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MIND, BRAIN, AND EDUCATION

Loudness and Intelligibility of Irrelevant Background Speech Differentially Hinder Children's Short Story Reading

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ABSTRACT— Reading skills are usually assessed in silent conditions, but children often experience noisy educational settings. Effects of auditory distraction on children's reading skills remain relatively unexplored. The present study investigates the influence of two features of background speech—intelligibility and loudness—on children's reading speed and comprehension. Sixty-three 8-to-10-year-old elementary school children performed a reading task in the context of single-talker background speech. Background speech was either intelligible or unintelligible and presented at low (45–50 dB SPL) or moderate (65–72 dB SPL) sound intensity (here termed "loudness"). Results showed a differential effect of intelligibility and loudness, respectively affecting children's comprehension and reading speed. In addition, the intelligibility effect was larger in children with lower interference control, as assessed with an auditory Stroop task. Our findings provide evidence for the influence of different properties of background speech on children's text reading with implications for reading in everyday classroom environments.

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LAY SUMMARY

Children often read in noisy environments, but we know little about how background chatter might affect their reading. Here, we found that 8–10-year-old children read stories more slowly with louder background speech. The children also understood less about a story if the background voice was speaking in their own language—especially those who, in a different task, were less able to ignore irrelevant but attention-grabbing information. This suggests background speech differentially affects beginning readers.

Whereas reading skills are typically investigated in silent conditions, children often experience noisy learning environments, for example, in crowded classroom settings at school or at home. Reading in such environments requires ignoring potentially distracting background sounds while mapping visual onto spoken language representations and integrating semantic information into a narrative or argument. There is some evidence that background noise has detrimental effects on reading, but the evidence and underlying mechanisms are still under debate (Klatte, Bergström, & Lachmann, 2013; Vasilev, Kirkby, & Angele, 2018). Rather surprisingly, it is still unclear whether and how different acoustic- and content-related characteristics of background noise might influence children's concurrent reading comprehension and speed.

The effect of noise on children's reading performance has typically been investigated in terms of its long-term consequences, with results showing (for example) that protracted exposure to traffic or aircraft noise at school is related to poorer reading comprehension (e.g., Clark et al., 2005; Haines, Stansfeld, Job, Berglund, & Head, 2001; Papanikolaou, Skenteris, & Piperakis, 2015). Only a handful

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of studies—with somewhat conflicting results—have experimentally tested how background speech and other noise types might have an impact on children's reading skills. For instance, Shield and Dockrell (2003) investigated the effect of classroom noise on reading comprehension in 8-year-old children, finding more accurate reading comprehension in a quiet condition than with recorded children's babble in the background. Unexpectedly, reading performance was best when babble was combined with intermittent environmental noise, which the authors interpreted as an active re-focusing of attention in the context of their relatively short and time-unlimited reading task. Ljung, Sorqvist, and Hygge (2009) found that previously-recorded road traffic noise slowed down reading in 12-to-13-year-old children, but did not affect their comprehension. A mix of background babble and conversational speech featuring one talker at a time did not affect either measure.

Single-talker background speech is also a common source of auditory distraction in daily life situations and may be particularly difficult to ignore given its salience for human listeners. In fact, for adults, speech is typically observed to have a more deleterious effect on reading comprehension than non-verbal acoustic noise (Landström, Söderberg, Kjellberg, & Nordström, 2002; Vasilev et al., 2018) with comparable but less well-studied effects on reading speed (Cauchard, Cane, & Weger, 2012; Hyönä & Ekholm, 2016; Vasilev et al., 2018; Vasilev, Liversedge, Rowan, Kirkby, & Angele, 2019). Typically, our understanding of the potential causal mechanisms underlying auditory distraction has relied on measuring its effect on serial recall or other working memory tasks—but these factors may also affect complex tasks such as reading (Jones, 1995). An early account suggested that any type of irrelevant background speech, whether intelligible or not, automatically engages verbal working memory capacity, thus interfering with ongoing task performance (phonological-interference hypothesis; Salamé & Baddeley, 1982, 1987). However, accumulating evidence suggests that the disruptive effect of unattended speech is mostly due to its conveyed meaning rather than to its acoustic or phonological features, and therefore has a semantic origin. For instance, Martin, Wogalter, and Forlano (1988) found that English-speaking participants' reading comprehension was more affected by English than by Russian speech. To test whether phonological or semantic information was driving this effect, Martin et al. (1988) performed a subsequent experiment comparing the effect of random sequences of auditorily presented English words, non-words, white noise or silence on reading performance. Hearing random English words impaired reading comprehension significantly more than non-word speech, which had an effect comparable to that of white noise (Martin et al., 1988). These findings suggest that the semantic content of background speech plays a stronger role than familiar phonological characteristics, in line with a second theoretical account, the interference-by-process account (Hughes, 2014; Marsh, Hughes, & Jones, 2008). This account suggests that intelligible background speech elicits automatic semantic processes that interfere with the extraction of meaning from the text.

