

# Individual Differences in Dealing With Classroom Noise Disturbances

Jessica Massonnié<sup>1,2,3</sup> , Denis Mareschal<sup>2</sup> , and Natasha Z. Kirkham<sup>2</sup> 

**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 (Sörqvist, 2010), text recall (Sörqvist, Ljungberg, & Ljung, 2010), and reading comprehension (Sörqvist, Halin, & Hygge, 2010).

<sup>1</sup>Institute of Education, University College London

<sup>2</sup>Birkbeck, University of London

<sup>3</sup>University of Portsmouth

Address correspondence to Jessica Massonnié, School of Education and Sociology, Faculty of Humanities & Social Sciences, University of Portsmouth, St George's Building, 141 High Street, Portsmouth PO1 2HY, United Kingdom; e-mail: jessica.massonnie@port.ac.uk

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, Mareschal, 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,

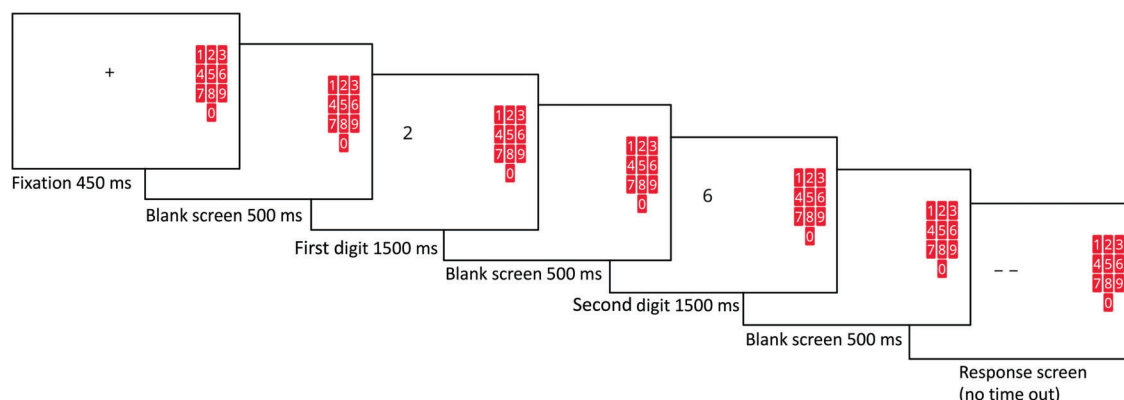


Fig. 1. Time course of a trial (two-digits list) in the backward digit span task.

