Multimodal-Multisensory Experiments

Moein Razavi [1],*, Takashi Yamauchi [1], Vahid Janfaza [2], Anton Leontyev [1], Shanle Longmire-Monford [1], Joseph Orr [1]

[1] Department of Psychological and Brain Sciences, Texas A&M University; moeinrazavi@tamu.edu, takashi-yamauchi@tamu.edu, a.g.leontiev@tamu.edu, college4me@tamu.edu, joseph.orr@tamu.edu

[2] Department of Computer Science and Engineering, Texas A&M University; vahidjanfaza@tamu.edu

* Correspondence: moeinrazavi@tamu.edu; Tel.: +1-979-676-7486

Abstract: The human mind is multimodal. Yet most behavioral studies rely on century-old measures of behavior—task accuracy and latency (response time). Multimodal and multisensory analysis of human behavior creates a better understanding of how the mind works. The problem is that designing and implementing these experiments is technically complex and costly. This paper introduces versatile and economical means of developing multimodal-multisensory human experiments. We provide an experimental design framework that automatically integrates and synchronizes measures including electroencephalogram (EEG), galvanic skin response (GSR), eye-tracking, virtual reality (**VR**), body movement, mouse/cursor motion and response time. Unlike proprietary systems (e.g., iMotions), our system is free and open-source; it integrates **PsychoPy**, **Unity** and Lab Streaming Layer (**LSL**). The system embeds LSL inside **PsychoPy/Unity** for the synchronization of multiple sensory signals—gaze motion, electroencephalogram (EEG), galvanic skin response (GSR), mouse/cursor movement, and body motion—with low-cost consumer-grade devices in a simple behavioral task designed by **PsychoPy** and a virtual reality environment designed by **Unity**. This tutorial shows a step-by-step process by which a complex multimodal-multisensory experiment can be designed and implemented in a few hours. When conducting the experiment, all of the data synchronization and recoding of the data to disk will be done automatically.

Keywords: multimodal experiment; multisensory experiment; automatic device integration; open-source; PsychoPy; Unity; Virtual Reality (VR); Lab Streaming Layer; LabRecorder; LabRecorderCLI; Windows command line (cmd.exe)

1. Introduction

1.1. The mind is multimodal

Psychology is the scientific study of the brain, mind and behavior. The brain supervises different autonomic functions such as cardiac activity, respiration, perspiration, etc. Current methods to study human behavior include self-report, observation, task performance, gaze, gait and body motion, and physiological measures such as electroencephalogram (EEG), electrocardiogram (ECG), functional magnetic resonance imaging (fMRI). These measures are indicators of human behavior; however, the gap here is that they are mostly studied separately from each other, while human behavior is inherently multimodal and multisensory, where different measures are connected and dependent on each other. Signals from multiple sources have overlap in locations (spatial) or timing (temporal) in the brain; hence, a single measurement cannot be as informative as multiple measurements in distinguishing between different functions [1].

A more accurate behavioral measurement needs different measures to be recorded and analyzed concurrently [2]. Hochenberger (2015) suggests that multimodal experiments facilitate the perception of senses that operate in parallel [3]. Similar to using multiple classifiers to improve accuracy in a

classification task, combining different measures in studies of brain functionality and its association with behavior helps to improve the predictions of human behavior [4].

However, designing and developing a multimodal and multisensory study is complicated and costly. All events and time series must be recorded and timestamped together; data from multiple measurements and multiple subjects should be stored in an easily accessible and analyzable format. All the devices must start recording at the same time without the effort of running the devices one by one. There are several proprietary systems that ease multimodal-multisensory experimentation (e.g., iMotions). Yet, it is costly and challenging to integrate different devices with these systems. Here we provide a tutorial on how to use free opensource software and packages to build a multisensory experiment that can be easily adapted for research purposes.

In what follows, we first review previous works and their findings that elucidate the importance of using multisensory experiments; we then discuss major challenges of implementing multisensory experiments and the available methods of addressing those challenges. Finally, we present a step-by-step tutorial on developing multimodal/multisensory experiments.

1.2. Related Work

Although many past studies provided useful information about human behavior using only a single source, multiple sources are involved with actual behavior in the natural environment [5]. A few studies tried to integrate multiple measures into the experimental psychology/neuroscience portal. Reeves et al. (2007) state the importance of using multiple measures in the goals of Augmented Cognition (AUGCOG) [6]; they discuss the combination of multiple measures together as a factor for the technologies that improve Cognitive State Assessment (CSA). Jimenez-Molina et al. (2018) showed that analyzing all measures of electrodermal activity (EDA), photoplethysmogram (PPG), EEG, temperature and pupil dilation at the same time, significantly improves the classification accuracy in a web-browsing workload classification task, compared to using a single measure or a combination of some of them [7].

Several studies to date have put these recommendations to work by integrating several measures concurrently. Born et al. (2019) used EEG, GSR and eye-tracking to predict task performance in a task load experiment; they found that low-beta frequency bands, pupil dilations and phasic components of GSR were correlated with task difficulty [8]. They also showed that the statistical results of analyzing EEG and GSR together were more reliable than analyzing them individually. Leontyev et al. combined user response time and mouse movement features with machine learning technics and found an improvement in the accuracy of predicting attention-deficit/hyperactivity disorder (ADHD) [9–11]. Yamauchi et al. combined behavioral measures and multiple mouse motion features to better predict people's emotions and cognitive conflict in computer tasks [12–15]. Yamauchi et al. further demonstrated that people's emotional experiences change as their tactile sense (touching a plant) was augmented with visual sense ("seeing" their touch) in a multisensory interface system [16]. Chen et al. (2012) tried to identify possible correlations between increasing levels of cognitive demand and modalities from speech, digital pen, and freehand gesture to eye activity, galvanic skin response, and EEG [17]. Lazzeri et al. (2014) used physiological signals, eye gaze, video and audio acquisition to perform an integrated affective and behavioral analysis in Human-Robot Interaction (HRI) [18]; by acquiring synchronized data from multiple sources, they investigated how autism patients can interact with affective robots. Charles and Nixon (2019) reviewed 58 articles on mental workload tasks. They found that physiological measurements such as ECG, respiration, GSR, blood pressure, EOG and EEG need to be triangulated because though they are sensitive to mental workload, no single measure satisfies to predict mental workload [19]. Lohani et al. (2019) suggest that analyzing multiple measures such as head movement together with physiological measures (e.g., EEG, heart rate, etc.) can be used for the drivers to detect cognitive states (e.g., distraction) [20]. Gibson et al. (2014) integrated questionnaires, qualitative methods, and physiological measures including ECG, respiration, electrodermal activity (EDA) and skin temperature to study activity settings in disabled youth [21]; they stated that using multiple measures reflects a better real-world setting of the youth experiences. Sciarini and Nicholson (2009) used EEG,

eye blink, respiration, cardiovascular activity and speech measures in a workload task performance [22]; as they outlined, using only one measure is not sufficient in the multidimensional tasks in a dynamic environment. Thus, multiple measures should be considered. The authors also highlighted the lack of clear guidance on how to integrate different systems as an important issue.