Further evidence for the interference-by-process account comes from recent eye-tracking studies showing how online reading processes are affected by different types of background speech. These studies (Hyönä & Ekholm, 2016; Vasilev et al., 2019; Yan, Meng, Liu, He, & Paterson, 2018) showed that overall reading time slows down in the presence of intelligible background speech. In addition, background speech was found to affect the latency of word frequency effects (Yan et al., 2018). Specifically, when reading in quiet conditions, word frequency influenced first fixation duration, with longer fixation times for low- compared to high-frequency words. By contrast, when reading in the presence of background speech, this effect was seen for later fixations (Yan et al., 2018). Vasilev et al. (2019) found similar word frequency effects in the context of intelligible and unintelligible background speech, suggesting a similar effect on lexical access. But intelligible background speech was found to increase re-reading fixations in close proximity to the initial, first-pass fixations on words, suggesting an increased difficulty in integrating recently-read words into the sentence context due to the intelligibility of the speech. Finally, offline reading comprehension scores were reduced only when participants were prevented from re-reading the text (Vasilev et al., 2019), suggesting that re-reading may be an effective adaptive strategy to cope with noise. Overall, these results suggest that intelligibility of distracting speech can affect both reading speed and comprehension.

To date, the immediate effects of the loudness of background speech on reading remain unexplored. Effects of loudness have only been experimentally investigated using other types of cognitive tasks such as verbal memory and reasoning (Colle, 1980; Ellermeier & Hellbrück, 1998; LaPointe, Heald, Stierwalt, Kemker, & Maurice, 2007; Schlittmeier, Hellbrück, Thaden, & Vorländer, 2008) and math (Schlittmeier et al., 2008). Among them, only the study of LaPointe et al. (2007) found that louder speech adversely affected adults' working memory performance. On the other hand, correlational studies investigating the relationship between long-term exposure to low versus high levels of road traffic or aircraft noise in school environments and scholastic performance have suggested that high noise levels may have a considerable effect on children's reading comprehension (Haines et al., 2001; Papanikolaou et al., 2015). However, to our knowledge, there are no published studies that have investigated whether differences in the intensity or perceived loudness of background speech differentially affect reading performance. It also remains unknown whether the effects of intelligibility and loudness interact; for example, high-intensity intelligible background speech might be particularly decremental for reading performance.

Children's task performance may be more susceptible to distracting sounds due to both their immature cognitive and attentional skills, and their less automatized reading skills. Greater distractibility by noise in children has indeed been shown for a broad range of tasks, including speech perception and working memory (Hughes, 2014; Joseph, Hughes, Sorqvist, & Marsh, 2018; Klatte et al., 2013; Klatte, Lachmann, Schlittmeier, & Hellbrück, 2010). These previous studies did not directly assess children's attention skills. Accounting for individual differences in attentional control may allow us to hone in the processes by which background speech affects children's reading performance. Thus, the aim of the current study is to investigate how varying both the intelligibility and intensity of background speech affects children's reading speed and comprehension. Further, we asked whether individual differences in attentional skills—specifically in interference control—might modulate these effects. Finally, we also investigated whether children's vocabulary, reading proficiency, and visuo-spatial skills modulate their susceptibility to the effects of background noise on reading.

MATERIALS AND METHODS

Participants

Participants were 63 third- and fourth-grade children (33 boys, 31 in 3rd grade, age: 9.32 ± 0.65 years, range: 8.01–10.74), recruited from an elementary school in Amsterdam, the Netherlands. All were native Dutch speakers, with 11 also speaking a second language. None spoke Hungarian, the 'unintelligible' language used in the reading-in-distracting-speech task. The experiment was approved by the ethics committee of the Department of Psychology, University of Amsterdam, with informed consent obtained from the children's parents. Books were given to the school as a gift for participation. Children's cognitive and reading skills were assessed with standardized tests in Dutch (Table 1). Visuo-spatial skills and vocabulary skills were estimated using the Block Design subtest of the WISC-III and the vocabulary subtest of the Revisie Amsterdamse Kinder Intelligentie Test (RAKIT; Bleichrodt, Drenth, Zaal, & Resing, 1984). The RAKIT vocabulary test was administered at group level. Single word reading fluency was tested with the "Een-Minuut-Test" (EMT, Brus & Voeten, 1973). Eight children were previously diagnosed with dyslexia (n = 5), ADHD (n = 2) or co-occurrence of dyslexia and ADD (n = 1). These children were not excluded from the analyses, as the study explicitly aimed to test a representative sample of school-aged children. Importantly, reanalyses showed that the statistical significance (at $p < .05$ thresholds) of our results did not change after excluding the eight children with dyslexia and/or ADHD.

