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# NOISE PERCEPTION AND COGNITIVE EFFORT IN THE NEW CIVIC CENTRAL LIBRARY OF TORINO

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## ABSTRACT

The transformation of libraries into multifunctional hubs for social, cultural, and academic activities has introduced significant challenges in managing their acoustic environments. Noise perception and its impact on cognitive tasks of occupants have become critical areas of investigation. This study examines the noise perception and the cognitive effort in the historical New Civic Central Library of Torino (Italy). A geometrical acoustic simulation was performed using Odeon 18 at two receiver positions in the middle of the library, accounting for various noise sources. The library, with a volume of about 160,000 m³ and a mid-frequency reverberation time of approximately 6 seconds, is protected by cultural heritage authorities. Simulated noise sources included traffic, ventilation, ambient buzz from occupied areas, footsteps, page-turning, pens, and syntactically correct but semantically meaningless sentences. Noise levels at the receiver was between 44.9–45.4 dB(A). Subjective tests were conducted on 12 participants (20–55, normal hearing) to evaluate the impact of noise and reverberation on their noise perception and cognitive effort.

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**Keywords:** *noise perception, cognitive effort, library*

## 1. INTRODUCTION

In recent years, libraries have shifted from being solely quiet study areas to multifunctional spaces hosting social, cultural, and collaborative activities [1]. This shift highlights the need for a deeper understanding of their acoustic environment, focusing on noise perception, user well-being, and cognitive impact [2]. Spatial layout and surface materials play a key role in sound propagation, acting as absorbers or diffusers. Various noise sources — such as conversations, footsteps, electrical equipment, HVAC systems, doors, electronic devices, and external traffic — can raise noise levels up to 60 dBA [3, 4]. Reflective surfaces like wood floors, stone, plaster, and glass contribute to longer reverberation times, intensifying overall noise. To address the gaps in the current understanding of library acoustics, this study proposes to answer the following research questions: What is the impact of noise in multifunctional libraries on tasks which require concentration? What is the impact of high reverberation time in a crowded library?

## 2. METHODOLOGY

### 2.1 Case study

This study focuses on the acoustic environment of the New Civic Central Library of Torino, under renovation. Built in 1938, the library aims to blend its traditional study and research function with a modern role as a social, digital, and cultural space. The design features various areas as the ground floor, that offers formal and informal study spaces, the apsidal area, overlooking Valentino park and including a children's section, the basement houses an archive and a reading space surrounded by flowers and trees, the upper floor provides areas for collaborative study.

### 2.2 Acoustic simulation

#### 2.2.1 *3D GA model of the library*

The three-dimensional Geometrical Acoustics (GA) model of the New Civic Central Library of Torino used for the simulations was developed with Odeon 18 software [5]. Once the 3D model was completed, materials were assigned to each surface based on the renovation project, incorporating typical library finishes such as plaster, glass, carpet, and bookshelves, along with their corresponding octave-band absorption and scattering coefficients. The scattering coefficient was set uniformly low to keep most surfaces specularly reflective, except for the vertical surface near the apse, which is covered with sound-absorbing plaster. Acoustic simulations were performed using a transition order of 2 and 50,000 rays to ensure accurate sound propagation. The reverberation time (T30) varied by frequency, showing prolonged decay of about 8.5 s at 125 Hz and shorter decay of about 5 s at 1 kHz. However, potential acoustic enhancements are constrained by heritage protection regulations, as the building is designated as a historical monument.

#### 2.2.2 *Sound sources and receivers*

The sound sources in the Odeon 18 GA model were placed as follows:

- S1: ventilation system, represented as one surface source distributed over the entire floor area.
- S2: ventilation system, represented as two linear sources simulating the ceiling diffusers, 8.4 m high above the floor.
- S3: traffic noise, represented as a surface source divided into 3 sub-areas (3A, 3B, 3C) on the roof of the building.
- S4: unintelligible buzzing considered as surface source above the tables, at the level of about 1.2 m above the floor, that is the hypothetical speaker's mouth.
- S5: intelligible buzzing, represented as omnidirectional point source representing intelligible buzzing with one person talking as in a conversation, or with one person saying equivalent intelligible phrases. Equivalent intelligible 5-sentences phrases from the Matrix Sentence Test [6] are activated instead of the intelligible buzz source when placed close to the receivers.
- S6: omnidirectional point source of noise coming from flipping pages, pens and notifications from personal devices.
- S7: array of 35 omnidirectional point sources representing footsteps, that simulate a person going down the stairs quickly.
- S8: array of 14 omnidirectional point sources representing footsteps, that simulate a person walking slowly inside the library.

