DESIGN OF A COMBINED AUGMENTED REALITY AND NIRS BRAIN IMAGING SYSTEM

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1   INTRODUCTION

This user's manual contains the product description of the AR Paradigms, the Synchronization Box, and the Physical Description. The product specifications, installation procedure, operation procedure, maintenance and debugging of the various project aspects can be found in this manual.

2   PRODUCT DESCRIPTION

2.1   AR Description

2.1.1   General Description

The AR paradigms are stored in the file named *AR Psychological Paradigms* which can be found in the GitHub (https://github.com/potvingab/GBM8970-ARNIRS) or the USB key provided by the developer team. There are two paradigms: Stroop and N-Back. Both are visualized with the *Meta 2* AR headset. Stroop is a color-word interference test and only requires the headset. In Stroop, a word is displayed on the participant's screen, as well as 3 buttons allowing the participant to answer the questions. The buttons are presented as 3 cubes with the words GREEN, BLUE and RED that the participant must grab for the question to be answered. N-back is a memory test that asks the patient if the current stimulus is the same as the one from n-steps earlier in the sequence. In our case the stimulus is an audio and/or a visual image. The participant is provided with two press buttons to indicate if the stimuli are the same or different.

2.1.2   Stroop Description

2.1.2.1   Menu

The first step of the Stroop game is to set multiple parameters in the *AR Stroop Study Parameters*. Each description is described in section **2.2.1.2.** This section aims to help the researcher determine to order of setting the parameters (**Figure 2.1**).

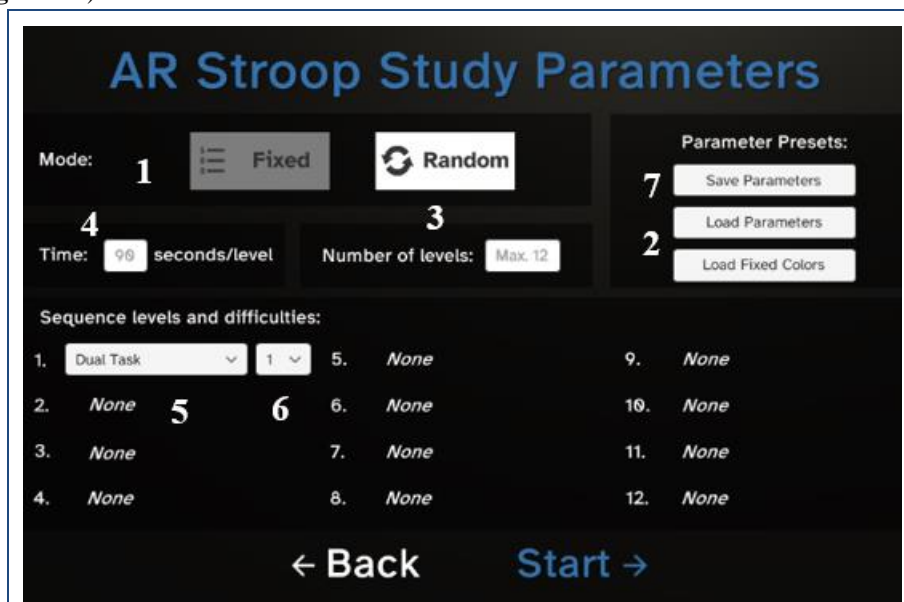
Figure 2.1: Example of the Stroop menu.

1. Choose between Fixed or Random in the game mode section.
2. If needed, the researcher can load previously saved parameters or a new sequence of questions.
3. Enter the number of levels for the trial.
4. Enter the time of each level in seconds.
5. Choose the type of task (*dual task*, *single cognitive task*, *single walking task*) for each level.

6. Choose the difficulty (*1*, *2*, *3*, *4*) of each level.
7. If needed, save the parameters for use in a future trial.

2.1.2.2 Parameter Description

2.1.2.2.a Game Mode

DESCRIPTION:

There are two games mode that use different approaches to display the question. The fixed method is a predetermined sequence of 50 questions provided by Dr. Karen Li. These sequences are stored in the text file (GBM8970-VRNIRS/AR-NIRS Psychological Paradigms/Assets/C# Scripts/StroopScripts/Resources/fixed_sequence.txt) and can be modified. If modified, a guideline, explained in **section 2.1.1.2g**, must be followed for the Stroop to be valid. The random method uses a random generator which chooses between RED, BLUE, and GREEN for the word and the color of the word displayed in the participant's screen. It also verifies that the word and the color of the word are not the same for the level 3 and 4, as explained in the next section.

OPTIONS: Fixed, Random

2.1.2.2.b Level of Difficulty

DESCRIPTION:

There are 4 levels of difficulty, each displaying a different type of question. The first level displays a blue, red, or green rectangle and the participant must select the color of the rectangle. The second level displays the word BLUE, RED and GREEN in white for the participant to choose the written word in front of them. For the third level, the color of the word displayed is different from the written color. The participant is instructed to select the color of the word. For the fourth and last level the color of the word displayed is also different from the written color. In this level, the participant will have to select the written color if the word is surrounded by a rectangle. Otherwise, the participant must select the color of the word.

OPTIONS: 1, 2, 3, 4

2.1.2.2.c Number of Levels

The researcher can choose up to 12 levels for one session.

