Individual Differences in Dealing With Classroom Noise Disturbances

Jessica Massonnié¹,², Denis Mareschal², and Natasha Z. Kirkham²

ABSTRACT—Classrooms are noisy: when children are engaged in solo work, they also hear background babble, noise from outdoor, and people moving around. Few studies investigating the effects of noise on academic tasks use naturalistic stimuli. Questions also remain regarding why some children are more impaired by noise than others. This study compared primary school children's performance at three academic tasks (text recall, reading comprehension, mathematics) in silence, and while hearing irrelevant verbal noise (storytelling, n = 33) or mixed noise (outdoor noise, movement, babble, n = 31). We found that noise does not impair overall performance. Children might use compensatory strategies (e.g., re-reading) to reach the same level of performance in silence and noise. Individual differences in selective attention and working memory were not related to the impact of noise, with one exception: children with lower working memory were more impaired by noise when doing mathematics. Replication on a larger sample is needed.

Classrooms are full of life and full of sounds, generated by discussions, movements, objects, and events occurring outdoors (e.g., road traffic). As far as instruction is concerned, any sound that is not related to the current learning objectives and is unwanted, nonmeaningful, distracting, and/or unpleasant can be defined as a noise. This study investigated (1) to what extent noise impacts on children's performance on academic tasks and (2) potential individual differences in children's performance when working with background noise, compared to silence.

According to current theories, noise can impact task performance via three main mechanisms: (1) order processing, (2) phonological and/or semantic processing, and (3) attentional capture (Hughes, Vachon, & Jones, 2007; Klatte, Bergström, & Lachmann, 2013, a summary of previous studies is in Appendix).

According to the order processing account, background noise composed of a series of distinct, successive sounds, is perceived as ordered and interferes with tasks involving order processing, such as serial recall. This interpretation is supported by laboratory experiments in which adults (Jones & Macken, 1993; Jones, Macken, & Murray, 1993) and children (Elliott, 2002; Elliott et al., 2016; Elliott & Briganti, 2012; Klatte, Lachmann, Schlittmeier, & Hellbrück, 2010; Klatte, Meis, Sukowski, & Schick, 2007) remember series of items (e.g., letter, words) in the presence of various distracting sounds (e.g., series of digits, words, tones). It is hard to generalize results to naturalistic noise stimuli that are not explicitly segmented (e.g., full utterances or conversations with overlapping sources of noise) and to tasks beyond serial recall. This lack of generalization reduces the educational and practical relevance of the findings.

The phonological processing account suggests that noise interference occurs in working memory, a system allowing for the maintenance, storage, and manipulation of information. In working memory, the phonological loop stores and rehearses phonological representations that are presented visually (e.g., when reading words) and auditorily (e.g., when hearing speech; Baddeley, 2003). When visual and auditory representations are processed at the same time, they interfere with each other. This account explains the negative impact of background speech on serial recall, text recall (Boman, 2004), mathematics, reading, and spelling (Dockrell & Shield, 2006); all of which involve the processing of phonological information in working memory. As shown in adult experiments, having a better working memory reduces the impact of noise on serial recall (Söqvist, 2010), text recall (Söqvist, Ljungberg, & Ljung, 2010), and reading comprehension (Söqvist, Halin, & Hygge, 2010).
Noise is expected to be less detrimental to task performance when its phonological features are less salient. This is the case when multiple people talk at the same time or when conversations overlap with environmental noise. These types of noise do not impact on primary school students’ mathematics performance (Dockrell & Shield, 2006) or on middle school students’ reading (Slater, 1968) and mathematics (Ljung, Sörqvist, & Hygge, 2009) performance. Neely and LeCompte (1999) suggested that it was competing semantic, and not phonological, processing that explained the amount of interference between the noise and the task at hand. Importantly, both of the phonological and semantic explanations focus on the speech-like properties of the distracting sounds.

Some evidence runs counter to the phonological and semantic accounts of noise interference: (1) Kassinove (1972) found no impact of verbal noise on mathematics performance in primary and middle school students, (2) classroom noise without speech impairs children’s ability to recall a text (Klatte et al., 2010), and (3) background conversations overlapping with environmental noise can have a positive impact on reading, spelling (Dockrell & Shield, 2006), reading comprehension (Connolly et al., 2019), and mathematics (Zentall & Shaw, 1980).

This is where the attentional capture account comes into play. It posits that noise captures attention and, in doing so, distracts participants from their main task (Hughes et al., 2007). According to Klatte et al. (2013), “auditory events that are salient (e.g., of personal significance), unexpected (e.g., slamming of a door), or deviant from the recent auditory context (e.g., change in voice in a speech stream) have a strong potential to capture attention.” (p. 3).