The receiver R1 sit 1.2 m high from the floor, overlooking the balcony, close to the underground courtyard named "Enchanted Garden". Receiver R2 stands 1.6 m from the floor, in the center of the exedra.

To simulate the overall sound pressure level at the receivers' positions, octave band sound power level (SWL) and directivity index (DI) have been attributed to each sound source. In order to perform the auralization of the different sound source with an anechoic signal, the frequency dependent SWL has been flattered in frequency, maintaining the same overall energy. To this scope the average sound power was calculated for each source and converted to decibel using the following formula, to obtain the average sound power level (ASWL) for each octave band:

$$ASWL = 10\log\left(\frac{1}{N}\sum_{i=1}^{N}10^{\frac{SWL_i}{10}}\right) \quad (1)$$

where $N$ is the number of octave bands and $SWL_i$ is the sound power level for each band in decibel.

A-weighted SPL has been simulated for each source receiver pair. The resulting A-weighted SPL are shown

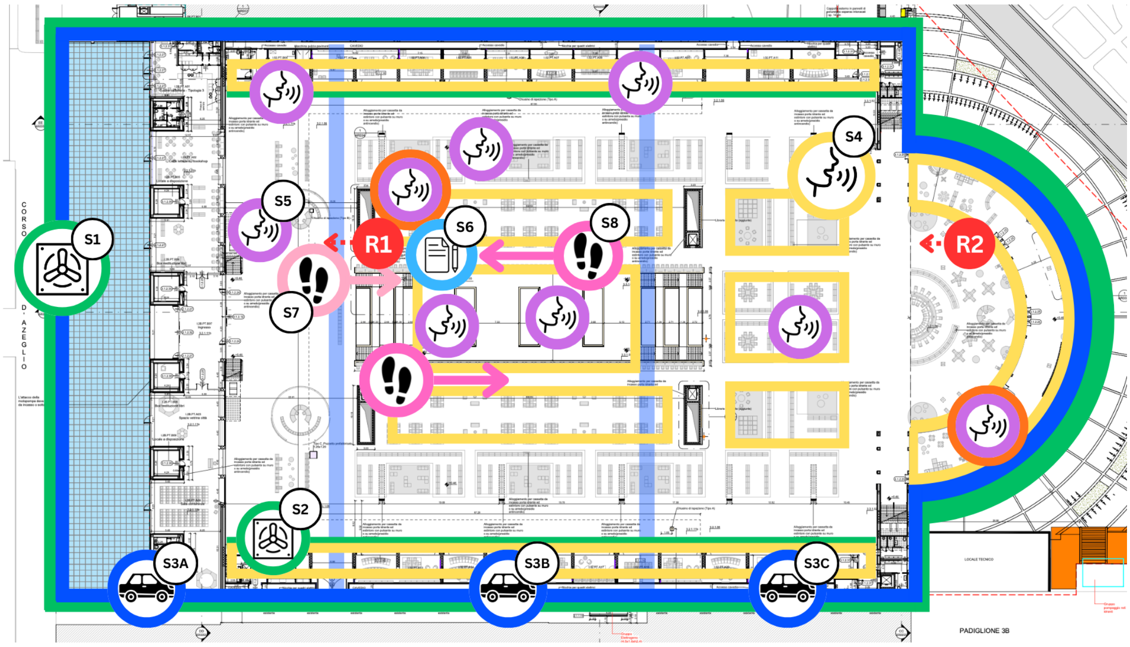


**Figure 1**. Plan of the reading room of the New Civic Central Library of Torino with sources and the receiver. The orientation of the receiver is indicated with a red arrow. Traffic is shown as blue surface source, subdivided in 3 areas. HVAC is shown both as green surface source and two multiple line sources. Unintelligible buzz is shown as yellow surface source. Intelligible buzz is shown as purple point source. Equivalent sentences are shown as orange point source and are activated instead of the intelligible buzz purple source when placed close to the receivers. Footsteps are shown as multiple pink and fuchsia multiple point sources. Noise from pens and pages is shown as light blue point source.

