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Licence Sciences, Technologies, Santé
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18/11/2018

INTERNSHIP REPORT

Study of steady-state somatosensory evoked potentials: towards a new type of Brain-Computer Interface

University of origin: Université Lille 1 - Sciences et Technologies; Université Lille Nord de France

Institution of arrival: Brain-Computer Interface team in the Centre de Recherche en Informatique, Signal et Automatique de Lille

Academic tutor: Mrs Marie-Hélène CANU

Internship tutor: Mr François CABESTAING

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SUMMARY

THE LABORATORY PRESENTATION

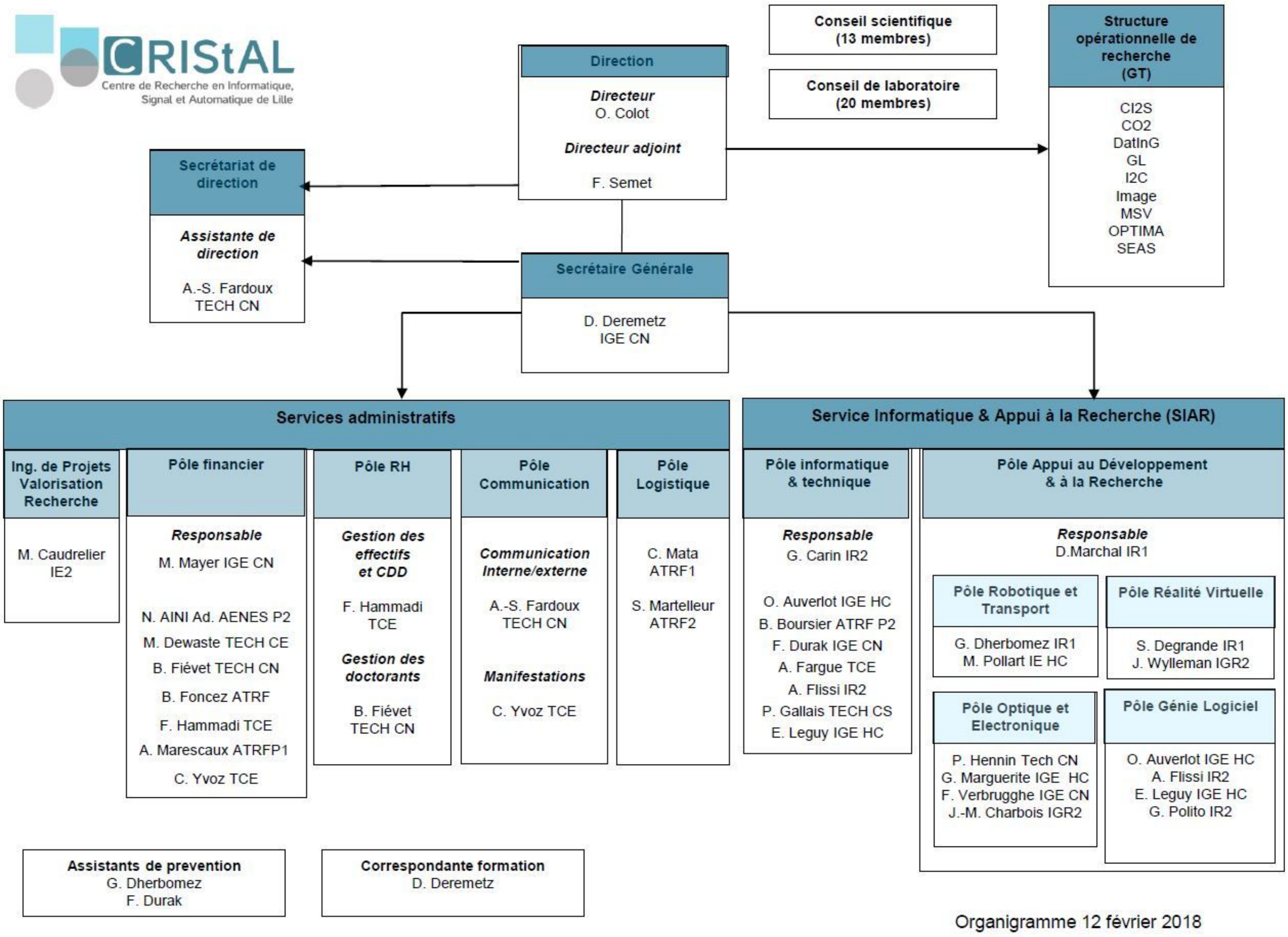


Fig 1. Organizational chart of the CRIStAL laboratory on the 12th February 2018 [1]

My traineeship is undergoing in the BCI team which is part of the I2C: *Interaction et intelligence collective* research group.

The head of the BCI team and my internship tutor is Mr. François CABESTAING.

LIST OF ABBREVIATIONS

BCI : Brain computer interface

DMD: Duchenne muscular dystrophy

ECoG: Electrocorticography

EEG: electroencephalography

ERD/ERS: Event related desynchronization, event related synchronization

FC: Frontal cortex

FFT: Fast Fourier Transform

fMRI: functional magnetic resonance imaging

KMI: Kinesthetic motor imagery

NIRS: Near Infrared Spectroscopy

PC: Parietal cortex

P300: Potential 300 ms

SCP: Slow cortical potentials

SSSEP: Steady-state somatosensory-evoked potentials

TMS: Transcranial magnetic stimulation

STATE OF THE ART AND OBJECTIVES

1. Brain-Computer interfaces

The direct observation of brain activity was performed by Berger in the early 20th century who published the first human EEG data in 1924, 50 years later Vidal introduced the term “Direct brain-computer communication” [2].

A BCI is an artificial system that measures the brain activity and translates it into corresponding control signals therefore bypassing the efferent pathways [3].

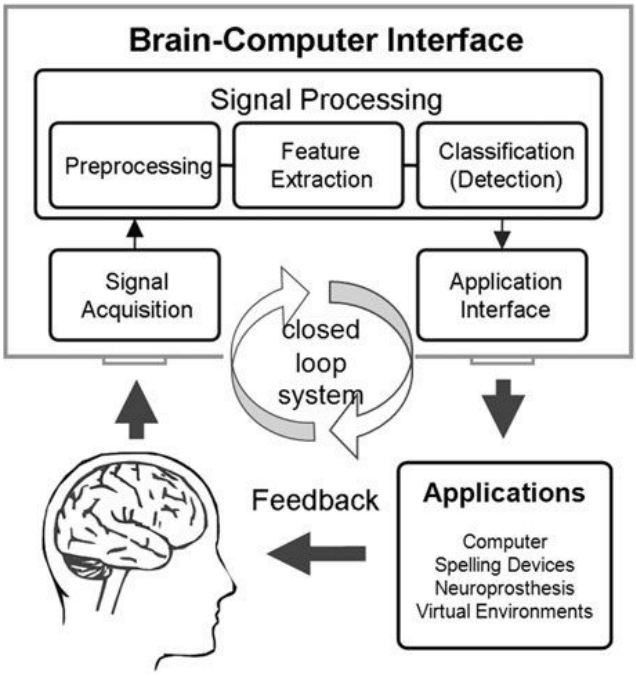


Fig 2: The basic components of a BCI [4]: brain signals are acquired and processed, detected features are classified and turned into a command. Finally, the user receives a feedback.

