euronoise 2021
25th to 27th of October
Madeira, Portugal - online

Sentence comprehension and word recall in noisy classrooms: links with cognitive and noise-sensitivity measures

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Abstract
The theoretical framework of Ease of Language Understanding suggests that individual characteristics, both cognitive and personality-related, might modulate the effects of listening condition on the children's performance in complex tasks.
In this study we investigate the effect of competing speakers on children's accuracy and effort in a task combining sentence comprehension and word recall, and how children's performance relates to their cognitive functioning and noise sensitivity. A total of 95 children (aged 10 to 12 years) with normal hearing participated in the experiment. They completed the task in three listening conditions: quiet, two competing speakers, and four competing speakers. The signal-to-noise ratio was fixed at +5 dB. Children also performed tasks that gauged their executive functions and completed questionnaires to assess their noise sensitivity.
The outcomes of accuracy, perceived effort and motivation are used in the investigation. Cognitive and sensitivity measures are also included in the statistical modeling to evaluate if they can predict individual differences in children's performance.

Keywords: classroom acoustics, comprehension, recall, listening effort.

1 Introduction

School-age children spend almost 90% of their time at school listening to speech in the presence of background noise [1]. The ability to comprehend and recall complex auditory information in adverse listening conditions is crucial for children to achieve academic success and it is therefore important to understand how this ability is influenced either by extrinsic (i.e., listening condition) and intrinsic factors (i.e., individual characteristics).
Processing speech relies on general cognitive mechanisms and individual differences in cognitive abilities account for a significant portion of the variance in performance on speech tasks [2]. The theoretical framework of Ease of Language Understanding (ELU [3]) suggests that individual characteristics such as knowledge of language and cognitive skills (e.g., working memory and attention) might modulate the effects of listening condition on the performance in listening tasks. Research indicated that children with better working memory and language skills often have better speech recognition in noise than children with poorer working memory and language [4]. However, in [5] no association between speech perception in noise and working memory capacity was found for children with normal hearing. Studies with adults suggested that selective attention mediates the effect of noise on serial recall [6] and reading comprehension [7], and

children with low selective attention skills were found to be especially vulnerable to the effects of noise when performing a creativity task [8].
Another aspect that might influence children's speech processing and perceived effort in noise is their noise sensitivity (self-rated by questionnaires). Individuals with high noise sensitivity are believed to have a lower perceptual threshold and might be particularly impaired by the presence of background noise. In recent studies in open-plan study environments, noise sensitivity was found to be related to the disturbance of students by the background noise [9] and to mediate the effect of noise in a writing task [10]. However, to date, no studies have explored the association for school-age children.
This study aimed to explore two specific aspects, namely, whether and how (i) self-reported noise sensitivity and (ii) executive functions (i.e., selective attention and working memory) modulated the impact of listening condition on a complex speech processing task, independently or in conjunction with age. To the scope, we choose a task that was highly representative of the activities that children performed during lessons, namely comprehending the oral message and memorize (a part of) it.

2 Materials and methods

2.1 Participants

A total of 101 children from three different schools (five classes) in Ferrara (Italy) participated in the experiment. Six children diagnosed with intellectual disabilities were subsequently excluded. The final sample included 95 children, which were split in two age groups according to the grade: grade 5 (n=32; age: M=10.2, SD = 0.5 yrs; 16 female) and grade 7 (n=63; age: M=12.6, SD = 0.7; 28 female).
The study was approved by the school management; written information consent was obtained from the parents of each child involved in the experiment.

