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NOISE CONTROL FOR A BETTER ENVIRONMENT

Assessment of the helicopter cabin noise impact on mental calculation and memory performance

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ABSTRACT

Helicopters passengers are more and more demanding in terms of acoustic comfort inside the cabin. They wish to work, read, or relax, without the need of wearing a noise cancelling headset. Recently, active noise control has made considerable progress, and systems can be embedded in the passengers' seats. Yet, this technique requires to carefully design filters that target the frequencies that are the most annoying. However, predict and characterise the discomfort and the negative impact of noise on passengers can be difficult for manufacturers, the effects of noise on cognitive functioning and emotional state is complex. In this study, the impact of various helicopter cabin noises was evaluated on perceived acoustic comfort, cognitive performance and physiological activity. 20 volunteers were asked to perform the "TNT", a task combining mental arithmetic and memory load, while they were submitted to 5 different noises and a silent condition. These five noises varied in terms of tonal frequencies amplitude: *raw*, *filtered*, *low-frequency*, *high-frequency* and *isophonic*. Subjective results showed that the silent condition was less stressful than all noises. More importantly, the raw sound was evaluated as the most annoying. No difference of task performance across the different noises were found, which is consistent with the literature. Cardiac and brain activities were measured during the experiment via electroencephalography and electrocardiography and showed an effect of time on workload and fatigue. Ultimately, these results will allow to define filters for an active noise control system to optimize acoustic comfort. Filters might be tuned according to the type of task performed by the passengers and as a function of their actual physiological activity.

Keywords: Helicopter noise, Cognitive performances, Electroencephalography
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1. INTRODUCTION

1.1 Impact of noise cognitive performance

Helicopters passengers are more and more demanding in terms of acoustic comfort inside the cabin. They wish to work, read, or relax, without the need of wearing a noise cancelling headset. One solution to improve acoustic comport without disturbing the passenger is to attenuate the noise remotely. Active noise control is a technique to reduce unwanted noise by superimposing a second sound source on the original source in order to remove it. Active noise control has made considerable progress, for example, a new system developed by Airbus Helicopters [1] can reduce the noise locally around the passengers' heads (the systems is embedded in the passengers' seats). Yet, this method has technical limitations and requires to carefully design filters that target the frequencies that are the most annoying. However, predict and characterise the discomfort and the negative impact of noise on passengers can be difficult for manufacturers. Noise is commonly perceived as a disturbing and annoying phenomenon, but its impact on humans, and in particular on their cognitive functioning remains complex and sometimes contradictory.

For example, it has been shown that noise has a negative effect on short-term memory [2]. Another study revealed that noise provokes a faster search in memory, but at the cost of more errors and less accuracy [3]. Noise has also less visible impact, for example it can increase the subjective workload by reducing the cognitive resources available for performing the focal task [4]. It also has an effect on concentration with a deterioration of selective attention [5]. Stressors are distracting and generate thoughts that can conflict with the task at hand [6].

Interestingly, the effects of noise on cognitive functioning seem to be modulated by several factors: the type of task, the type of noise, its intensity, its duration and its intermittency. Regarding the type of noise, a tonal noise is generally perceived as disturbing and unpleasant due to its intense, dominant, and clearly audible pure-tone components [7]. In this sense, a broadband noise combined with a tonal noise will be considered noisier than the same noise, played at the same sound-pressure level, but without the tonal noise [7]. Tonal noise are also perceived as more tiring [8] and high tonal frequencies are correlated with greater annoyance, discomfort, and lower task performance [9].

It is also important to take into account inter-individual variations. Personality traits are important mitigator of the effect of noise. It has been observed that introverts, compared to extroverts individuals, express a greater disruption of their concentration and their logical reasoning in noisy conditions [10]. Noise sensitivity, as a personality trait, is defined as attitudes towards different environmental noises [11]. A negative affect (such as annoyance) and higher noise sensitivity are associated with reduced working memory, short-term memory, and attention capacities, when exposed to environmental noises. Excessive arousal seems to be the main causal factor of this loss of performance [10].