The attentional capture account explains why verbal and classroom noise without speech both have a negative impact on memory: by redirecting participants’ attention away from the information to be remembered, it can lead them to “miss out” some items. This theory can also explain why, paradoxically, some types of noise, such as a mix of background conversations and environmental noise, have a positive impact on reading and mathematics. This could be due to: (1) attention being redirected away, and then back to the main task, involving a re-focus of attention (Dockrell & Shield, 2006), (2) attentional disruption favoring abstract processing and conceptual association, as suggested in the creativity literature (Mehta, Zhu, & Cheema, 2012). It is possible that, for these positive effects to occur, the noise should not contain salient phonological information that interferes with working memory.

Few experiments have directly measured working memory and attentional processes to test the phonological processing and attentional capture accounts. Studies investigating the role of working memory in noise interference have only involved adults (Sörqvist, 2010; Sörqvist, Halin, & Hygge, 2010; Sörqvist, Ljungberg, & Ljung, 2010). Developmental studies have indirectly tested the role of attention by showing that children (whose attentional skills are still developing) generally have a greater noise-related impediment than adults (Elliott, 2002; Elliott et al., 2016; Joseph, Hughes, Sörqvist, & Marsh, 2018; Klatte et al., 2010). Massonnié, Rogers, Mareshal, and Kirkham (2019) showed that primary school children with poor selective attention were particularly vulnerable to mixed noise when completing a divergent thinking task. This effect was driven by children who were in their early primary school years (from 5 up to 8 years of age). Older children, between 8 and 11 years of age, did not perform differently in silence and noise irrespective of their selective attention skills. More work needs to be done to understand why children may struggle with noise and if this is related to general attention mechanisms (Erickson & Newman, 2017). Furthermore, more studies are needed to specifically replicate the positive impact of hearing a mix of background conversations and environmental noise on academic tasks, and connect this impact to attentional mechanisms.

**Study Aims**

The present study investigated whether individual differences in working memory and selective attention relate to the impact of noise on academic tasks. It focuses on children in upper primary school (Key stage 2 in the United Kingdom), an age at which foundational literacy and numeracy skills are in place, the focus being on utilizing these skills in the context of elaboration, problem solving, and comprehension skills (Department for Education, 2013). The additional reflective components of this higher-level work may be particularly vulnerable to the distracting effects of noise. Three outcome measures were selected: reading comprehension, mathematics (two compulsory national subjects), and text recall (a testing method used in schools, and a more naturalistic measure of memory than serial recall). Two types of noise were selected to allow for comparison with the literature: (1) verbal noise (e.g., someone telling a story) and (2) a mix of overlapping conversations and background noise (henceforth called “mixed noise”).

Verbal noise was predicted to have a negative impact on all three tasks, due to phonological interference. Because phonological interference is hypothesized to take place in working memory, lower working memory was expected to relate to a higher impact of verbal noise. Mixed noise contains less salient phonological information and, due to the overlapping of noise sources, was predicted to redirect attention (Klatte et al., 2013). In line with previous studies, this redirection of attention was expected to be detrimental for the memory task (i.e., text recall). We expected children with lower selective attention to be more impaired. In addition, mixed noise was expected to either (1) have no impact on
reading comprehension and mathematics or (2) have a positive impact due to its potential to favor a refocus on the task at hand and to stimulate conceptual associations. Due to the inconsistencies in previous research, we did not favor one hypothesis over the other.

METHODS

Participants
Sixty-five children were recruited from five schools in London, United Kingdom. Data from one child, who had a hearing impairment, were subsequently removed from the analyses. Children were all in Key stage 2. They were between 8.82 years and 11.40 years of age (M = 10.23; SD = 0.67, 73.4% girls), which, in the United Kingdom, relates to the end of Year 4 (n = 10), Year 5 (n = 24), or the beginning of Year 6 (n = 30). Schools contributed a different number of participants (from 7 to 20) and represented different socio-economic backgrounds, when indexed by the percentage of children eligible for free school meals (from 0% to 40%, weighted average: 24.09%, see Supporting Information; London average: 16.6%, Department for Education, 2017).

The project received ethical approval from the Departmental and College Ethics Committees. All the participants gave verbal consent to participate. Written informed consent was obtained from their guardian. The study was conducted in accordance with the Declaration of Helsinki.