2.2 Measures

2.2.1 Executive functions: selective attention

Selective attention represents resistance to external distractors. It is an aspect of inhibitory control, that, as stated by Diamond [11] "involves being able to control one's attention […] to override a strong internal predisposition or external lure, and instead do what's more appropriate and needed". At the perceptual level, the inhibitory control enables to selectively attend a target, focusing on it and suppressing attention to other salient stimuli that attract the attention whether we want it to or not (e.g., a loud noise, a movement).
Selective attention was tested using child-friendly Simon and Flanker tasks. Both were programmed with PsyToolkit and presented in quiet via tablet.
In the Simon task, participants were presented with two visual stimuli and a simple rule: for stimulus A press on the left, for stimulus B press on the right. Only one stimulus appeared at a time; either stimulus could appear on the right or the left. There were 150 trials (50% congruent). Trials terminated after 4000 ms. In the Simon task location of the stimulus is irrelevant, but people tend to respond more slowly when the stimulus appears on the side opposite its associated response, as the tendency to respond on the same side of the stimulus has to be inhibited; this is termed as the Simon effect.
In the Flanker task the children saw a row of five letters and were asked to attend the centrally presented one (either pressing on the left or the right depending on the letter), ignoring the flanking stimuli surrounding it. There were 120 trials. Trials terminated after 3000 ms. In this task people tend to respond more slowly when there is a mismatch between the flanking letters response and the response required by the central letter (incongruent condition), due to the need to exercise top-down control.
For both the Simon and the Flanker tasks, RTs under 150 ms were excluded from the analysis (being too short to allow perception of the stimulus). Additionally, the Median Absolute Deviation criterion (MAD [12]) with a deviation of 2.5 units was used to detect and remove outliers. The difference between the average RTs in incompatible trials and the average RTs in compatible trials was used as a performance

measure. Participants were then sorted in two groups ("low" and "high") based on the median score of the sample for each test.

2.2.2 Executive functions: working memory

In this study verbal working memory (WM) was tested using a 2-back task. The 2-back task is a continuous recognition task in which participants must decide whether a stimulus was previously presented or not. A sequence of four different letters (A–D) was shown and for each item children must determine whether the letter shown was identical to the stimulus presented 2 trials back. Participants had to tap on the tablet whether the response to the trial was "yes". There were 60 trials (30% were correct) which were presented in random order. The task was programmed with PsyToolkit and presented to the children collectively in quiet. Task performance was assessed using the discrimination index *d'* [13], which is a composite index calculated from hits (i.e., participant correctly touch the device in response to a target) and false alarms (i.e., participant incorrectly touch the device in response to non-targets). The better the participant maximize hits (and thus minimizes misses) and minimizes false alarms (and thus maximizes correct rejections) the better the discrimination index, and the better the participant is able to discriminate target from non-target when performing a task. Participants were then sorted in two groups ("low" and "high" WM) based on the median score of the sample.

2.2.3 Noise sensitivity

Noise sensitivity was assessed using a reduced Italian version of the Weinstein Noise Sensitivity Scale (WNSS [14]). The children had to indicate their agreement on five statements related to their sensitivity to noise. For each statement, the level of agreement could be chosen on a 5-point scale (from 1 "not at all" to 5 "very much"). The noise sensitivity questions were part of a broader questionnaire, implemented in Google Forms and presented to the students one week after the experimental task.
To derive a single "Noise Sensitivity Scale" (NSS) score, the score of the last statement was flipped to match the direction of the others (i.e., higher scores imply a higher sensitivity to noise) and the average of the scores over the five statements was calculated. Participants were then sorted in two groups ("low" and "high" noise sensitivity) based on the median score of the sample.

2.2.4 Comprehension and recall task

The experimental task assesses both the listener's ability to comprehend a sentence in noise and his/her ability to memorize and recall the words previously heard.
For each listening condition, 15 sentences were aurally presented to the participants. The sentences were split in three blocks, in which the sentences were counterbalanced by syntactic complexity. For each trial, participants listened to the playback of a sentence. Then, at the audio offset, two images appeared on their tablet and they had to select the image that best matched the sentence content (Figure 1a). After a block (five comprehension trials), children were asked to perform a recall task, selecting the three words previously heard among a set of six alternatives displayed on the tablet (Figure 1b). The recall task was time-limited to 20 seconds and always performed in quiet.
Accuracy and RTs (defined as the time elapsing between the end of the audio playback and the moment an answer was selected) were recorded for each sentence in the comprehension task. Recall performance was measured as the number of words correctly recalled of the nine presented in a listening condition.

