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An enhanced experimental paradigm for auditory BCIs by addressing both acoustic and human factors

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Abstract—This paper describes an experimental paradigm designed to evaluate the usability of non-sinusoidal amplitude-modulated stimuli for Brain-Computer Interfaces (BCIs) based on steady-state auditory evoked potentials. Instead of the commonly used pure tone, which can be uncomfortable, detectability of alternatives like Brownian noise or natural sounds (e.g. cicada song and cat’s purr), which are expected to be more pleasant to listen to, is assessed. Brain responses from 48 participants are recorded while listening to various amplitude-modulated sounds. To ensure accurate sound reproduction, the audio setup’s frequency response is measured and compensated for, using an Head And Torso Simulator (HATS). All stimuli are also equalized in loudness to prevent perceived level differences between stimuli. Participants’ hearing acuity is measured using an audiometric procedure developed for the needs of the experiment. Participants also completed questionnaires to collect information about their laterality, musicality, age and sex, as these factors may influence auditory perception.

Index Terms—Brain-Computer Interface, Steady-State Auditory Evoked Potential, Auditory Perception

I. INTRODUCTION

Brain-Computer Interfaces (BCIs) analyze individuals’ brain activity and translate it into actions for device interaction. In reactive BCIs, external periodic sensory stimulation elicit steady-state evoked potentials, which can be used to trigger specific action [1]. The visual modality is most commonly used. For instance, a light flickering at a specific frequency induces Steady-State Visually Evoked Potentials (SSVEPs) at the same frequency (and its harmonics), which is detectable in brain signals [2]. However, flashing visual stimuli may not be suitable for everyone and can cause visual fatigue [3]. Hence, auditory stimulation can be used as an alternative. Users are then exposed to an amplitude-modulated sound, where an audible carrier signal is modulated by a low-frequency sine wave around 40 Hz. This frequency, which maximizes Steady-State Auditory Evoked Potentials (SSAEPs) in humans [4], and

its harmonics can be detected in brain signals [3] [5]. Auditory BCIs may offer faster responsiveness, as the brain reacts more quickly to sounds than to visual cues [6]. Furthermore, sounds can be delivered privately via headphones, while visual stimuli require a screen or a virtual reality headset, which may be less practical and/or compromise confidentiality.

Nonetheless, auditory BCIs typically use pure tones as carrier signals [7] [8], which can become uncomfortable during prolonged listening and limit their usability. To address this, it is necessary to identify new sound carriers that are both pleasant and preserve the detectability of the modulation frequency in brain signals. To this end, we decided to test the potential of nature sounds, such as cicada song [5] and cat’s purr, which are expected to be more comfortable to listen to. We also included a Brownian noise, an artificial but configurable signal with a spectral content similar to sounds found in nature like water noises, which are often perceived as pleasant. As a result, it sounds similar to a cascade, a natural sound used by Heo et al. [5]. Consequently an experiment was designed to assess the performance of these three audio signals as carriers for an auditory BCI based on SSAEPs, compared to a 1-kHz pure tone, used as a reference. Each carrier signal (1-kHz pure tone, cicada song, cat’s purr and Brownian noise) is amplitude-modulated by a 40-Hz sine wave. Participants listen to these stimuli while their brain activity is recorded by an ElectroEncephaloGraphic (EEG) cap. The goal is to measure the detectability of the modulation frequency as a function of the carrier signal. To do this, classification is applied to EEG data to check whether the modulation frequency can be detected in the EEG responses to amplitude-modulated stimuli in comparison to the EEG responses to silence [9] [10]. At the end of the experiment, participants rated the pleasantness of each auditory stimuli. Because sound level may affect EEG responses, and increasing loudness could potentially enhance the detectability of the modulation frequency, the experiment was divided into two sub-experiments, each using a different loudness level (namely, 50 and 56 phons).