All children were tested on the school tasks in both silence and noise, but the type of noise varied between participants (verbal noise, n = 33; mixed noise, n = 31). This mixed design was chosen to minimize practice effects and to lower logistical burdens on the schools. The design and sample size of this study were based on: (1) Szalma and Hancock (2011)’s meta-analysis specifying a medium effect of noise on adults’ accuracy at cognitive tasks and (2) the sample size of up to 34 used in previous noise studies on children (Boman, 2004; Elliott & Briganti, 2012; Klatte et al., 2007, 2010; Zentall & Shaw, 1980). Our main interest was in the within-subject comparison between noise and quiet and the interaction between the effect of noise and the type of noise (verbal vs. mixed). Our study provides 98% power to detect a medium effect size (f = 0.25) for these comparisons. The power analyses were performed a posteriori with GPower 3.1 using the analysis of variance (ANOVA) repeated measures, within-between interaction function, and a correlation between repeated measures of 0.5.

Procedure
Testing occurred in a quiet room in the participant’s school, across two sessions occurring within a 2-week period. The first session started with the selective attention task performed in silence, followed by the first set of school tasks. The second session started with the working memory task performed in silence followed by the second set of school tasks. One set of school tasks was performed in silence, the other in noise. The order of presentation of the two sessions, whether noise was first or second, and the order of the three school tasks were counterbalanced across participants.

Materials
The verbal noise was created by recording a female, fluent English speaker, who narrated a story. The noise was played through head-mounted headphones (M = 60 dB(A); L_{Aeq(7min30)} = 65 dB; range: 50–81 dB(A)). The mixed noise consisted of a recording of classroom noise, which included babble, movement noise, and outside noise. The noise was played through head-mounted headphones (M = 60 dB(A); L_{Aeq(7min30)} = 65 dB; range: 50–80 dB(A)). The headphones were used in order to control for differences in background noise between classrooms. Three different sounds files were created for each type of noise, each lasting 7 minutes 30 seconds to match the duration of one school task. The order of the sound files was constant. Since the order of the school tasks was counterbalanced, each possible combination of sound file and school task was used.

During the silent testing session, pupils were exposed to low levels of noise naturally occurring from outside of the testing room, ranging from 35 to 45 dB. This was reduced by the use of noise canceling headphones (noise reduction rating of 34 dB; ANSI S3.19 and CE EN352-1 Approved).

Measures
Tasks were programmed on Gorilla.sc (https://gorilla.sc; Anwyl-Irvine et al., 2019) and presented on a laptop with a 13 inch screen. Each school task lasted 7 minutes 30 seconds (with no timer on the screen) and two versions were created: one to use in the silent session, and one to use in the noisy session. The material and scoring rules are available upon request.

Text Recall
Children read a 545-word narrative text during 4 minutes 30 seconds. The text was taken from an official school textbook for children in Key stage 2 (Collinson, 2015; Hearn & Barber, 2015). They were then asked 6 successive questions (for 30 seconds each) that assessed memory of literal information (i.e., information stated directly in the text). One point was awarded per correct answer. Two independent raters, blind to conditions, scored each answer (ICC_{TextA} = 0.94, ICC_{TextB} = 0.97).

Reading Comprehension
Two texts were taken from official school textbooks for children in Key stage 2 (Collinson, 2015; Hearn & Barber, 2015).
First, pupils read a 114-word narrative text and answered a comprehension question. Both the text and the question were displayed at the same time, to avoid overloading memory, during 3 minutes 45 seconds. A second, 141-word narrative text was then presented with its accompanying question for 3 minutes 45 seconds. Each question was scored 0, 1, 2, or 3, depending on whether the answer was correct, and how much justification from the text was provided (Collinson, 2015). Two independent raters, blind to conditions, scored each answer (ICC: 0.85–0.93, $M = 0.89$).

**Mathematics**  
Children answered 12 successive questions, which were based on the skills that are expected to be mastered by the end of the first term of Year 5 (Pearce, 2014). Performance was measured with 12 short open questions taken from Pearce (2014), and related to the core curriculum themes of: ordering numbers, addition, subtraction, multiplication, division, fractions, measurement, geometry, and statistics. One point was given per correct answer.

**Verbal Working Memory**  
In the backward digit span task (St Clair-Thompson, 2010, Figure 1), children were presented with visual lists of digits to repeat backwards. After two practice trials with immediate feedback, five lists of two digits were presented. Participants had to succeed on at least three trials to move on to the next level, at which three digits were presented. This procedure of increasing the span of digits was repeated until children could not progress onto the next level. The total number of correct trials was recorded. The task is openly available at: https://app.gorilla.sc/openmaterials/36699.