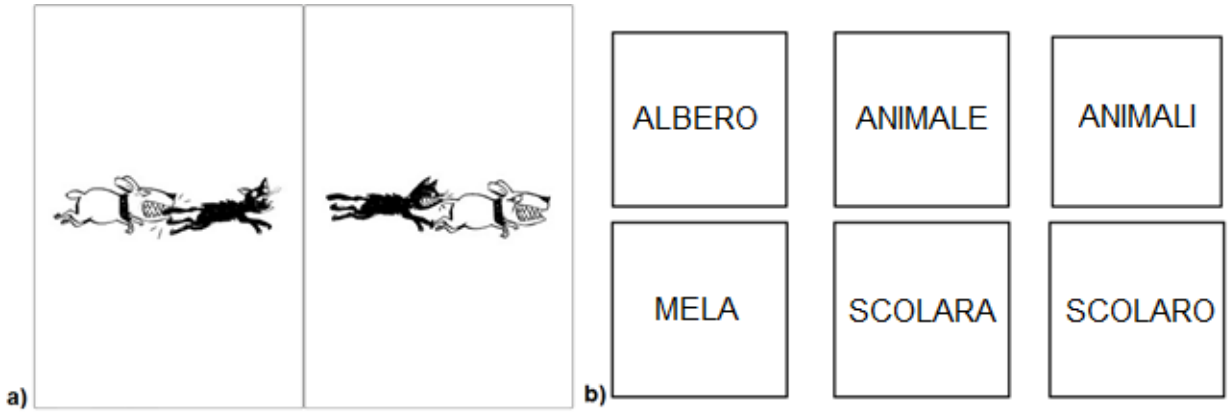

Figure 1 – (a) Example of a set of images in the comprehension task. The target sentence was "Point to the cat that bite the dog". (b) Example of six words presented for the recall task.

2.2.5 Self-ratings

The self-ratings of effort and motivation were measured following the completion of the experimental task in a given listening condition. The following questions were formulated:

- How hard did you have to work to understand the previous sentences?
- How hard did you have to work to recall the words?
- How important was it to you to perform well in the task?

Visual analog scales were used to collect the responses. Participants responded to the questions in the same order, using a slider bar with values ranging from 0 to 100 in increments of 1. The slider was initially positioned on the midpoint of the scale. Verbal anchors ("Not at all", "Extremely") were positioned at each endpoint of the slider bar.

2.3 Listening conditions

The experimental task was presented in three listening conditions: quiet, two competing talkers, and four competing talkers.

In quiet, no background noise was played back and the speech signal was presented in anechoic conditions (frontal talker).

To obtain the conditions with competing talkers, three girls and a boy (aged 7 to 11 years) were recorded individually in an anechoic chamber while reading aloud passages from different age-appropriate books. The individual anechoic recordings were normalized and convolved with the BRIRs simulated in a virtual classroom. The classroom had a volume of 256 m^3, a reverberation time at the medium frequencies equal to 0.73 s and as simulated in the room acoustic modelling program ODEON. In the classroom, the receiver was positioned in the centre of the area where students usually sit, and the competing talkers surrounded it, at nearly 1.5 m of distance (Figure 2). The anechoic recordings of the children were then convolved with the BRIRs in positions S1 and S3 to obtain the condition with two competing talkers, and with the four BRIRs to obtain the condition with four competing talkers. The anechoic recording of a female speaker reading the target material of the comprehension task were convolved with the BRIR simulated at the teacher position, close to the end of the classroom.

In all conditions the speech level was set to 60 dB(A). The background noise level was set to 55 dB(A), so as to obtain a signal-to-noise ratio (SNR) of +5 dB. This SNR is representative of the acoustic conditions in actual classrooms and guarantees an uncompromised speech signal audibility.

