Research Report

A PROSPECTIVE STUDY OF SOME EFFECTS OF AIRCRAFT NOISE ON COGNITIVE PERFORMANCE IN SCHOOLCHILDREN

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Abstract—*Before the opening of the new Munich International Airport and the termination of the old airport, children near both sites were recruited into aircraft-noise groups (aircraft noise at present or pending) and control groups with no aircraft noise (closely matched for socioeconomic status). A total of 326 children (mean age = 10.4 years) took part in three data-collection waves, one before and two after the switch-over of the airports. After the switch, long-term memory and reading were impaired in the noise group at the new airport. and improved in the formerly noise-exposed group at the old airport. Short-term memory also improved in the latter group after the old airport was closed. At the new airport, speech perception was impaired in the newly noise-exposed group. Mediational analyses suggest that poorer reading was not mediated by speech perception, and that impaired recall was in part mediated by reading.*

A consequence of modern means of transportation is widespread noise exposure. In Europe, almost 25% of the population is exposed to equivalent noise levels (L_{eq}) of 65 dBA or more (Berglund & Lindvall, 1995). At this level, annoyance is marked, sleep is disturbed, and some cognitive processes are impaired (Cohen, Evans, Stokols, & Krantz, 1986; Evans & Lepore, 1993; Smith & Jones, 1992). Noise exposure is consistently correlated with reading deficits and may interfere with speech perception and long-term memory in primary-school children (Evans & Lepore, 1993).

The simultaneous opening and closing of the new and former Munich Airport provided us with an unprecedented opportunity to conduct a prospective study of the effects of aircraft noise on children. This is the only prospective study of nonauditory effects of noise on children that has been undertaken. Moreover, cessation of noise at the old airport provided a unique opportunity to assess whether expected, noise-related impairments are reversible. Sociodemographically matched control groups exposed to little aircraft noise were formed at both airports. By testing the children in silence and not in everyday-noise settings, we eliminated confounds between chronic versus acute noise. Furthermore, examination of the interplay among attention, memory, and reading over time enabled us to test whether expected noise-related reading deficits could be accounted for by shifts in underlying cognitive processes.

Previous cross-sectional research (Cohen et al., 1986; Cohen, Glass, & Singer, 1973; Evans & Maxwell, 1997) indicated that noise-related reading deficits might be mediated by a cognitive strategy wherein children become less attentive to auditory stimuli as a way to cope with noise. It is unclear whether such shifts in attentional strategies are general to noise or specific to speech. Laboratory noise also impairs both long-term memory (Hygge, 1997; Hygge, Boman, & Enmarker, in press) and short-term memory (Hamilton, Hockey, & Rejman, 1977; Hockey, 1979). Both speech perception and memory are related to reading acquisition (Crowder & Wagner, 1992; Mann & Brady, 1988).

In summary, we collected prospective data to assess how children's reading was affected by changes in ambient noise levels caused by modified airport operations. In addition, we investigated two cognitive processes, attention and memory, implicated in prior experimental work on acute noise exposure, and how they relate to speech perception.

METHOD

Design and Subjects

The two experimental groups comprised children who were (old airport) or would be (new airport) exposed to aircraft noise. The two control groups were selected from areas that had little exposure to aircraft noise. The control groups were matched with their respective experimental groups on the basis of sociodemographic characteristics. One wave of data collection started 6 months prior to the changeover of airports, the second wave was 1 year later, and the third wave 2 years later. A total of 326 children participated: 43 in the old-airport, no-noise group; 65 in the old-airport, noise group; 107 in the new-airport, no-noise group; and 111 in the new-airport, noise group. Their ages ranged from 8 to 12 ($M = 10.4$, $SD = 0.85$). The children at the new airport were tested 3 to 5 months before the children at the old airport, but there was no difference in average year of birth. Criteria for taking part in the study were a minimum of 2 years of residence and German fluency, which ruled out confounds with ethnicity. Normal hearing, as assessed by audiometric screening, was also a criterion for participation. The experimental and control groups at the two airports did not differ in age, gender, ethnicity, number of family members, parental occupation, or education, and attrition did not differ among the four groups, $\chi^2(3, N = 326) = 1.64, p > .10$.