There are three types of BCIs [5]:

- Active BCIs

The user has to perform a mental task that specifically corresponds to a control signal for the BCI.

- Reactive BCIs

The user has to perform a mental task in response to a cue given by the interface.

- Passive BCIs

The interface detects spontaneous changes in the mental state of the user when he performs an unrelated task.

They can also be characterized by their invasiveness [6]:

- Invasive BCIs

Record or stimulate directly neurons in the brain

- Semi-invasive BCIs

Record or stimulate the brain surface or nerves.

- Noninvasive BCIs

Record or stimulate the surface of the scalp in a non penetrating way.

And finally they can be characterized by the type of mental task they require [6]:

- Conditioned responses

Operant conditioning of up to a single neuron can be used to control an interface [7].

- Imagined motor and cognitive activity

The user can imagine making a movement or perform a mental calculation that can be mapped to a control signal.

- Stimulus evoked activity

The stereotyped activity of the brain in response to a visual, auditory or sensory stimulus.

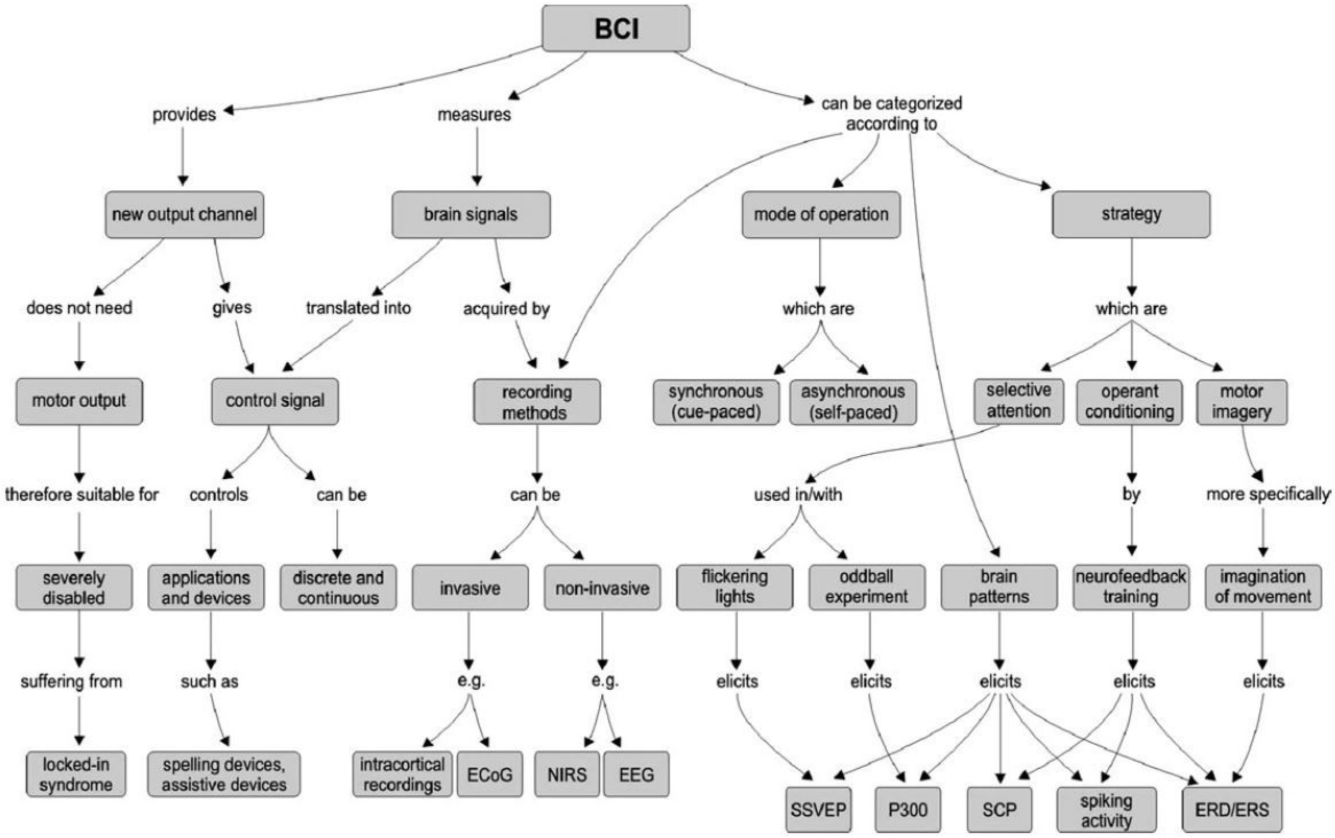
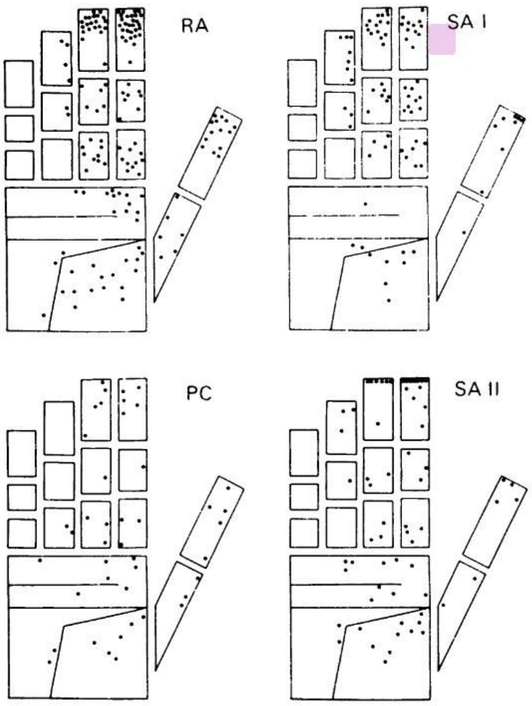


Fig 3. Diagram on the different types of BCI [8]

2. Steady-state somatosensory evoked potentials

An evoked potential, as Vidal puts it, is the synchronous activity of the neurons beneath an electrode that produce a short aperiodic waveform buried under the background activity in response to a visual, auditory or somesthetic stimulus [2]. Steady-state evoked potentials however *"reflect a sustained cortical response induced by the long-lasting periodic repetition of a sensory stimulus. [...] These steady-state responses remain constant in amplitude and phase over time, and are thought to result from an entrainment or resonance of a population of neurons responding to the stimulus at the frequency of stimulation"* [9].