In designing the experiment, two issues were given par-

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ticular attention. First, it seemed essential to us to ensure that auditory stimuli are reproduced and perceived accurately. Second, since various individual factors can affect cognitive processes, questionnaires were elaborated to collect detailed information about each participant (i.e. laterality, musicality, sex and age). The goal is to refine the analysis of individual EEG responses in light of these profiles. As for acoustic factors, each component of the sound reproduction system has been carefully selected and measured. In-ear earphones were chosen as they are compatible with an EEG cap and allow precise control over the acoustic pressure at the entrance of the participants' ear canal (unlike speakers). The frequency response of all audio components was measured by an Head And Torso Simulator (HATS) [11]. In addition, each participant's hearing ability was assessed prior to the experiment, to detect any fundamental impairment. An hearing test was specifically developed to avoid complicating the experimental procedure by adding an audiometric measurement in dedicated medical facilities. This adaptable test can be reused in future studies. Moreover the information on the hearing threshold as a function of frequency for each participant may be useful in the subsequent analysis of EEG recording. For instance, if individual differences in brain activation are observed, comparing participants' hearing thresholds is useful, before proceeding further with the interpretation of results.

All of these considerations led to the development of an experimental paradigm for assessing auditory BCIs distinguished by its careful attention to both acoustic and human factors. This focus represents the main contribution of the paper. Procedures related to acoustic factors are described in Section II, which covers electroacoustic measurement and correction of headphones, loudness measurement, auditory stimulus construction and the audiometric procedure. Section III addresses human factors by first inventorying all aspects that could influence brain activity, and then presenting the resulting questionnaires. Finally, the questionnaire responses are summarized in Section IV.

II. ACOUSTIC FACTORS

Given the purpose of this experiment, it is crucial to ensure that auditory stimuli are reproduced with the highest quality. Therefore, acoustic properties of each sound reproduction component are measured and compensated for if necessary. It is also essential to ensure that participants in the experiment perceive the auditory stimuli correctly, which is achieved by an audiometric test. This section details all the procedures implemented to reach these objectives.

A. Headphones

1) *Measurement setup:* The frequency response of the headphones is measured with an HATS, an acoustic manikin simulating the interaction between acoustic waves (such as diffraction) and the human body (mainly head, torso and pinna). It allows to record the acoustic pressure at the entrance of the ear canal, as it would be perceived by humans. The HATS output is connected to a preamplifier [12] that converts

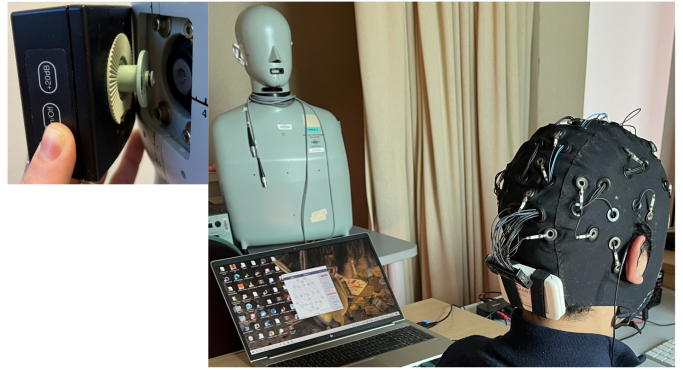


Fig. 1: The left side of the figure shows the standard source [14] (Compliant with NF EN/IEC 60942 (2017) Class LS, Class 1, ANSI S1.40–2006) with the calibration adapter at the entrance of the HATS ear. On the right, the HATS is in the background, while a subject wears an EEG cap and in-ear earphones, in the experimental room.

the signal amplitude into a Sound Pressure Level expressed in dB SPL. For further processing and analysis, the preamplifier output is then connected to a computer via a Focusrite Scarlett 6i6 2nd generation soundcard.

2) *Calibration:* HATS calibration is required before any measurement. This essential step enables the amplitude of HATS output signal to be interpreted directly in terms of sound pressure level in dB SPL. A standard source emitting a 1000-Hz sine wave at 94 dB SPL is coupled to one ear of the HATS via a calibration adapter (figure 1). Each ear is equipped with a microphone. The coupling increases the sound level induced by the standard source by 3.1 dB [13]. Consequently, the expected level at the output of the measuring chain must be 97.1 dB SPL. If this is not the case, the measurement preamplifier gain must be adjusted until it reads exactly 97.1 dB SPL. This calibration must be completed for both ears.