Procedure and Materials

At each data-collection wave, the children were tested individually in silence for 1.5 hr on 2 consecutive days in a specially designed temperature-controlled and sound-attenuated mobile laboratory that traveled to their schools. The children worked individually on an array of different tasks. In this article, we present only the cognitive dependent measures. (For data on physiological stress and mental health, see Bullinger, Hygge, Evans, Meis, & von Mackensen, 1999; Evans, Bullinger, & Hygge, 1998; Evans, Hygge, & Bullinger, 1995.)

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Reading

A standardized German reading test was employed (Biglmaier, 1969). The children read paragraphs and word lists of increasing difficulty. Some of the words in the lists were pseudowords, but phonologically appropriate in German.

Memory

On the first day, the children read a text in intermittent broadband noise at 80 dBA L_{eq}, and the number of lines read within the 12-min time limit was noted. On the second day, the children were tested for long-term memory (recall) in silence. We introduced noise exposure during encoding to make the task more difficult. Children's performance on this test is sensitive to acute noise exposure (Hygge, 1997). For the short-term memory test, strings of consonants were presented one per second over headphones. Randomly, the sequence was stopped, and the children were asked to write down as many consonants as they could remember, in the correct position, starting at the end of the sequence. Letters in the correct or adjacent positions were scored as correct. Acute noise is known to impair performance on this task (Hamilton et al., 1977).

Attention

Two indices of general attention were used: visual search and reaction time. The visual search task is sensitive to ventilation noise (Hygge, 1991) and chronic stress (Baum, Gatchel, & Schaeffer, 1983). For this task, the children were presented with 12 complex figures and 5 simple target figures and asked to identify which one of the target figures was embedded in each complex figure. In the reaction time task, the children responded to random occurrences of red and green lights by pressing two different buttons. The children performed this task first in a silent 5-min session and then in an equally long session with aircraft noise at 85 dBA L_{eq}.

Speech perception

The speech perception measure was adapted from Hygge, Rönnberg, Larsby, and Arlinger (1992). The children heard a story against different noise backgrounds (aircraft noise, road noise, and broadband noise) and used buttons labeled "+" and "-" to adjust the sound level of the story when it dropped randomly by 10 dBA. They were instructed to readjust the volume to the point where they could understand what was said if they concentrated. Noise-exposed children appear to ignore or tune out speech-relevant stimuli (Cohen et al., 1973, 1986; Evans & Maxwell, 1997) and are expected to require better signal-to-noise ratios than children who have not been exposed to noise.

RESULTS

Noise Levels

Noise levels were measured with a Brüel & Kjær (Copenhagen, Denmark) Community noise-level analyzer for a 24-hr period during data collection at the mobile laboratory. The expected changes in noise levels were observed at both airports (see Table 1).

Table 1. *Noise levels (24-hr dBA L_{eq}) before and after the airport switch*

Airport and group	Before switch (Wave 1)	After switch (Wave 3)
Old airport—aircraft noise	68	54[a]
Old airport—no aircraft noise	59	55
New airport—aircraft noise	53	62
New airport—no aircraft noise	53	55

[a]This number is an average from Waves 2 and 3 because there was only one observation in Wave 3, at a suspect value of 49.