Steady state visual evoked potentials (SSVEP) have been extensively used for BCIs but they require a high amount of visual attention which can be tiring as well as a limiting factor for the visually impaired [10]. An alternative approach can be the use of the somatosensory evoked potentials which are triggered by the activation of the mechanoreceptors on the skin.



In particular, the glabrous skin has 4 types of mechanoreceptors (Fig 4), 2 slow adapting Ruffini endings and Merkel cells that respond to low frequencies (5-15 Hz) and 2 fast adapting mechanoreceptors, the Meissner corpuscles and Pacinian Corpuscles that respond to high frequencies (20-50 Hz and 60-400 Hz respectively) [12] by producing responses in the frontal (Primary motor) and parietal (Primary somatosensory) cortices of the hemisphere contralateral to the stimulation site (Fig 5).

Fig 4. Distribution of the hand mechanoreceptors [23].
RA: Rapidly adapting Meissner corpuscles,
SA I: Slowly adapting type 1 Merkel corpuscles,
PC: Rapidly adapting Pacini corpuscles and
SA II: slowly adapting type 2 Ruffini corpuscles.
The individual blocks are proportional to the corresponding skin area.

The use of SSSEP is promising for BCI research as patients suffering from severe neurological and muscular diseases are thought to still have a functional somatosensory system [13].

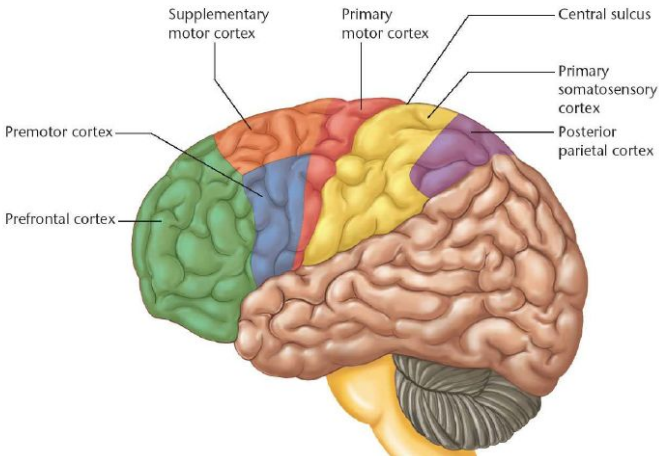


Fig 5. Localisation of the primary somatosensory cortex on the brain map [11]

3. The sensory gating effect

We know from several studies that moving the hand or watching a hand perform an action can interfere with the somatosensory information that comes from the vibrotactile stimulation of one's own hand. This process is known as a "gating" effect [14,15] and produces a small deflexion of the SSSEP signals. In this study we will try to identify one such effect when a person is thinking about doing a task which is defined as Motor Imagery, but to be more precise, the subject has to perform a kinesthetic motor imagery task. Studies have shown that kinesthetic motor imagery, the act of imagining oneself doing the action (first-person process) is better than motor imagery, the act of simply visualizing an action (third-person process) [16].

MATERIAL AND METHODS

The volunteers

The experiments were made on 4 neurotypical subjects (3 men and one woman) that had no records of any physical disability, or of any substance abuse at the time of the study.

The environment

The study was conducted in the CRIStAL laboratory in the P2 building of the University of Lille campus.

We tried our best to isolate the room, the user and the material from electric and electromagnetic currents by running on batteries, removing everything from mains electricity, using anti static wristbands and optocoupler cables.

EEG recordings and apparatus

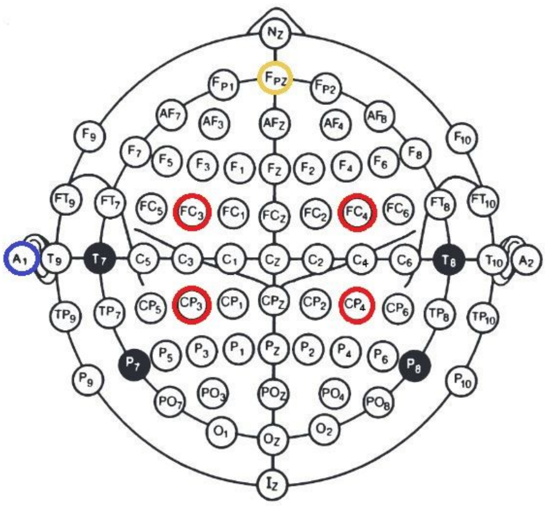


Fig 6. The electrode nomenclature of the International Federation [18]. The reference is on A1 (blue) and the ground electrode is on Fpz (yellow).

The tactile stimulation device, a C-2 tactor was bought from the USA (Engineering Acoustics, Inc., Casselberry, Florida, USA). And was piloted through an Arduino Box made by Mr. Cabestaing.

Since SSSEP represent a current from the motor and somesthetic cortex that can diffuse to the scalp we can measure it with a non invasive technique, the electroencephalography (EEG). The EEG cap was made with Ag/Cl wet electrodes placed on FC3, FC4, CP3 and CP4 (Fig 5).

The recordings were made with the OpenVibe software. And the resonance frequency was found using the MNE library in Python.

The programming of the OpenVibe scenario, made by the BCI team, was inspired by the Breitwieser, Pokorny and Müller-Putz's 2016 paper [19] with the purpose of making a hybrid BCI using SSSEP and motor imagery.

In order to make a user-centered BCI and to optimize the learning process [20] we imagined making a 3 step experimental protocol (Annex 1): the first step consisting in finding the resonance frequency which is the highest amplitude of the SSSEP of a given frequency, on both the left and right index fingers of the volunteers in a non control state. The non control state was reached by the user by gazing at the window. The second step consisting in a cue-based training in which they had to figure out how KMI would work best for them. And finally the final step consisting in repeating the previous step for some time, followed by free training where they could improve their KMI skills thanks to a gamified feedback on Openvibe.

To further elaborate on the 1st step, which is the one we have been working on the most, the resonance frequencies were found under minimal attention conditions obtained by a relaxation state as it is well known that concentrating on the stimulation increases the amplitudes of the SSSEP, this precisely is the paradigm of numerous BCI such as the brain controlled wheelchair of Kim et Al., [21]. However, for the present study we wanted to avoid any interference with the SSSEP.

The objectives of this preliminary research were:

- Find the best method to stimulate the mechanoreceptors on the skin
- From the SSSEP recordings, find the tuning curve of both index fingers for each user
- Make a training protocol for a BCI using KMI and SSSEP

To conclude, the BCI paradigm that we will use here will be, a person-adapted, non invasive, asynchronous (self-paced) and hybrid (SSSEP and kinesthetic Motor imagery) BCI with feedback for a better learning experience.