3) *Running in of headphones:* For headphones that have never been used, it is recommended to run them in, by playing pink noise (i.e. a sound covering a wide frequency range) for about 20 hours. This process softens the transducers to achieve optimal sound properties, but also to stabilize the frequency response, as it depends on transducer flexibility.

4) *Frequency response:* To measure their frequency response, headphones are positioned on the HATS ears, ensuring proper alignment of the emitters with the measurement microphones. Pink noise is played for 30 seconds in one ear, and the resulting acoustic pressure captured by the HATS is recorded by a computer. Each measurement is repeated five times per ear, with the headphones repositioned between trials to allow for averaging. The frequency response is calculated by dividing the output signal (i.e. recorded from the HATS) by the input signal (i.e. played to the HATS) in the frequency domain. Measurements are performed for both channels of two headphones: Shure SE215-K in-ear earphones (figure 2), used in the main experiment, and Sennheiser HD650 circumaural headphones, used for audiometry.

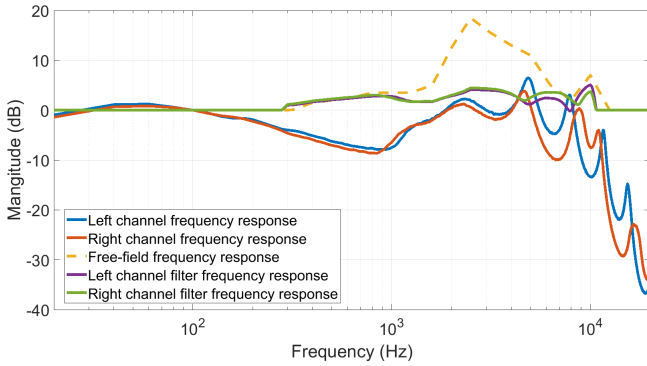


Fig. 2: Shure SE215-K earphones: Frequency response measured, free-field frequency response and frequency response of the correction filter taking into account the measured frequency response and the free-field frequency response.

5) *Headphone correction:* The Shure SE215-K (figure 2) shows a flat frequency response from 20 Hz to 100 Hz, then a gradual decrease up to 1 kHz. For the Sennheiser HD650, the frequency response is flat in the range [100-1000 Hz]. For both, sharp peaks and notches are observed above 1 kHz. Besides, there are differences between the left and right channel responses from 4 kHz onwards. All these irregularities in the frequency responses must be compensated for in order to achieve faithful auditory stimuli reproduction. However, for headphone-based listening tests, the target is not a flat response, but the free-field frequency response, which is defined as the acoustic pressure induced at the ear canal entrance by a sound source emitting in front of the listener in free field (i.e. in an anechoic chamber) [15]. This response is based on the average of measurements taken on a large number of human morphologies [16]. Thus, the correction filter’s frequency response is obtained by dividing the free-field response by the headphone response. Its impulse response is then calculated using the inverse Fourier transform. All stimuli are processed with this filter via a time-domain convolution.

B. Auditory stimuli

Auditory stimuli are constructed using a carrier signal and a modulating signal. As a preliminary step, each carrier signal is band-limited with a 300 Hz high-pass filter and a 10000 Hz low-pass filter, thereby minimizing artifacts introduced by the headphone correction filter (section II-A5). The modulating signal $m(t) = A_m \cos(2\pi f_m t)$ is then constructed, with f_m being the modulation frequency. Modulated signals are generated as $y(t) = [1 + m(t)]c(t)$, with $c(t)$ being the carrier signal of amplitude A_c . The modulation index is defined as the ratio of the amplitudes of the modulating signal (A_m) and the carrier signal (A_c) [5]. An headphone correction filter is applied (section II-A5) and each modulated signal is then normalized by dividing it by its maximum absolute value, before equalizing its loudness (section II-C).