Reading

On the word-list part of the reading test, only difficult words showed differences between the groups (see Fig. 1). The Airport × Group × Wave interaction was significant, $F(2, 252) = 5.10$, $p = .007$. (All F tests with repeated measures of wave were treated as multivariate analyses of variance, MANOVAs, rather than univariate analyses of variance, ANOVAs. These MANOVAs yield higher p values,

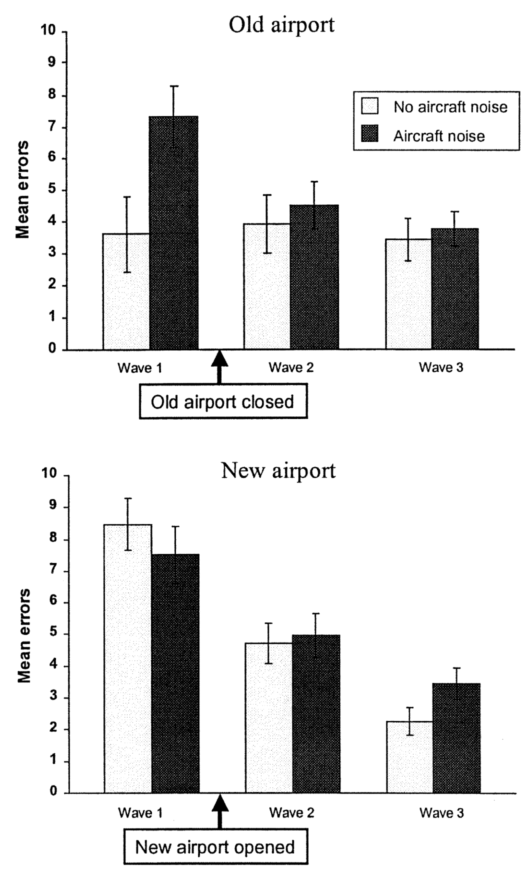


Fig. 1. Mean number of errors on the difficult word list as a function of airport, noise group, and measurement wave. Error bars show standard errors of the means.

and thus are more conservative, than the corresponding univariate epsilon-corrected Greenhouse-Geisser ANOVAs.) Separate *t* tests (two-tailed throughout, except as noted) showed a difference between groups at the old airport at Wave 1, $t(99) = 2.68$, $p = .009$, but not at Waves 2 and 3 (ts < 1). At the new airport, there was a marginal difference between groups at Wave 3, $t(154) = 1.80$, $p = .074$, but not at Waves 1 and 2 (ts < 1).

The results for the prose component of the reading test were similar to those for the word-list test, but not as marked. For the most difficult paragraphs (Numbers 8–12), there was a weak Airport × Group × Wave interaction, $F(2, 172) = 2.16$, $p = .118$ (see Fig. 2). Separate *t* tests revealed a difference between groups at the old airport at Wave 1, $t(82) = 2.79$, $p = .007$, but not at Waves 2 and 3 (ts < 1). At the new airport there were no significant effects.

Memory

On the long-term recall task (see Fig. 3), there was a significant Airport × Group × Wave interaction, $F(2, 311) = 4.25$, $p = .015$. Separate *t* tests showed a marginally significant difference between groups at the old airport at Wave 1, $t(104) = 1.88$, $p = .062$, one-tailed, but not at Waves 2 and 3 (ts < 1.28). At the new airport, there was a difference between groups at Wave 3, $t(208) = 2.72$, $p = .007$, but not at Waves 1 and 2 (ts < 1.12). For the number of lines completed, there were no noise effects.