**Selective Attention**  
We used the Flanker task from Anwyl-Irvine et al. (2019), which is an adaptation from Rueda et al. (2004) keeping only the conflict network from the Attention Network task, not the alerting and orienting cues corresponding to different attentional networks. Participants saw a horizontal row of five cartoon fish and had to indicate the direction the middle fish was pointing (left or right). The middle fish was surrounded by flanking fish that were either pointing in the same direction (congruent trials, 50% of all trials) or by flanking fish pointing in the opposite direction (incongruent trials, 50%; Figure 2). After 12 practice trials with immediate feedback, four blocks of 24 trials each were presented. Response times for correct answers (RTs) were recorded. RTs under 200 ms and above 3 SDs from the mean of each participant were excluded. Response time costs ($RTs_{\text{incongruent}} - RTs_{\text{congruent}}$) were used as the main measure of selective attention. Higher values indicate poorer selective attention. Data from one outlier were removed from the analyses. The task is openly available at: https://app.gorilla.sc/openmaterials/36172.

The classification of the Flanker task as a measure of selective attention or of inhibitory control is debated. This can be resolved by considering the Flanker task as a measure of selective attention assessing inhibitory control at the level of attention. As such, selective attention is a subcomponent of inhibitory control, which also includes inhibition at the level of thoughts and memories (cognitive inhibition) and inhibition at the level of behavior (behavioral inhibition; Diamond, 2013).

**RESULTS**  
The dataset analyzed in the current study is openly available (Massonnié, Mareschal & Kirkham, 2021). Table 1 summarizes the descriptive statistics. Due to a technical error, data were missing for two children at the text recall task.

**Analyses Plan**  
A multivariate analysis of covariance was run for each of the three school tasks (text recall, reading comprehension,
Fig. 2. Time course of a trial in the Flanker task.

Table 1
Descriptive Statistics for Each Task and Noise Condition

|                     | Mixed noise | Verbal noise | Combined sample |
|---------------------|-------------|--------------|-----------------|
|                     | M           | SD           | M               | SD           | M           | SD           |
| Age                 | 9.82\(^a\)  | .55          | 10.61\(^a\)    | .54          | 10.23       | .67          |
| Working memory      | 11.90       | 4.83         | 9.76           | 5.87         | 10.80       | 5.46         |
| Selective attention (response time costs) | 43.02\(^a\) | 52.39        | .36\(^a\)      | 72.01        | 21.35       | 66.20        |
| Silence             |             |              |                |              |             |              |
| Text recall         | 2.77        | 1.55         | 2.79           | 1.71         | 2.78        | 1.62         |
| Reading comprehension| 2.29        | 1.99         | 2.30           | 1.88         | 2.30        | 1.92         |
| Maths               | 5.61        | 3.04         | 6.27           | 3.02         | 5.95        | 3.03         |
| Noise               |             |              |                |              |             |              |
| Text recall         | 2.67        | 1.56         | 2.64           | 1.58         | 2.65        | 1.56         |
| Reading comprehension| 2.32        | 1.70         | 2.36           | 1.87         | 2.34        | 1.77         |
| Maths               | 5.71        | 3.25         | 5.85           | 3.41         | 5.78        | 3.31         |

\(^a\) Significant difference between participants in the verbal noise and in the mixed noise conditions.
Dealing With Classroom Noise

maths) on SPSS 26. The scores obtained in silence and in noise were entered as two (repeated measures) dependent variables. The type of noise (verbal or mixed) was entered as between-subject factor, and age was a covariate. The assumption of homogeneity of variance between the group exposed to verbal noise and the group exposed to mixed noise was verified with the Levene’s test.

Bayes factors were extracted from the analysis of effect of Bayesian Repeated Measures ANOVAs, using the same variables as the classical models, and the default prior included in JAPS 0.9.2. They weight the evidence for the variables as the classical models, and the default prior evidence (Wagenmakers et al., 2018).

For the three school tasks, the impact of noise (noise vs. silence) did not interact with the type of noise $[F_{\text{Recall}}(1, 59) = 0.02, p = .879, BF_{01} = 24.39]$; $F_{\text{ReadingComprehension}}(1, 61) = 0.01, p = .921, BF_{01} = 11.24$; $F_{\text{Maths}}(1, 61) = 1.67, p = .202, BF_{01} = 9.35]$. There was no main effect of type of noise for text recall $F(1, 59) = 0.49, p = .485, BF_{01} = 4.88$ and maths $F(1, 61) = 0.85, p = .359, BF_{01} = 2.51$]. There was a main effect of type of noise for reading comprehension $[F(1, 61) = 4.90, p = .031]$. Children in the mixed noise condition performed better than those in the verbal noise condition. This was not supported by the descriptive statistics nor by Bayesian analyses ($BF_{01} = 1.18$) and was likely to stem from the fact that means were adjusted for age. In the following analyses, the impact of noise was therefore collapsed across the two types of noise. Age was kept as a covariate.