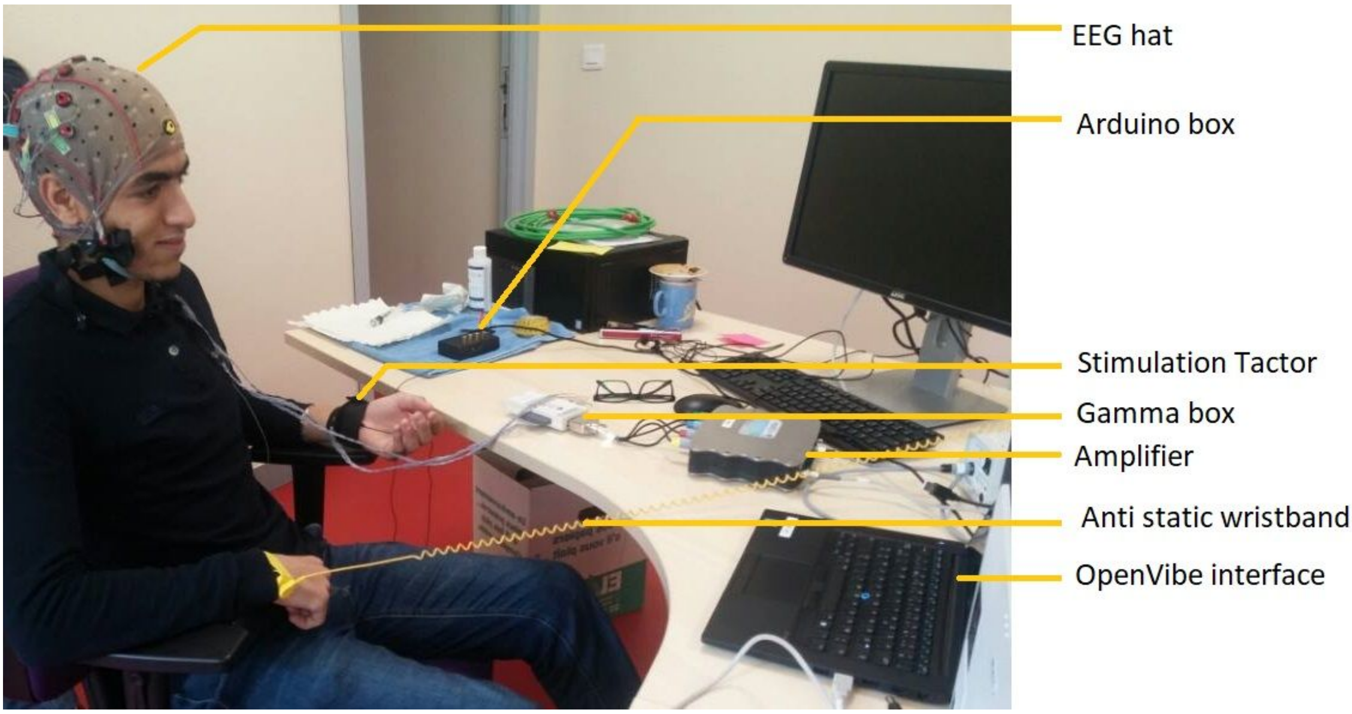


Fig 6. The experimental set-up

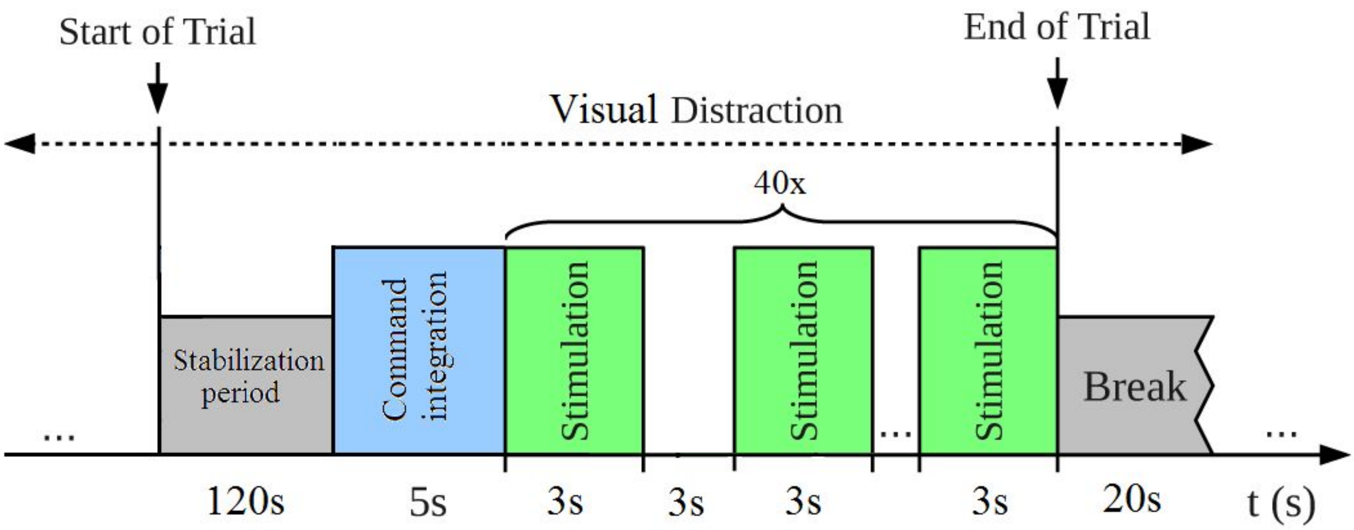


Fig 7. Screening paradigm adapted from [12].

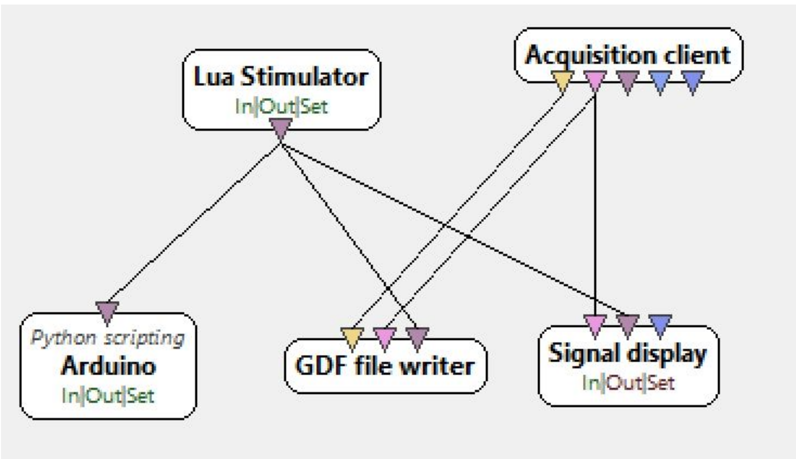


Fig 8. The OpenVibe program

RESULTS

1. Finding the stimulation method

At first, we tried to stimulate different parts of the hand in order to see where the SSSEP were the highest:

1. the wrists
2. the palms
3. the volar wrists
4. the index fingertips when the arms were in a supination position on the armrests of the chair
5. the index fingertips when the arms were in a pronation position on the table

But after some empirical observations we chose the fifth stimulation method as it was perceived to be the most comfortable and the fastest to set up. Furthermore, based on physiology research we can argue that the index fingertips have the most important mechanoreceptor density [23].