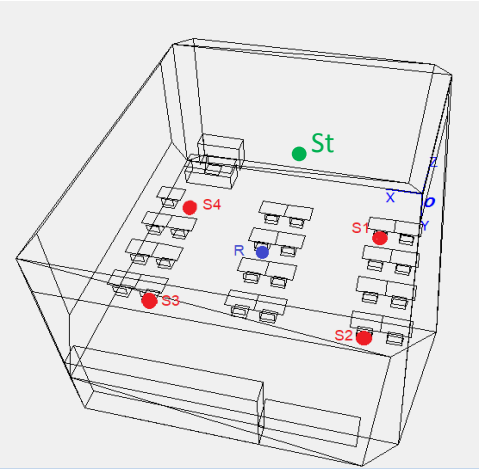

Figure 2– Virtual model of the classroom with the positions of the talker (St), the receiver (R), and the two (S1 and S3) and four (S1–S4) competing talkers.

2.4 Procedures and data analysis

A repeated-measures design was used in the study, with all children performing the comprehension and recall task in the three listening conditions. Children took part in the experiment as a whole class, and the tasks were administered collectively in the classroom in which they usually have lessons. They completed the experimental task in one session, and the FE tasks and the noise sensitivity questionnaire in a second session, one week later. All tasks were completed using tablets; noise and signals were delivered via headphones (Sony MDR-ZX310).
Generalized linear mixed-effects models (GLMMs) were used for the statistical analysis, using the *R* software and the *lme4* package. In the models listening condition (quiet, two talkers, four talkers), grade (grade 5, grade 7), Simon and Flanker performance, working memory and noise sensitivity were included as fixed effects. The participant and item variables were included as random intercept; moreover, the listening condition was included as a random slope allowing for the possibility that the effect of the acoustic conditions could affect differently each participant.

3 Results

3.1 Sentence comprehension performance

In Figure 3 the percentage of correct responses for the sentence comprehension task is reported. The analysis revealed a significant interaction between listening condition and selective attention as assessed by the Simon task ($\chi^2(2)=11.82$, $p = 0.003$), a significant interaction between grade and selective attention, as assessed by the Flanker task ($\chi^2(1)=6.99$, $p = 0.008$) and a significant three-way interaction between listening condition, grade and selective attention, as assessed by the Flanker task ($\chi^2(2)=6.66$, $p = 0.036$).
Pairwise comparisons for the interaction between listening condition and selective attention as assessed by the Simon task revealed that children with low selective attention control had a worst performance in the two-talker condition than in quiet or in the four-talker condition (two-talkers < quiet: z=-3.31, p = 0.008; two-talkers < four talkers: z=-2.78, p=0.022); no difference was found between the quiet and the four-talkers conditions. In other words, children who were sensitive to incongruent distractors at the Simon task were also impaired by the presence of an intelligible background noise in the comprehension task. In contrast, there was no significant difference in performance between the listening condition for children with high selective attention.

Pairwise comparisons for the three-way interaction revealed a significant drop in the comprehension performance for the children with a low score in the Flanker task compared to the children with a high score (low < high: z=-2.87, p=0.048), but only for the students of grade 5 in the quiet condition.