Comparison Between Silence and Noise for each School Task

Text Recall
There was no main effect of noise $[F(1, 60) = 0.04, p = .838, BF_{01} = 5.88]$, no main effect of age $[F(1, 60) = 0.86, p = .356, BF_{01} = 3.51]$, and no interaction between noise and age $[F(1, 60) = 0.03, p = .871, BF_{01} = 15.63]$. $p = .594, BF_{01} = 8.55]$. There was a main effect of age $[F(1, 62) = 4.73, p = .033]$. Older children performed better in silence ($r = 0.27, p = .028$) and tended to perform better in noise ($r = 0.24, p = .058$). This was not supported by Bayesian analyses ($BF_{01} = 0.68$).

Correlations Between the Impact of Noise, Selective Attention, and Working Memory
In order to investigate individual differences, the difference in performance between the silent and noisy sessions was correlated with working memory and selective attention (Table 2). Positive scores indicate a better performance in silence. The hypothesis was that higher selective attention and working memory would be related to a smaller noise impediment. One-tailed correlations were therefore used. Selective attention did not correlate with any of the difference scores. Children with lower working memory tend to perform better in silence when engaged in a mathematics task ($r = −0.23, p = .032$). As can be seen in Figure 3, this is particularly true for children with a working memory score between 0 and 5. Children with higher working memory scores were more likely to either show no difference in performance between the silent and noisy sessions, or to perform better in noise. These results held after controlling for age, but not after controlling for multiple comparisons. Controlling for multiple comparisons was done by dividing the acceptable $p$-value of .05 by three, given that working memory was correlated with the difference score in three different tasks: text recall, reading comprehension and mathematics. This gives a threshold for a significant $p$-value of .017.

DISCUSSION

No Detrimental Effect of Noise on Academic Performance at the Group Level
This study investigated the impact of verbal and mixed noise on text recall, reading comprehension and mathematics in primary school students. Contrary to our expectations, the impact of noise did not interact with the type of noise, and none of the noise stimuli was detrimental to performance at the group level.

Mathematics
The fact that noise did not impair mathematics performance was consistent with previous studies using verbal noise (Kassinove, 1972, but see Dockrell & Shield, 2006) and mixed noise (Dockrell & Shield, 2006; Ljung et al., 2009; Slater, 1968). Positive impacts of mixed noise on mathematics performance might happen at higher levels of noise (beyond 65 dB; Zentall & Shaw, 1980).
Table 2
One-Tailed Spearman Correlations Between All the Measures

|                  | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       | 10      | 11      | 12      |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1. Age           | −0.07   | −0.43   | 0.10    | 0.29    | 0.27    | 0.15    | 0.34    | 0.22    | −0.05   | −0.03   | 0.04    |
|                  | p = .282| p < .001| p = .209| p = .09 | p = .017| p = .127| p = .003| p = .038| p = .341| p = .416| p = .370|
| 2. Working memory| −0.17   | 0.31    | 0.34    | 0.34    | 0.41    | 0.32    | 0.43    | −11     | 0.04    | −0.23   |         |
|                  | p = .09 | p = .007| p = .003| p = .003| p < .001| p = .005| p < .001| p = .206| p = .388| p = .032|         |
| 3. Selective attention (response time costs) | −0.09 | −0.15 | −0.39 | −0.01 | −0.32 | −0.37 | −0.05 | 0.14 | 0.05 |         |         |
|                  | p = .248| p = .12 | p = .001| p = .467| p = .005| p = .002| p = .361| p = .141| p = .356|         |         |
| 4. Text recall   |         | 0.62    | 0.46    | 0.43    | 0.44    | 0.43    | 0.58    | 0.23    | −0.02   |         |         |
|                  |         | p < .001| p < .001| p < .001| p < .001| p < .001| p < .001| p = .32  | p = .434|         |         |
| 5. Reading comprehension |         |         | 0.37    | 0.42    | 0.49    | 0.43    | 0.18    | 0.55    | −0.11   |         |         |
|                  |         |         | p < .001| p < .001| p < .001| p < .001| p = .076| p < .001| p = .187|         |         |
| 6. Maths         |         |         |         | 0.36    | 0.44    | 0.84    | 0.10    | −0.02   | 0.102   |         |         |
|                  |         |         |         | p = .002| p < .001| p < .001| p = .214| p = .454| p = .211|         |         |
| 7. Noise         |         |         |         |         |         |         |         |         |         |         |         |
| 8. Text recall   |         |         |         |         |         |         |         |         |         |         |         |
| 9. Reading comprehension |         |         |         |         |         |         |         |         |         |         |         |
| 10. Maths        |         |         |         |         |         |         |         |         |         |         |         |

Note: p values in bold are significant at the .05 level.
Dealing With Classroom Noise

Mathematics performance (silence - noise)

![Graph showing the difference in mathematics performance between the silent and noisy sessions plotted against children’s working memory score.]