Integrating multiple measurements is quite complicated. Although the aforementioned studies integrated multiple measures, they did not synchronize these measures together. They have different sampling rates and also lack a coherent and easy to implement method for combining the measures. Using multiple measurements that were not collected at the same time will produce less accurate results since it is not possible to combine these measures and consider their interactions with each other.

In the following sections, we first provide a summary of the challenges for device integration and different methods of addressing them. We then describe the software and applications that can be used for this purpose. Finally, we provide a tutorial on how to use the preferred method for synchronizing and combining multiple measures. We also show how to make this process automatic in a computer program so that minimal human intervention is required.

2. Multisensory Experiments

2. 1. Challenges of Implementation

There are several challenges to be addressed during the integration process:
1. All events and time series must be recorded and timestamped together, with the same timing reference, to be analyzable.
2. Because multiple subjects (N>50) are needed in psychological experiments for statistical analysis, data from multiple measures and multiple subjects should be stored in a format that can be easily analyzed together.
3. A method should be used to record the data from all the devices simultaneously without the need to run the devices one by one.

Here we show different ways in which these challenges can be mitigated. First, to synchronize different time series and stream data, we can use either UDP (User Datagram Protocol) or TCP (Transmission Control Protocol). UDP is unreliable. It is a connectionless protocol that does not guarantee data delivery, order, or duplicate protection. On the other hand, TCP is a connection-oriented protocol that guarantees errorless, reliable and ordered data streaming. TCP works with internet protocol (IP) for data streaming. Thus, for reliable data transport, TCP is preferred.

For the second and third challenges, there are at least two options. One is to use proprietary software (e.g., iMotions, Biopac, etc.). Using proprietary software has its advantages: for example, it has extensive support and is relatively easy to implement. However, proprietary software is costly and restrictive; it often forces the researchers to purchase other proprietary devices that are functional only for that particular software design. Because of that, the users are limited in the number of experimental manipulations they can introduce. Finally, proprietary software developers often charge steep licensing fees, which limit people's access (especially in developing countries). Thus, it is imperative to devise a system that will address the problem of simultaneous observation, but that is also accessible to everyone.

Another method, which is more versatile and preferred for our use, is to employ opensource tools that are available for multiple platforms (e.g., Lab Streaming Layer). Lab Streaming Layer (**LSL,** https://github.com/sccn/labstreaminglayer/wiki) is available on almost all open-source platforms including, Python, C, C++, C#, Java, Octave, etc. Currently, the majority of the consumer and research-grade devices support LSL. Above all, as long as these devices are capable of sending their data to the platforms like Python, C, MATLAB, etc., **LSL** can be used for streaming their data. **LSL** uses TCP for stream transport and UDP for stream discovery and time synchronization.

LSL is developed by the Swartz Center for Computational Neuroscience (SCCN) at the University of California San Diego (UCSD).

LSL can be embedded in free and open-source stimulus presentation platforms like **PsychoPy** (https://www.psychopy.org/) and **Unity** (https://unity.com/, Figure 1). Wang et al. (2014) used **PsychoPy**, EEG, and **LSL** for Brain-Computer Interface (BCI) stimulus presentations. They used these to synchronize the stimulus markers and EEG measurements.

In the following, we first provide a brief introduction to **PsychoPy**, **Unity**, **LSL**, and **LabRecorder** (https://github.com/labstreaminglayer/App-LabRecorder/releases**).** Then, we present a step-by-step case study detailing the integration of multiple sensory devices into **PsychoPy**, **LSL**, and **LabRecorder** for an automatic and easy-to-use multimodal-multisensory experiment.

The devices that we use for this paper can be called and start recording by running child processes in Python/C#, which allows the processes to be directly embedded in **PsychoPy/Unity**. Finally, everything can be started from a main **PsychoPy** experiment or **Unity VR** project.
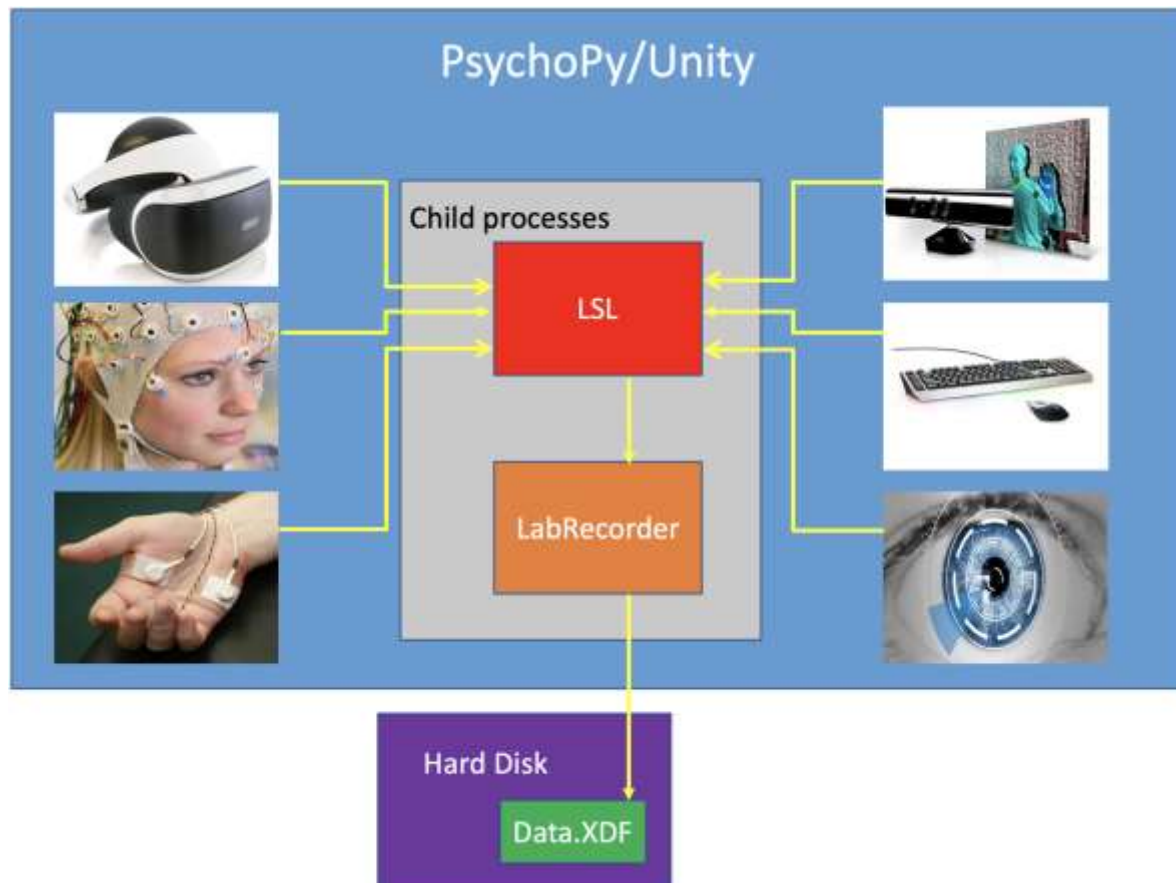
Figure 1. Schematic architecture for integrating devices: Objects that are defined in **PsychoPy/Unity** (usually task markers) can send data to directly to **LSL**; different devices can send data to **LSL** by calling child processes inside **PsychoPy/Unity**

