, M.C., Mammarella, I.C., & Altoè, G. (2008). Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. Developmental Neuropsychology, 33(3), 229–250. doi:10.1080/87565640801982320.
Peng, P., Namkung, J., Barnes, M., & Sun, C. (2016). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. Journal of Educational Psychology, 108(4), 455–473. doi:10.1037/edu0000079.
Perham, N., Hodgetts, H., & Banbury, S. (2013). Mental arithmetic and non-speech office noise: An exploration of interference-by-content. Noise and Health, 15(62), 73.
Prodi, N., Visentin, C., & Feletti, A. (2013). On the perception of speech in primary school classrooms: Ranking of noise interference and of age influence. Journal of the Acoustical Society of America, 133(1), 255–268. doi:10.1121/1.4770259.
Reinten, J., Braat-Eggen, P.E., Hornikx, M., Kort, H.S., & Kohlrausch, A. (2017). The indoor sound environment and human task performance: A literature review on

the role of room acoustics. Building and Environment, 123, 315–332. doi:10.1016/j.buildenv.2017.07.005.
Rittle-Johnson, B., & Schneider, M. (2015). Developing conceptual and procedural knowledge of mathematics. Oxford Handbook of Numerical Cognition. doi:10.1093/oxfordhb/9780199642342.013.014.
Rönnberg, J., Lunner, T., Zekveld, A., Sörqvist, P., Danielsson, H., Lyxell, B., … Rudner, M. (2013). The Ease of Language Understanding (ELU) model: Theoretical, empirical, and clinical advances. Frontiers in Systems Neuroscience, 7, 31. doi:10.3389/fnsys.2013.00031.
Rudner, M., Lyberg-Åhlander, V., Brännström, J., Nirme, J., Pichora-Fuller, M.K., & Sahlén, B. (2018). Listening comprehension and listening effort in the primary school classroom. Frontiers in Psychology, 9, 1193. doi:10.3389/fpsyg.2018.01193.
Sahlén, B., Haake, M., von Lochow, H., Holm, L., Kastberg, T., & Brännström, K.J., et al. (2018). Is children's listening effort in background noise influenced by the speaker's voice quality? Logopedics Phoniatrics Vocology, 43(2), 47–55. doi:10.1080/14015439.2017.1324914.
Shield, B., Conetta, R., Dockrell, J., Connolly, D., Cox, T., & Mydlarz, C. (2015). A survey of acoustic conditions and noise levels in secondary school classrooms in England. Journal of the Acoustical Society of America, 137(1), 177–188. doi:10.1121/1.4904528.
Shield, B.M., & Dockrell, J.E. (2003). The effects of noise on children at school: A review. Building Acoustics, 10(2), 97–116. doi:10.1260/135101003768965960.
Shield, B.M., & Dockrell, J.E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. Journal of the Acoustical Society of America, 123(1), 133–144. doi:10.1121/1.2812596.
Sörqvist, P. (2010). The role of working memory capacity in auditory distraction: A review. Noise and Health, 12(49), 217.
Sörqvist, P., & Marsh, J.E. (2015). How concentration shields against distraction. Current Directions in Psychological Science, 24(4), 267–272. doi:10.1177/0963721415577356.
Sörqvist, P., Nöstl, A., & Halin, N. (2012a). Disruption of writing processes by the semanticity of background speech. Scandinavian Journal of Psychology, 53(2), 97–102. doi:10.1111/j.1467-9450.2011.00936.x.
Sörqvist, P., & Rönnberg, J. (2014). Individual differences in distractibility: An update and a model. PsyCh Journal, 3(1), 42–57. doi:10.1002/pchj.47.
Sörqvist, P., Stenfelt, S., & Rönnberg, J. (2012b). Working memory capacity and visual-verbal cognitive load modulate auditory-sensory gating in the brainstem: Toward a unified view of attention. Journal of Cognitive Neuroscience, 24(11), 2147–2154. doi:10.1162/jocn_a_00275.
Sowinski, C., LeFevre, J.A., Skwarchuk, S.L., Kamawar, D., Bisanz, J., & Smith-Chant, B. (2015). Refining the quantitative pathway of the Pathways to Mathematics model. Journal of Experimental Child Psychology, 131, 73–93. doi:10.1016/j.jecp.2014.11.004.
Thevenot, C., & Barrouillet, P. (2010). Children's number processing is context dependent. European Journal of Cognitive Psychology, 22(3), 348–359. doi:10.1080/09541440903130743.
Valente, D.L., Plevinsky, H.M., Franco, J.M., Heinrichs-Graham, E.C., & Lewis, D.E. (2012). Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children. Journal of the Acoustical Society of America, 131(1), 232–246. doi:10.1121/1.3662059.
Wang, M.T., & Degol, J.L. (2016). School climate: A review of the construct, measurement, and impact on student outcomes. Educational Psychology Review, 28(2), 315–352. doi:10.1007/s10648-015-9319-1.
Weiss, C.C., Carolan, B.V., & Baker-Smith, E.C. (2010). Big school, small school: (Re)testing assumptions about high school size, school engagement and mathematics achievement. Journal of Youth and Adolescence, 39, 163–176. doi:10.1007/s10964-009-9408-3.
Wightman, F.L., & Kistler, D.J. (2005). Informational masking of speech in children: Effects of ipsilateral and contralateral distracters. Journal of the Acoustical Society of America, 118(5), 3164–3176. doi:10.1121/1.2082567.
Wróblewski, M., Lewis, D.E., Valente, D.L., & Stelmachowicz, P.G. (2012). Effects of reverberation on speech recognition in stationary and modulated noise by school-aged children and young adults. Ear and Hearing, 33(6), 731–744. doi:10.1097/AUD.0b013e31825aecad.
Zentall, S.S., & Shaw, J.H. (1980). Effects of classroom noise on performance and activity of second-grade hyperactive and control children. Journal of Educational Psychology, 72(6), 830–840. doi:10.1037/0022-0663.72.6.830.
Prodi, N., Visentin, C., Borella, E., Mammarella, I. C., & Di Domenico, A. (2019). Noise, Age, and Gender Effects on Speech Intelligibility and Sentence Comprehension for 11- to 13-Year-Old Children in Real Classrooms. Frontiers in Psychology. doi:10.3389/fpsyg.2019.02166.