Fig. 3. Difference in mathematics performance between the silent and noisy sessions plotted against children’s working memory score.

Reading Comprehension

Early studies showed that mixed noise had no impact on middle school students reading speed and reading accuracy (Ljung et al., 2009; Slater, 1968). Connolly et al. (2019) revealed complex interactions between the specific outcome measure and participants’ age. Mixed noise had no impact on inferential comprehension among 11- to 13-year-olds and 14- to 16-year-olds. However, 11- to 13-year-olds read faster and answered literal comprehension questions more accurately when exposed to moderate mixed noise. These positive effects were not seen on the 14- to 16-year-olds. We used an inferential comprehension task because it required children to integrate multiple pieces of information from the text. The lack of impact of noise in our study is therefore congruent with the existing literature focusing on middle school children. Dockrell and Shield (2006) reported a positive impact of mixed noise and a detrimental effect of verbal noise on 8-year-olds’ reading performance, but it is unclear whether the task used assessed literal or inferential comprehension. Moreover, an adult study using eye-tracking showed that participants are able to overcome noise interference as long as they are able to re-read the text (Vasilev, Liversedge, Rowan, Kirkby, & Angele, 2019). Children might have used similar strategies in our study, which would have helped for both the reading comprehension and the text recall task.

Text Recall

Previous studies assessing the impact of noise on primary school children’s memory used serial recall tasks, which require to maintain and rehearse a list of items in short-term memory (Elliott, 2002; Elliott et al., 2016; Elliott & Briganti, 2012; Klatte et al., 2007, 2010). In contrast, our text recall task required children to remember interconnected events from a narrative. Children might have relied on reading comprehension strategies to build a coherent representation of the stories and remember specific events. Hygge (2003) found no impact of verbal noise on middle school students’ text recall. Boman (2004) did find a detrimental impact on a similar population, but several tasks were interspersed between the moments when students read the text and replied to the questions, which could have increased cognitive load and have rendered memory traces particularly vulnerable.

Interindividual Differences in the Impact of Noise Based on Selective Attention and Working Memory

Selective Attention

The differences in performance between the silent and noisy sessions for all three tasks were not significantly correlated with the measure of selective attention. A certain level of attention is required for children to perform the academic
tasks, whether in silence or in noise (Diamond, 2013). In our data, selective attention was related to better performance in mathematics when measured in the silent and noisy sessions. Better selective attention was also related to better reading comprehension when measured in the noisy session. The difference score (performance in silence – performance in noise) that was the main basis for our analyses specifically extracted the potential extra burden on attentional resources caused by the addition of noise on the main task. The baseline involvement of attentional resources required by the academic tasks per se would not be reflected in the difference score because the versions used in silence and noise are similar. This might be why the correlations between selective attention and difference scores were not significant.

**Working Memory**

Similar to what we observed for selective attention, working memory was significantly correlated to each academic task when measured in silence and in noise. However, when using difference scores in our analyses, working memory was only related to the impact of noise on mathematics, but this effect did not survive the correction for multiple comparisons. To solve a mathematical problem, children need to keep multiple elements in mind (e.g., two sets of digits) while manipulating them (e.g., adding the digits). According to Baddeley (2003)’s model of working memory, an articulatory process analogous to subvocal speech takes place in the phonological loop to avoid memory traces fading. The presence of background noise might interfere with this phonological rehearsal strategy, thereby increasing the load on working memory over and above what is present when the task is performed in silence.

**Limitations**

**Sample Size**

Our study has a sample size that was consistent with the previous literature. However, a metanalysis published after study design highlighted that the impact of noise on reading tasks was small (Vasilev et al., 2018). Our study has limited power to detect these small effects, and the one-tailed correlation between working memory and the impact of noise on mathematic performance does not hold after adjusting for multiple comparisons. A larger sample including children from a more restricted age range might reduce variability in baseline performance and give a more accurate estimate of noise effects.

**Age- and Grade-Related Variability**

Our sample includes children in Year 4, Year 5 and Year 6. There was therefore both age and grade variability in the data. The academic tasks might have had different difficulty levels for children from different grades. The mean and standard deviation for each year group is reported in Supporting Information. Despite this variability, it is important to remember that the current study does not compare performance across grades, but instead compared performance between the silent and noisy sessions within individuals, while controlling for age.