Table 1
Descriptive Statistics Showing Verbal and Non-Verbal Scores, and Word Reading Fluency

N = *56*	Mean	SD	*Min*	*Max*
EMT[a]—Word Reading fluency	9.84	3.25	1	17
WISC[a]—Block Design	11.45	3.12	4	18
RAKIT[b]—Vocabulary	50.34	3.64	42	60

[a] Standard scores (range 1–19, mean 10).
[b] Raw scores (range 1–65).

Procedure and Measures

All children were tested individually in a quiet room at school. Testing sessions lasted 1.5 h and included a range of behavioral measures. Here, we present the results from two experimental tasks: a reading in distracting speech task and an auditory Stroop task. In addition, we analyzed these experimental measures in relation to participants' word reading fluency and vocabulary and visuo-spatial skills as assessed with the standardized tests mentioned above. Task order was counterbalanced across participants. The computerized tasks were programmed and presented with Psychtoolbox-3 in MATLAB 9.1.0 (Mathworks). Two Dell Latitude E5570 laptops, with a 1920 x 1,080 screen, Core i5-6200 microprocessor, Intel HD Graphics 520 were used.

Reading in Distracting Speech

Here, children silently read four short narrative texts consisting of two paragraphs, each followed by a brief reading comprehension test. Texts and questions were adapted from a reading comprehension workbook for 3rd- and 4th-grade children (Ajodakt Lezen—Goed begrepen 5, Van Merbergen, 2005). The number of words was kept comparable across texts (AVI E5 level length indicator, M = 84.5; SD = 4.9; range: 79–95 words per text) and provided a similar structure and plot. To reduce the time between reading and testing phases, paragraphs were presented one at a time on the laptop screen, each followed by two multiple-choice questions. Children advanced to the reading comprehension questions by pressing the space bar; the measure of reading speed was the time between paragraph appearance on the screen and spacebar press to advance, averaged across all paragraphs in a condition.

During paragraph presentation, children heard either a native Dutch female talker (intelligible speech) or a native Hungarian female talker (unintelligible speech) reading a newspaper article in their native language. Background speech was presented over headphones (IMG Stage Line MD-5000DR) at two different intensity levels, 45–50 dB and 65–72 dB SPL (measured using a RION NA-27 Sound Level Meter with a NH-20 microphone). The sound intensity levels were chosen so that the moderate intensity was close to the maximum sound intensity considered safe for young children, 75 dB (WHO, 2018). The low intensity level was chosen so that the speech was still understandable but clearly different from the moderate level. Thus, the four experimental conditions were the following: (i) intelligible speech at low intensity level, (ii) intelligible speech at moderate intensity level, (iii) unintelligible speech at low intensity level, and (iv) unintelligible speech at moderate intensity level. Texts were presented in the same order to each participant, but condition order was randomized. Children were asked to silently read through the texts as accurately and quickly as possible without going back to previously read sentences, and then to answer the comprehension questions. They were also told they would hear speech in the background they could ignore.

Interference Control

Interference control was tested with an auditory version (Green & Barber, 1981) of the Stroop task (Stroop, 1935). Similar to the original Stroop test, it requires the listener to ignore lexical information and to respond on the basis of a perceptual feature. The stimuli consisted of four words: "boy," "girl," "house" and "game" ("jongen," "meisje," "huis" and "spel" in Dutch) spoken by two female and two male Dutch native talkers. There were congruent, incongruent and neutral trials. On congruent trials, the word "boy" and the word "girl" were spoken by a male and female talker, respectively. On incongruent trials, the word "boy" was spoken by a female talker, and the word "girl" was spoken by a male talker. Neutral trials used the words "game" and "house," both spoken by a female and a male talker. The participants were asked to ignore the meaning of the words and to respond to the gender of the talker by pressing one of two keys (one on the left, one on the right side of the keyboard, each marked by an orange sticker to guide the children to the correct key). Trials timed out after 1,500 milliseconds (ms). There were 32 trials per condition, with presentation order randomized. Before beginning the experimental task, children practiced 10 or 20 trials (with more trials indicated if the child performed poorly) which included all conditions. During practice trials only, response feedback (happy/sad cartoon face) was displayed. Both accuracy and reaction time (RT) of correct trials were used for analysis.

Statistical Analyses

For the "reading in distracting speech task," data from two children were excluded because the task was not administered due to time constraints, with data from an additional five children excluded due to a procedural error that occurred in one of the four conditions when children inadvertently pressed the button to advance to the next paragraph too early.