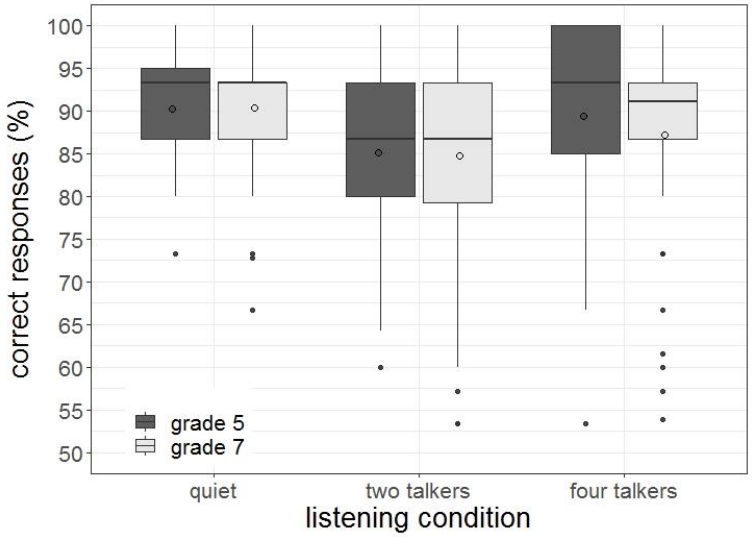

Figure 3 – Percentage correct responses by listening condition and grade, for the sentence comprehension task.

3.2 Word recall performance

The number of words correctly recalled by listening condition and grade is shown in Figure 4. The analysis revealed a significant effect of the working memory, as measured by the 2-back task ($\chi^2(1)=3.82$, p = 0.048). The result indicates that children with a low working memory capacity recalled significantly less words than children with a high working memory capacity (mean difference: 0.45). No significant effects of either listening condition and grade, or the other cognitive variables were found.

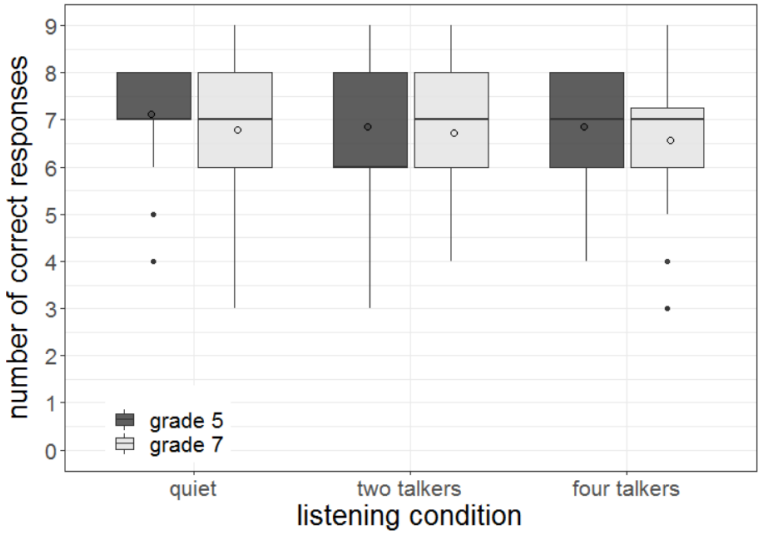

Figure 4 – Number of words correctly recalled (out of nine) by listening condition and grade.

3.3 Self-ratings of effort and motivation

The self-ratings of effort are displayed in Figure 5 for the two tasks of sentence comprehension and word recall. Regarding the former task, the analysis revealed a significant main effect of the listening condition ($\chi^2(2)=11.16$, $p = 0.004$) and the grade ($\chi^2(1)=7.33$, $p = 0.007$). Pairwise comparisons indicated that younger children tended to report a higher perceived effort then children of grade 7, in all listening conditions (mean difference = 14.8). Moreover, when results were averaged over grade, pairwise comparisons indicated that children reported higher effort in the two-talkers condition than in quiet (p=0.007; mean difference: 15.5). No difference was found between the two noisy conditions (p=0.07).
Regarding the word recall task, no significant effect of the explanatory variables was found on the effort ratings.
Figure 6 displays the self-ratings of motivation. The analysis revealed a significant interaction between the listening condition and the working memory ($\chi^2(2)=10.59$, $p = 0.005$). Pairwise comparison revealed that children with a low working memory self-reported a higher motivation in the quiet and the four-talkers condition compared with the two-talkers condition (quiet > two-talkers: z=3.19, p=0.013; four-talkers > two-talkers: z=3.03, p=0.013). No difference in motivation between the listening conditions was found instead for the children with high working memory capacity.