**Executive Function Tasks**

Another limitation pertains to our choice of executive function tasks. Our working memory task shared similar content with our mathematics task (i.e., digits), which might have driven associations between the two measures. Future replications using a variety of working memory tasks is needed to generalize our findings. The use of experimental tasks such as the Flanker task to study interindividual differences has recently been questioned (Hedge, Powell, & Sumner, 2018). More naturalistic tasks measuring accuracy, instead of response times, and focusing on the auditory modality (Guerra et al., 2021) might be more promising. Finally, the executive function battery might be complemented with a switching task. Indeed, primary school children who have difficulties to switch from one task to another also report being more distracted by noise (Massonnié, Frasseto, Mareschal, & Kirkham, 2022).

**CONCLUSION**

To sum up, this study found no group-level significant impact of verbal noise and mixed noise on academic tasks. It is interesting to consider whether testing in a more naturalistic setting and using naturalistic school tasks enables children to draw on strategies to compensate for the distracting effect of noise. Re-reading strategies, for example, could have helped during the reading comprehension and text recall tasks. Such strategies could be more difficult to implement in laboratory experiments, when items are presented quickly and sequentially. Furthermore, children with low working memory were more impaired by noise when doing mathematics. More research is needed to replicate and extend these findings.

**Acknowledgments**—This work was funded by the UK Economic and Social Research Council (Grant reference: 1788414). We would like to thank all the schools, parents, and children who made this study possible. We are also grateful to Anna Peng, Katy Packer, and Page Frankson for their help with school recruitment and data collection.

**Conflict of interest**

The UK Economic and Social Research Council Grant (Grant reference: 1788414) was established in partnership with Cauldron Science which own Gorilla™.
SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1 Supporting information.

REFERENCES

Anwyl-Irvine, A., Massonnié, J., Flitton, A., Kirkham, N., & Ever-shed, J. (2019). Gorillas in our Midst: an online behavioural experiment builder. *Behavior Research Methods, 52*, 388–407. https://doi.org/10.3758/s13428-019-01237-x

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829–839. https://doi.org/10.1038/nrn1201

Boman, E. (2004). The effects of noise and gender on children's episodic and semantic memory. *Scandinavian Journal of Psychology, 45*(5), 407–416. https://doi.org/10.1111/j.1467-9450.2004.00422.x

Collinson, L. (2015) *Achieve100 reading revision key stage 2*. (UK ed.). London, UK: Rising Stars.

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

Department for Education. (2013). *National curriculum in England: Primary curriculum*. Retrieved from https://www.gov.uk/government/publications/national-curriculum-in-england-primary-curriculum

Department for Education. (2017). *National Statistics—Schools, pupils and their characteristics: January 2017* (Local authority and regional tables: SFR28/2017). Retrieved from https://www.gov.uk/government/statistics/schools-pupils-and-their-characteristics-january-2017

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology, 5*, 781. https://doi.org/10.3389/fpsyg.2014.00781

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. https://doi.org/10.1080/01411920600635494

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

Elliott, E. M., & Briganti, A. M. (2012). Investigating the role of attentional resources in the irrelevant speech effect. *Acta Psychologica, 140*(1), 64–74. https://doi.org/10.1016/j.actpsy.2012.02.009

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. https://doi.org/10.1016/j.jml.2015.12.008

Erickson, L. C., & Newman, R. S. (2017). Influences of background noise on infants and children. *Current Directions in Psychological Science, 26*(5), 451–457. https://doi.org/10.1177/0963721417709087

Guerra, G., Tijms, J., Vaessen, A., Tierney, A., Dick, F., & Bonte, M. (2021). Loudness and intelligibility of irrelevant background speech differentially hinder children's short story reading. *Mind, Brain, and Education, 15*(1), 77–87. https://doi.org/10.1111/mbe.12264

Hearn, I., & Barber, A. (2015) *Oxford English for Cambridge primary student book 5*. Oxford, UK: Oxford University Press.

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods, 50*(3), 1166–1186. https://doi.org/10.3758/s13428-017-0935-1

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), 1050–1061. https://doi.org/10.1037/0278-7393.33.6.1050

Hygge, S. (2003). Classroom experiments on the effects of different noise sources and sound levels on long-term recall and recognition in children. *Applied Cognitive Psychology, 17*(8), 895–914. https://doi.org/10.1002/acp.926

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369. https://doi.org/10.1037/0278-7393.19.2.369

Jones, D. M., Macken, W. J., & Murray, A. C. (1993). Disruption of visual short-term memory by changing-state auditory stimuli: The role of segmentation. *Memory & Cognition, 21*(3), 318–328. https://doi.org/10.3758/BF03208264