All remaining data were inspected for outliers that were identified based on standardized residuals, and data points with values below −3 and above 3 were excluded from the analyses (Osborne & Overbay, 2004). Based on this criterion, one datapoint was excluded from the reading speed data (standardized residuals >3 in two of the four conditions, intelligible moderate and unintelligible moderate), and one datapoint was excluded from the reading comprehension data (standardized residuals <3 in the intelligible moderate condition, and in the average reading comprehension scores). In summary, we excluded 12.6% (8 out 63) of the 'reading-in-distracting-speech' participants. A repeated-measures analysis of variance (ANOVA; SPSS version 26.0, IBM Corp., Armonk, NY, United States) was conducted to test for main and interaction effects of speech intensity (low, moderate) and intelligibility (intelligible, unintelligible) on reading speed; reading speed was log-transformed to normalize the underlying reading time distribution. Log-transformed reading speed data met ANOVA assumptions, with analyses showing homoscedasticity and normality of the residuals. Effect sizes reported are partial eta-squared (ηp^2). Reading comprehension scores showed limited variance and were negatively skewed so a Generalized Estimating Equation (GEE; SPSS version 26.0, IBM Corp.) for repeated categorical data was constructed, again with speech intensity and intelligibility as within-subjects factors.

We also ran Spearman's rank correlation analyses between children's overall text reading comprehension and speed and word reading fluency (EMT test), vocabulary (RAKIT test) and visuo-spatial skills (WISC block design) scores. All results were Bonferroni-corrected for multiple comparisons.

For Auditory Stroop data, one participant (1.6% of total *N*) was excluded because s/he omitted 45% of responses. For the remaining 62 participants, we used non-parametric Friedman tests with post-hoc Wilcoxon pairwise analyses corrected for multiple comparison (Bonferroni) to analyze the median RTs and mean accuracy because the data did not meet the assumption of normality.

Finally, we used two linear regression models to ask whether individual differences in interference control (children's accuracy on incongruent—congruent Stroop task trials, see Results) were associated with effects of background speech on text reading. In a first model, we included only Stroop-based interference control and age in months as regressors. In a second model, we added reading fluency (measured by the EMT) and vocabulary size (the vocabulary subscore of the RAKIT) as regressors in order to clarify

Table 2
Children's Text Reading Speed and Comprehension Results

	N	Mean	SE	*Min*	*Max*
Reading Speed[a] (Intelligible, Low intensity)	55	38.38	1.90	16.02	73.83
Reading Speed[a] (Intelligible Moderate intensity)	55	41.17	1.82	21.44	86.72
Reading Speed[a] (Unintelligible Low intensity)	55	38.59	2.02	16.98	82.23
Reading Speed[a] (Unintelligible Moderate intensity)	55	39.58	1.80	19.25	69.99
Reading Speed[a] (Average)	55	39.42	1.76	21.40	70.27
Reading Comprehension[b] (Intelligible Low intensity)	55	80.45	2.5	25	100
Reading Comprehension[b] (Intelligible Moderate intensity)	55	78.18	3.0	25	100
Reading Comprehension[b] (Unintelligible Low intensity)	55	82.27	2.7	25	100
Reading Comprehension[b] (Unintelligible Moderate intensity)	55	85.91	2.5	25	100
Reading Comprehension[b] (Average)	55	81.7	1.6	50	100

[a] Reading speed: average reading time (in seconds) for both paragraphs per text.
[b] Reading comprehension: percentage of correctly responded comprehension questions.

the extent to which background speech interference on reading might be modulated by individual differences in these skills, above and beyond that contributed by interference control and age. The assumptions of linearity, independence of errors, homoscedasticity and normality of residuals were met for each of the regression models.

RESULTS

Descriptive statistics of reading fluency (EMT) and estimates of vocabulary (RAKIT) and visuo-spatial (WISC block design) skills are presented in Table 1.

Text Reading Speed and Comprehension Accuracy

The children who completed all the four conditions took on average 39.42 s ($SD = 13.1$) to read a paragraph (Table 2) with considerable variability between children. Most of them correctly understood the texts (mean reading comprehension 81.7% ($SD = 11.8$)).

On average, faster readers were also more able to accurately respond to the comprehension questions (rho = −0.359, $p = .032$). More fluent readers, indicated by the number of correctly-read words within 1 minute on a standardized reading fluency test (EMT), were faster in reading the texts (rho = −0.766, $p < .001$), but were not significantly more accurate in responding to comprehension questions (rho = 0.212, $p = .480$). Children with richer vocabulary required less time to read (rho = −0.445, $p = .004$), and had higher reading comprehension scores (rho = 0.444, $p = .004$). Visuo-spatial skills were not correlated with average reading comprehension (rho = 0.245, $p = .284$) nor with reading speed (rho = −0.084, $p \cong 1$).

Effects of Background Speech: Intensity Versus Intelligibility

Reading comprehension and speed were differentially influenced by acoustic (speech intensity) versus semantic (speech intelligibility) characteristics of distracting speech. Reading speed was significantly slowed when the distracting speech was more intense, $F(1, 54) = 12.389$, $p = .001$, $\eta p^2 = .187$; Figure 1a. However, distractor speech intelligibility did not significantly influence reading speed, $F(1, 54) = 1.123$, $p = .294$, $\eta p^2 = .020$, and did not significantly interact with intensity, $F(1, 54) = 1.505$, $p = .225$, $\eta p^2 = .027$.