1.2 Improving acoustic comfort in helicopters

Helicopters emit noise in a wide frequency range from 10 to 12000 Hz. The four main sources of noise inside the cabin are: the main transmission gearbox noise, the aerodynamic noise, the main rotor noise and the engine noise. The main transmission is particularly problematic as gearbox emits a strong tonal noise. Due to the presence of multiple gears, the transmission gearbox generates tonal frequencies emerging from the spectrum in the range from 500 to 5000 Hz. These frequencies correspond approximately to the frequencies of speech (600 to 6000 Hz) to which human audition is very sensitive. The average overall intensity of a helicopter's internal noise is around 85 to 95 dB(A). Active noise control is particularly interesting in the helicopter industry to improve the acoustic comfort for pilots and passengers. Due to its wide frequency range, helicopter noise is difficult to attenuate significantly by simple passive control using absorbent materials. Active and passive techniques are complementary because active noise control is effective for middle frequencies (500-3000 Hz), while passive absorbers are more effective for high frequencies. The active control noise system developed by Airbus Helicopters [1] use a multi-tone algorithm focusing the calculation only on emerging tonal frequencies in the spectrum. Acoustic measurements show that the algorithm allows higher gains than a conventional algorithm reaching up to 4 dB(A). A next research step is to improve the noise control algorithm by identifying the frequencies that are the most relevant to filter (i.e. the most annoying for the passengers).

In addition to the classical subjective and behavioural measurements [12], physiological measures, such as cerebral activity or electrocardiography (ECG), can be used to finely assess the impact of noise on humans. To analyse cerebral activity, spectral variations of electroencephalographic (EEG) data can be used. The decrease in the power of the alpha rhythm (8-12 Hz) on the parietal areas indicates higher levels of attention [13] and workload [14]. In addition, an increase in theta rhythm (4-7 Hz) on frontal areas is associated with a higher task demands [15], which can reflect a reduction of the cognitive resources due to the noise. A ratio called the Task Load Index (TLI) has been proposed to combine these two measures. It seems to provide a good indicator of cognitive overload and mental fatigue [14]. This ratio is higher when the difficulty of the task, the attention the vigilance, and the fatigue increase [16]. After exposure to noise, a decrease in the amplitude of both theta (4-7 Hz) and alpha (8-12 Hz) bands has been be observed [17, 18].

In addition, ECG measurements provide a measure of participants' cognitive and emotional state. The heart rate is sensitive to the level of stress and the heart rate variability (HRV) may indicate a higher workload [19]. The NN50 is one of the main measures used to analyse HRV. It correspond to the differences of successive NN intervals (NN correspond to a normal RR intervals) greater than 50ms.

1.3 Objectives and hypotheses

In the current research, we combined the subjective assessment of noise with behavioural (mental calculation and working memory performance) and physiological measurements (EEG and ECG) to have an objective measure of the participants' state. The goal was to identify among different helicopter noise, the ones that are the most deleterious for passengers in a calculation task. Six conditions were analysed in this experiment. Five helicopter cabin noises were filtered differently on their emerging tonal frequencies and a silent condition was added.

The hypotheses of this experiment were that the helicopter noise with a high tonal component would be perceived as more annoying and would be less well assessed subjectively. We assumed that it would be more detrimental to cognitive functioning, generating more errors and slower reaction time. Finally, we assumed that tonal noise would have an effect on available cognitive resources and stress, as indexed by physiological activity (EEG and ECG).

2. METHODOLOGY

2.1 Material

The experiment was conducted in a helicopter cabin (called VASCO, cf. Figure 1) to facilitate the immersion and the sense of presence [20]. The background noise level in the helicopter cabin was 33 dB(A).

Helicopter noises were sent at 84 dB(A) through a headset (AKG K812, cf. Figure 2). Its frequency response was tested before the experiment to ensure that it is accurately rendered. A white noise was sent into the headset and a microphone recorded the loudspeakers frequency responses through different positions. A transfer function had been established for each loudspeaker of the headset. Microphone measurements have been highly fluctuating depending on the headset positions under 100 Hz and over 4500 Hz. These fluctuations were due to destructive and constructive waves generated by the size and the depth of the loudspeaker cavity. For this reason, noise conditions were only presented between frequencies range from 20 and 4546 Hz were the measures for the transfer function were stables.

Figure 1. The VASCO helicopter segment

Figure 2. Illustration of the AKG K812 headset on its holder with the microphone to evaluate its frequency response.