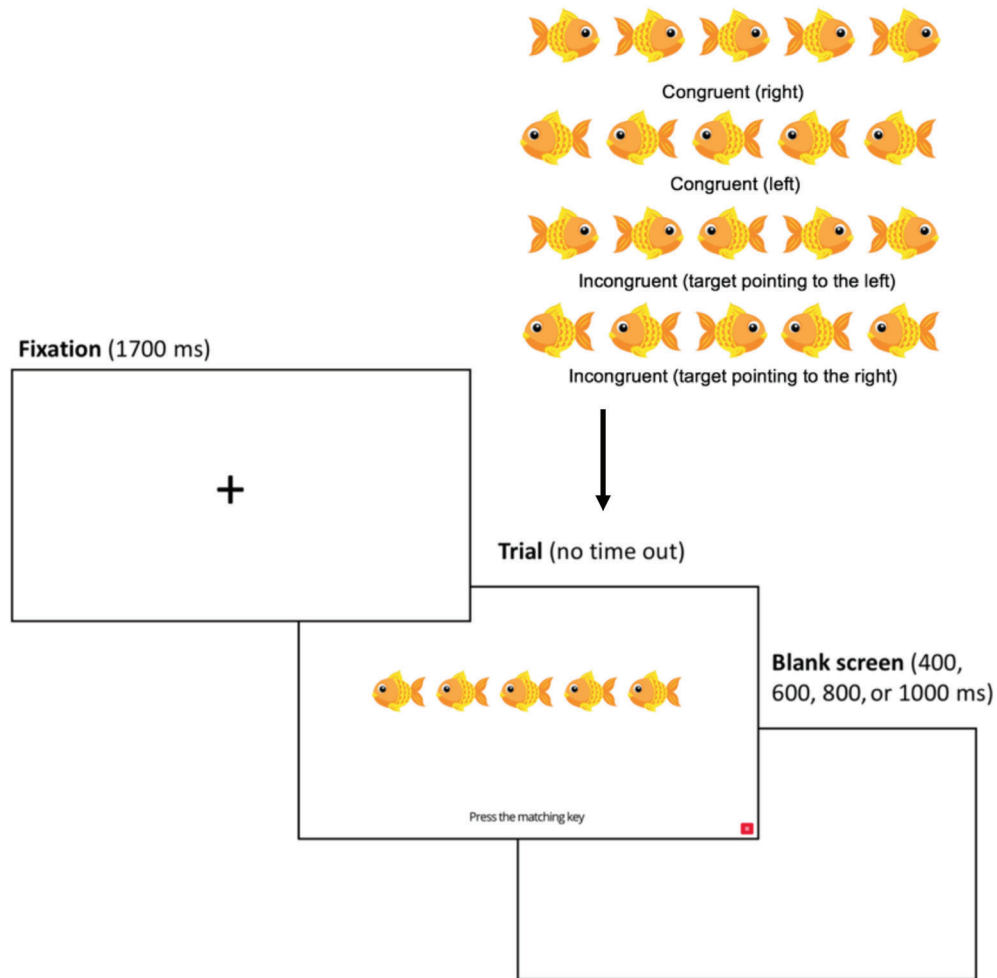


Fig. 2. Time course of a trial in the Flanker task.

**Table 1**  
Descriptive Statistics for Each Task and Noise Condition

	<i>Mixed noise</i>		<i>Verbal noise</i>		<i>Combined sample</i>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age	9.82 <sup>a</sup>	.55	10.61 <sup>a</sup>	.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 <sup>a</sup>	52.39	.36 <sup>a</sup>	72.01	21.35	66.20
<i>Silence</i>						
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
<i>Noise</i>						
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

<sup>a</sup>Significant difference between participants in the verbal noise and in the mixed noise conditions.

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 absence of an effect of noise, noted  $BF_{01}$  (Dienes, 2014).  $BF_{01}$  between 1 and 3 represents anecdotal evidence; between 3 and 10, moderate evidence; and between 10 and 30, strong 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 [ $F(1, 60) = 0.03, p = .871, BF_{01} = 15.63$ ].

#### *Reading Comprehension*

There was no main effect of noise [ $F(1, 62) < 0.00, p = .963, BF_{01} = 6.54$ ], and no interaction with age [ $F(1, 62) < 0.00, p = .973, BF_{01} = 8.13$ ]. There was a main effect of age [ $F(1, 62) = 9.28, p = .003, BF_{01} = 0.12$ ], older children performing better in silence ( $r = 0.30, p = .015$ ) and noise ( $r = 0.32, p = .009$ ).

#### *Mathematics*

There was no main effect of noise [ $F(1, 62) = 0.02, p = .898, BF_{01} = 5.26$ ] and no interaction with age [ $F(1, 62) = 0.03,$

$p = .859, BF_{01} = 8.55$ ]. 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 <i>p</i> = .282	<b>-0.43</b> <i>p</i> < .001	0.10 <i>p</i> = .209	<b>0.29</b> <i>p</i> = .009	<b>0.27</b> <i>p</i> = .017	0.15 <i>p</i> = .127	<b>0.34</b> <i>p</i> = .003	<b>0.22</b> <i>p</i> = .038	-0.05 <i>p</i> = .341	-0.03 <i>p</i> = .416	0.04 <i>p</i> = .370
2. Working memory		-0.17 <i>p</i> = .09	<b>0.31</b> <i>p</i> = .007	<b>0.34</b> <i>p</i> = .003	<b>0.34</b> <i>p</i> = .003	<b>0.41</b> <i>p</i> < .001	<b>0.32</b> <i>p</i> = .005	<b>0.43</b> <i>p</i> < .001	-11 <i>p</i> = .206	0.04 <i>p</i> = .388	<b>-0.23</b> <i>p</i> = .032
3. Selective attention (response time costs)			-0.09 <i>p</i> = .248	-0.15 <i>p</i> = .12	<b>-0.39</b> <i>p</i> = .001	<b>-0.01</b> <i>p</i> = .467	<b>-0.32</b> <i>p</i> = .005	<b>-0.37</b> <i>p</i> = .002	-0.05 <i>p</i> = .361	0.14 <i>p</i> = .141	0.05 <i>p</i> = .356
<i>Silence</i>											
4. Text recall				<b>0.62</b> <i>p</i> < .001	<b>0.46</b> <i>p</i> < .001	<b>0.43</b> <i>p</i> < .001	<b>0.44</b> <i>p</i> < .001	<b>0.43</b> <i>p</i> < .001	<b>0.58</b> <i>p</i> < .001	<b>0.23</b> <i>p</i> = .032	-0.02 <i>p</i> = .434
5. Reading comprehension					<b>0.37</b> <i>p</i> < .001	<b>0.42</b> <i>p</i> < .001	<b>0.49</b> <i>p</i> < .001	<b>0.43</b> <i>p</i> < .001	0.18 <i>p</i> = .076	<b>0.55</b> <i>p</i> < .001	-0.11 <i>p</i> = .187
6. Maths						<b>0.36</b> <i>p</i> = .002	<b>0.44</b> <i>p</i> < .001	<b>0.84</b> <i>p</i> < .001	0.10 <i>p</i> = .214	-0.02 <i>p</i> = .454	0.102 <i>p</i> = .211
<i>Noise</i>											
7. Text recall							<b>0.27</b> <i>p</i> = .016	<b>0.40</b> <i>p</i> = .001	-0.48 <i>p</i> < .001	0.16 <i>p</i> = .11	-0.09 <i>p</i> = .24
8. Reading comprehension								<b>0.44</b> <i>p</i> < .001	0.14 <i>p</i> = .143	<b>-0.41</b> <i>p</i> < .001	-0.13 <i>p</i> = .160
9. Maths									0.04 <i>p</i> = .367	-0.002 <i>p</i> = .494	-0.43 <i>p</i> < .001
<i>Difference score (silence – noise)</i>											
10 Text recall											
11. Reading comprehension										0.08 <i>p</i> = .265	0.05 <i>p</i> = .360
12. Maths											0.06 <i>p</i> = .308