2.1.2.2.d Sequence Task

There are three types of tasks: *Dual Task*, *Single Task (Stroop)*, and *Single Task (Walk)*. For *Dual Task*, the participant will play Stroop while walking on the treadmill. For *Single Task (Walk)*, the participant will only walk on the treadmill and for *Single Task (Stroop)*, only the Stroop game will be played.

2.1.2.2.e Time

DESCRIPTION:

The participant has a set time to answer the question. In other words, each time the participant selects an answer, another question will be displayed until the time specified earlier in the menu has elapsed. The default time is 90 seconds, but can be modified in the *AR Stroop Study Parameters*

DEFAULT: 90s

2.1.2.2.f Load parameters

The button *Load parameters* allows the researcher to choose a text file that contains the participant's saved parameters. For the Stroop to be functional the text file needs to be written according to the following guideline:

1. The line before the parameters must indicate *AR Stroop Study Parameters*.
2. Each parameters needs to be set in the file such as **Figure 2.2**.
3. The parameters must be separated with a coma.

```
AR Stroop Study Parameters
Trial Time:5
Number Trials:5
Sequence:Dual Task,Dual Task,Single Task (Stroop),Single Task (Stroop),Single Task (Walk
Sequence Levels:1,2,3,4,1
Game Mode:Random
```

Figure 2.2: Example of the text file for the loaded parameters.

2.1.2.2.g   Load Fixed Colors

The button *Load Fixed Colors* allows the researcher to choose a text file that contains the sequence of questions when the fixed method is used. For the Stroop to be functional, the text file needs to be written according to the following guideline (see **Figure 2.3**):

1. The line before the sequence must indicate the level of difficulty of the sequence.
2. Each question needs to be separated by a semicolon.
3. The sequence ends with the word "END".
4. For level 3, the first character is the color of the word and the second is the written color. The characters need to be separated with a coma.
5. For level 4, the first character is the color of the word, the second is the written color. The third character is either 1 to frame the word with a rectangle or 0, otherwise. The letters need to be separated with a coma.

```
Level1
G;R;B;G;B;R;B;G;B;G;END
Level2
R;B;G;R;B;G;B;G;R;B;END
Level3
G,R;R,B;B,G;G,B;R,G;B,R;R,B;G,R;R,G;G,R;END
Level4
R,B,0;B,R,0;R,G,1;B,R,0;G,B,0;B,G,0;G,R,1;B,G,0;G,R,0;R,B,1;END
```

Figure 2.3: Example of the text file for the fixed sequence.

2.1.2.2.h   Save Parameters

After all the parameters are set, the researcher can save the parameters in a text file by clicking on the button *Save parameters*. The file explorer will open to allow the researcher to pick the file location.

2.1.2.3   Baseline

For each session, a baseline level, in which the color of the word is the same as the written word, is present. The goal of this level is to measure and record of the participant's response time.

2.1.2.4 **Tutorials**

Before each level, there is a tutorial for the participant to get acquainted with the instructions of the difficulty level. Each tutorial is a sequence of questions provided by Dr. Karen Li. They can be skipped or replayed multiple times. If the latter is chosen, the questions will be randomized so the sequence is different from the previous tutorial.

2.1.2.5 **How to Answer**

To select an answer, the participant needs to hover their open hand over the chosen cube and form a fist to select the answer. To answer another question, the participant must pull their fist out of the AR field of view and open it to restart the answering process as presented in **Figure 2.4**.
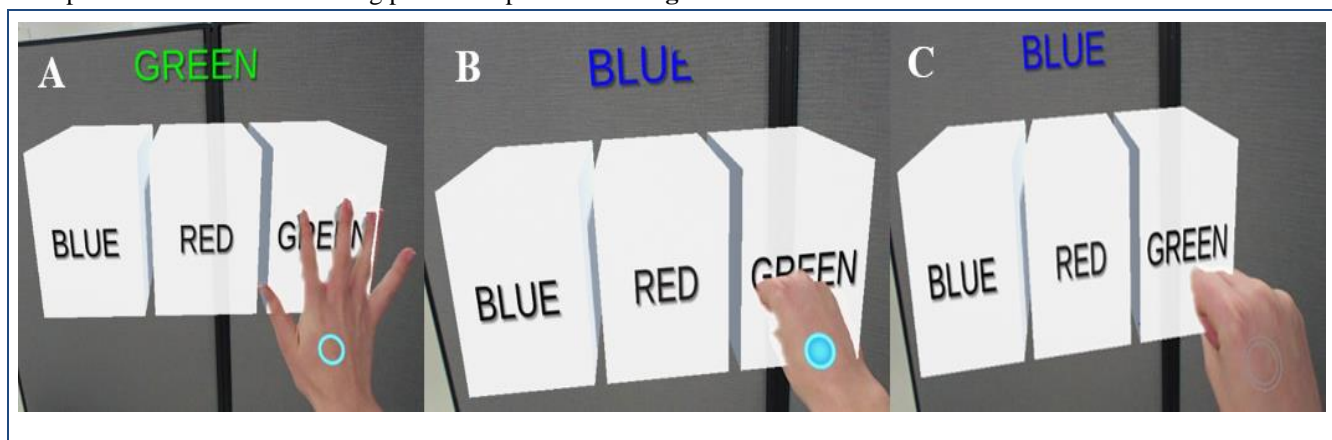

Figure 2.4: Steps to select an answer. A, open the hand on the button. B, close the hand while on the button. C, retrieve the hand still with a closed hand.