2.2 Subjective measurements

Different tests and questionnaires were used in this study. Noise sensitivity of participants was assessed using the *Noise Sensitivity Scale - Short Form* (NSS-SF [21]). This version establishes the noise sensitivity of the participants thanks to a score ranging from a minimum of 5 (not very sensitive) to a maximum of 30 (very sensitive).

Extraversion of participants was assessed using the French version of the *Eysenck Personality Questionnaire Revised and Abbreviated* (EPQR-A [22]). This questionnaire allows to measure four dimensions of personality: Psychoticism, Extraversion, neuroticism and a Social Desirability scale. For the extraversion scale, a high score represents an outgoing person and a low score represents an introverted person.

The subjective difficulty was assessed with an 11-points Likert scale from 0 to 10 (0 corresponded to “no difficulty” and 10 corresponded to “impossible to achieve”). The fatigue level was assessed with an 9-points Likert scale from 1 to 9 (1 corresponded to “very awake”, 3 to “awake (normal)”, 5 to “neither awake nor tired”, 7 to “drowsy” and 9 to “very sleepy, I fight not to sleep”).

To measure the state of stress the *Short Stress State Questionnaire* (SSSQ [23]) was used. This questionnaire measures three dimensions: Distress, Task Engagement and Worry. The SSSQ is a short and reliable measure of stress and is sensitive to the stressors associated with the task[23].

To rate subjectively the noise condition, eight noise questions were used similar to those used by Ryherd & Wang [24, 25] about loudness, rumble, roar, hiss, tonality, fluctuations over time, distraction and annoyance. To be able to answer these questions, participants had a training session to expose them to “rumbly”, “roaring”, “hissy” and “tonal” noise. The “rumbly”, “roaring” and “hissy” noises were white noise with higher low (16-63 Hz), medium (125-500 Hz), high (1-8 kHz) frequency amplitude respectively. The tonal noise was a white noise with a tone at 500 Hz. Three additional questions were added to assess whether the noise was tiring over time, whether participants had become accustomed to the noise over time and whether they had found the noise stressful. These last 11 questions were presented with a 7-points Likert scale (1 corresponded to “not …” and 7 to “very …” associated to the correspondent adjective of the question).

All questionnaires were presented in French.

2.3 Noise conditions

The effects of six noise conditions were examined:

- A *silent condition*: no sound was played on the headset.
- *Raw noise*: corresponding to a broadband helicopter obtained by recording the cabin noise of a helicopter in flight. This noise was emitted in the headset at a level of 84 dB(A) corresponding to the actual sound level in the helicopter cabin. This noise is the one in which there are the most tonal components.
- *Filtered noise*: based on the raw noise, this noise was filtered on the emerging frequencies of the spectrum between 500 and 3000 Hz. This noise was created in order to reproduce the filtering of an active noise controller with a multi-tone algorithm. This noise corresponds to a decrease of 3.52 dB(A) compared to the raw noise.
- *High-frequency filtered noise*: based on the raw noise, this noise was filtered on the emerging high frequencies of the spectrum between 500 and 3000 Hz. This noise corresponds to a decrease of 1.70 dB(A) compared to the raw noise.
- *Low-frequency filtered noise*: based on the raw noise, this noise was filtered on the emerging low frequencies of the spectrum between 500 and 3000 Hz. This noise corresponds to a decrease of 1.14 dB(A) compared to the raw noise.
- *Isophonic filtered noise*: based on the raw noise, this noise was isophonically filtered on the emerging frequencies of the spectrum between 500 and 3000 Hz. A filter following the A-weighting curve was used on the emerging frequencies to give them the same perception of loudness. This noise corresponds to a decrease of 3.32 dB(A) compared to the raw noise.

Due to fluctuations in the headset frequency response, sound conditions were only emitted between 20 and 4546 Hz. The signals were lengthened by concatenating them with a crossfading.

2.4 Participants

Twenty participants (M_{age} = 26.3 years, *SD* ± 2.0, age range 23-30 years old; 2 females) participated in this study. Only one participant reported a hearing loss of more than 25 dB on the 8 kHz frequency, all the others had normal hearing. Fourteen were French native speakers, three were Italian native speakers and one was Spanish native speaker. All had a good level of French. Eighteen participants were right-handed and two were left-handed. All had normal or corrected-to-normal vision. None of the participants reported a history of prior neurological disorder. All subjects gave written informed consent in accordance with the Declaration of Helsinki. This study was carried out in accordance with the recommendations of CERNI no. 2017-042, the Research Ethics Committee of the University of Toulouse (France) with written informed consent from all subjects.