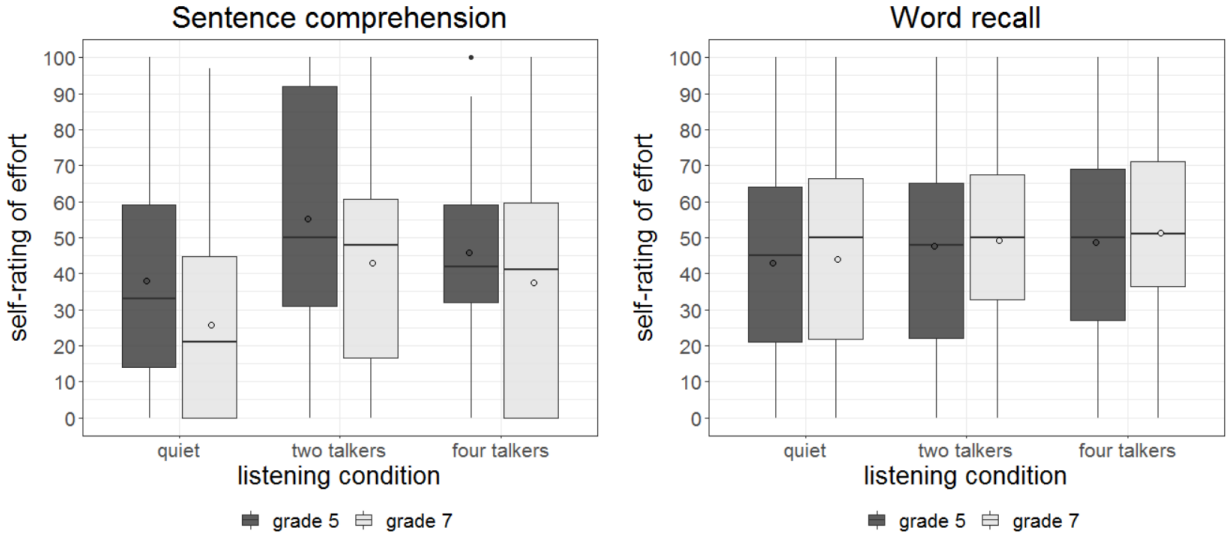

Figure 5 – Self-ratings of effort by listening condition and grade: (left) sentence comprehension task, and (right) word recall task

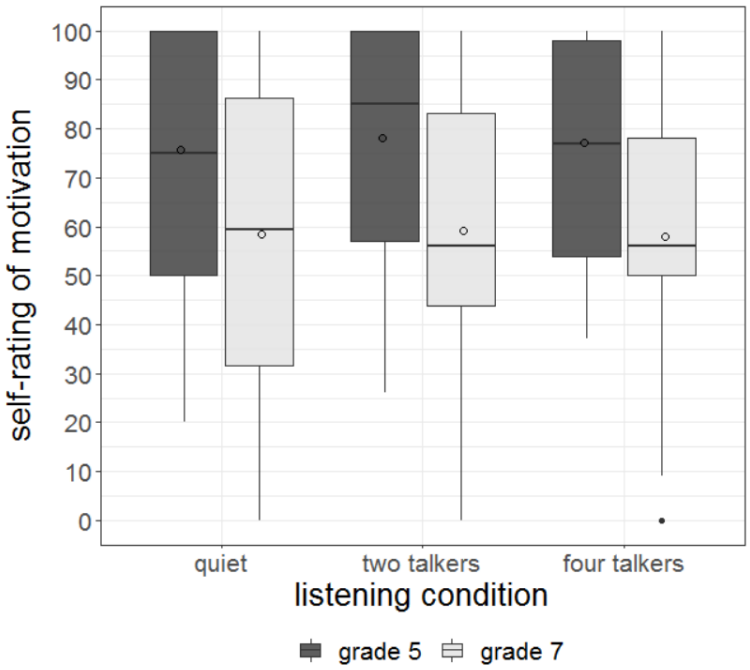

Figure 6 – Self-ratings of motivation in performing the task, by listening condition and grade

4 Discussion

In this study, children of grade 5 and 7 completed a sentence comprehension and recall task in quiet and two noisy conditions. A behavioural assessment of both working memory and selective attention was performed, and questionnaires on noise sensitivity were completed by the children. These individual characteristics were included in the data analysis to understand whether and how they might modulate the effect of background noise on the task performance and self-reported effort and motivation.