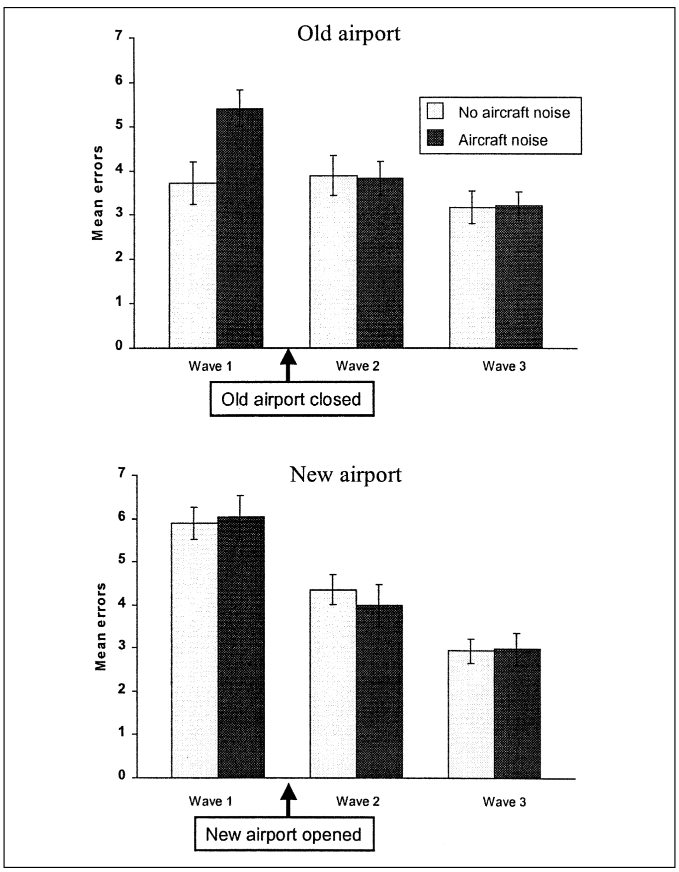


Fig. 2. Mean number of errors on the difficult paragraphs in the reading test as a function of airport, noise group, and measurement wave. Error bars show standard errors of the means.

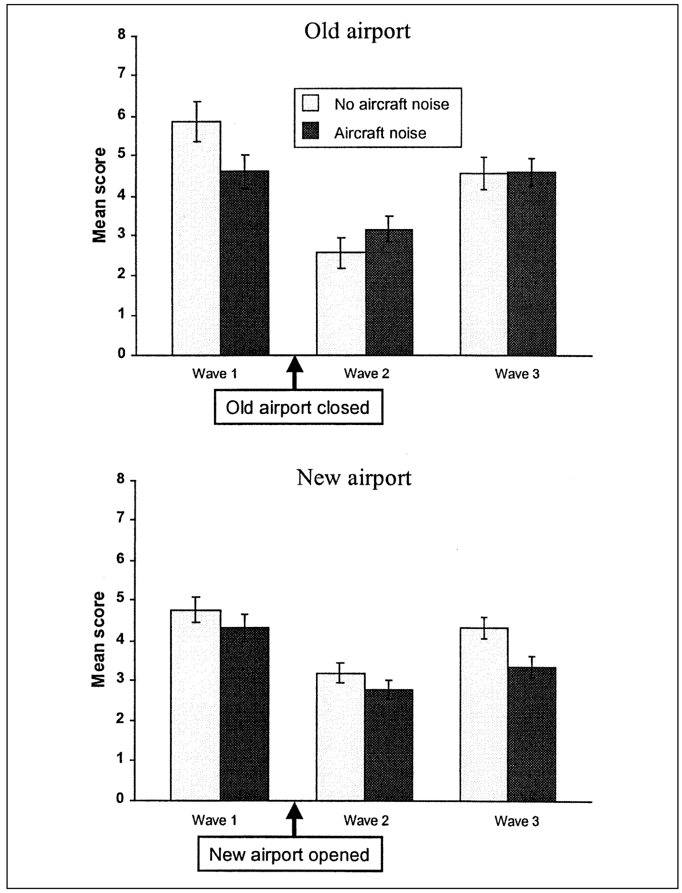


Fig. 3. Mean score on the long-term memory task as a function of airport, noise group, and measurement wave. Error bars show standard errors of the means.

At the old airport, the short-term memory test showed a significant Group × Wave interaction, $F(2, 203) = 5.97$, $p = .004$. The poorer short-term memory performance of the noise group recovered to reach the level of the control group's performance at Waves 2 and 3 (see Fig. 4). Separate *t* tests showed tendencies toward more correct responses in the no-noise group than in the noise group at Wave 1, $t(104) = 1.70$, $p = .092$; the difference was in the opposite direction at Wave 2, $t(104) = 1.63$, $p = .108$, and there was no difference between groups at Wave 3. At the new airport, there were no differences between the groups across the waves.

Attention

For the embedded-figures task, there were no reliable interactions involving chronic aircraft noise over time.