C. Loudness

To ensure that sound stimuli are perceived with the same sensation of sound intensity regardless of their frequency content, they must be of equal loudness [17]. Loudness depends on sound properties (i.e. acoustic pressure, spectral content and duration) and the listener [15]. It exists several models based entirely or partly on Zwicker’s loudness model [18]. The unit of equal-loudness is the ”phon”, with 1 phon corresponding to the perceived loudness of 1 dB SPL at 1000 Hz. At equal loudness, a sound presented to both ears is perceived as louder than the same sound presented to one ear, this difference is called the binaural gain [15]. According to Whilby et al. [19], binaural gain is nearly 10 dB for sounds between 50 and 60 dB SPL. For example, a 1000-Hz sine wave at 50 dB SPL (i.e. 50 phons) in one ear is perceived at 60 dB SPL (i.e. 60 phons) when presented to both ears. For speech, a sound level of 65 dB SPL is considered a comfortable listening level [15]. To ensure participant comfort, the sound stimuli loudness is set to 50 phons (i.e. 50 dB SPL for the 1000-Hz sine wave) for the first sub-experiment and 56 phons (i.e. 56 dB SPL for the 1000-Hz sine wave) for the second one. Sound stimuli are reproduced to both ears, meaning that for each sub-experiment, the perceived loudness is 60 and 66 phons, respectively.

D. Audiometer

Standardized procedure for hearing assessment requires dedicated facilities (e.g. a soundproof booth, a standardized audiometer, specific headphones such as the Sennheiser HDA 200 type), which are not always available due to practical or cost constraints. It can also be difficult to integrate it into an experimental protocol that is already complex in itself. For all these reasons, we decided to develop a simplified audiometric procedure, which are not to make a medical diagnosis, but aimed only at detecting fundamental impairment (leading to subject exclusion) or measuring participants’ hearing curve as a function of frequency.

1) *Material setup:* The audiometer uses a graphical interface developed in Matlab and run on a Mac Mini. Auditory stimuli are delivered via a Focusrite Scarlett 6i6 2nd generation soundcard and Sennheiser HD650 headphones, chosen for their comfort. Only the subject is present in the room during this procedure to avoid experimenter-related noise.

2) *Hearing Level vs Sound Pressure Level:* In a tonal audiometry test, headphones deliver stimuli at controlled sound pressure levels to the ear canal entrance. The goal is to determine the thresholds below which the listener can no longer perceive the sounds at specific frequencies. These thresholds are initially measured in dB SPL using an HATS, but must be converted to dB HL (Hearing Level), which represents the difference between the participant’s hearing thresholds and the standard reference hearing thresholds (audiometric zeros, first column of table I). This reference is defined as the average thresholds measured for a population of young people of both sexes, aged 18 to 25 (ISO 389-x) [20] [21]. In other words, dB HL values account for the average frequency response of the human auditory system. Hearing loss is considered to be

Frequency (Hz)	Standard reference hearing threshold (dB SPL)	Calibration sound levels	
		in dB HL	in dB SPL
125	23.4	60	83.4
250	12.3	70	83.3
500	5.1	80	85.1
750	3.1	80	83.1
1000	3	80	83
1500	2.9	80	82.9
2000	-0.6	80	79.4
3000	-4.9	90	85.1
4000	-4.6	90	85.4
6000	5.1	80	85.1
8000	13.3	70	83.3

TABLE I: Standard reference hearing thresholds expressed in dB SPL, and correspondence between calibration sound levels expressed in dB HL and dB SPL, for each frequency.

present when the hearing level is 20 dB HL higher than the audiometric zeros [22].

3) *Calibration*: As a preliminary step, the entire measurement chain (audiometer and headphones) must be calibrated, to ensure accurate hearing level measurements in dB HL at each tested frequency. Standard calibration procedure requires an ear simulator (IEC 60318-1) and an acoustic coupler (IEC 60318-3), following ISO 389 standards [22]. Reference sound levels induced at the ear canal entrance in dB SPL are specified for each frequency and headphone model. However, in the absence of this standardized equipment, an alternative solution was developed to replicate the standards as closely as possible.