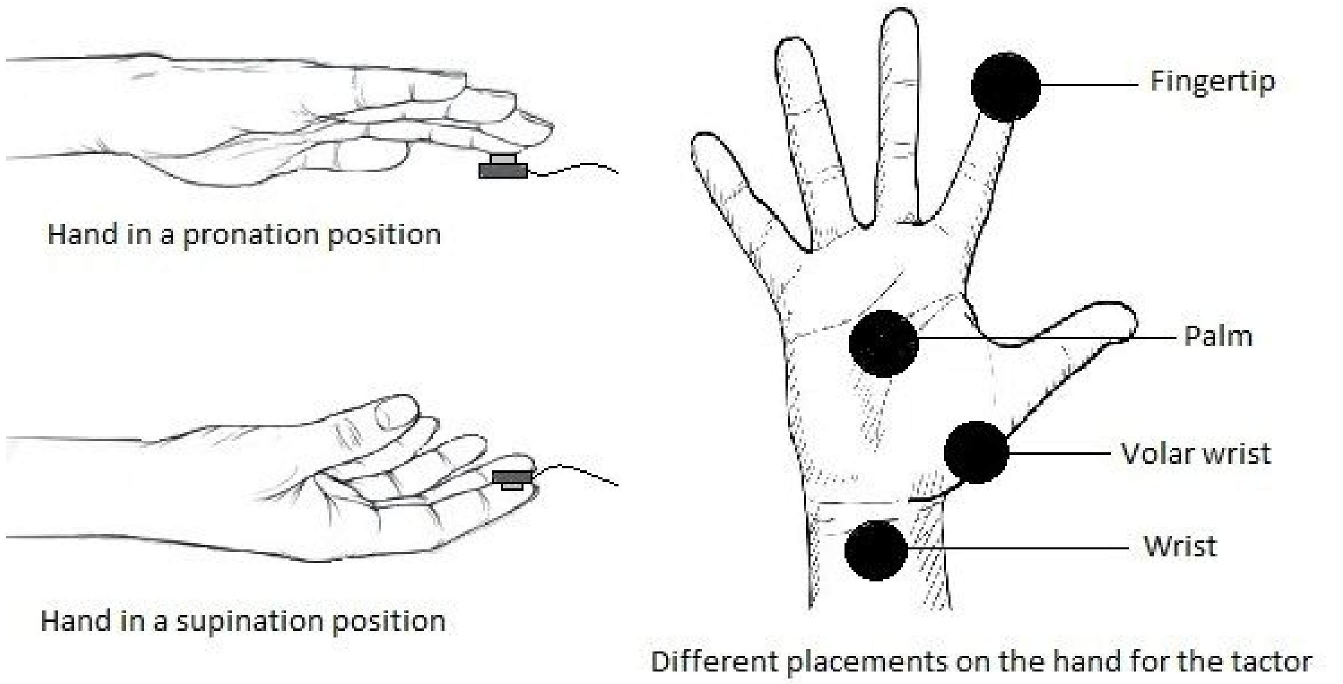


Fig 8. The different stimulation sites that were tested.

2. Measuring the reference signal

We needed a control condition to which we would compare the SSSEP that we were hoping to find. So for each subject we ran the experimental protocol but we disabled the arduino to prevent the vibrotactile stimulations.

We observed that subject 1 and 2 presented a high amount of alpha waves around 10 Hz and its harmonic around 20 Hz even though they kept their eyes open during the entire protocol. Consequently there was a chance of interference with the SSSEP and we were afraid that for the stimulation at 20 Hz the SSSEP would be indistinguishable from the alpha waves.

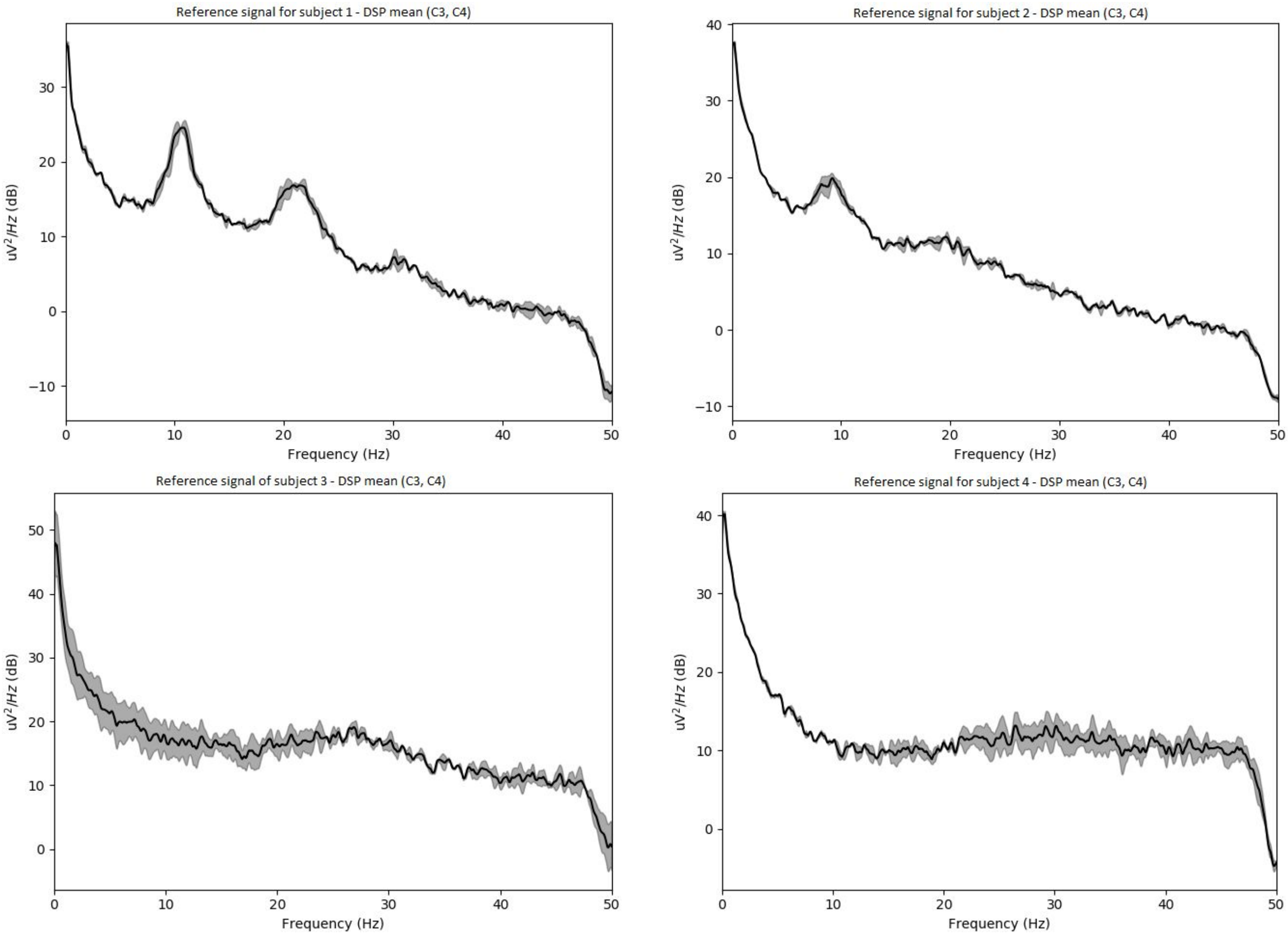
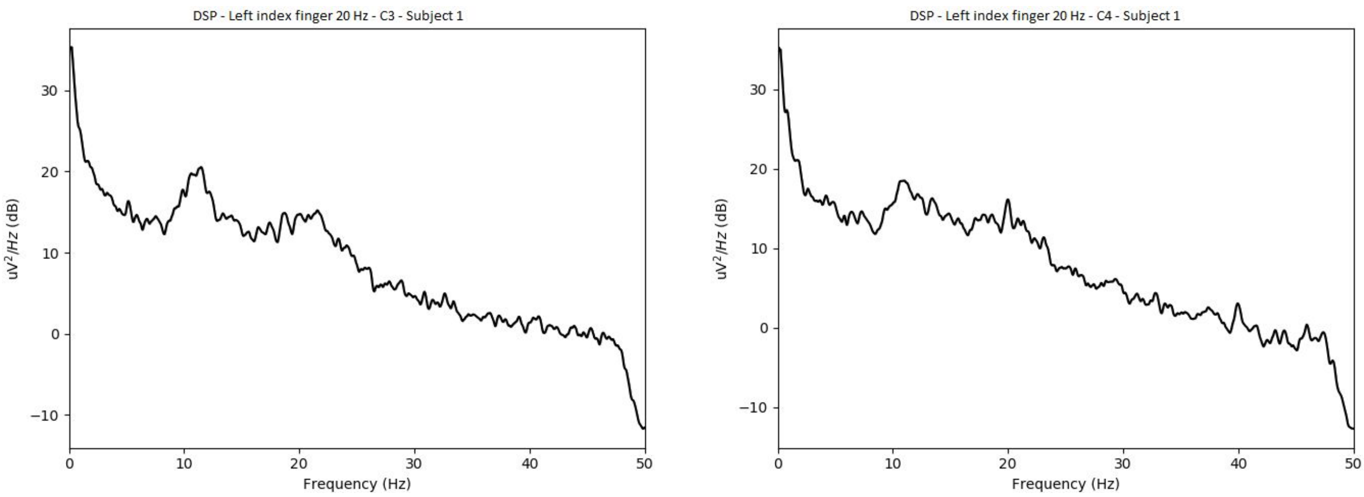