3. Overview: PsychoPy, Unity, Lab Stream Layer, Lab Recorder

Our overall strategy for building a multimodal and multisensory experiment is to bridge **PsychoPy/Unity,** Lab Stream Layer, and Lab Recorder. The principle of integration is to call different devices from **PsychoPy/Unity** to send their data streams to **LSL**; **LabRecorder** starts recording the streams available on **LSL** from **command line**, which would also be embedded in **PsychoPy/Unity**.

PsychoPy allows the building of behavioral experiments with little to no programming experience using premade templates for stimulus presentation and response collection. **Unity** enables the creation of 2D and 3D gaming environments. Lab streaming layer (**LSL**) is a set of libraries for synchronous collection of multiple time series in research experiments (https://labstreaminglayer.readthedocs.io/info/intro.html). **LabRecorder** is an **LSL** application that allows saving all the streams that are available on **LSL** on disk in a single *.xdf* file.

PsychoPy

PsychoPy is an open-source software package written in the Python programming language primarily for use in Neuroscience and Experimental Psychology research [23,24] (https://www.psychopy.org/). **PsychoPy** has three main building blocks for constructing behavioral experiments: stimulus/response components, routines and loops (Figure 2).

Stimulus components are premade templates for displaying various types of stimuli: geometric shapes, pictures, videos, audio signals, etc. The user can control which stimuli they want to present, in what order and for how long (along with other stimulus-specific properties). Similarly, response components allow for recording different types of responses: key press, mouse clicks/moves, as well as vocal responses.

Stimulus and response components are organized within routines, which are a sequence of events within one experimental trial. For example, consider a Flanker task (Figure 2) in which a participant is presented with five arrows, with the middle arrow pointing to the same direction as surrounding arrows (congruent) or to the opposite direction (incongruent). The participant has to press the key on the keyboard indicating the direction of the middle arrow ("left" or "right" arrow key). In this task, the stimulus component "arrows" (Figure 2C) presents the arrangement of letters for a given trial, while component "key_resp" (Figure 2D) records the participant's response. Altogether, they constitute the routine "flanker_task" (Figure 2A).

The trial parameters (in this case, which succession of arrows to show, e.g., →→→→→ or ←←→←←) are controlled by the loop "trials_loop" (Figure 2B). Loops contain information about the variables that are supposed to change from trial to trial. As the name suggests, loops repeat routines updating the routine components with the values prescribed by the experimenter.
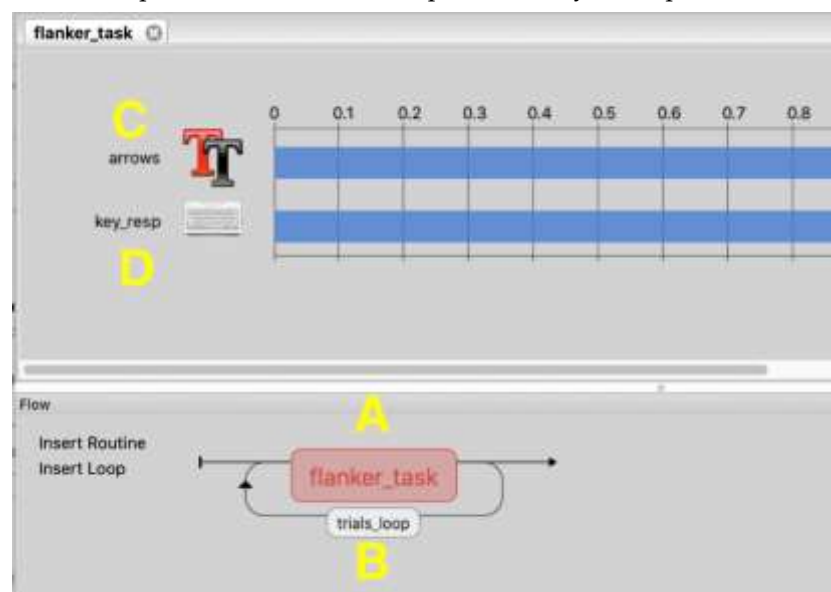
Figure 2. **PsychoPy** components: A) routine B) loop C) text stimulus D) keyboard response