The Sennheiser HD650 headphones are placed on a pre-calibrated HATS (see section II-A2), used here instead of the standardized ear simulator. First, for each frequency f tested in the audiometric procedure, a sine wave $S(t) = A \sin(2\pi ft)$ of amplitude A is generated. This signal is processed by the correction filter specific to the HD650 headphones (see section II-A5). The resulting sound level at the entrance of the HATS ear canal is measured in dB SPL for each frequency and for both channels. The experimenter then adjusts the amplitude A so that the measured sound level matches the required calibration level listed in table I. Low and high frequencies are produced at lower perceived sound levels (i.e. dB HL) than mid frequencies. As a result, the maximum deviation between sound levels in dB SPL is only 6 dB, allowing audio components to operate at similar levels regardless of frequency. This calibration step sets the nominal amplitude A of the stimulus $S(t)$ for each frequency. During audiometry, the sound level in dB HL is set by applying a gain equal to the difference between the desired and calibration levels (i.e. second column of table I). For example, for a target level of 40 dB HL at 125 Hz, the gain is $G = 40 - 60 = -20$ dB, corresponding to an amplitude attenuation of $g = 10^{G/20} = 0.1$.

4) *Procedure*: The procedure used in our experiment follows the "ascending method" [23] [24]: the minimum audibility is measured by gradually increasing the stimulus sound level. However, the test begins at 40 dB HL [25] [24]. As long as the subject hears the tone, the sound level is lowered by 10 dB HL [26] [25], allowing the ascent to start closer to the

individual's hearing threshold and saving time compared to starting at 0 dB HL or lower. When the participant no longer hears the stimulus, the sound level is increased by 5 dB HL [26] [25] until they indicate that they can hear the tone again. Then the next stimulus level is lowered by 10 dB HL and another ascending step of 5 dB HL begins. In this procedure, the hearing threshold is defined as the lowest level at which the stimulus is perceived in more than half of the ascending steps [26] [27]. The procedure is performed for all frequencies, from 1000 to 8000 Hz and from 1000 to 125 Hz, per octave and half-octave. As recommended by [22], the stimulation duration is $t = 1$ second, with a signal ramp of 250 ms. The interval between stimuli is randomly set between 0 and 3 seconds to prevent subjects from anticipating the rhythm. The process is automated, with frequency and level changes made independently based on the subject's responses.

III. INDIVIDUAL FACTORS

A. Inventory

Inter-individual differences in cognitive processes, such as auditory perception and language processing, are influenced by factors such as laterality [28], musicality [29] and sex [30].

1) *Laterality*: Manual preference and cerebral asymmetry are correlated, though not perfectly [29]. While 95 – 99% of right-handed people have left-brain dominance for language, this is also the case for 70 – 80% of left-handed people [31]. Although handedness affects speech lateralization, there is a natural predisposition for the left hemisphere to process language. The right hemisphere, even when not dominant, contributes to understanding simple words, short sentences, metaphorical language and prosody. Moreover, if the left hemisphere is damaged, the right hemisphere may play an even more important role in language. In right-handed individuals, the left planum temporale, which covers Wernicke's area, is generally larger than the right, whereas left-handed individuals show no overall difference. Additionally, in right-handed people, the left central sulcus is deeper than the right, and the opposite is observed in left-handed people.

In addition, musical perception differs between right- and left-handed individuals when exposed to auditory illusions highlighted by Deutsch et al. [32]. When a low note and its octave are presented simultaneously to each ear, alternating sides, perception of right- and left-handed people differs statistically in two ways. Right-handed people are more likely to perceive a pure tone alternating between ears, with the low note always in one ear (the left one) and the high note in the other (the right one), which is not necessarily the case for left-handed people.

2) *Musicality*: Several individual factors, such as musical training, possession of absolute pitch and familiarity with the musical excerpts, are known to influence hemispheric asymmetry in the auditory cortex [28]. Individuals with greater musical expertise show increased centrality in the left supplementary motor area, superior temporal gyrus and right insula when listening to musical sounds [33]. Furthermore, unfamiliarity with the musical excerpts leads to significantly

greater centrality in the right medial orbitofrontal cortex during sound encoding.

3) *Sex*: While men primarily rely on the left hemisphere for speech-related functions, women tend to exhibit a more balanced hemispheric involvement [30].

B. Questionnaires

Therefore, information on these factors was collected from participants using the questionnaires below.