2.1.2.6 **Results**

At the end of the game, there is a summary of participant's results shown in **Figure 2.5**. Full information is available in the .txt file created.

Figure 2.5: Summary of the participant's results.

2.1.3 N-back

2.1.3.1 Parameter Description

The first step of the N-back game is to set multiple parameters in the *AR N-back Study Parameters*. **Section 2.1.2.1** contains the description of each parameter. This section aims to aid the researcher in setting the parameters in adequate order (**Figure 2.6**).

Figure 2.6: Example of the N-back menu.

2.1.3.1.a Game Mode

There are two games mode that use different approaches to display the question. The fixed method is a predetermined sequence of 15 objects with 8 different types of objects provided by Dr. Karen Li. These sequences are stored in the text file (GBM8970-VRNIRS/AR-NIRS Psychological Paradigms/Assets/C# Scripts/NBackScripts/Resources/FixedSequenceNBack.txt) and can be modified following the guideline in **section 2.1.2.1g.** The random method uses a random object generator dependant on the number and type of objects the researcher selected to include in the session.
OPTIONS: Fixed, Random

2.1.3.1.b Visual /Audio

There can be two types of stimuli for the objects. The first one is visual, so the objects appear and move towards the participant. The second one is auditory, so a voice will state each object. They can be selected together or individually.

2.1.3.1.c Volume

When the auditory stimulus is selected, the volume control is available. It can be set by entering a number between 0 and 100 or by moving the slider in the volume field.
DEFAULT: 50

2.1.3.1.d Number of Levels

The researcher can choose up to 12 levels for one session.

2.1.3.1.e   Number of Objects

When the game mode is random, the researcher can set the number of objects by entering a number greater than 2.
DEFAULT: 15

2.1.3.1.f   Select the Objects

If the researcher does not wish to use all 8 types of objects, they can specify the type of objects by clicking on *Select the objects* and selecting the objects as illustrated in **Figure 2.7**.
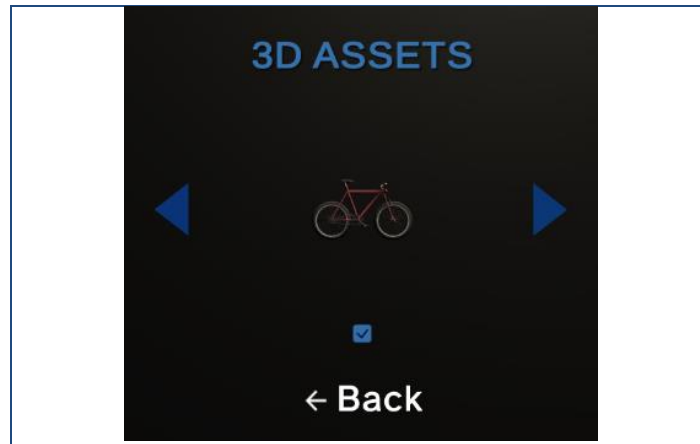

Figure 2.7: Example of select the objects in parameters.

2.1.3.1.g   Save Parameters

After all the parameters are set, the researcher can save the parameters in a text file by clicking on the button *Save parameters*. The fie explorer will open allowing the researcher to select the location to save the file.

2.1.3.1.h   Load Parameters

The *Load parameters* button allows the researcher to choose a text file that contains the participant's previously saved parameters. For the N-back to be functional, the text file needs to be written according to the following guideline (**Figure 2.8**):

1. The line before the parameters must indicate *AR N-Back Study Parameters*.
2. Each parameters needs to be set in the file as in **Figure 2.8** below.
3. The parameters must be separated with a coma.
4. For the Sequence N, there must be a written number of either 1 or 2, even for the Single Task (Walk).
5. For the chosen objects, true will select the objects and false will deselect the objects.

```
AR N-Back Study Parameters
Number of objects:15
Number Trials:5
Sequence:Dual Task,Dual Task,Single Task (N-Back),Dual Task,Single Task (Walk)
Sequence N:1,2,1,1,2
Game Mode:Random
Speed:1
Use Visual:True
Use Audio:True
Chosen Objects:True,False,False,True,False,True,True,True,True
Volume:50
```

Figure 2.8: Example of the text file for the loaded parameters.

2.1.3.1.i   Load Fixed Objects

The button *Load Fixed Objects* allows the researcher to choose a text file that contains the sequence of questions when the fixed method is used. For the N-back to be functional, the text file needs to be written according to the following guideline (**Figure 2.9**):

1. The numbers 0,1,2,3,4,5,6,7 and 8 respectively mean girl, flag, bench, bike, car, cat, tree, stop sign and house.
2. The first line of the file must indicate the number of items and the number of tutorials separated by a semicolon.
3. Before the sequence, the type of level and the number of levels must be identified.
4. Each question needs to be separated by a semicolon.
5. The sequence ends with the word "END".