Joseph, T. N., Hughes, R. W., Sörrqvist, P., & Marsh, J. E. (2018). Differences in auditory distraction between adults and children: A duplex-mechanism approach. *Journal of Cognition, 1*(1), 1–11. https://doi.org/10.5334/joc.15

Kassinove, H. (1972). Effects of meaningful auditory stimulation on children's scholastic performance. *Journal of Educational Psychology, 63*(6), 526–530. https://doi.org/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. https://doi.org/10.3389/fpsyg.2013.00578

Klatte, M., Lachmann, T., Schlittmeier, S., & Hellbrück, J. (2010). The irrelevant sound effect in short-term memory: Is there developmental change? *European Journal of Cognitive Psychology, 22*(8), 1168–1191. https://doi.org/10.1080/09541440903378250

Klatte, M., Meis, M., Sukowski, H., & Schick, A. (2007). Effects of irrelevant speech and traffic noise on speech perception and cognitive performance in elementary school children. *Noise & Health, 9*(36), 64–74.

Ljung, R., Sörrqvist, P., & Hygge, S. (2009). Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. *Noise & Health, 11*(45), 194–198. https://doi.org/10.4103/1463-1741.56212
Massonnié, J., Frasseto, P., Mareschal, D., & Kirkham, N. Z. (2022). Learning in noisy classrooms: Children's reports of annoyance and distraction from noise are associated with individual differences in mind-wandering and switching skills. *Environment and Behavior, 54*(1), 58–88. https://doi.org/10.1177/0013916520950277

Massonnié, J., Mareschal, D., & Kirkham, N. Z. (2021). Individual differences in dealing with classroom noise disturbances. Birbeck College, University of London. https://doi.org/10.18743/DATA.00109

Massonnié, J., Rogers, C. J., Mareschal, D., & Kirkham, N. Z. (2019). Is classroom noise always bad for children? The contribution of age and selective attention to creative performance in noise. *Frontiers in Psychology, 10*(381). https://doi.org/10.3389/fpsyg.2019.00381

Mehta, R., Zhu, R. J., & Cheema, A. (2012). Is noise always bad? Exploring the effects of ambient noise on creative cognition. *Journal of Consumer Research, 39*(4), 784–799. https://doi.org/10.1086/665048

Neely, C. B., & LeCompte, D. C. (1999). The importance of semantic similarity to the irrelevant speech effect. *Memory & Cognition, 27*(1), 37–44. https://doi.org/10.3758/BF03201211

Pearce, S. (2014) *Target your maths year 5*. Hertfordshire, UK: Elmwood Education Limited.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Michael, I. P (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*, 1029–1040. https://doi.org/10.1016/j.neuropsychologia.2003.12.012

Slater, B. R. (1968). Effects of noise on pupil performance. *Journal of Educational Psychology, 59*(4), 239–243.

Sörqvist, P. (2010). High working memory capacity attenuates the deviation effect but not the changing-state effect: Further support for the duplex-mechanism account of auditory distraction. *Memory & Cognition, 38*(5), 651–658.

Sörqvist, P., Halin, N., & Hygge, S. (2010). Individual differences in susceptibility to the effects of speech on reading comprehension. *Applied Cognitive Psychology, 24*(1), 67–76. https://doi.org/10.1002/acp.1543

Sörqvist, P., Ljungberg, J. K., & Ljung, R. (2010). A sub-process view of working memory capacity: Evidence from effects of speech on prose memory. *Memory, 18*(3), 310–326. https://doi.org/10.1080/09658211003601530

St Clair-Thompson, H. L. (2010). Backwards digit recall: A measure of short-term memory or working memory? *European Journal of Cognitive Psychology, 22*(2), 286–296. https://doi.org/10.1080/0954140902771299

Sörla, J. L., & Hancock, P. A. (2011). Noise effects on human performance: A meta-analytic synthesis. *Psychological Bulletin, 137*(4), 682–707. https://doi.org/10.1037/a0023987

Vasilev, M. R., Liversedge, S. P., Rowan, D., Kirkby, J. A., & Angele, B. (2019). Reading is disrupted by intelligible background speech: Evidence from eye-tracking. *Journal of Experimental Psychology: Human Perception and Performance, 45*(11), 1484–1512. https://doi.org/10.1037/xhp0000680

Vasilev, M. R., Kirkby, J. A., & Angele, B. (2018). Auditory distraction during reading: A Bayesian meta-analysis of a continuing controversy. *Perspectives on Psychological Science, 13*(5), 567–597. https://doi.org/10.1177/1745691617747398

Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., & Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review, 25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

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. https://doi.org/10.1037/0022-0663.72.6.830

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. https://doi.org/10.1037/0022-0663.72.6.830