in Table 1. It is worth mentioning that the overall A-weighted SPLs of all the sources simulated with the original non-flat spectrum differ by less than 1.3 dB from those obtained using the flat spectrum. The overall A-weigheted SPL calculated for R1 and R2 are 44.9 dB and 45.1 dB, respectively. These levels are in agreement to the SPL(A) measured by the Authors in the Main Reading Room of the Richelieu and the Beaubourg Library, which is equal to 47 dB for both of them.

### 2.2.3 *Auralisation*

In Odeon 18, binaural auralisation was performed by HRTF-based convolution of anechoic recordings with room impulse responses. Sennheiser HD600 headphones were used to listen the auralised files. The equalisation filter for the headphones provided by Odeon 18 has been applied to flatten their frequency response. The playback level was calibrated using a dummy head in anechoic chamber. Binaural impulse responses (BRIRs) for each receiver were convolved with corresponding anechoic tracks, producing two-channel signals calibrated to simulated A-weighted SPL levels. To generate complete audio mixes for each receiver, individual sounds were inserted at staggered time intervals using a structured scheme. Six mixes per receiver were created, each three minutes long and divided into 20-second segments, with different sounds assigned based on a time-distribution matrix. This allowed to vary the temporal distribution of sounds across mixes while keeping energy content consistent.

### 2.2.4 *Subjective tests*

The tests were conducted in an anechoic chamber at Politecnico di Torino, with 12 participants (mean age 31.6) wearing headphones for each receiver position. Each of them listened to six audio files simulating sound environ-

**Table 1**. A-weighted SPL for each source and for all the sources vs each receiver from the 3D GA model in Odeon 18.

| No. | Name | Type (N) | SPL dB(A) | |
|---|---|---|---|---|
| | | | R1 | R2 |
| 1 | HVAC | Surf. (1) | 18.1 | 27.7 |
| 2 | HVAC | Line (2) | 18.4 | 11.4 |
| 3a–c | Traffic | Surf. (1) | 38.9 | 35.6 |
| 4 | Buzz (unintell.) | Surf. (1) | 34.6 | 43.9 |
| 5 | Buzz (intell.) | Point (8) | 35.3 | 25.9 |
| | Sentences | Point (2) | 36.1 | 36.9 |
| 6 | Pages, pens | Point (1) | 28.2 | 7.1 |
| 7 | Stairs steps | Point (35) | 37.8 | 26.5 |
| 8 | Walking steps | Point (14) | 38.1 | 25.7 |
| All | All sources | – | 44.9 | 45.4 |

ments from the receiver perspective. The survey included a noise disturbance test followed by six cognitive tasks, performed by each participant both in noise and in silence using equivalent test versions (A and B) in counterbalanced order. Each task lasted 2.5 minutes, preceded by a one-minute training, and followed by a 5–10 minute break. The disturbance test assessed the perceived annoyance of library-like noise. Participants rated the disturbance of the reproduced noise on a discrete scale of 0 ('not annoying') to 10 ('extremely annoying').

### 2.2.5 *Cognitive tasks*

The cognitive tasks included:

- Task A: Silent reading of a 15-word list from the "Rey's 15-Word Test" [7].
- Task B: Reading aloud a passage, where reading speed was calculated by dividing the total time by the number of syllables, and errors were recorded [8–13].
- Task C: Trail Making Test (TMT), where participants have to connect randomly arranged numbers (TMT version A) or alternating numbers and letters (TMT version B) in ascending order to measure processing speed [14].
- Task D: Semantic Verbal Fluency (SVF) test, where participants generate as many words as possible from a given category [15].
- Task E: Open-source Open-access Reaction Time Test (OORTT) using OpenSesame [16], where participants respond to a visual stimulus by pressing a button.
- Task F: Verbally recalling the words presented in Task A.