For the fixed game mode, it is mandatory that the number of levels indicated in the *AR N-back Study Parameters* **is equal to the number of sequences of each level minus the Single Task (Walk).**

```
Number of item;3;Number of tutorial;4
Tutorial1;3;8;8;END
Tutorial2;1;7;4;END
Tutorial3;4;2;5;END
Tutorial4;7;1;1;END
Level1;0;2;1;END
Level2;2;0;4;END
Level3;7;6;3;END
Level4;2;0;4;END
```

Figure 2.9: Example of the text file for the fixed sequence

2.1.3.1.j   Speed

The speed in the parameters is the forward speed of the objects. We recommend a speed between 0.5 and 2.

2.1.3.1.k   Sequence levels

There are three types of levels: *Dual Task*, *Single Task (N-back)*, and *Single Task (Walk)*. For the *Dual Task*, the participant will play the N-back while walking on the treadmill. For the *Single Task (Walk)*, the participant will only walk on the treadmill and for *Single Task (N-back)*, only the N-back will be played.

2.1.3.1.l   N-Back number

The N-back number is the number of previous objects with which the participant must compare the current object. It can either be 1 or 2.

Note: The N-back number of the first level is also the N-back number of the tutorials

2.1.3.2   Results

At the end of the game, there is a summary of the participant's results, as shown in **Figure 2.10**.
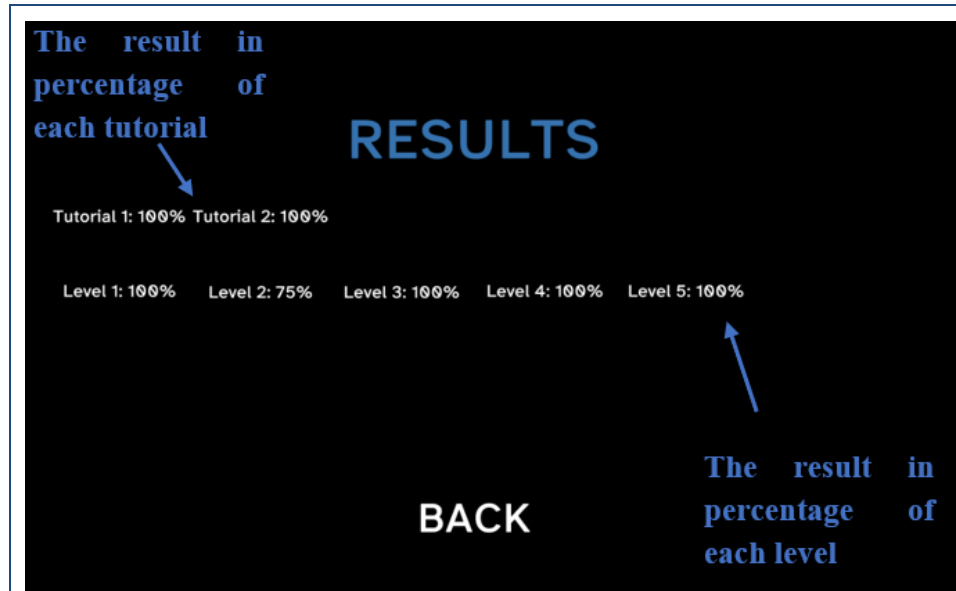

Figure 2.10: Example of the text file for the fixed sequence.

2.1.4   Error message

The following section aims to explain and find a solution for each error message that might appear during the game:

- "Error: The parameters are not valid. Read the instruction manual for more information."
  - The loaded parameters are not correctly written in the file please make sure the guideline in **section 2.1.1.2.f** for the Stroop and 2.1.2.1.h for the N-Back is respected.
- "Error: Please select a .txt file."
  - The selected file is not a .txt file. Please make sure the file extension is .txt.
- "Error: The fixed sequence file is not valid. Read the instruction manual for more information."
  - The written sequence in the text file for the N-Back doesn't follow the specific guideline for the game. Please refer to the **section 2.1.2.1.i** to make sure your text file is written adequately.
- "Error: Please select a valid folder."
  - No folder was selected, or the selected folder is not valid. Please try to select a folder again.
- "Error: Please choose a valid filename and port."
  - The file name or the port is not valid. Please try to select a folder again. Please refer to **section 5.1.1** to select the right port. Also check if the Arduino is connected.
- "Error: The fixed colors sequence file is not valid. Read the instruction manual for more information."

- The written sequence in the text file for the Stroop doesn't follow the specific guideline for the game. Please refer to the **section 2.1.1.2.g** to make sure your text file is written adequately.
  - `"Error: The Arduino seems disconnected. Read the instruction manual for more information."`
    - Please make sure the light of the synchronization box is on. If not, plug and unplug the USB cable from the outlet 1. Please verify that the USB port on your computer is functional.