Note: *p* values in bold are significant at the .05 level.

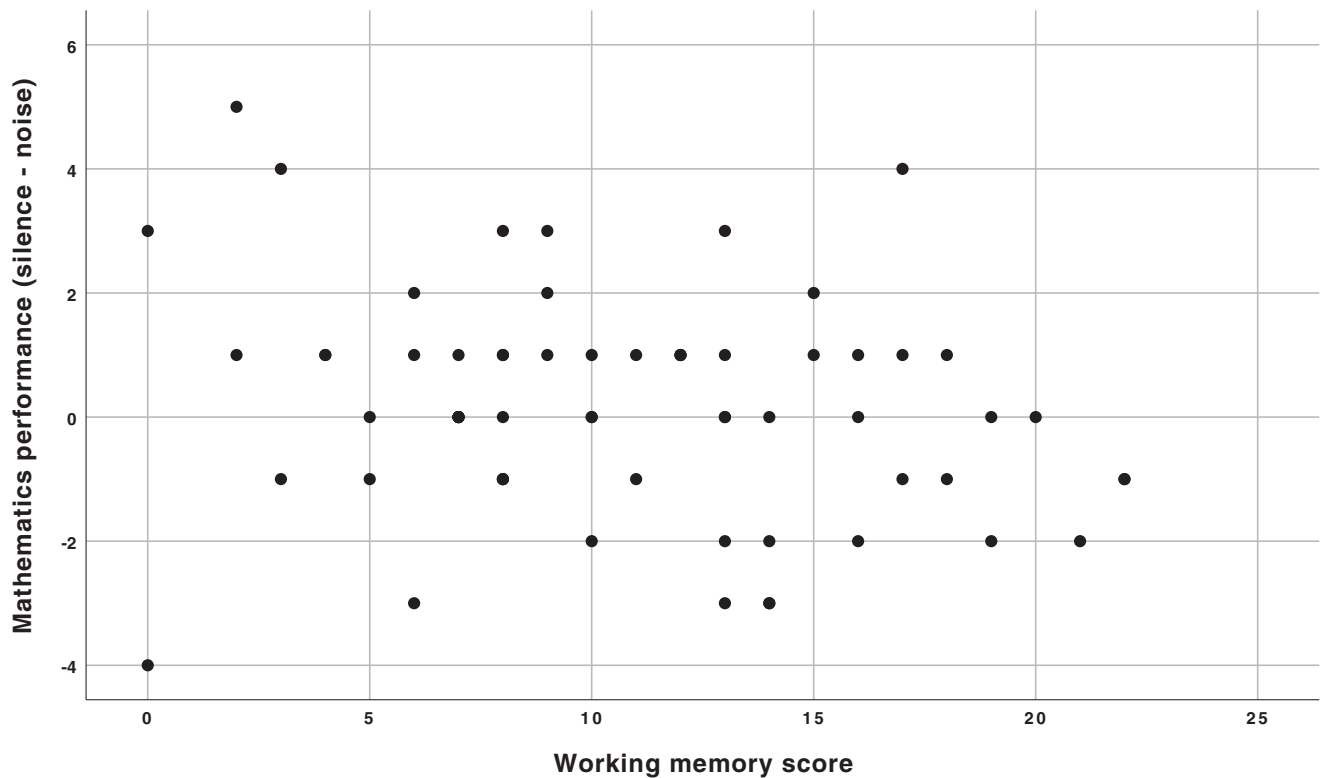


Fig. 3. Difference in mathematics performance between the silent and noisy sessions plotted against children's working memory score.

#### *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 meta-analysis 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, Frassetto, 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.

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### **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** Review of the experimental studies investigating the impact of noise on children's performance.

**Data S1** Supporting information.

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