By contrast, intelligible distracting speech did significantly affect reading comprehension more than unintelligible speech, GEE model; Exp(B) = 0.484; CI = 0.253 to 0.925, $p = .028$; Figure 1b. Reading comprehension was not significantly influenced by distracting speech intensity, Exp(B) = 0.700, $p = .283$, CI = 0.365 to 1.342, and there was no significant interaction, Exp(B) = 1.621, $p = .290$, CI = 0.662 to 3.969.

Interference Control—Auditory Stroop Task

Children showed accurate task performance with an average accuracy of 87.03% ($SD = 9.04\%$). In the congruent condition, children's average accuracy was 90.67% ($SD = 9.93\%$), 81.12% ($SD = 12.4\%$) in the incongruent condition and 89.32% ($SD = 9.19\%$) on the neutral trials (Table 3).

A Friedman test with Condition as a within-subjects factor (Congruent, Incongruent, Neutral) revealed a significant Stroop effect on accuracy, $\chi^2(2) = 44.451$, $p = < .001$; Figure 2a), with accuracy in the incongruent condition lower than in the congruent ($Z = -5.823$, $p < .001$) and neutral conditions ($Z = -5.741$, $p < .001$), neutral and congruent condition did not differ from each other ($Z = -1.391$, $p = .492$), Bonferroni-corrected.

There was also a main effect of Condition on RTs, $\chi^2(2) = 21.77$, $p < .001$, with slower RTs in the neutral as compared to the congruent condition ($Z = -3.600$, $p = .001$) and to the incongruent condition ($Z = 3.923$, $p < .001$), which did not differ from each other ($Z = -0.011$, $p = .992$, Bonferroni-corrected; Figure 2b).

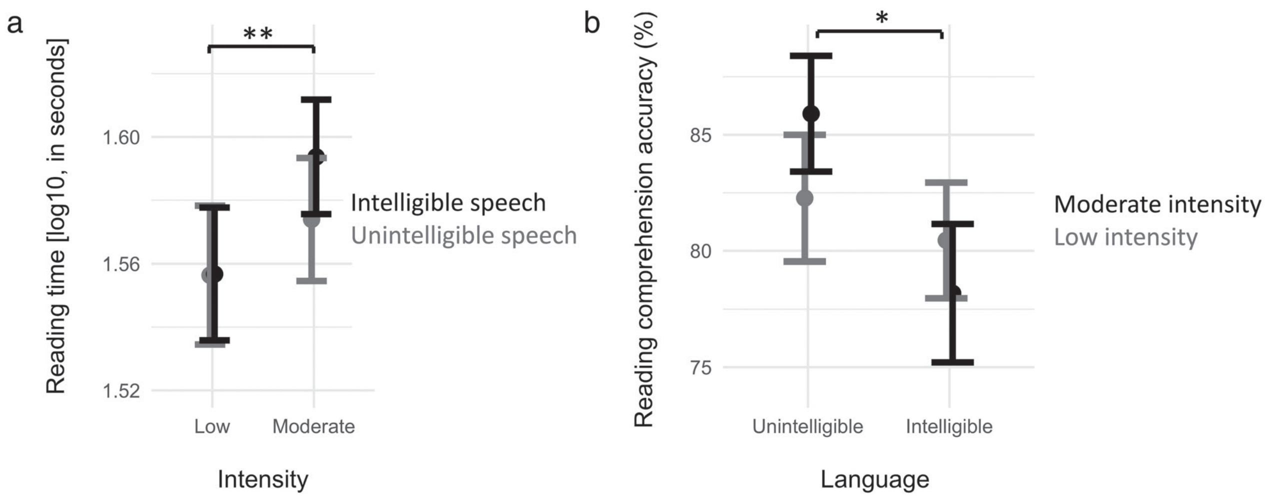

Fig 1. (a) The intensity of the background speech (low versus moderate) significantly affected children's text reading speed. Reading speed is expressed in seconds on a logarithmic scale. (b) The intelligibility of the background speech significantly affected children's reading comprehension. Reading comprehension is expressed as the percentage of correctly responded questions. Error bars = ± 1 standard error. $^{**}p < .01$, $^{*}p < .05$.

Table 3
Auditory Stroop task. Accuracy (percentage correct) and RT on correctly responded trials (in milliseconds) for the congruent, incongruent and neutral conditions

	N	Mean	SD	*Min*	*Max*
Accuracy Congruent	62	90.7	9.9	48.1	100
Accuracy Incongruent	62	81.1	12.4	50	100
Accuracy Neutral	62	89.3	9.2	60	100
Accuracy Total	62	87.0	9.0	54.6	100
Stroop interference effect (Accuracy Inc.—Cong.)	**62**	**−8.54**	**10.56**	**−50**	**7.4**
RTs Congruent	62	746	113	407	1,035
RTs Incongruent	62	742	123	274	1,106
RTs Neutral	62	776	107	340	1,028
RTs Total	62	755	105	340	1,004

This unexpected result may be due to the fact that the words used for the neutral condition (game, house) appeared only in 33.3% of trials whereas words used in both congruent and incongruent conditions (boy, girl) appeared in 66.7% of the trials. This difference in relative frequency of occurrence may have resulted in an 'oddball' effect and thus in longer RTs (Miller, 1998). Accuracy scores were not affected and were similar to those of the congruent condition (compatible with the fact that the neutral condition was not semantically incongruent).