### 2.2.6 *Statistical analysis*

Box plots were generated to visually represent the distribution of data and to compare variables, highlighting the mean, median, dispersion, and presence of outliers. The Mann–Whitney U test [17] is a non-parametric test used for comparing two group of independent samples of equal or different sample sizes. It was applied with a p-value threshold of 0.05, to evaluate if differences occurred between the samples which answered for the two receivers to the noise disturbance tests. The Wilcoxon test for paired samples [18], with a p-value threshold of 0.05, was applied to investigate significant differences from the cognitive tasks performed under noise and quiet condition for each receiver.

## 3. RESULTS

Figure 2 shows the results of the noise disturbance test. An average annoyance score of 5.0 (s.d.= 2.0) and 4.0 (s.d.= 2.7), on a scale from 1 to 10, is shown, for R1 and R2, respctively, suggesting a slight perception of disturbance for R1, while a lower disturbance was experienced for R2. However, the Mann–Whitney U test revealed no differences among the distributions of the two receivers (p-value equal to 0.31).
Table 2 shows the mean value and standard deviation of the scores for the different cognitive tasks, while Figures 3 -9 show the boxplots generated to visually represent the distribution of data and to compare the results.

Figure 3 shows the boxplots related to the distributions of the answers for Tasks F connected with A. Results highlight that the number of recalled words slightly increased in quiet conditions for both the receivers. Overall, better results were obtained in R2 than in R1. For this task Wilcoxon test did not reveal statistical significance when comparing the noise and quiet conditions, with a p-value of 0.75 and 0.58, for R1 and R2, respectively. Figure 4 and Figure 5 show the results obtained for the Task B, related to the errors and the speed scores made in reading the passage, respectively. Both receivers performed slightly better in quiet and overall R2 performed better than R1. Wilcoxon test did not reveal statistical significant differences when comparing the noise and quiet conditions for R1, with a p-value equal to 0.10 for the errors and to 0.13 for the speed score, and for R2, with a p-value equal to 0.32 for the errors and to 0.08 for the speed score. Figure 6 and Figure 7 show the boxplots of the distribution of the answers related to the time taken to complete Task C.

**Table 2**. Mean score (m) and standard deviation (sd) for the cognitive tasks.

| **A** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 7.3 | 3.9 | 9.7 | 3.3 | 11.2 | 1.7 | 12.5 | 2.4 |
| **B - errors** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 3.2 | 2.2 | 1.8 | 1.5 | 1.3 | 1.5 | 1.0 | 1.5 |
| **B - speed score** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 0.2 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 |
| **C - TMT-A** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 31.2 | 7.9 | 25.5 | 5.0 | 29.7 | 10.8 | 27.5 | 9.7 |
| **C - TMT-B** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 58.3 | 11.6 | 55.8 | 17.3 | 49.3 | 16.8 | 41.2 | 14.6 |
| **D** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 17.3 | 4.0 | 21.5 | 4.7 | 21.2 | 3.1 | 22.8 | 12.2 |
| **E** | | | | | | | |
| **noise R1** | | **quiet R1** | | **noise R2** | | **quiet R2** | |
| **m** | **sd** | **m** | **sd** | **m** | **sd** | **m** | **sd** |
| 318.8 | 54.9 | 308.8 | 73.2 | 282.2 | 32.5 | 266.7 | 25.9 |