Fig 9. Curves representing the mean reference signals of the 4 subjects

Fortunately this was not the case, for instance, when the stimulation protocol for 20 Hz on the left fingertip was done on subject 1, a spike representing the SSSEP of 20 Hz was clearly visible in the contralateral side of the brain (C4).



3. The screening protocol

By doing the mean of the 40 repetitions for each hand of the 4 subjects we obtained the following results:

	Subject 1	Subject 2	Subject 3	Subject 4
Frequency with the highest SSSEP for the right index stimulation	17 Hz	20 Hz	20 Hz	17 Hz
Frequency with the highest SSSEP for the left index stimulation	20 Hz	17 Hz	23 Hz *	20 Hz

* The curve for 26 Hz for subject 3 was lost and therefore was not considered here.

Oussama SADDOUK had to use matlab to find the mean curve of the 40 repetitions of each frequency of stimulation but perhaps we could find a way to add a signal display box in the OpenVibe setup that could give us instant feedback on the highest SSSEP so that the screening process could be faster and more efficient.

DISCUSSION AND PERSPECTIVES

1. Putting our results into context

In 2014 Pokorny and his team found that a vibrotactile stimulation on the index fingers would produce a spike of the same frequency in the contralateral somesthetic cortex [12], this activity was identified as a steady-state somatosensory evoked potential (SSSEP). These potentials have been proven by Breitwieser and his team [10] to be stable enough to be exploited in a brain-computer interface.

In the present study we were able to obtain visibles spikes corresponding to the SSSEP elicited by vibrotactile stimulations, meaning that we have cleared the first requirement for our new type of BCI and we can now move forward towards measuring the sensory gating effect.

2. Perspectives on our hybrid BCI

The first part of our protocol and the BCI we designed has worked for our 4 volunteers, however there are still areas in which we can improve. First of all, as said earlier, we could make the screening process more efficient. Secondly, in order to be more truthful to real life situations and to make the screening process less boring for the subjects we could engage them into a high visual perception load task such as:

- A letter search task
- A shape search task
- A word finding task (See annex 3 for some examples for each of them).

Or we could provide them with images of picturesque sites and landscapes but only if we can prove beforehand that this addition will not influence the perception of the vibrotactile stimuli nor the sensory gating effect.

And lastly we should have a bigger sample size to be more confident in our results.

Thereafter, if the gating phenomenon is systematically found, it could be associated with an intent of action and could potentially be linked to a numerically controlled wheelchair. People suffering from a neurological disease such as DMD could benefit from its use from early on since they lose their moving abilities with this pathology [22] and thus would be able to keep their independence by progressively relying on their Kinesthetic Motor Imagery to control the wheelchair.

The ultimate goal of this project would be to confront our new paradigm to the one of the Kim et Al. team [21] and the Breitwieser et Al. team [19], on the basis of performance (classification accuracy) and cognitive load as defined by Paas in 1994 as "the load that performing a particular task imposes on the learner's cognitive system".

Furthermore, some more documentary research is needed to improve the experimental survey (Annex 4), particularly to find a reliable scale to measure the discomfort and the cognitive load the users go through.

3. Final thoughts

To finish, it is perhaps important to address that although BCI hold a lot of potential, not everyone will be able to use them because they may have some psychological conditions such as schizophrenia in which sensorimotor gating is impaired [24] or they may be BCI illiterate, which means that they are not able to control a motor imagery-based BCI, fortunately some researchers are looking for BCI illiteracy markers and ways to improve the learning protocol right now [17].

New discoveries in related fields such as psychology, engineering, neuroscience and computer science are made everyday, what an exciting time for BCI research !

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THANKS

First of all I would like to thank Mr François CABESTAING who allowed my aspirations to come true by letting me join his BCI team. He is a wise tutor, that lets us try and fail but whose expertise we can always rely on for responses or advices.

I would like to thank also Mr Oussama SADDOUK, my fellow intern who teasingly, but rightfully so, pointed out my mistakes so that I could learn from them and make some new ones instead.