PsychoPy provides an option to include custom python code, which can be embedded in the beginning or the end of the experiment, in the beginning or the end of each routine, and for each frame of the screen; the code written in Each Frame will run every refreshment cycle of the monitor screen (Figure 3).
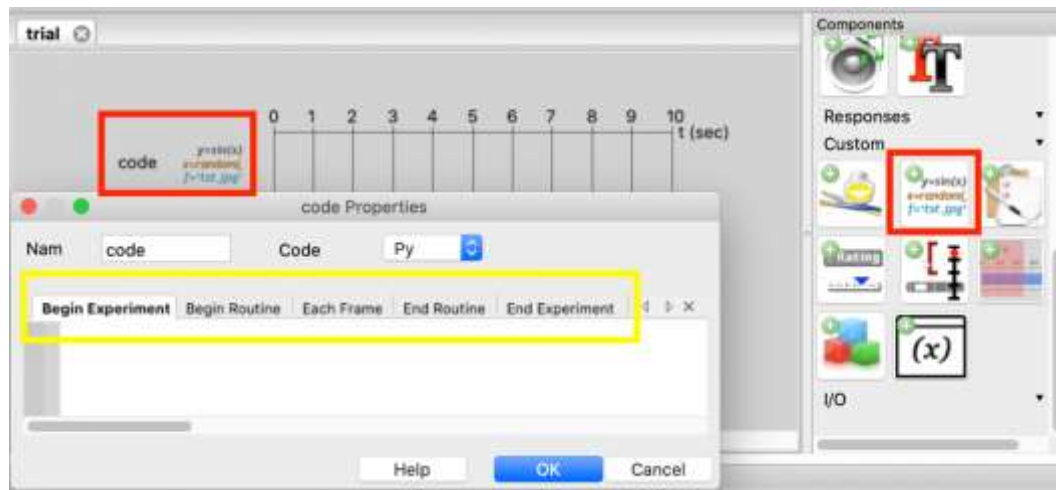
Figure 3. PsychoPy python custom code component

Unity

Unity is a game engine platform that allows creating games in 2D and 3D environments. It enables the users to script in C# for handling the scenes and objects. In **Unity**, the game environment is called a **Scene**, and each component in the environment (e.g., characters) is called a **GameObject**. Every **GameObject** will be defined in a **Scene**. Complete documentation of **Unity** is available on https://docs.unity3d.com/Manual/UsingTheEditor.html (Figure 4).
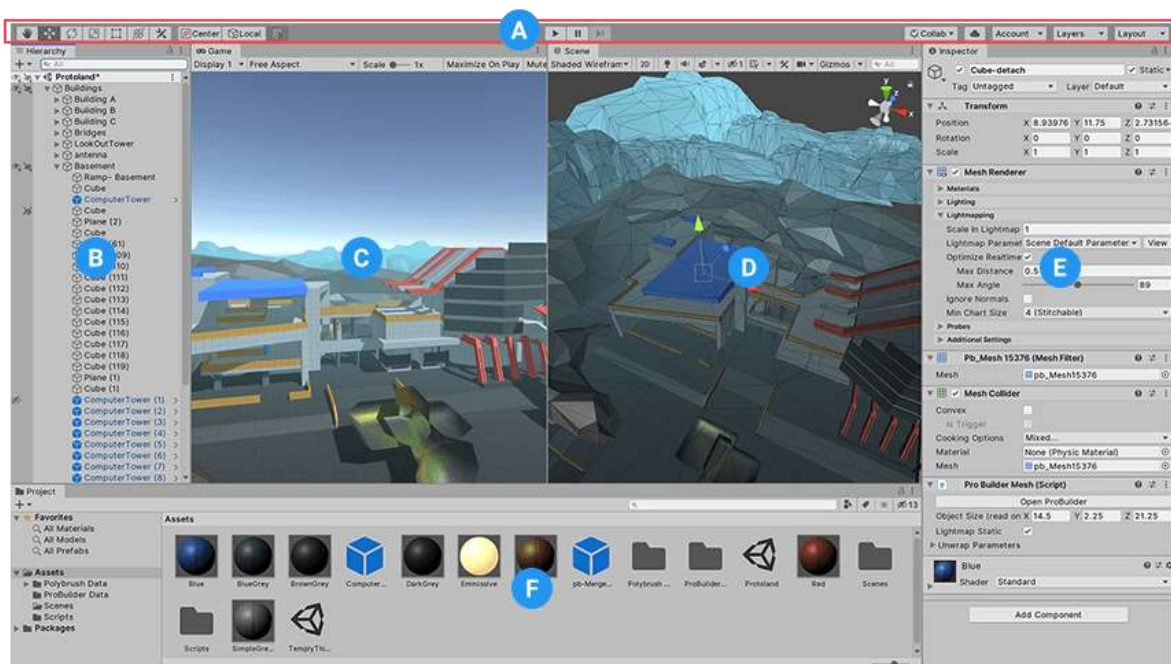
Figure 4. (A) Left: tools for manipulating the Scene view and the GameObjects within Scene; Centre: play, pause and step buttons. (B) Hierarchy of every GameObject in the Scene shows how GameObjects attach together. (C) The Game view shows the final rendered game. The play button can start the game simulation. (D) The Scene view allows to visually navigate and edit your Scene. (E) The Inspector Window allows to view and edit all the properties of the currently selected GameObject. (F) The Project window shows the imported Assets of the game.

We created a multisensory experiment by embedding **LSL** in the **PsychoPy** custom code component and **Unity**. This process is discussed in detail in Sections 4.4 and 5 for **PsychoPy** and **Unity**, respectively.

Lab Streaming Layer

The lab streaming layer (**LSL**) connects a **Psychopy** experiment or a game in **Unity** (stimulus presentation and data acquisition) with multiple sensor devices. **LSL** consists of a core library and applications built on top of that library, which allows synchronous collection of multiple time series in research experiments and recording the collected data on disk. In **LSL**, a single measurement from a device (from all channels) is called a **Sample**. Samples can be sent individually for improved latency or in chunks of multiple samples for improved throughput. All the information about data streams (series of sampled data) is sent through an XML as the metadata which contains **name**, **type**, **channel_count**, **channel_format** and **source_id** for each stream. Through Stream Outlet, chunks or samples of data are made available on **LSL** network and these streams are visible to all the computers connected to the same local network, LAN (Local Area Network) or WLAN (Wireless Local Area Network). Streams can be distinguished with their assigned name, type and other queries created on the XML metadata. The streams that are available on the **LSL** network can be received by the computers that call the Stream Inlet.

To define a stream in **LSL**, we created stream outlets by calling StreamOutlet functions that take StreamInfo as the input. StreamInfo includes name, type, number of channels, channel format (string, int, float, etc.) and source ID as the input. Name, type and source ID are arbitrary and can be defined by the user; the number of channels and channels format depends on the characteristics of the streams. Then whenever needed, we can transport the data by calling the functions that push the data in Samples or Chunks to the **LSL**. Once all the stream outlets are available on the **LSL** network, they can be saved in a single XDF using **LabRecorder** application, or they can be received in another platform by means of StreamInlet functions.

This complicated data acquisition and synchronization process can be semi-automated by **LabRecorder**, which is explained in the next section.