2.2 Synchronization Box Description

The synchronization box allows the connection between the computer running the AR, the *PortaSync,* and the *Footswitch* trigger system (*Vicon)*. There are 4 outlets on the synchronization box allowing these connections. These outlets can be seen, as well as their reference numbers, in **Figure 2.11**. Outlet 1 allows the box to be connected to the computer using a USB 2.0 Cable Type A/B. Outlet 2 allows the box to be connected to the *PortaSync* using a Female BNC to 3.5mm jack cable. Outlet 3 allows the box to be connected to the *Footswitch* trigger system using a Female BNC to Female BNC cable. The 4th outlet is an extra Male BNC outlet that allows the possibility of adding EEG measurements in the future. An RGB (Red-Green-Blue) LED is present on the top of the box which allows the researcher to verify if the synchronization box is connected to the AR computer. A support is also available for the synchronization box to insure to stability of the box and the cables, as seen in **Figure 2.12**.
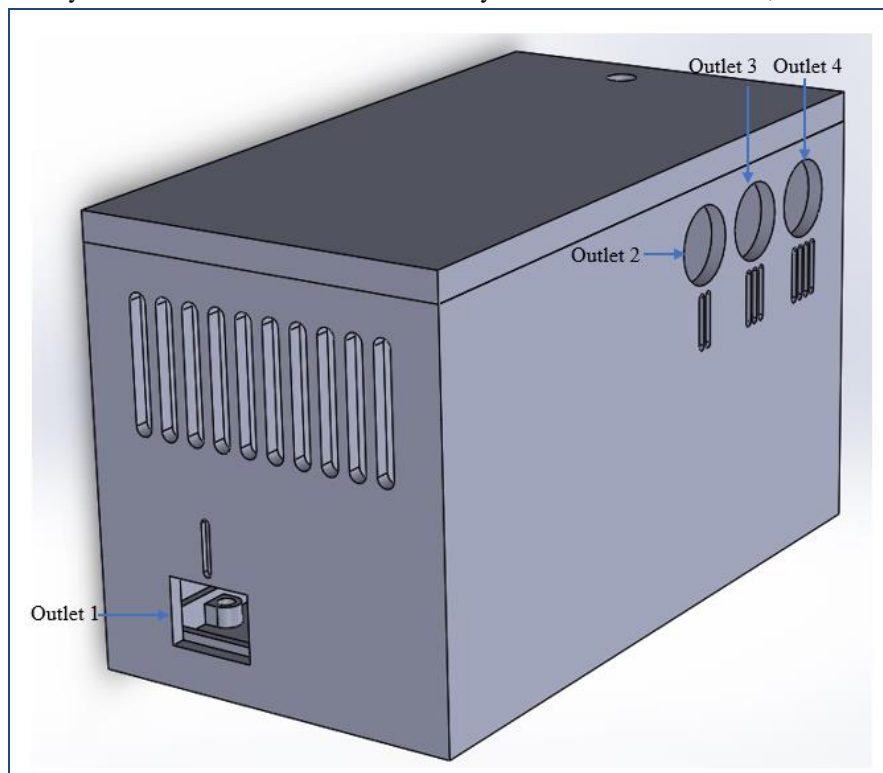

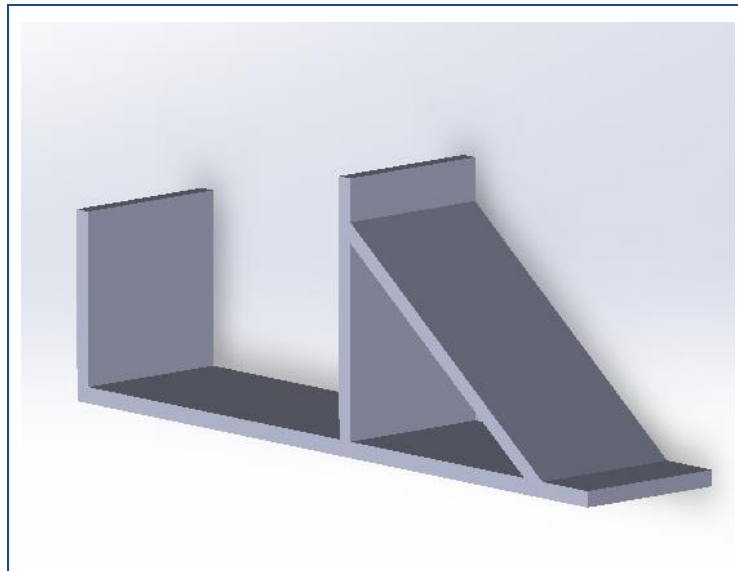**Figure 2.11:** Orthogonal view of the synchronization box.

Figure 2.12: Orthogonal view of the support for the synchronization box.

The interior of the box is accessible by removing the upper panel where the LED is located. The interior contains a printed circuit board (PCB) and an *Arduino Mega 2560 Rev3*. The PCB allows the connections to be made securely and the *Arduino* controls the reception and sending of Triggers. When the AR computer successfully connects to the *Arduino*, the green LED lights up. When triggers are received from the AR computer, the *Arduino* sends the information to the *PortaSync* and *Footswitches*. The PCB and the *Arduino* are connected through wires connecting the corresponding header pins. Both the *Arduino* and the PCB have the pin numbers written on the boards to allow easy and fast connection. **Figure 2.13** demonstrates the 3D model of the PCB and **Figure 2.14** demonstrates the *Arduino* with arrows showing the location of the connected pins.
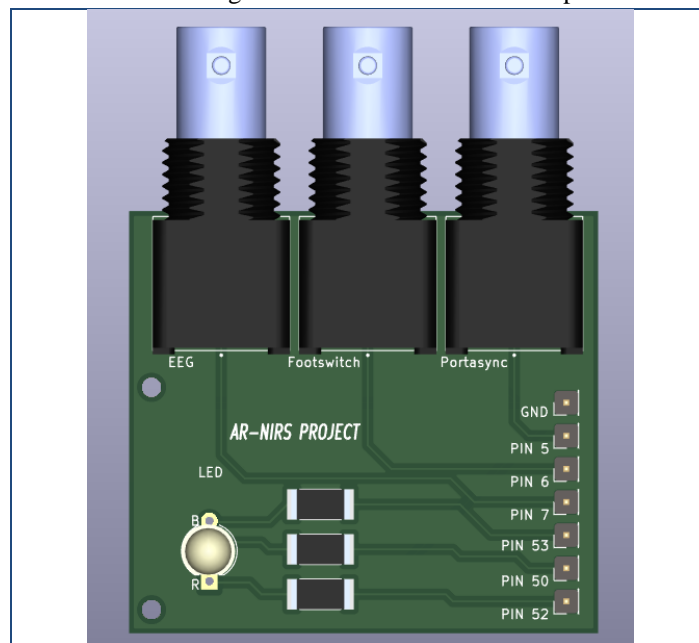