Because the classic Stroop effect was reflected in accuracy scores, we quantified children's interference control skills as the accuracy difference between incongruent and congruent trials (Table 3; note that higher values indicate better interference control).

Potential Modulatory Effects of Interference Control, Vocabulary, and Reading Fluency on Children's Susceptibility to Background Speech During Reading

In a final analysis we investigated whether variability in interference control explained individual differences in susceptibility to auditory distraction during reading. Specifically, we wanted to understand whether interference control predicted change in reading speed and comprehension, due to the intensity and the intelligibility of the distraction, respectively. As described above, interference control was quantified as the accuracy difference on incongruent versus congruent Auditory Stroop trials, where positive scores indicate greater interference control. We used difference scores to create a measure that quantifies the effect of each experimental manipulation. The loudness effect on speed

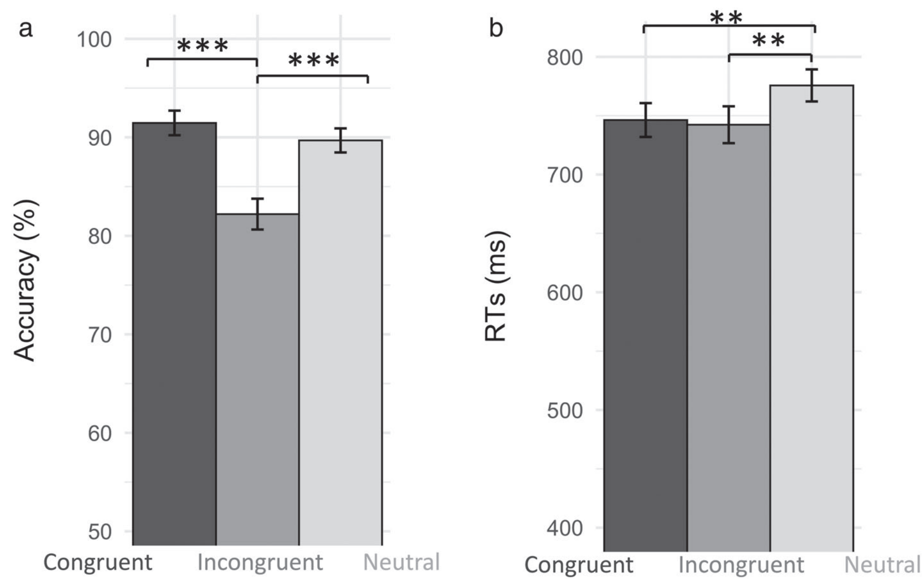

Fig 2. (a) Children's accuracy in the Auditory Stroop task per condition. (b) Children's reaction times (RTs) on correctly responded trials of the Auditory Stroop task per condition. Error bars = ± 1 standard error.***$p < .001$, **$p < .01$.

was quantified as the reading speed difference between moderate- versus low-intensity speech distractor conditions, and the intelligibility effect on comprehension as the reading comprehension difference between unintelligible versus intelligible conditions. The loudness effect on speed and the intelligibility effect on comprehension measures were first analyzed in two separate linear regression models, with interference control (Stroop effect interference) and age in months as predictors.

Here, the degree to which intelligibility affected a child's reading comprehension was associated with their interference control ($\beta = -.374$, $p = .007$; CI = −1.145 to −0.192), but not with children's age, $\beta = .014$, $p = .916$; CI = −0.589 to 0.654; overall regression model: $R^2 = 0.142$, $F(2, 51) = 4.244$, $p = .020$; Figure 3. Thus, the less interference control a child had, the more strongly influenced s/he was by the intelligibility of background speech. By contrast, the difference in reading speed due to the intensity of the background speech was neither predicted by the amount of interference experienced during the interference control task ($\beta = 0.096$, $p = .494$; CI = −0.082 to 0.168), nor by age, $\beta = .240$, $p = .091$; CI = −0.023 to 0.307; overall regression model: $R^2 = 0.057$, $F(2, 51) = 1.539$, $p = .224$.