LabRecorder

LabRecorder is responsible for recording the streams available on **LSL** on the hard disk (you can download it from https://github.com/labstreaminglayer/App-LabRecorder/releases). In Figure 5, you can see **LabRecorder** GUI; names of the streams that are available on **LSL** can be seen on the left panel. However, in the latest version of **LabRecorder**, you do not need **LabRecoder** GUI for recording. **LabRecorder** can start recording the available **LSL** streams by writing one line of code that opens the **LabRecorder** command line interface (**LabRecorderCLI**) in the background. This process is explained in Sections 4 and 5.
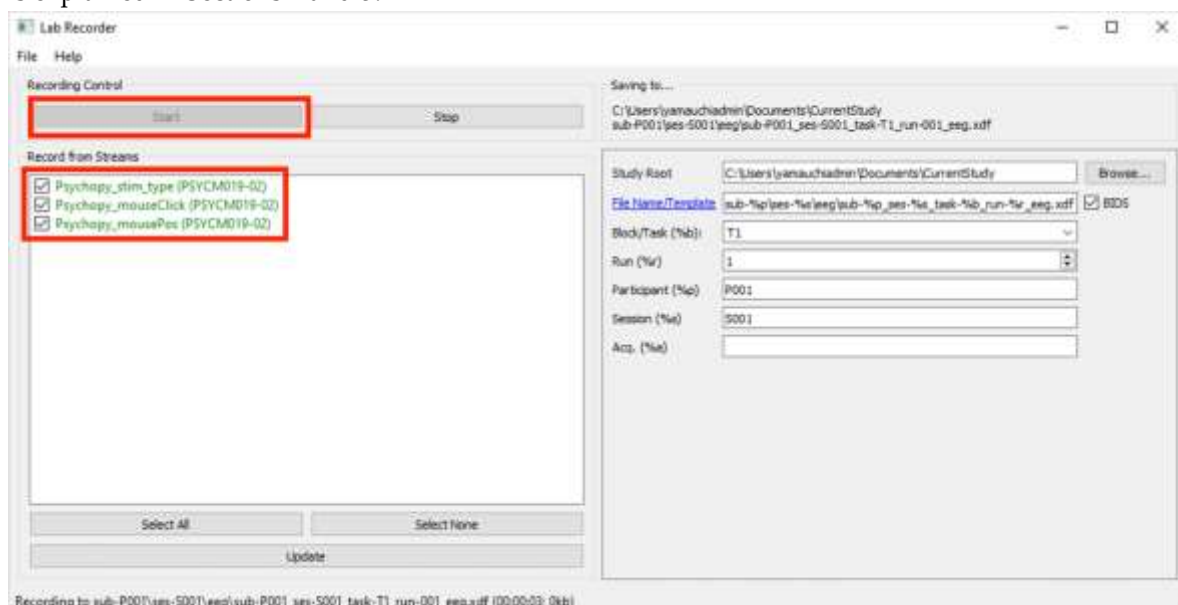
Figure 5. **LabRecorder** GUI

In sections 4 and 5, we provide a case study on integrating multiple devices such as EEG, GSR, Eyetracking, Bodymotion, mouse trajectories, button click, and task-related markers within a stimulus presentation software, **PsychoPy** (section 4) and **Unity** (section 5). The program automatically saves all the recording data into a single *.xdf* file in a user-specified folder. All these would be done with the aid of the lab streaming layer (**LSL**) embedded in **PsychoPy/Unity**.

We used opensource software for the integration of different sensors and devices. We also used different consumer-grade and affordable devices. For EEG, we used g.tec Unicorn, Muse, Neurosky Mindwave, BrainProducts LiveAmp, OpenBCI Cyton (8-Channel) and OpenBCI Cyton + Daisy (16-Channel). For GSR, we used e-Health Sensor Platform v2.0 for **Arduino** and also Gazepoint biometrics device. For eyetracking we have used Gazepoint. For body motion, we used Microsoft Kinect Sensor V2 for Windows. A basic sample experiment in **PsychoPy** and a basic **VR** environment in **Unity** that integrate different devices are available on our GitHub: PsychoPy_Example_GitHub and VR_Example_GitHub. Table 1 shows the list of the devices we used for the case study.

Table 1. The devices used for integration in the sample experiment.

Type	Device	Method for sending data to LSL	Link
Mouse clicks/coordinates	Mouse	define LSL stream in PsychoPy	-------
EEG	g.tec Unicorn	C++ application called from PsychoPy/Unity	https://github.com/moeinrazavi/Unicorn_LSL
	BrainProducts LiveAmp	C++ application called from PsychoPy/Unity	https://github.com/moeinrazavi/LiveAmp-LSL
	OpenBCI Cyton (+Daisy)	Python script called from PsychoPy/Unity	https://github.com/moeinrazavi/OpenBCI-LSL
	NeuroSky Mindwave	NeuroSky Python library and functions in Psychopy/Call a Python script in Unity	-------
	Muse	Muse Python library and functions in Psychopy/Call a Python Script in Unity	Link 1: BlueMuse_Application Link 2: BlueMuse_Installation_Guide
GSR	eHealth Sensor v2.0 Arduino Shield	Python script called from PsychoPy/Unity	https://github.com/moeinrazavi/eHealth-GSR-LSL
	Gazepoint Biometrics Device	Python script called from PsychoPy/Unity	https://github.com/moeinrazavi/Gazepoint-Eyetracking-GSR-HeartRate--LSL
Eyetracking	Gazepoint	Python script called from PsychoPy/Unity	https://github.com/moeinrazavi/Gazepoint-Eyetracking-GSR-HeartRate--LSL
Body Motion	Kinect	C++ application called from PsychoPy/Unity	https://github.com/moeinrazavi/Kinect-BodyBasics-LSL