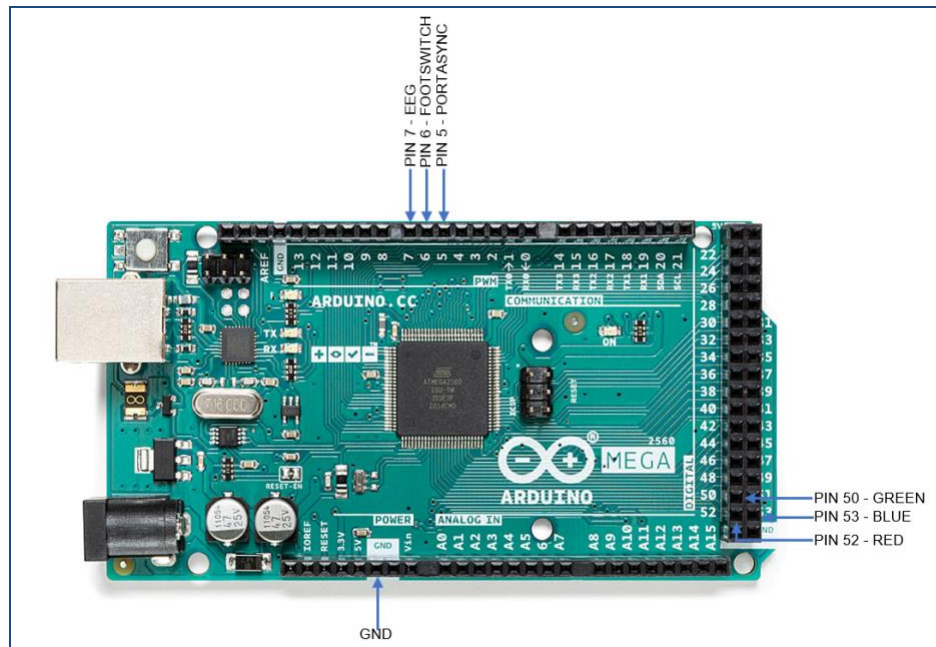**Figure 2.13:** Top view of the printed circuit board.

Figure 2.14: *Arduino* pinout for the printed circuit board.

2.3   Physical Integration Tools Description

The physical integration tools allow the use of the NIRS headset with the AR headset, simultaneously. It includes 3 different foam pieces that stick on the NIRS headset during installation. The Comfort Foam can be seen in **Figure 2.15** and will be placed on the participant's forehead after the NIRS installation. The holes correspond to the NIRS sensors and can be installed as illustrated in **Figure 2.16**. The Adjust Foams shown in **Figure 2.17** are small pieces of foam that can be added after the AR headset installation if some NIRS sensors cause pain or discomfort to the side of the participant's head. The pieces have been designed to be installed as illustrated in **Figure 2.18.(a)** with the hole around a NIRS sensor or as the **Figure 2.18.(b)** just between sensors and the AR headset as the user requires.

Figure 2.15: Comfort Foam.

Figure 2.16: Comfort Foam on the NIRS headset.

Figure 2.17: Adjust foams.
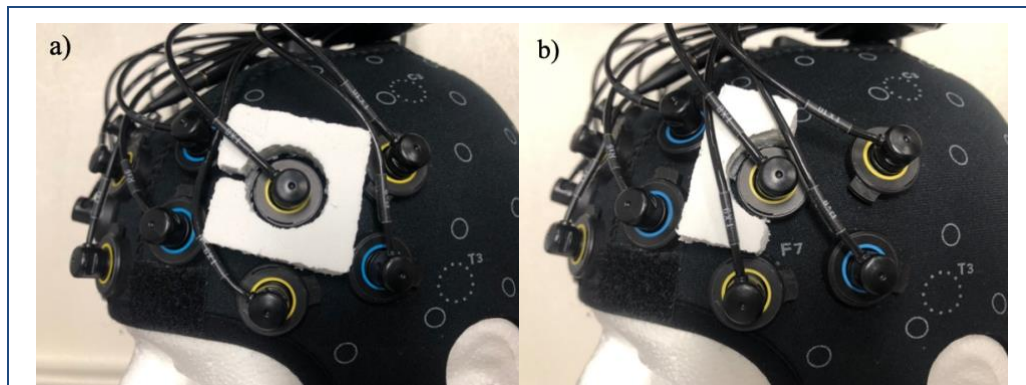
Figure 2.18: Adjust foams installation: (a) Sensor in the hole, (b) Between sensors.