In a second step, we additionally entered both EMT (reading fluency) and RAKIT (vocabulary) scores in our linear regression models. Similar to above, results showed that the intelligibility effect on comprehension was associated with children's interference control ($\beta = -0.418$, $p = .005$; CI = −1.251 to 0.241), but not with their age ($\beta = -0.028$, $p = .851$; CI = −0.751 to 0.622). Vocabulary skills ($\beta = .208$, $p = .133$; CI = −0.333 to 2.441) and reading fluency skills ($\beta = -0.022$, $p = .879$; CI = −0.372 to 0.319) did not explain additional variance, R^2 change = .039, $F(2, 49)$ change = 1.166; $p = 0.320$; overall regression model: $R^2 = 0.182$, $F(4, 49) = 2.719$, $p = .040$. These results suggest that the reading comprehension of children with richer vocabulary and more fluent reading skills was not

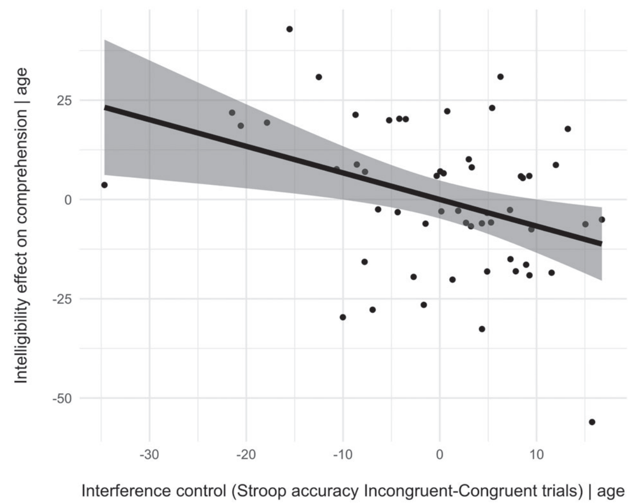

Fig 3. Added variable (partial regression) plot displaying the modulatory effect of interference control on the effect of intelligibility of background speech on children's reading comprehension, once the effect of age was removed. Interference control was measured as the Stroop interference effect (accuracy for incongruent versus congruent trials). The effect of intelligibility on comprehension was quantified by children's comprehension during the unintelligible versus intelligible speech conditions.

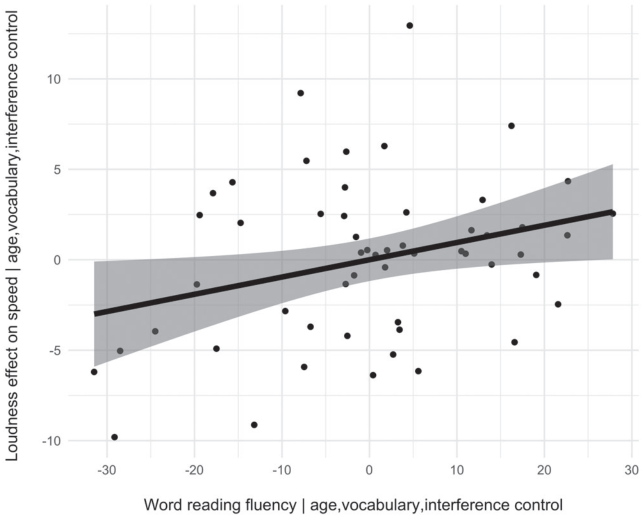

Fig 4. Added variable (partial regression) plot displaying the modulatory effect of reading fluency skills on the effect of the loudness of background speech on children's reading speed, after removal of age, vocabulary and interference control effects. The effect of background speech loudness on reading speed was quantified by taking the difference between reading speed in moderate versus low background speech loudness conditions.

less susceptible to the effect of intelligibility of background speech.

The extended regression model further showed that the loudness effect on reading speed was not predicted by vocabulary skills (β = .165, p = .234; CI = − 0.140 to 0.559). However, we did find a significant effect of reading fluency on the loudness effect on reading speed (β = .318, p = .033; CI = 0.008 to 0.182; Figure 4). Unexpectedly, for children with better word reading fluency, background speech loudness had a greater effect on reading speed compared to children with poorer reading fluency. Interference control (β = −.033, p = .813; CI = −0.142 to 0.112) and age (β = .079, p = .592; CI = −0.127 to 0.220) remained non-significant, R^2 change = .119, $F(2, 49)$ change = 3.543; p = .037; overall regression model: R^2 = .176, $F(4, 49) = 2.618$, p = .046.

DISCUSSION

Here we asked how intensity and intelligibility of an irrelevant background talker affected school-age children's text reading speed and comprehension. We also asked whether children's ability to successfully ignore the irrelevant talker and focus on reading was related to interference control. On average, children's reading speed was more adversely affected by 'louder' irrelevant speech, whereas their comprehension was more adversely affected by intelligible speech, with the latter result modulated by children's interference control. Finally, as compared to children with lower reading proficiency, those with higher proficiency were faster in reading the texts in distracting speech, but their speed was more strongly affected by speech loudness.