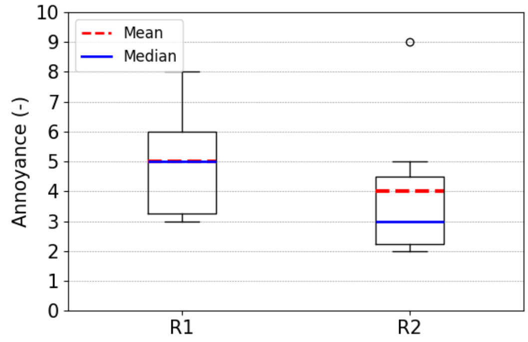


**Figure 2**. Results of the noise disturbance test - annoyance.

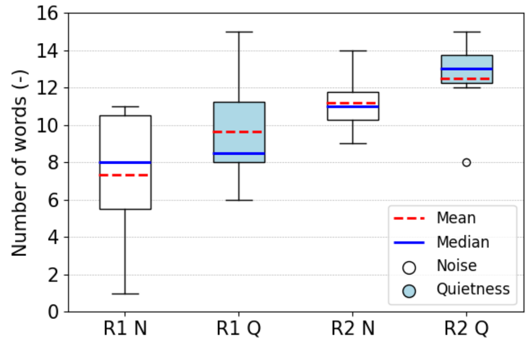


**Figure 3**. Number of words recalled in Task F connected with Task A.

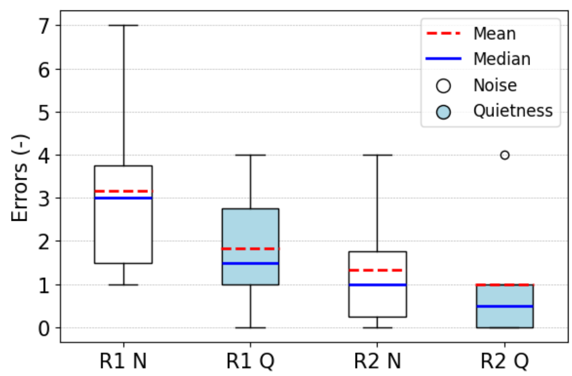


**Figure 4**. Number of errors depicted in reading a text aloud during Task B.

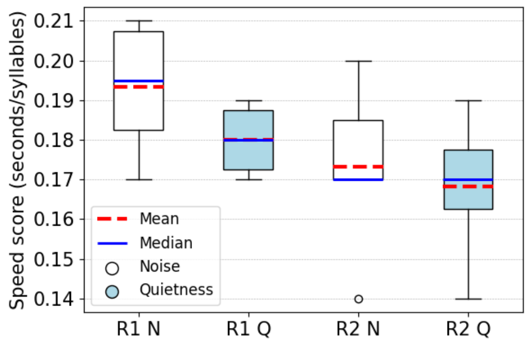


**Figure 5**. Speed scores obtained in reading a text aloud during Task B.

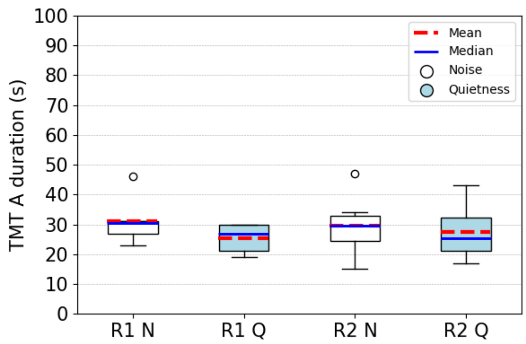


**Figure 6**. Time taken to complete the Trail Making Test version A during Task C.

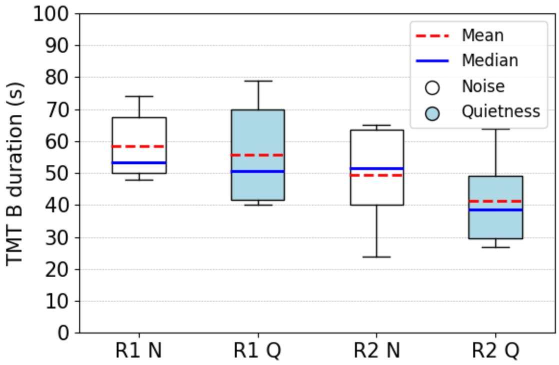


**Figure 7**. Time taken to complete the Trail Making Test version B during Task C.

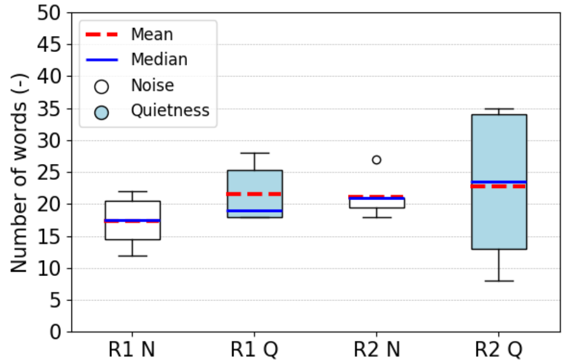


**Figure 8**. Number of words collected in Semantic Verbal Fluency Test during Task D.

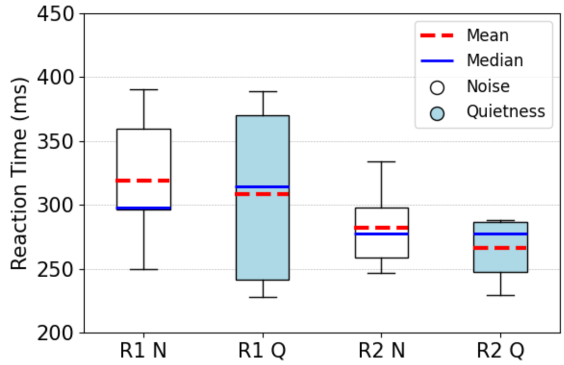


**Figure 9**. Time taken to complete the Open-source Open-access Reaction Time Test during Task E.

While TMT-A shows relatively stable completion time across conditions, TMT-B shows greater variability, with longer times especially in R1. For this task Wilcoxon test revealed statistical significant differences only when comparing the noise and quiet conditions for R1 in the case of TMT-A, with a p-value of 0.03. For the other conditions, the test did not reveal statistical significant differences when comparing the noise and quiet conditions. The p-value resulted equal to 0.75 for R1 in the case of TMT-B, to 0.21 for R2 in the case of TMT-A and of 0.09 in the case of TMT-B. Figure 8 shows the boxplot for Task D. It shows that participants produced more words in the Semantic Verbal Fluency test in the quiet conditions, particularly in R2, where the performance showed the highest variability. However, for this task, Wilcoxon test showed no statistical significance when comparing the noise and quiet conditions for R1, with a p-value of 0.14, and for R2, with a p-value of 0.53. Figure 9 shows the boxplots of the distribution of the reaction time in Task E. The results show faster