2.5 Procedure

First, participants were asked to read the information sheet and complete the consent form. They performed an audiogram to ensure their good hearing. Then, they were installed in the experimental helicopter cabin and completed demographics questionnaire (age, gender, level of education, handedness, native language, level of awareness, etc.). A questionnaire on listening habits when working was proposed to them to define which type of sound environment they used to work with. Participants were asked to complete the NSS-SF and the EPQR-A. They were equipped with a 64-electrodes EEG headset and two cardiac electrodes. After this installation, participants performed a span memory test forward and reverse.

The headset was placed on the participants' heads, over the EEG cap and they performed the training session to expose them to “rumbly”, “roaring”, “hissy” and “tonal” noise. Participants took as much time as they wanted to familiarize themselves with these sounds and had to listen to them at least once.

A training session to the TNT has been conducted to give them instructions for the task and to practice on it. They could repeat the training as many times as necessary. Instructions were no longer given afterwards.

The tasks were carried out in 6 sets. First, a 2-minute period of noise habituation was performed by participants only for the noisy conditions (not the silent condition). Then, the TNT began. At the end of the TNT, the sound stop and participants were asked to complete questionnaires to define the difficulty experienced, the current level of fatigue, to evaluate their sound perception and to measure their stress level (SSSQ). A pause of 1 minute and 30 seconds in silent was proposed before starting a new set. The total duration of the experiment was about 2 hours and 15 minutes.

2.6 Toulouse N-back Task

The Toulouse N-back Task (TNT [26]) combines the classic n-back task [27] with mental arithmetic. In the classic n-back task, participants are asked to memorize and compare items while in this version participants are asked to calculate, memorize and compare the results of arithmetic operations with the results of previous operations. Arithmetic operations consisted of adding or subtracting multiples of 5 between 10 and 95 (e.g., 15 + 40, 90 – 35; see Figure 3). Two levels of difficulty were used in this experiment: 0-back and 2-back. The duration of a TNT was 5 minutes and 30 seconds.

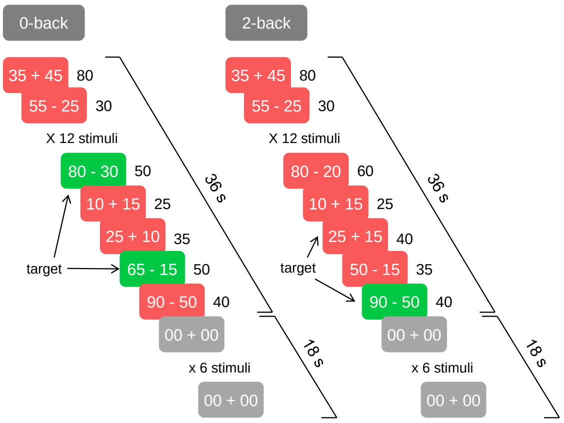

Figure 3. Presentation sequence of arithmetic operations for the 0-back and 2-back difficulties to the Toulouse N-back Task. The red colour corresponds to the non-targets and the green to the targets. The “00+00” operations was the rest condition.

2.7 Data Analysis

All data were analysed with Statistica 10©. A Kolmogorov-Smirnov test was performed on the data to determine if the data followed a normal distribution.

For the normal distributed data, a one-way (Noise conditions [Raw noise, Filtered noise, High-frequency filtered noise, Low-frequency filtered noise, Isophonic filtered noise, Silence]) ANOVA was conducted. LSD post-hoc tests were carried out to further examine significant effects ($\alpha < 0.05$).

For the non-normal distributed data, non-parametric Friedman ANOVA was conducted. Wilcoxon tests were used to analyse the between-effects of the noise conditions.

3. RESULTS

3.1 Subjective results

Subjective difficulty.

The analysis of the subjective difficulty revealed a significant effect of time for the 2-back condition [$F(1,19) = 3.64$, $p < 0.01$; cf. Figure 4]. There was no significant effect of time on subjective difficulty for the 0-back condition [$F(1,19) = 2.16$, $p = 0.06$] and on subjective difficulty regarding noise conditions [0-back: $F(1,19) = 1.65$, $p = 0.15$; 2-back: $F(1,19) = 1.65$, $p = 0.15$].