1) *Laterality questionnaire*: The Edinburgh Handedness Inventory (EHI) is the most common handedness measure [34]. It comprises 41 items, where participants indicate their preferred hand for each. To save time, the aim is to use a brief subset of these items. Individual researchers have adopted a variety of modified versions of the EHI, each addressing perceived shortcomings in its own way [35]. Therefore, a pilot study with 28 participants compared scores from the full EHI and from the most commonly used items according to Edlin et al. [35] (short EHI). For participants near category boundaries (e.g., right-handed vs. ambidextrous or left-handed vs. ambidextrous), classifications sometimes differed between the full and short forms. To better match the full test results, 11 items were selected: writing, throwing, combing hair, opening a box (hand holding the lid), dealing cards (hand holding the card being dealt), holding a bottle, holding a glass, opening a door (put the key in the lock), playing balls, pointing accurately (e.g., at a place), using a remote control and stapling paper sheets (hand holding the stapler).

2) *Musical sophistication questionnaire*: Musical sophistication does not depend solely on formal instrumental training. It also reflects engagement in various musical activities [36]. Many musical skills develop through repeated, focused interaction with music rather than explicit instruction [37]. The Goldsmiths Musical Sophistication Index (Gold-MSI) is designed to capture this broad range of musical expertise as it occurs in Western society. It comprises five categories: Active Engagement (active musical engagement behaviors), Perceptual Abilities (musical abilities most related to music listening skills), Musical Training (extent of musical training and practice), Singing Abilities (singing skills and activities) and Emotions (behaviors related to emotional responses to music). A General Musical Sophistication factor combines aspects of all categories. To minimize testing time, only the General Musical Sophistication questionnaire is used, providing an overall estimate of each subject's musical abilities, with 18 items [36].

3) *Initial questionnaire*: Subjects also complete an initial questionnaire (figure 3) covering general aspect such as sex and age, current state of mind (valence and arousal), dominant emotion, and recent use of substances (e.g. caffeine, theine, cigarettes, alcohol, narcotics, medication) within the past 24 hours. The questionnaire also asks about hyperacusis or tinnitus, and familiarity with hearing tests and BCIs. All of these factors may influence brain activity.

In fact, various substances can influence EEG activity. Caffeine decreases EEG power across all frequency bands, but the

Fig. 3: Initial questionnaire interface developed in MATLAB.

size's effects are modulated by EEG electrode site, nicotine use, and whether eyes are opened or closed [38]. This reduction is particularly notable at fronto-parieto-occipital and central sites of both hemispheres when eyes are open [39]. Nicotine can increase power in higher-frequency bands under certain conditions. Green and black tea consumption (i.e. theine) increases alpha- (8-12 Hz), theta- (4-8 Hz) and beta-band (12-35 Hz) activity, though effects vary between individuals [40]. Low doses of alcohol mainly affect theta and slow frequency alpha waves [41], while effects on higher frequency ranges depend on factors such as drinking history and baseline EEG patterns. Drug effects are fairly predictable, including: no effect, accentuation of beta activity, decreased amplitude and/or frequency of the alpha rhythm, intermixed theta and/or delta (0.5-4 Hz) activity, decreased seizure activity, and lowering of the seizure threshold with increased spike and wave discharges [42]. Most common medication-related EEG alterations are excess beta and a mild theta increase [43].

Hyperacusis, tinnitus, or hearing loss can affect sound perception. Participants' familiarity with hearing tests and BCIs is also assessed, as prior experience may improve focus on stimuli and therefore, performance [44].

4) *Final questionnaire*: The final questionnaire (figure 4) assesses subjects' state of mind and feedback on the experiment. They are asked to rank stimuli by preference, to indicate any that are unpleasant, seem louder than the others, and to provide general comments. At this point, they are

How would you assess your state of mind?

Unpleasant feelings
1
2
3
4
5
6
7
8
9
 Pleasant feelings

Sleepiness
1
2
3
4
5
6
7
8
9
 High arousal

What is your dominant state? Neutral

Listen to the stimuli again by clicking on them!

Stimulus 1 Stimulus 2 Stimulus 3 Stimulus 4

Sort stimuli by order of preference

1. Choose

2. Choose

3. Choose

4. Choose

1 being your favourite and 4, the one you liked least

Are one or more of the stimuli annoying?