reaction times in quiet conditions. R1 values are more spread, especially in quiet conditions, while R2 obtained more consistent values. For this task Wilcoxon test did not reveal statistical significant differences when comparing the noise and quiet conditions for R1, with a p-value of 0.67, and for R2, with a p-value of 0.15.

## 4. CONCLUSIONS

In this study the virtual acoustic environment of the New Civic Central Library of Torino, which is currently under renovation, has been recreated with GA acoustic simulation. Built in 1938, the library aims to blend its traditional study and research function with a modern role as a social, digital, and cultural space. The library, with a volume of about 160,000 m³ and a mid-frequency reverberation time of approximately 6 seconds, is protected by cultural heritage authorities. Simulated noise sources included traffic, ventilation, ambient buzz from occupied areas, footsteps, page-turning, pens, and syntactically correct but semantically meaningless sentences. Noise level at two receivers was between 44.9 and 45.4 dB(A). Subjective tests were conducted on 12 participants (20–55, normal hearing) to evaluate the impact of noise and reverberation on their noise perception and cognitive effort.

It is a preliminary study that searches to address the gap in the current understanding of library acoustics. The answer to the research question on the impact of noise in multifunctional libraries on cognitive effort is that with low noise levels around 45 dB(A), which are similar to the level measured in existing historical reverberant libraries in Paris, the scores of the different cognitive tasks did not differ significantly in noise and in quiet. Further studies will be aimed to test higher noise levels, up to 62 dB(A), as documented in literature for new multifunctional libraries [4]. Anyway, high reverberation time in crowded libraries seems not to impact on the increase in background noise level as already documented in literature [19].

## 5. ACKNOWLEDGMENTS

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