Figure 2.19: Total installation with AR and NIRS headsets, the Comfort Foam and an Adjust Foam on the right side.

The physical integration tools also include the Transmitter Pocket, shown in **Figure 2.20**, that allows to carry and store the *NIRS transmitter*. The pocket is placed on the AR headset at the back of the participant's head to limit transmitter movement and enable stable signal transmission.

Figure 2.20: NIRS pocket.

Figure 2.21: NIRS pocket installed.

3   PRODUCT SPECIFICATIONS

3.1   Constraints

- The Arduino box must be plugged into the computer.
- The AR headset must be plugged into a power outlet.
- The room around the user head must be clear, so it does not affect the calibration of the AR headset.
- The user must be in a bright place while using the headset.

3.2   Requirements

- The computer requirements to use the AR headset (**Mandatory**)
  - Hard drive space: 10 GB
  - Memory: 16 GB RAM DDR4
  - CPU: Intel Core i7 6700 processor FX 9590
  - GPU: NVIDIA GeForceGTX 970, AMD
  - Video output: 1X HDMI 1.4b port
  - USB: 1X USB 3.0 ports or higher
- SDK of the Meta 2 headset (**Mandatory**)
  - The package is only available on Windows.
  - Link to the package: https://s3-us-west-1.amazonaws.com/meta-sdk/MetaSDK2Beta_Installer-2.7.0.38.exe
- Unity 2018.2.5f1 (**Optional**)
  - For development only
- Arduino IDE 1.8.16 (**Optional**)
  - For development only

4   INSTALLATION

For the complete installation of the product, this section will be separated by product component and by the type of installation, like software installation, physical installation, and electrical installation, if applicable.

Here are the steps that must be followed by the user:

1. Footswitch installation
2. AR software installation
3. NIRS physical installation
4. NIRS software installation
5. AR physical installation
6. AR calibration
7. Arduino installation

4.1   Footswitch installation

1. Open the Footswitch computer.
2. Follow the installation protocol.
3. Connect the Female BNC to Female BNC cable between channel 15 on the *Vicon* system and port 3 on the synchronization box.

4.2   AR software installation

1. Download the precompiled game: https://github.com/potvingab/GBM8970-ARNIRS/raw/main/build_final_04-13.zip
2. Click on the precompiled game *AR-NIRS Psychological Paradigms*.
3. Take the headset and the power wire out off the box.

4. Connect the power wire according to the instructions in the AR headset's user guide.
5. Connect the HDMI cable in the port connected to the graphics card of the computer.
6. Connect the USB cable in the USB 3.0 port of the computer.

4.3 NIRS physical installation

1. Put the NIRS headset on the participant's head.
2. Remove the participant's hair under each hole, as much as possible.
3. The sensors and light transmitters will be installed in the next section.

4.4 NIRS software installation

1. Open the NIRS computer
2. Plug the Bluetooth and the license keys in their designated USB ports. License key should be plugged in the port labelled Rockey.
3. Start the *Oxysoft* software
4. Create new simulation and follow the steps indicated by the software
5. When asked to enable the NIRS transmitter, click on the Bluetooth button until the blue light starts blinking.
6. When asked to enable the PortaSync, click on the 2 buttons on the PortaSync at the same time until the blue light starts blinking.
7. Connect the PortaSync analog input to port 2 of the synchronization box using a Female BNC to 3.5mm jack cable.
8. Insert the light transmitters and electrode sensors following the sensors' map for the intended use. Make sure to clip in the transmitters and sensors to allow maximum contact on the participant's head. Electrodes should be placed according to the template presented in *Oxysoft*.
9. Skip the NIRS calibration.

4.5 AR physical installation

1. Secure the foam head support on the NIRS headset using Velcro by aligning the cut-outs with the electrodes.
2. Remove the Bluetooth transmitter from the back of the headset.
3. Put the AR headset on the participant's head.
4. At the participant's request, install the comfort foam along the sides of the head.
5. Install the pocket for the Bluetooth transmitter on the strap of the NIRS headset at the back of the participant's head.
6. Place the Bluetooth transmitter in the pocket.
7. Check that the NIRS calibration is still valid.
   a. Validate that *Oxysoft* software does not ask for another calibration.
   b. Validate that all the sensors are still in place.
8. Start the recording in the Oxysoft software

4.6 AR calibration

1. Start the AR calibration according to the AR software, using *Meta Headset Setup*. Make sure the NIRS and the foam is in place to have a good calibration. A calibration is needed for each participant. It is possible to do the calibration before the NIRS is installed, however the comfort foam must be used instead of the Meta foam.

4.7   Arduino installation

1.   Connect port 1 of the synchronization box to the AR computer using a USB 2.0 Cable Type A/B.

5   OPERATION

5.1   Game start-up

This section presents the start-up of the test protocol.