Similarly to the results with adults in [7] and with children in [8], in our sentence comprehension task selective attention but not working memory mediated the effect of noise. Children experiencing more interference in the Simon task had a poorer performance in the listening condition with more informative masking (i.e., two-talker condition) compared with quiet and the four-talker condition. Differently, for children with better selective attention there was no difference between the three listening condition, suggesting that the individual ability to resist external distractors mediates the comprehension of the aurally presented message in a noisy context such as the classroom.

It is worth noticing that no mediation effect of the cognitive abilities on listening conditions was found for the recall task, either for performance or self-ratings of effort. Given the near-ceiling performance of the children in the task, which was independent on the listening condition and the grade, it might be hypothesized that the task was easy enough for all of them to prevent observing an effect of the individual abilities.

Interestingly, a significant interaction was found between listening condition and working memory in the self-rating of motivation. This subjective assessment was included in the study as the listener's motivation is thought to modulate the listening effort. That is, the stronger a listener's motivation, the more willing he/she will be to put effort into the task, irrespective of its demands. Our results reveal that children with low working memory might be less motivated in performing a task in more challenging listening conditions (i.e, two concomitant talkers) compared to quiet or a background noise condition with a less informative masking. Differently, children with high working memory do not report any difference in the motivation related to the listening condition. Exploring the motivation dimension in the classrooms is important in the view of setting up appropriate acoustic design and teaching strategies. An appropriate design and/or teaching

methodology can increase the listener's motivation to continue listening, even in the presence of a high acoustic challenge, thus helping to maintain the effort and avoiding disengagement from the task [15,16].
Finally, no significant influence of the noise sensitivity of children was found on their task performance or self-ratings. Other studies with adults found no correlation between cognitive performance and noise sensitivity (e.g. [17]), and the reason was attributed to task engagement and difficulty which would shield performance from the effect of background noise. An alternative explanation was formulated in [18], in which noise sensitivity was found to modulate the effect of background speech on cognitive performance. In particular, the Authors hypothesized that the WSNN scale (the one used also in the present study) was not specific enough to be substantially related to measures of performance, suggesting instead the use of more specific questionnaires to assess noise sensitivity. More research is warranted to understand whether the absence of mediation effects observed in the present study for school-age children is related to the scale chosen for the assessment of noise sensitivity or to the task (type and difficulty).

5 Conclusions

In this study we explored the mediation effect of individual characteristics (noise sensitivity and cognitive abilities) on the impact of listening conditions on a comprehension and recall task, for school-age children. Consistent with the ELU model, our results revealed that children with lower cognitive abilities might be especially vulnerable to the effect of an informative noise, even though it is presented at a favourable SNR. The effect was apparent on both the performance in the sentence comprehension task and the self-ratings of motivation to perform the task. Differently, no effect of the self-rated noise sensitivity was found for all the outcomes considered.
The present findings add to the existing literature showing that cognitive abilities (and selective attention in particular) improve performance on complex listening tasks. Moreover, this is one of the first studies exploring the dimensions of motivation in relation to complex listening task, with reference to the school-age population. Futures studies might help shed light on the mechanisms underling this dimension, which could be crucial to avoid disengagement of children from the attended lessons.

Acknowledgements

The authors would like to thank Maria Garraffa (Heriot-Watt University, UK) and Alberto Di Domenico (University of Chieti, Italy), who developed and provided the materials for the experimental tasks, and Stefano Uccelli (University of Parma, Italy), who developed the tasks for the assessment of the executive functions. The children and the teachers from the I.C. Cosmè Tura and the I.C. F. De Pisis in Ferrara are also gratefully acknowledged for their role in the study.

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