For the reaction time task, a MANOVA of reaction time and errors together yielded an Airport × Group × Wave interaction, $F(4, 179) = 5.58$, $p = .004$. Performing the task in acute noise or no noise did not qualify this interaction, and there was no main effect of acute noise, Fs < 1. Only reaction time, not errors, contributed to the interaction. The aircraft-noise group at the old airport was slower than its control group

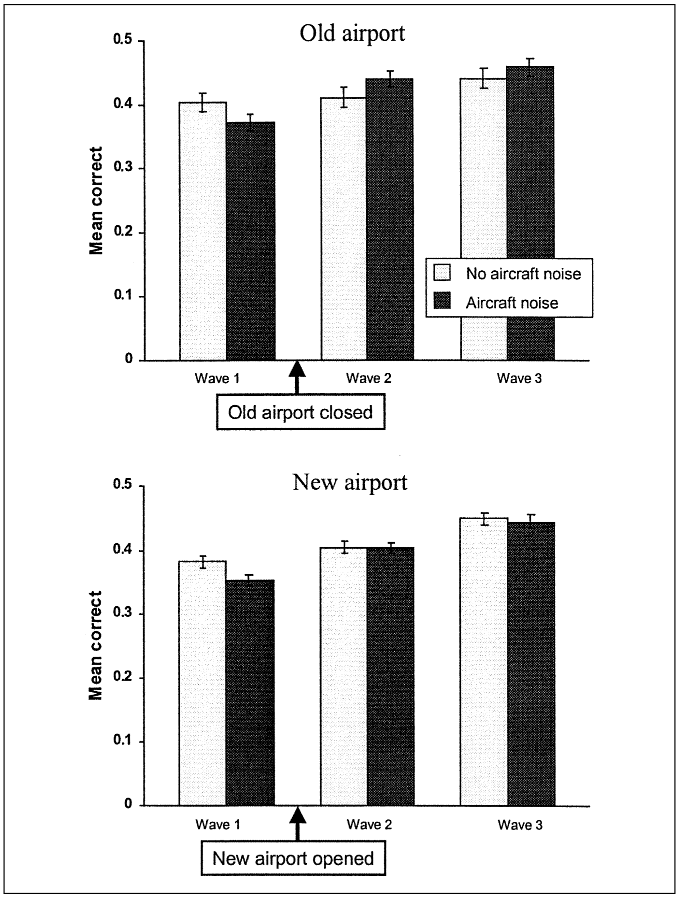


Fig. 4. Mean proportion of correct items on the short-term memory task as a function of airport, noise group, and measurement wave. Error bars show standard errors of the means.