Stimulus 1 Stimulus 2

No Yes No Yes

Stimulus 3 Stimulus 4

No Yes No Yes

Did one or more stimuli seem louder or weaker than the others?

Louder Weaker

Did you find the whole experience pleasant? Yes

Why?

Fig. 4: Final questionnaire interface developed in MATLAB.

not aware of the true nature of the stimulation. Therefore, the aim is to compare subjects' state of mind before and after the experiment, evaluate its impact, and assess whether the experiment is perceived as pleasant. Preference rankings help identify which stimuli participants favor, highlighting promising candidates for use in a BCI. Despite normative equalization, perceived intensity can vary across individuals, a stimulus perceived as louder by a subject could elicit stronger neural responses, making it more detectable in brain signals.

IV. QUESTIONNAIRE ANALYSIS

61 participants were recruited. Ultimately, 24 were retained for each loudness level (figure 5), due to issues such as equipment dysfunctions (e.g. broken electrodes, software bug) and human factors (e.g. excessive movement, falling asleep). All have normal hearing for their age; but 5 reported tinnitus for the first sub-experiment (50 phons) and 3 for the second (56 phons). The distribution of women and men for each sub-experiment is the same, as are their ages. Overall, the

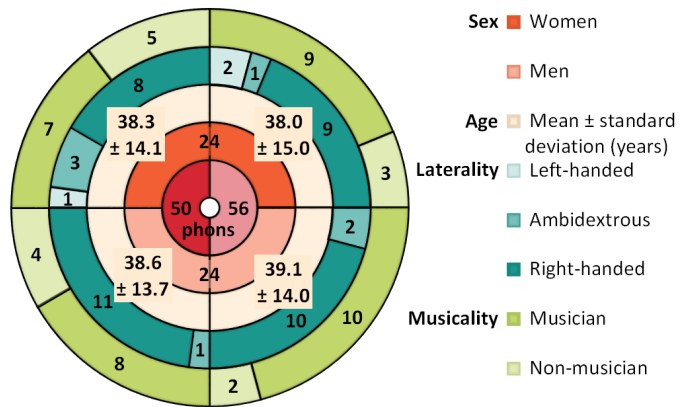


Fig. 5: Quantitative and qualitative description of the participants in the experiment.

proportion of the different profiles in terms of laterality and musicality is similar for each subgroup of participants: right-handed and musician individuals are dominant.

V. DISCUSSION AND FUTURE WORK

This paper focuses on an experimental paradigm designed to assess auditory BCIs based on SSAEPs while highlighting issues related to the accuracy of the sound reproduction of auditory stimuli and the collection of individual participant profiles. The creation of the auditory stimuli is described in detail, including the acoustic processing applied to compensate for the electro-acoustic response of the equipment. This research also led to the development of an audiometer that does not require dedicated medical facilities. All procedures are adaptable and reusable, provided an HATS is available for calibration or that an alternative calibration method is developed. The same applies to the questionnaires and interfaces designed to collect individual information that may influence EEG responses. Overall, this study provides a toolbox that can be applied in future audio or BCI experiments.

The result is a database containing EEG data of 48 participants and associated with a detailed description of individual profiles (including laterality, musicality, pre- and post-experimental states of mind). Open-access publication of this database is pending authorization and will provide the questionnaires and interfaces in addition to data. Individual information can facilitate a more thorough interpretation of EEG responses. Besides, as brain areas most responsive to specific sounds are identified, individual variability can be interpreted using participants' questionnaire responses. This approach could enable personalization of both the number and placement of electrodes for each participant in future studies.

The ultimate objective of this experiment is to evaluate natural sounds for auditory BCI. The challenge is to propose auditory stimuli that are both detectable by the SSAEP method and perceived as pleasant by users. To investigate this question, classification methods have been applied to the EEG responses contained in the database [10]. As a result, the detectability of stimuli has been measured in comparison to a 1-kHz pure

tone, showing that stimuli under test (cicada song, cat's purr and Brownian noise) achieved significantly lower detectability, whilst they are considered more pleasant to listen to. The next step will explore sound design and synthesis tools to improve the acoustic properties of stimuli in terms of detectability.

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