4. Case Study: Building a Multisensory Experiment (PsychoPy)

In the following, we provide a tutorial for building a multisensory experiment by embedding **LSL** in **PsychoPy**. The task that we used in this case study is a simple version of the Flanker task with

only 4 trials. On each screen, participants are presented with a sequence of arrows →→→→→, ←←←←←, →→←→→ or ←←→←← (Figure 6) and are asked to navigate their mouse cursor to a box on the top left or top right of the screen based on the direction of the center arrow in each sequence. Starting with this simple task, we show step by step how to add mouse/cursor motion, EEG (g.tec Unicorn, Muse, Neurosky Mindwave, BrainProducts LiveAmp, OpenBCI Cyton and OpenBCI Cyton + Daisy), GSR (e-Health Sensor Platform v2.0 for Arduino and also Gazepoint biometrics device), Eyetracking (Gazepoint), and Body Motion (Kinect) one by one to the experiment.
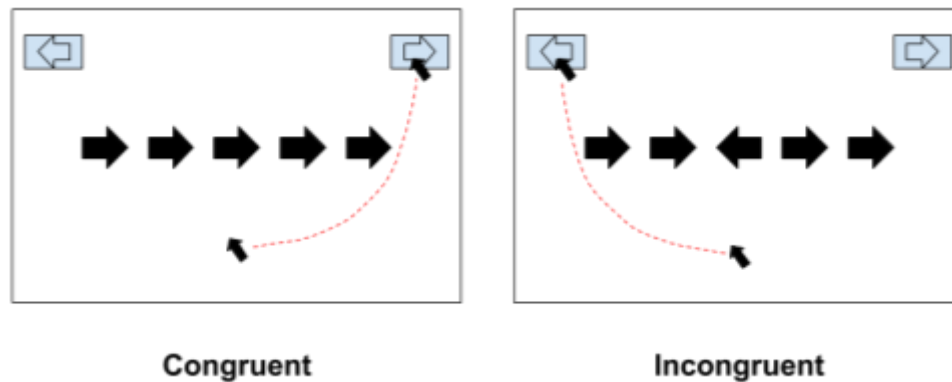
Figure 6. Arrow Flanker task

4. 1. Software and Plugin Installation

PsychoPy provides a graphical user interface for designing a wide range of psychological experiments without any programming (see Appendix for the installation process). For example, you can add text/picture in different routines as stimuli by adding text/picture items, and also you can add keyboard/mouse as items for recording response. **PsychoPy** uses Python programming language in the background; custom Python code items can be used to add the features which are not available in the **PsychoPy** GUI (e.g., **LSL**). You can add routines and loops for repeating one or several routines, including the stimuli, user's response, and sending their markers to **LSL** in the experiment. You can then compile and run all of these (routines, loops and custom code in routines) together using **PsychoPy**. **pylsl** is a Python library that allows using **LSL** in Python (see Appendix for installing **pylsl** on **PsychoPy**). We used module **Popen** from python **subprocess** library for sending data from different devices to **LSL**. Then, using module **popen** from python **os** library enables us to use **command line** to open **LabRecorder** in the background of the experiment. This will save all the streams automatically without needing to open the **LabRecorder** user interface (explained in section 4.3).

4. 2. Design

As shown in Figure 7, the example experiment contains 6 routines and one loop for the last 3 routines, which repeats the stimulus presentation. There are 3 main routines named **Initialize**, **Record_Start** and **Stimulus_Presentation**. The **Initialize** routine defines all the streams from the task that we want to send to **LSL**. In the **Record_Start** routine, we write a command to start recording all the streams that are available on **LSL** in a *.xdf* file. Finally, in the **Stimulus_Presentation** routine, we write the script to send the task stimulus markers and mouse coordinates to **LSL**.

Figure 7. Main components of the example multisensory experiment: 1) initializing **LSL** streams 2) start recording **LSL** streams 3) stimulus presentation and sending stimulus and response markers to **LSL**

In the **Experiment Settings**, as shown in Figure 8, we have defined one of the fields as **UIN**, which would be used in the recorded *.xdf* file name.
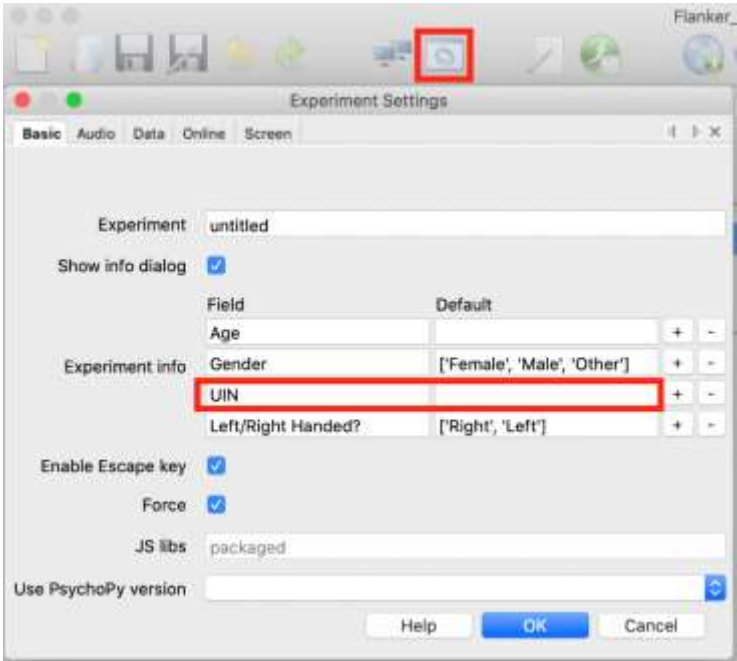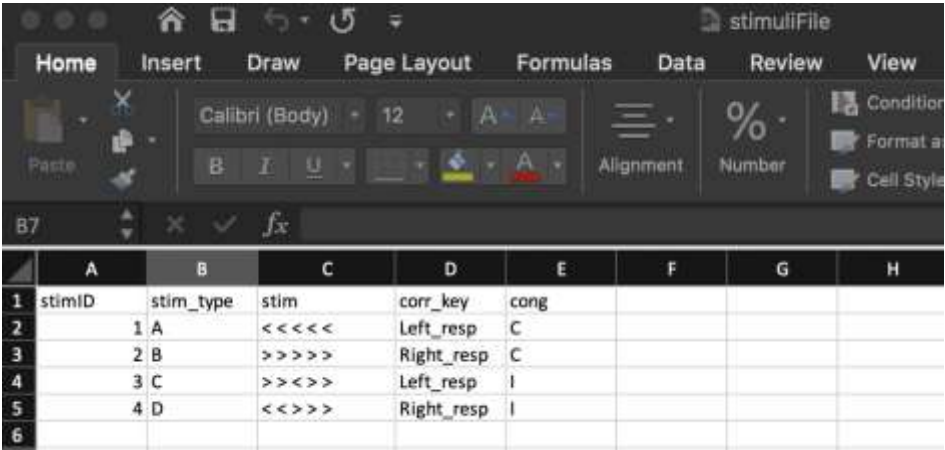
Figure 8. PsychoPy Experiment Settings

In the experiment folder, there is a folder, named *Stimuli* and there is a *stimuliFile.xlsx* inside it, which contains **stimID**, **stim_type**, **stim**, **corr_key** (shows the correct response) and **cong** (indicates whether the stimulus is congruent or incongruent) (Figure 9). We used this *.xlsx* file as the input for the Conditions of the loop component **Trials_Loop** (Figure 10).