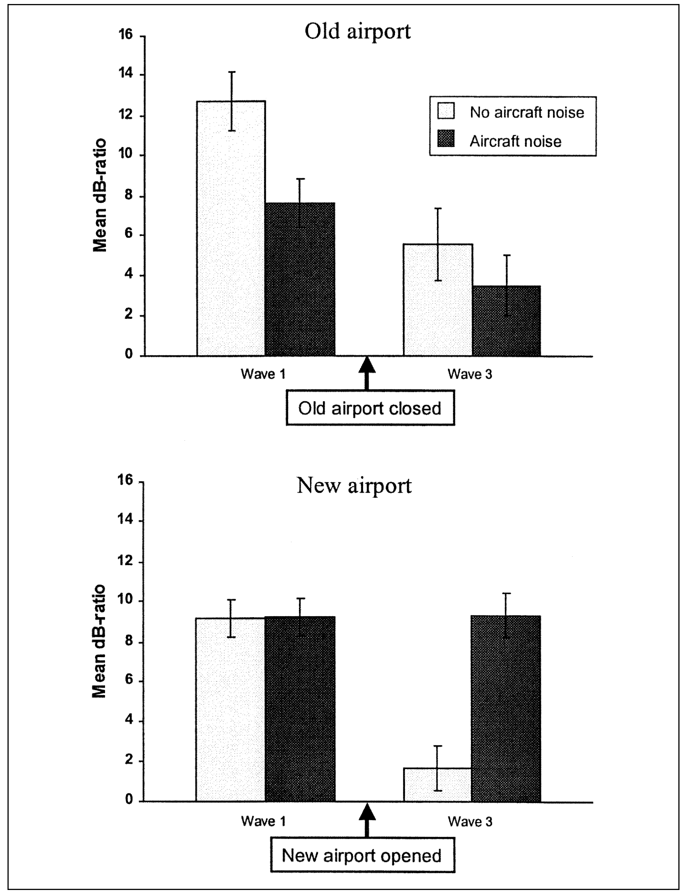


Fig. 5. Mean dB ratio of speech to noise on the speech perception task as a function of airport, noise group, and measurement wave. Error bars show standard errors of the means.

at Wave 2, $t(61) = 2.29$, $p = .026$, but not at the other waves (ts $<$ 1.34). At the new airport, the aircraft-noise group was slower than the no-aircraft-noise group at Wave 3, $t(121) = 2.09$, $p = .039$.

Speech Perception

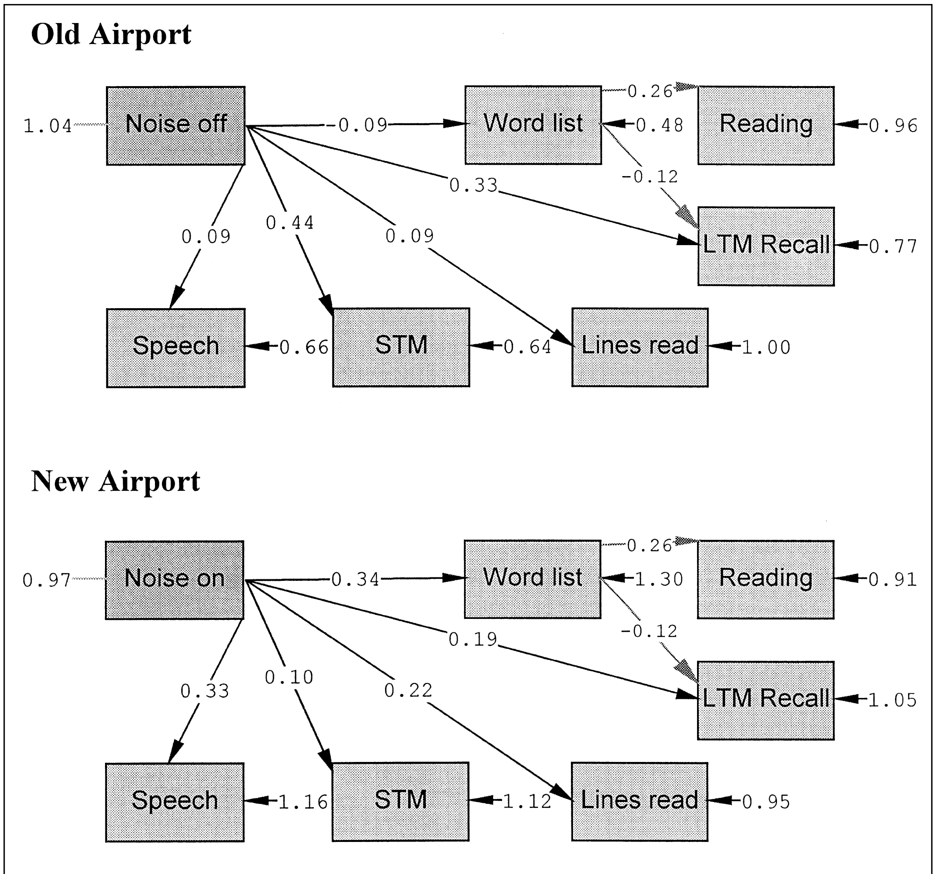
Because of apparatus failure and resulting low ns, data from Wave 2 on the speech perception task were discarded. As Figure 5 shows, speech perception improved from Wave 1 to Wave 3 at the old airport, but there was no differential improvement between the groups. At the new airport, the onset of aircraft noise seemed to block improvement in auditory discrimination from Wave 1 to Wave 3, as evidenced by the Group $\times$ Wave interaction, $F(3, 150) = 7.63$, $p = .000$.