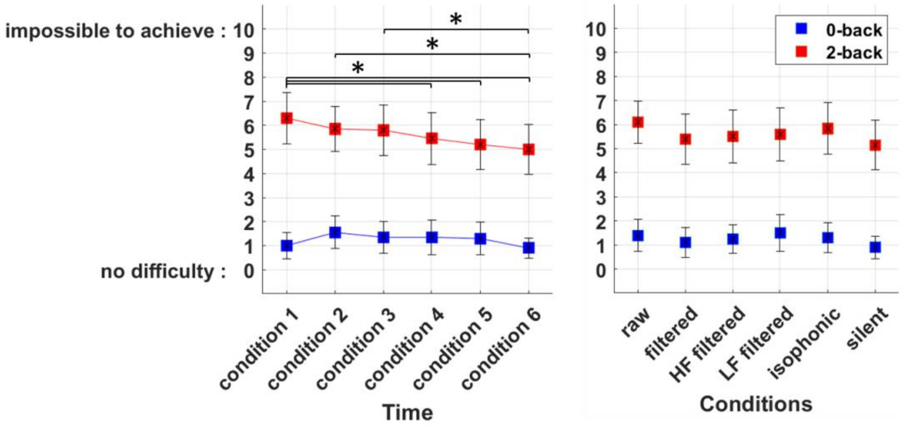

Figure 4. Subjective difficulty rated across time (left) and across noisy conditions (right). Errors bars represent 95% confidence intervals; * represent significant LSD's post hoc (p < 0.05).

Subjective level of fatigue.

The analysis of the subjective fatigue revealed a significant effect of time [$F(1,19) = 3.48$, $p < 0.01$; cf. Figure 5] but no significant effect of noise conditions on subjective fatigue [$F(1,19) = 0.42$, $p = 0.83$].

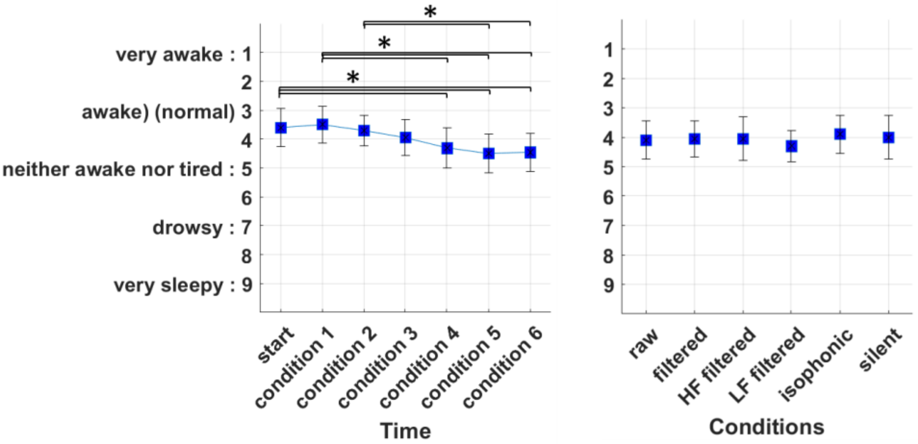

Figure 5. Subjective rating of fatigue across time (left) and across noisy conditions (right). Errors bars represent 95% confidence intervals; * represent significant LSD's post hoc (p < 0.05).

Subjective evaluation of the noise conditions.

The analyses of the subjective terms are summarized in Table 1.