Figure 9. the Excel file used for stimulus presentation in our **PsychoPy** example experiment
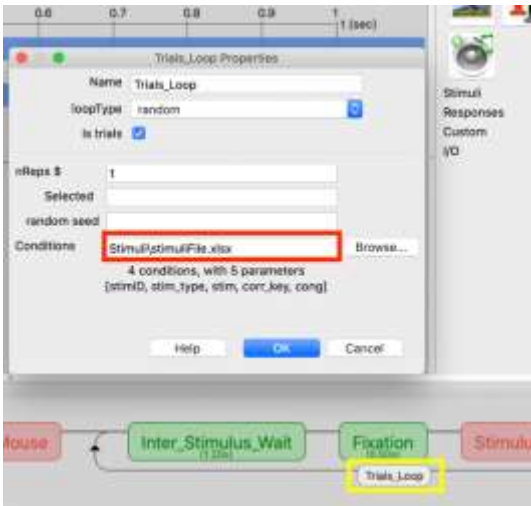
Figure 10. Choosing *stimuliFile.xlsx* as the input for the Conditions of the loop

4. 3. Adding Automatic Data Acquisition to the Experiment

To start recording the data streams available on **LSL** into a *.xdf* file, the code script shown in Figure 11 is added in the custom code named **xdf_record,** which is inside the **End Routine** tab of the **Recording_Start** routine. This script uses Windows **command line** to open the **LabRecorder** in the background of the experiment and starts recording the data. You should make sure that all the streams are created and initialized before this code starts running in the experiment.
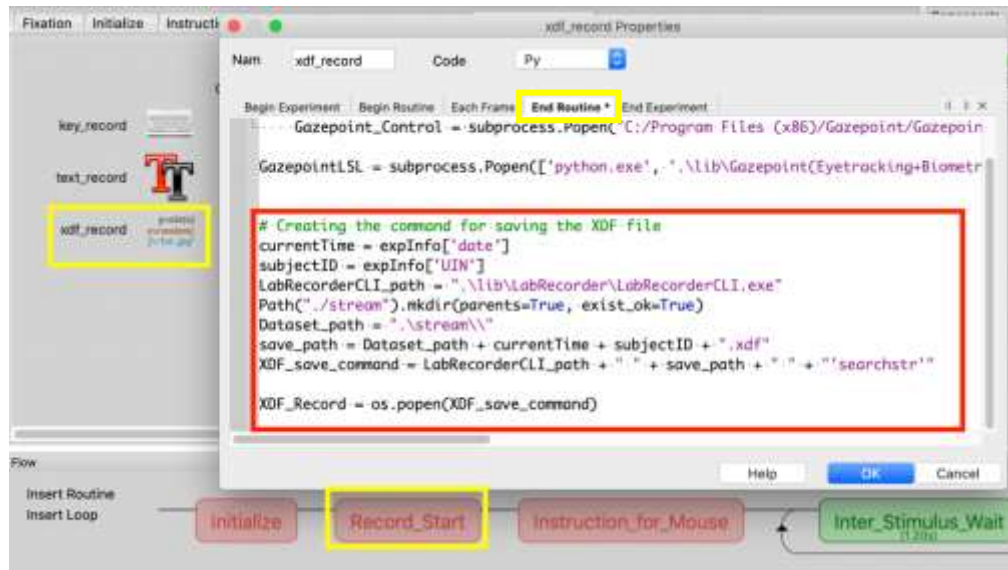
Figure 11. PsychoPy custom code from starting **LabRecorder** automatically from **command line**

In the following, we show step by step how to add different streams to the experiment.