My special thanks to Mr José ROUILLARD who took out time from his own work to help us and also let us run some trials on him.

Finally I would like to thank Mrs Marie-Hélène CANU for answering to my enquiries when she came for her visit.

ANNEX 1. Experimental protocol

STEP 1

OBJECTIVE: Find the resonance curve of the volunteer

The settings of the openVibe software were:

- Sample count set block: 32
- Common ground and common reference
- Notch filter: Low pass butterworth 4-[48;52] 512
  Low cut high cut butterworth 8-[5;60] 512
- The electrodes impedance should be below 1 kOhm.

Subject must be seated comfortably on a chair, arms resting on the table. The height of the chair must be adjusted to align the eyesight to the screen. The experimentator will explain the content of the session and tell them to do the psychometrics test.

1) Place the electrode hat on the head and the reference on the earlobe.

2) Sterilize with alcohol and place an EMG electrode on the back of both hands to relate any hand movements during the experiment.

3) Sterilize with alcohol and place the user's index finger on the stimulation Tactor.

4) Ask the volunteer to relax while the experimentator is checking the impedance.

5) Start the experimental acquisition on the OpenVibe software to measure the alpha wave frequency and its harmonics.

6) (Optional) Configure the stimulation frequencies in order to avoid the previously found harmonics.

7) Start the experimental acquisition on the OpenVibe software in order to stimulate from 14 to 26 Hz with a 3Hz increment for 3s and a 3s second pause between each stimulation.

8) Once the recording is complete, ask the volunteer if everything is alright and then repeat the stimulations on the other index.

9) When the experimentator has found the resonance frequencies for both sides, start a new recording scenario with the stimulation at the user-specific resonance frequency but with varying stimulation amplitudes to find the stimulation amplitude that produces the highest SSSEP.

10) Now repeat the above instructions (9) with the Tactor on the other index finger.

11) End of the experiment, ask the volunteer to fill the experimental survey (Annex 4) and then go on with another volunteer.

STEP 2

OBJECTIVE: Observe the sensory gating on the SSSEP recordings

Subject must be seated comfortably on a chair, arms resting on the table. The height of the chair must be adjusted to align the eyesight to the screen. The experimentator will explain the content of the session.

1) Sterilize with alcohol and place the index fingers of the user on the stimulation Tactors according to the results obtained in STEP 1.

2) Place the electrode hat on the head and the reference on the earlobe.

3) Sterilize with alcohol and place an EMG electrode on the back of both hands to relate any hands movements during the experiment.

4) Ask the volunteer to relax while the experimentator is checking the impedance.

5) Start the experimental acquisition on the OpenVibe software in order to have the raw EEG for 1 minute.

6) Then start the experimental acquisition on the OpenVibe software in order to stimulate at the resonance frequency specific to the fingers with a 3 second pause between each stimulation. During this scenario, the subject will have to perform randomly 2 Kinesthetic Motor Imagery tasks of his choice and 2 Motor tasks on his hands when a visual cue will be given (Annex 2).

7) Once the recording is complete, ask the volunteer if everything is alright and then repeat the experiment 2 times.

8) End of the experiment, ask the volunteer to fill the experimental survey and then go on with another volunteer.

STEP 3

OBJECTIVE: Play a video game with the brain thanks to the sensory gating in SSSEP

Subject must be seated comfortably on a chair, arms resting on the table. The height of the chair must be adjusted to align the eyesight to the screen. The experimentator will explain the content of the session.

1) Sterilize with alcohol and place both fingers on the stimulation Tactors according to the results obtained in STEP 1.

2) Place the electrode hat on the head and the reference on the earlobe.

3) Sterilize with alcohol and place an EMG electrode on the back of both hands to relate any hands movements during the experiment.

4) Ask the volunteer to relax while the experimentator is checking the impedance.

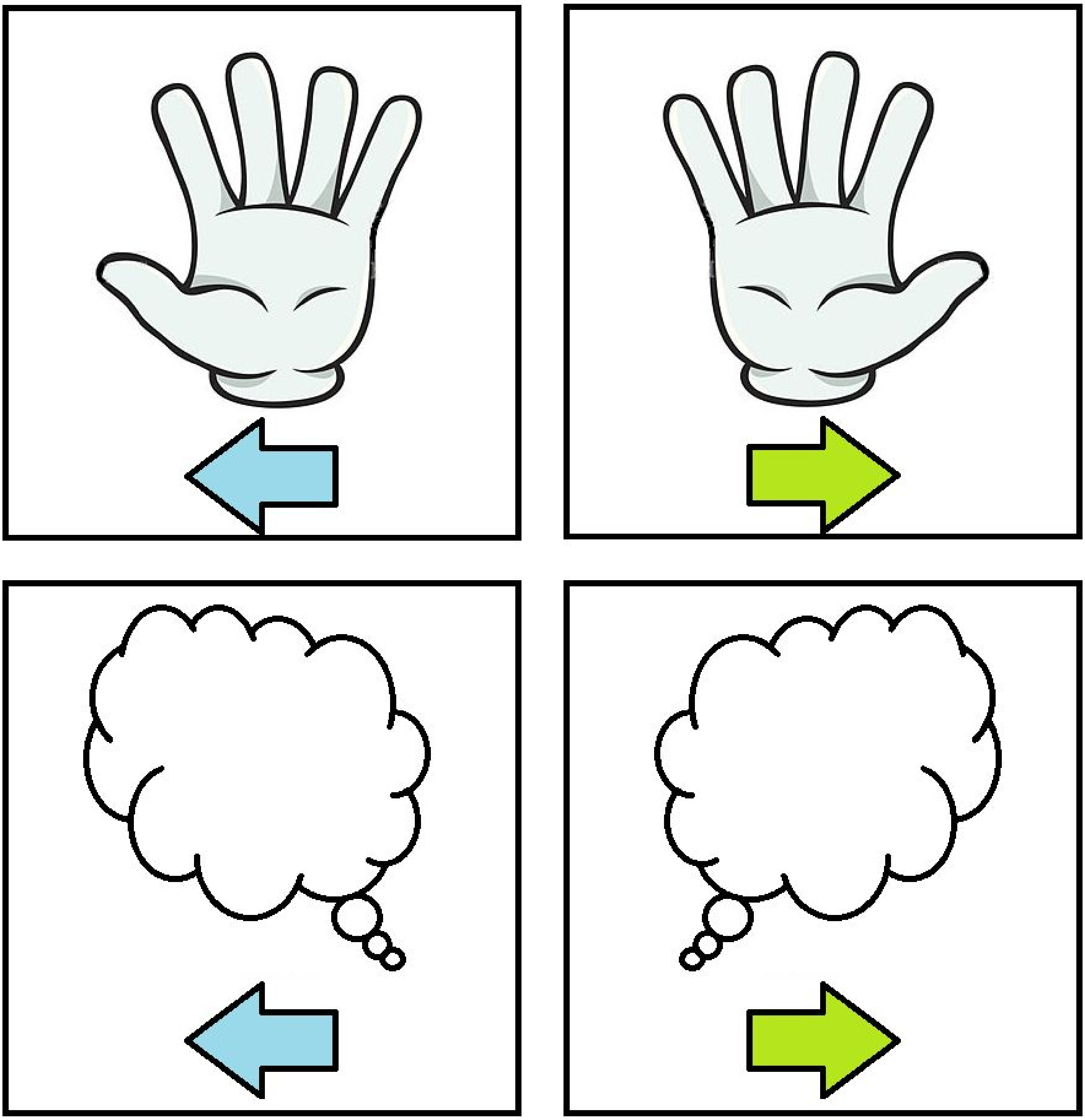
5) Start the experimental acquisition on the OpenVibe software in order to have the raw EEG for 1 minute.