	1: Raw noise	*2: Filtered noise*	*3: HF filtered*	*4: LF filtered*	*5: Isophonic*	*6: Silent*
Loudness	5.3 ± 0.8	5.0 ± 1.2	4.8 ± 1.3	5.6 ± 1.1 *$^{4 – 2, 3, 6}$	5.2 ± 1.1	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Rumble	4.0 ± 1.5	4.2 ± 1.5	4.2 ± 1.3	4.3 ± 1.4	4.7 ± 1.5	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Roar	4.6 ± 0.7	5.0 ± 1.0	4.6 ± 1.2	5.0 ± 1.4	4.4 ± 1.5	1.1 ± 0.4 *$^{6 – 1,2,3,4,5}$
Hiss	4.3 ± 1.7	3.6 ± 1.6	3.9 ± 1.6	4.2 ± 1.8	4.2 ± 2.1	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Tonality	3.8 ± 2.2	3.4 ± 2.2	4.2 ± 1.9	3.9 ± 1.9	3.9 ± 1.9	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Fluctuations over time	2.9 ± 1.3	2.6 ± 1.4	3.1 ± 1.7	2.9 ± 1.2	3.9 ± 1.8 *$^{5 – 2,4,6}$	1.2 ± 0.7 *$^{6 – 1,2,3,4,5}$
Distraction	3.4 ± 1.5	3.1 ± 1.6	2.8 ± 1.5	3.1 ± 1.7	3.2 ± 1.5	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Annoyance	4.2 ± 1.6 *$^{1 – 2,3,5,6}$	3.3 ± 1.6	3.3 ± 1.9	3.6 ± 1.7	3.4 ± 1.6	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Tiring over time	4.1 ± 1.7 *$^{1 – 2,3,6}$	3.4 ± 1.7	3.2 ± 2.0	3.5 ± 1.9	3.3 ± 1.7	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$
Habituation	4.4 ± 1.6	4.7 ± 1.7	5.0 ± 1.4	4.6 ± 1.8 *$^{4 –2,3,6}$	4.5 ± 1.7	1.9 ± 2.2 *$^{6 – 1,2,3,4,5}$
Stressful	2.6 ± 1.3	2.5 ± 1.6	2.4 ± 1.3	3.2 ± 1.8	2.6 ± 1.7	1.0 ± 0.0 *$^{6 – 1,2,3,4,5}$

Table 1. Summary of the results of the subjective evaluation of the noise conditions with the mean ± standard deviation. * represents significant Wilcoxon test depending on the conditions involved.

SSSQ results.

The analysis of the distress dimension revealed a significant effect of the noise conditions [$F(1,19) = 2.36$, $p < 0.05$]. LSD's post-hoc analysis revealed that the *silent condition* was considered less distressing than the *raw noise* ($M = -0.70$, $p < 0.05$), the *filtered noise* ($M = -0.71$, $p < 0.05$), the *low-frequency filtered noise* ($M = -0.67$, $p < 0.05$) and the *isophonic filtered noise* ($M = -0.70$, $p < 0.05$).

The analysis of the task engagement and the worry dimension revealed no significant effect of the noise conditions [Task Engagement: $F(1,19) = 0.71$, $p = 0.61$; Worry: $F(1,19) = 1.28$, $p = 0.28$].

Pairwise comparisons of noise conditions.

The analysis of the most disturbing noise revealed a significant effect of the noise conditions [$\chi^2(4) = 61.96$, $p < 0.01$; cf. Figure 6].

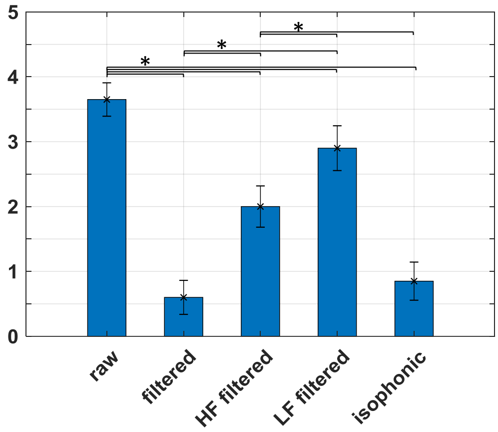

Figure 6. Histogram of sounds perceived as the most disturbing. Error bars represent 95% confidence intervals; * represent significant LSD's post hoc (p <0.01).

3.2 Behavioural results

The analysis of the TNT performance showed that there was a significant effect of time on the number of correct answers on the 2-back [0-back: $F(1,19) = 1,97$, $p = 0.09$; 2-back: $F(1,19) = 13,69$, $p < 0.01$; cf. Figure 7.B]. There was no significant effect of time on the number of incorrect answers [0-back: $F(1,19) = 1.35$, $p = 0.25$; 2-back: $F(1,19) = 2.05$, $p = 0.08$]. And there was a significant effect of time on the reaction time [0-back: $F(1,19) = 5.68$, $p < 0.01$; 2-back: $F(1,19) = 4.65$, $p < 0.01$; cf. Figure 7.B].