Our newly-developed reading-in-noise task featured an appropriate level of difficulty, as children performed well and were able to correctly answer most, but not all, of the comprehension questions. Furthermore children who were faster in reading the texts also scored higher on a separately administered standardized reading fluency test, indicating that our text reading task reflects relevant individual variability in reading ability. The observation that simultaneously presented intelligible speech drives poorer reading comprehension is in line with previous findings in adults (Martin et al., 1988; Vasilev et al., 2019) and is predicted by the interference-by-process-account according to which intelligible speech evokes automatic semantic processes which interfere with the ongoing processes relevant for text comprehension (Hughes, 2014; Marsh et al., 2008; Marsh, Hughes, & Jones, 2009).

In support of this interpretation, the intelligibility effect was stronger in children with less efficient interference control. Specifically, in our Stroop task, children were asked to ignore auditory semantic information. Therefore, greater interference due to meaningful background speech may occur in children who are less capable of inhibiting or suppressing automatic activation of this information. This finding is in keeping with previous evidence showing that auditory disruption is greater for adults and children who are more susceptible to intrusions, during number-updating memory tasks (Sörqvist, Halin, & Hygge, 2010) and creativity tasks (Massonnié, Rogers, Mareschal, & Kirkham, 2019). Contra our expectations, the effects of intelligible background speech on reading comprehension were not modulated by its relative intensity. Given that we only tested a narrow age range, it is possible that such effects might occur at different points of development, and might also depend on the familiarity of the distracting sounds (Matusz, Merkley, Faure, & Scerif, 2019) or on the strategies used to cope with auditory distraction (Massonnié et al., 2019). Useful follow-up experiments might more parametrically vary the perceptual and semantic features of distracting speech and test these across children in different age groups.

While previous studies have shown detrimental effects of long-term exposure to loud noise on children's reading ability (e.g., Haines et al., 2001; Papanikolaou et al., 2015), to our knowledge, this is the first study testing the immediate effect of background speech loudness on children's online text reading performance. Children's reading speed was significantly slower in the presence of higher compared to lower intensity speech, although the degree of slowing was mild. The small magnitude of this effect may relate to the fact that the background speech used here was homogeneous and continuous, that is, without dynamic changes in loudness, long silent pauses or other interruptions that may have been more distracting and may have yielded larger time effects due to the re-direction of attention (Escera, Alho, Winkler, & Näätänen, 1998). Nonetheless, this finding and the fact that the difference in reading speed was not predicted by children's performance on the interference control task, suggests that louder sounds may hinder reading on a more general perceptual level, possibly including early stage processes, such as the recoding of letters into their corresponding speech sounds or lexical access based on visual word forms (Schlaggar & McCandliss, 2007). As this hindrance may not only result in slower reading but also in re-reading previously read words or sentences, it would be very interesting to further clarify the online mechanisms underlying this effect in future studies using eye-tracking methodology (Hyönä & Ekholm, 2016; Vasilev et al., 2019; Yan et al., 2018). Of note, the effects of the loudness of the background speech on reading speed were not modulated by its intelligibility. It is possible that an interaction between background speech loudness and intelligibility might be observed if one were to use a more engaging (semantic) auditory distraction (like entertaining children's stories), or a more complex and informative text.

Longer reading times as a consequence of re-reading behaviors could be a functional coping mechanism in the context of auditory distraction, particularly in order to facilitate better text comprehension (Vasilev et al., 2019). Thus, the fact that more skilled readers actually take longer to read when background speech levels increase could indicate greater flexibility in adapting their reading strategies in order to preserve reading's ultimate goal, which is understanding what is written. Another possible explanation could be that louder background sounds affect the automaticity of the reading decoding processes, possibly due to the attentional burden imposed by suppressing the distracting speech (Elliott, 2002). In poorer readers, especially younger ones, decoding processes are not fully automatized (Chein & Schneider, 2012; Froyen, Bonte, van Atteveldt, & Blomert, 2009), and their reading speed thus might be less affected by loud background noise relative to more fluent readers. Future studies are needed to shed light on the mechanisms underlying this effect.

CONCLUSIONS

To our knowledge, this is the first study investigating the effect of different types of background speech on online text reading performance of children. Our results indicate that reading speed decreased with louder background speech while reading comprehension was disrupted by the intelligibility of the distraction. The larger intelligibility effect in children with poorer interference control suggests that these children may be more vulnerable in environments where background speech is present. The present study provides insight in the influence of different properties of background speech on children's text reading performance with relevant implications for reading in everyday classroom environments. In future studies it would be interesting to further investigate the observed effects as well as their underlying mechanisms by (e.g.) adding different types of speech conditions, including children's voices, testing in a virtual reality set-up simulating classroom environments, and using eye-tracking methodology and/or measurements of children's brain activity with electro-encephalography (EEG). Furthermore, our reading-in-noise paradigm may provide a valuable tool for studying the effect of different types of auditory distraction on reading skills in more vulnerable groups, such as children with developmental disorders and/or learning difficulties.

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