6) First start the experimental acquisition on the OpenVibe software in order to stimulate at the resonance frequency specific to the hand with a 3 second pause between each stimulation. During this scenario, the subject will have to perform randomly 2 Kinesthetic Motor Imagery tasks of his choice and 2 Motor tasks on his hands when a visual cue will be given just like in the previous session.

7) Then after making sure that it went well, start another experimental acquisition on the OpenVibe software in order to stimulate at the resonance frequency specific to the hand with a 3 second pause between each stimulation. However, during this scenario, the subject will have to perform randomly 2 Kinesthetic Motor Imagery tasks of his choice when he wants to make them and there will not be any visual cue but rather a visual feedback in the form of a game.

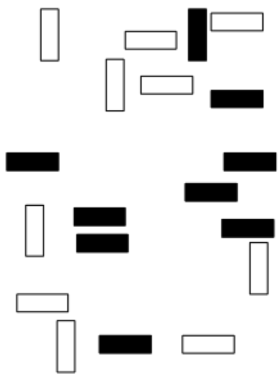
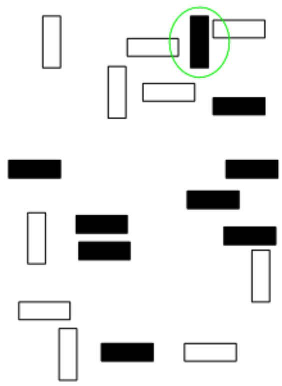
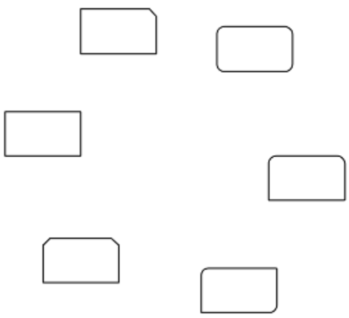
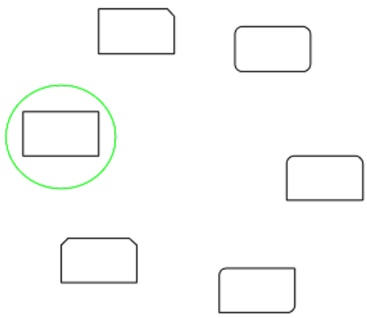
8) End of the experiment, ask the volunteer to fill the experimental survey and then go on with another volunteer.

ANNEX 2. Visual instructions for the second step



From the first to the forth: Move the left arm move the right arm, think about moving the left arm and think about moving the right arm with kinesthetic motor imagery.

ANNEX 3. Visual distractions : examples of task relevant high perceptual load stimuli

Tasks	Responses/feedbacks
Zodi□que	Zodiaque
Task 1: Find the missing letter from the word.	
	
Task 2: Find the black vertical rectangle.	
	
Task 3: Find the rectangle.	

ANNEX 4. The experimental survey

The collected informations will be anonymously treated and conserved.

It is highly advised to be present for all the experimental sessions.

However, the trials can be stopped at any moment in case of inconvenience.

1) SURNAME and name (Attributed number:):

2) Age:

3) Right handed or Left handed:

4) To the ladies, are you pregnant?

5) For the control group: Have you been diagnosed with any neurological disease?

Have you been diagnosed with any disability?

Have you had any kind of substance abuse in the previous week?

Step 1

1) Were the instructions clear to you?

2) How would you qualify the mean in which the instructions were given to you?

3) How would you qualify the length of today's experiment?

4) How would you qualify the difficulty of the mental tasks?

5) How would you describe the stimulation?

Step 2

1) How would you qualify the length of today's experiment?

2) How would you qualify the difficulty of the physical tasks?

3) How would you qualify the difficulty of the mental tasks?

4) How would you describe the stimulation?

Step 3

1) How would you qualify the length of today's experiment?

2) How would you qualify the difficulty of the physical tasks?

3) How would you qualify the difficulty of the mental tasks?

4) How would you describe the stimulation?

5) Can you think of any advice that would help us improve the experimental conditions or the experimental protocol itself?

ANNEX 5: Experimental checklist

The environment:

- ❑ Lights should remain off during the experimentation
- ❑ Check that every device is fully charged or has new batteries and is removed from the mains
- ❑ Configure the room temperature so that it is not too hot otherwise the user will face discomfort nor too cold otherwise the conductive gel will dry faster.

The experimental set up:

- ❑ Check that the gamma box is on and connected to the amplification device
- ❑ Check that the amplification device and the stimulation device are on and connected to the computer

The experimental protocol:

- ❑ Is the software openVibe 2.1.0 ?
- ❑ Check the driver (Legacy)
- ❑ Is the ground and reference common?
- ❑ Check the arduino channel
- ❑ Check the Notch filters
- ❑ Check that the channels of the electrodes are imported
- ❑ Check the impedance of the electrodes
- ❑ Establish the stimulation frequency, its length, the number of repetitions and the duration of the pauses
- ❑ Is the gdf file renamed with the stimulation frequency and the user's identification number?

The user:

- ❑ Feet should be on the tilting footrest
- ❑ The EEG hat should be positioned according to Cz.
- ❑ Is the reference electrode coated and on the ear?
- ❑ The arms should be in a relaxed position
- ❑ Check the position of the stimulation tactor
- ❑ The user should keep the eyes open during the experimentation

Brain computer interfaces are not a work of science fiction anymore, recent progress in this domain at the frontier of neuroscience and computer engineering has allowed amputees to gain prosthetic limbs, locked-in syndrome patients to communicate and Parkinson patients to move more freely. Every other day a new paradigm is put to the test for medical purposes. The present report is about one of them, specifically, the use of both kinesthetic motor imagery and sensory gating of the steady-state somatosensory evoked potentials (SSSEP) to make a self-paced BCI for Duchenne muscular dystrophy patients. We were successfully able to record SSSEP related to a vibrotactile stimulation and have proposed a training protocol for the continuation of the project.

Steady-state somatosensory evoked potential (SSSEP);

Electroencephalography (EEG);

Brain-computer interface (BCI)