The analysis of the TNT performance regarding noise conditions showed that there was no significant effect of noise conditions on the number of correct answers [0-back: $F(1,19) = 0.77$, $p = 0.58$; 2-back: $F(1,19) = 1.39$, $p = 0.23$]. There was no significant effect on the number of incorrect answers [0-back: $F(1,19) = 1.63$, $p = 0.16$; 2-back: $F(1,19) = 1.32$, $p = 0.26$]. And there was no significant effect on the reaction time [0-back: $F(1,19) = 0.25$, $p = 0.94$; 2-back: $F(1,19) = 0.612$, $p = 0.69$].

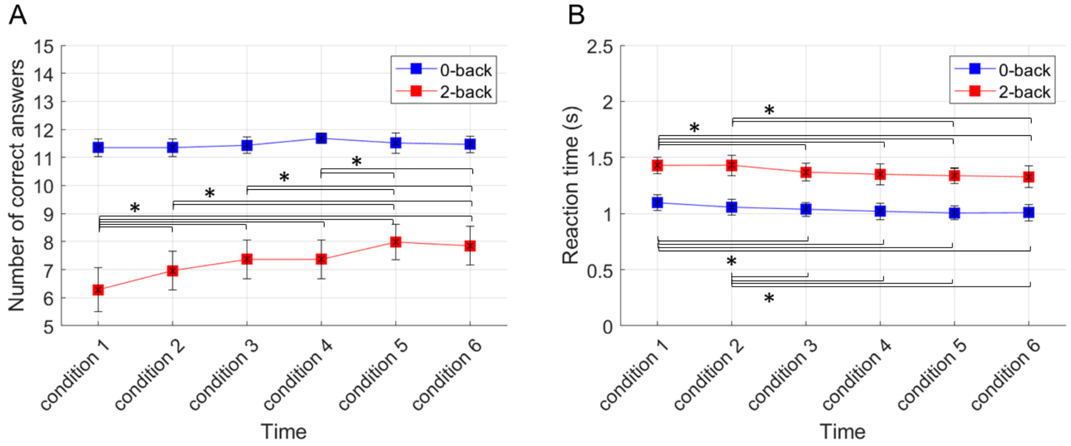

Figure 7. (A) Number of correct answers to the TNT across time. (B) Reaction time to the TNT across time. Error bars represent 95% confidence intervals; * represent significant LSD's post hoc (p <0.05).

3.3 Physiological results

EEG.

The analysis of the TLI ratio (theta $_{Fz}$ / alpha $_{Pz}$) revealed a significant effect of time [$\chi^2(5) = 14.69$, $p < 0.05$; cf. Figure 8.A].

The analysis of the TLI ratio (theta $_{Fz}$ / alpha $_{Pz}$) regarding noise conditions revealed no significant effect of the noise condition [$\chi^2(5) = 10.60$, $p = 0.06$].

ECG.

The analysis of the heart rate revealed a significant effect of time [$F(1,19) = 8.98$, $p < 0.01$; cf. Figure 8.B]. No significant effect of the noise conditions was found [$F(1,19) = 0.69$, $p = 0.64$].

The analysis of the NN50 from the HRV revealed a significant effect of time [$F(1,19) = 2.38$, $p < 0.05$; cf. Figure 8.C] but no significant effect of the noise condition [$F(1,19) = 0.38$, $p = 0.86$].