1.   Make sure all the installation steps (**section 4**) are completed.
2.   Connect the response buttons to the AR computer (N-back only).
3.   Click on the compiled game on the AR computer named: *AR-NIRS Psychological Paradigms*.
4.   Start the psychological test using the AR researcher interface.
5.   Choose the paradigm that you want to play and click *Next*.
6.   Choose a folder by clicking on the button *Choose a folder* and select a folder by using the computer's file explorer.
7.   Input the Arduino port. See **section 5.1.1** on how to find the Arduino Port. Click *Next*.
8.   Make sure the light on the Arduino box comes on when the port is input.
9.   Choose the parameters for the game. See **section 2.1.1.2** and **2.1.2.1**
     a.   **NOTE: For the N-back, the N for the tutorial is the N selected for the first level**
10. Click on *Dislpay Instructions*.
11. The timer will start. When the resting time is over, click on *Send Trigger* and *Play* to start the game.
12. N-Back: The game starts with tutorials (7).
     a.   The participant will respond using the buttons. Port 1 for *Same* and Port 2 for *Different*. The response will appear on the researcher's screen.
     b.   When the tutorial is over, to see the results, click on *Results*. You can skip the tutorials and continue with the entered sequence. It is possible to adjust the headset volume after each tutorial. A timer will start to check the resting time and you can click on *Send Trigger* when it is over.
     c.   Click on *Quit* when the game is over.
13. Stroop:
     a.   The first level is the baseline: 6 questions are presented to the participant to check his response time.
     b.   Click on *Next Level* or *Replay Level*.
     c.   The chosen sequence will start. You can either select to start the game (*Play*) or the tutorial (*Tutorial*). A timer will begin for the resting time, and you can send a trigger *Send Trigger*. The timer will also appear at the end of each level.
     d.   When all the sequence is over, a summary of the results will appear, and you can click *Quit* to exit the game.

5.1.1   How to find the Arduino Port

1.   Open the Device Manager
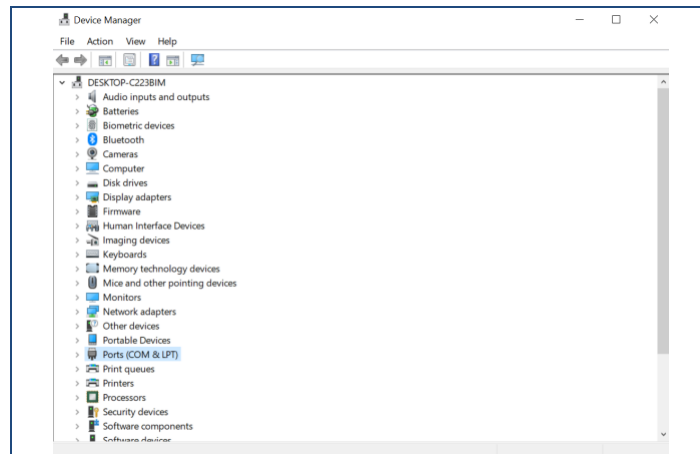2.   Find the *Ports* field (see **Figure 5.1**)

Figure 5.1: Device Manager screenshot

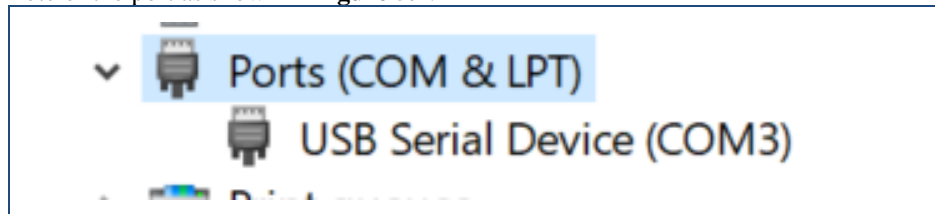3. Take note of the port as shown in **Figure 5.2**.

Figure 5.2: Identification of the port

6   MAINTENANCE

6.1   Synchronization box

The synchronization box and support should be stored in a cool and dry location. High temperatures may cause the box or support to melt and warp. Any liquids that enter the box could damage the internal components and cause the *Arduino* and PCB to malfunction. The synchronization box should not be dropped or have pressure applied to it as the box or LED light may break. A dry microfiber cloth can be used to remove dust from the box, the support, and the internal components.

6.2   Physical integration

The different components of the physical integration can be stored with the synchronization box. The Comfort Foam and the Adjust Foams can be washed with a humid tissue between uses. The Transmitter Pocket can be washed in the washing machine if necessary. In the case a foam is damaged, multiple foams are furnished.

7   DEBUGGING

7.1   Headset

1. Disconnect and reconnect the meta headset (power supply, USB, and HDMI).
2. Open the *Meta Display Manager* software and verify that the headset is using *Direct Mode*.
3. Open the *Meta Diagnostic Tool* and start diagnostics to validate if the headset works properly.
4. Make sure you have a computer that meets Meta's specifications (see **section 3.2**).
3. If the headset does not seem to respond, restart the computer.
4. If none of the above suggestions work, uninstall the Meta software from the computer and reinstall it.

7.2 Synchronization box

To verify if the *Arduino* is working properly:

1. Open the text file called *date_time_*Test_synchro_Arduino.txt
2. Verify that the times indicated are between 4 and 25µs.

In case of any problems:

1. Unplug the synchronization box from the computer port.
2. Plug the synchronization box in the same port.
3. Verify that the computer detects that the synchronization box is connected.
4. If problem persists, remove the lid from the box carefully.
5. Verify that all internal components are intact.
6. Verify that all internal wires are adequately plugged.