Mediation

To probe for mediation, we entered into path analyses (LISREL; Jöreskog & Sörbom, 1996) the difference scores between performance in the last and first measurement waves for the paragraph reading task, the difficult word list, the long-term memory task, the number of lines completed, the short-term memory task, and the speech perception task. The results of these path analyses were straightforward and showed a very good fit between data from both airports and one of the models (see Fig. 6). Good fits were indicated by both a high p value ($>.05$) for chi-square and a low value of the root mean square error of approximation ($<.08$; Jöreskog & Sörbom, 1996). In this model, the noise effect on the reading tasks was not mediated by memory or speech perception. For long-term memory, there was a partial mediation by the word-list component of the reading task. For all the other tested variables in different combinations there were no indications of mediating links. The value of N in this analysis was low, mainly because of participants not finishing the difficult reading paragraphs in Wave 1. However, path analyses not including reading, and thus having a higher N, yielded path coefficients between the other variables that were of approximately the same strength as shown in Figure 6.

DISCUSSION

These longitudinal data complement nearly 20 cross-sectional studies showing adverse impacts of aircraft noise on reading in elementary-school children. Moreover, these effects occur prospectively and may be reversible. We have also demonstrated prospective impacts of chronic noise on long-term memory. More work is needed to determine the sensitivity of this effect to the duration of exposure, as well as children's age.



$\chi^2(30, \underline{N} = 116) = 31.25$, $\underline{p} = .40$, $\underline{\text{RMSEA}} = .027$.

Fig. 6. Model fit (chi-square and root mean square error of approximation, RMSEA) and standardized path coefficients between cognitive measures. The cognitive measures were calculated as difference scores between the last and first measurement waves for the difficult word list ("Word list"), the paragraph reading task ("Reading"), the long-term memory task ("LTM Recall"), the number of lines completed ("Lines read"), the short-term memory task ("STM"), and the speech perception task ("Speech"). The paths from Word list to Reading (0.26) and LTM Recall (−0.12), with values in smaller print, were constrained to be equal at the two airports.

This is also the first study to show prospective impacts of chronic noise on a cognitive process, long-term memory. Weaker evidence suggests noise-induced deficiencies in speech perception and short-term memory.

Reading and long-term memory effects replicated, disappearing when the old airport closed and emerging after the new airport opened. This provides strong causal evidence for the vulnerability of central language processing to noise exposure, and the reversible nature of the impact. Additional research is needed to see whether the adverse noise effects on reading and recall continue over time. Note that at the new airport the negative effects were stronger at Wave 3 than at Wave 2, which suggests a cumulative noise effect.

The speech perception findings warrant further research. Differences in speech perception did not mediate noise effects on reading. The lack of mediation is inconsistent with prior cross-sectional studies (Cohen et al., 1973, 1986; Evans & Maxwell, 1997). The present longitudinal data raise doubts about the validity of inattention, or "tuning out," as an explanatory mechanism for the adverse impacts of noise on reading performance.

Furthermore, although children's reading worsened with cumulative noise exposure at the new airport and recovered following noise cessation at the old airport, speech perception deficits among noise-exposed children at the old airport did not recover. This suggests that speech perception did not mediate the noise effects on reading, a conclusion that is also indicated by the structural equation results. An explanation for this pattern of results may be the developmental timing of the noise exposure. Perhaps noise exposure damages the development of speech perception in different ways during the early and late portions of the reading-acquisition period.

Future research needs to address the importance of both the developmental timing and the duration of noise exposure in determining the effect of noise on reading and cognitive development. Research also needs to sample a wider range of noise levels in order to generate a dose-response function for reading, which would provide additional basic evidence and better inform public policy for noise protection of children.

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