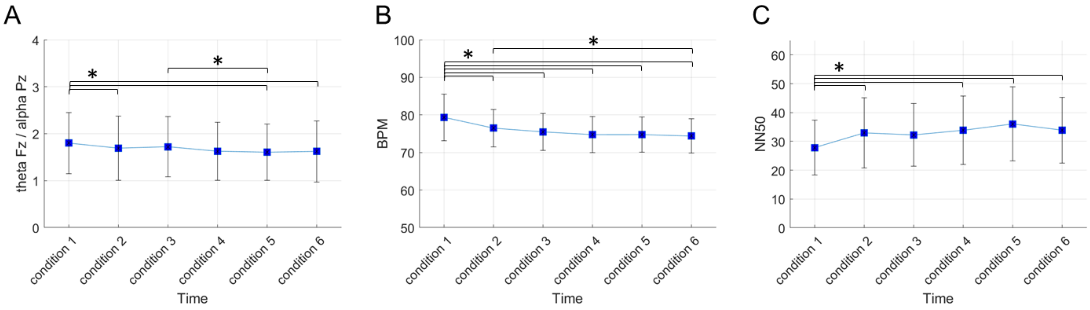

Figure 8. (A) EEG TLI ratio (theta$_{Fz}$ / alpha$_{Pz}$) across time (B) Heart rate illustrated by the average beat per minute (BPM) across time. (C) NN50 intervals values across time. Error bars represent 95% confidence intervals; * represent significant LSD's post-hoc (p <0.05).

4. CONCLUSIONS

The main purpose of this study was to objectively test the effect of emerging tonal components of a helicopter cabin noise on 20 participants. Subjective, behavioural and physiological measures were used to rate the effect of noise on a mental arithmetic and memory task (Toulouse N-back Task [26]). This task allowed to assess working memory capacities, information processing and mental calculation, mimicking the type of cognitive functions engaged when passengers work on-board. Participants had to perform this task while different helicopter noises were played in a headset. These different noises were created applying different filter parameters on their emerging tonal frequencies. The *raw noise* was the condition in which tonal components were the most predominant. The *filtered noise* had the lowest tonal components. The *high-frequency filtered noise* kept its low-frequency tonal components, while the *low-frequency filtered noise* kept its high-frequency tonal components. Finally, an *isophonically filtered noise* has been designed to ensure that the emerging tonal frequencies have the same perception of loudness.

The subjective results of this experiment showed that the *silent condition* was obviously perceived as less stressful, disturbing, annoying and distressful than all other conditions in which helicopter noises were administered. The *low-frequency filtered noise* was perceived louder and more stressful than the *filtered* and the *high-frequency filtered noises*. The noise perceived as the most disturbing was the *raw noise* followed by the *low-frequency* and the *high-frequency filtered noise*. The *filtered* and the *isophonically filtered noise* were perceived as the least disturbing in an equivalent way.

The behavioural results showed that there was an effect of time on the cognitive performance. There was a learning effect, participants made fewer errors and completed the task more quickly. There was no effect of the noise conditions on the cognitive performance. Noisy conditions did not lead to more errors and slower reaction time from the participants. This is not surprising as the literature generally shows that tonal noise has effect on subjective feeling (annoyance) [24, 25] rather than on behavioural performance. One can assume that intermittent noise would have affected task performance. Also, the noise exposure was quite short (7 minutes per condition). A longer exposure to noise (more than 1 hour) may have ended up by altering task performance, as short exposures to noise are less influencing cognitive functions and stress level during a task [28].

The EEG results showed that there was an effect of time on cognitive workload and mental fatigue. This mental fatigue is likely due to both noise exposition and fatigue related to the task performance. No effect of the noise conditions on EEG measurements was observed.

ECG results showed there was an effect of time on heart rate that decreased and on the variation of the NN intervals higher than 50 ms (NN50). This latter result means that the heart beat was less fluctuating at the beginning than at the end of the experiment. This suggests that workload and attention have decreased over time [29].

These physiological results show that there was a training effect. Participants trained on the task over time, resulting in a decrease in cognitive workload [30] and level of wakefulness [8]. A further study will be carried out to determine the effect of helicopter cabin noise on a resting task. It will allow the effect of noise conditions on cognitive workload to be assessed without a training effect. Even in the absence of visible impact on cognitive performance, physiological data reveal that prolonged exposition to sounds is not neutral.

To conclude, this experience shows that short exposition to helicopter noise is not disruptive to perform a mental arithmetic task. Filtered noise allows a better subjective experience. Moreover, it seems sufficient to filter the emerging tonal frequencies of the noise isophonically to have the same effect as filtering on all tonal frequencies. This last result shows that less power can be used from the loudspeakers to generate the counter-noise. Active noise cancelling system is limited in frequency (500-3000 Hz), it cannot filter everything. However, this system allows to target the irrelevant frequencies to be filtered among the most disturbing and to preserve useful sounds such as conversations and alarms. The gain obtained on the loudspeakers power could allow filtering more annoying frequencies.

5. ACKNOWLEDGEMENTS

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