4.3.1   Mouse data + Flanker task markers

When you open the experiment *Flanker_Mouse.psyexp*, inside the **Initialize** routine, there is a custom code named **initialize_code.** When you open it, in the **Begin Experiment** tab, first, the required modules are imported (Figure 12), then 3 **LSL** streams are created. The first stream is for sending stimulus markers (Figure 13); the second stream is for sending user response markers (Figure 14), and the third stream is for sending mouse coordinates to **LSL** (Figure 15).
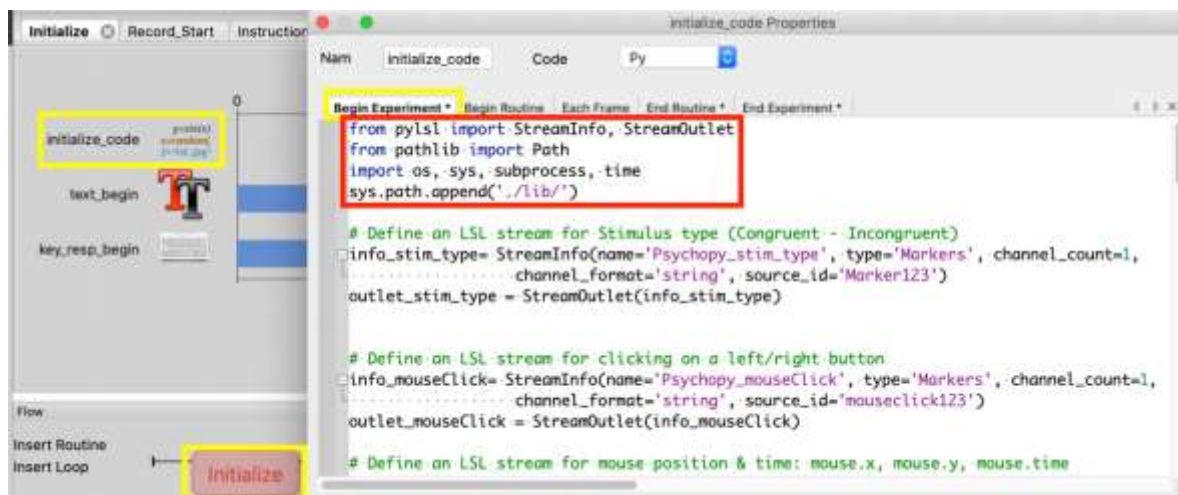
Figure 12. Importing the required modules
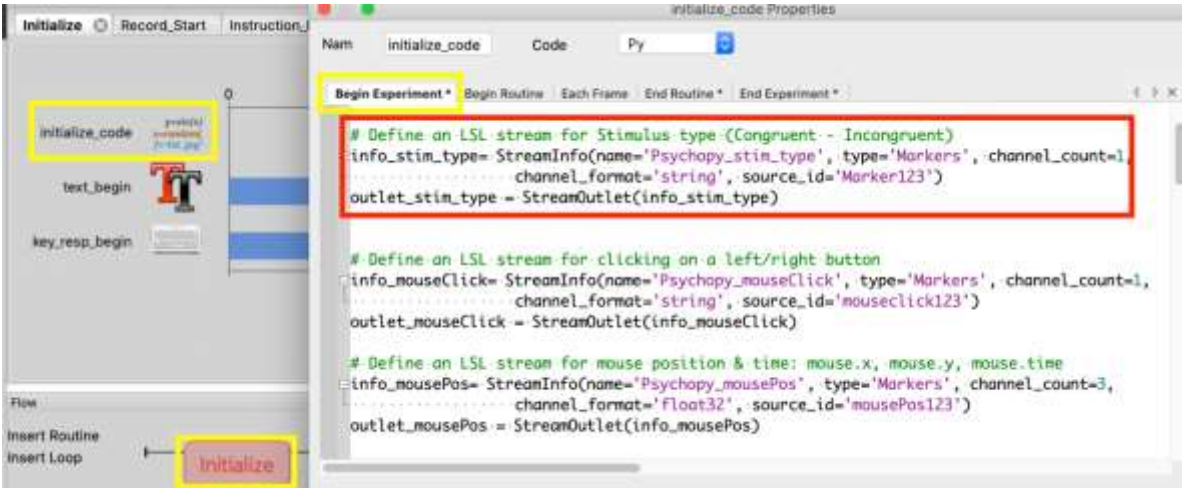
Figure 13. Defining a stream for sending stimulus type (congruent/incongruent) to **LSL** in each stimulus presentation
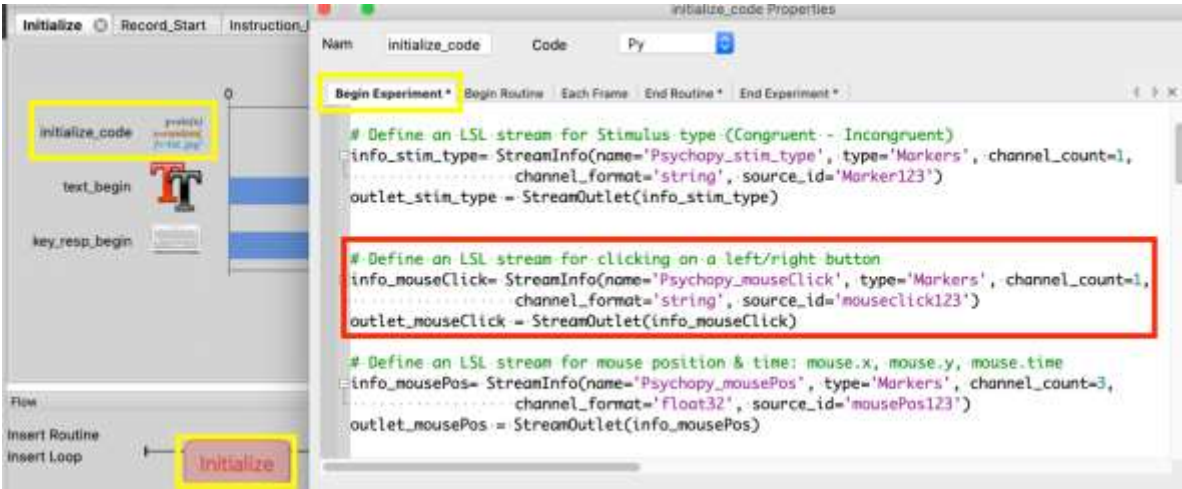
Figure 14. Defining a stream for sending user response (clicking on the left/right box) to **LSL**
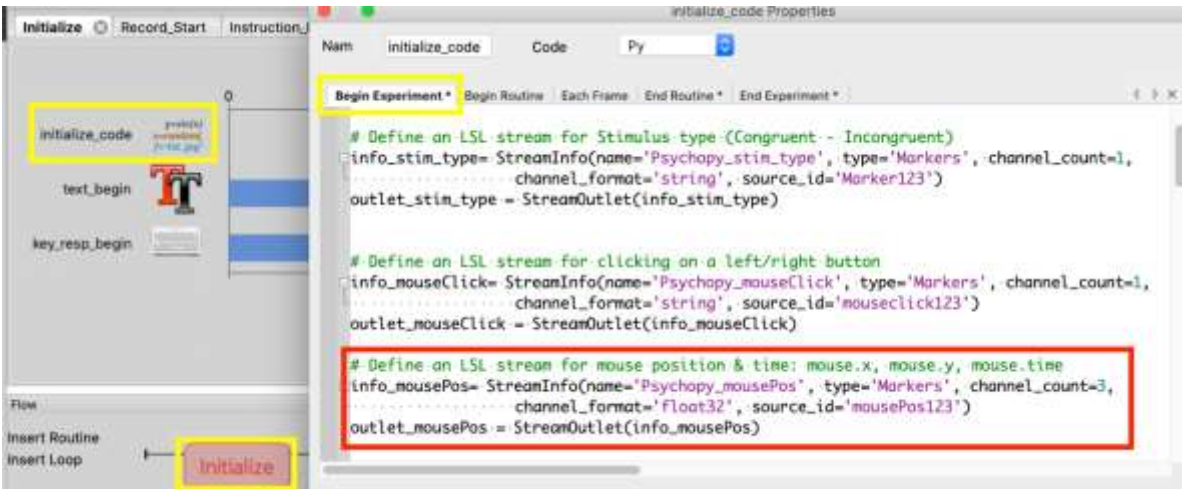
Figure 15. Defining a stream for sending mouse coordinates to **LSL** in each trial

In order to send a stimulus marker to **LSL**, in the **Begin Routine** tab of the custom code **stimulus_code**, which is inside the **Stimulus_Presentation** routine, we added the code shown in Figure 16. In order to send the user response data to **LSL**, in the same custom code, we added the code shown in Figure 17 in the **End Routine** tab (since we selected that the stimulus routine be ended on a valid mouse click in mouse component). Finally, to send mouse coordinates data to **LSL**, in the **Each Frame** tab (since the mouse coordinates should be sent in each refresh of the monitor screen), we added the code shown in Figure 18. Similarly, if keyboard is used instead of mouse for user response, to send keyboard data to **LSL**, we should use **key_resp.keys** as the argument for the outlet.push_chunk/outlet.push_sample (This is not shown here for brevity).
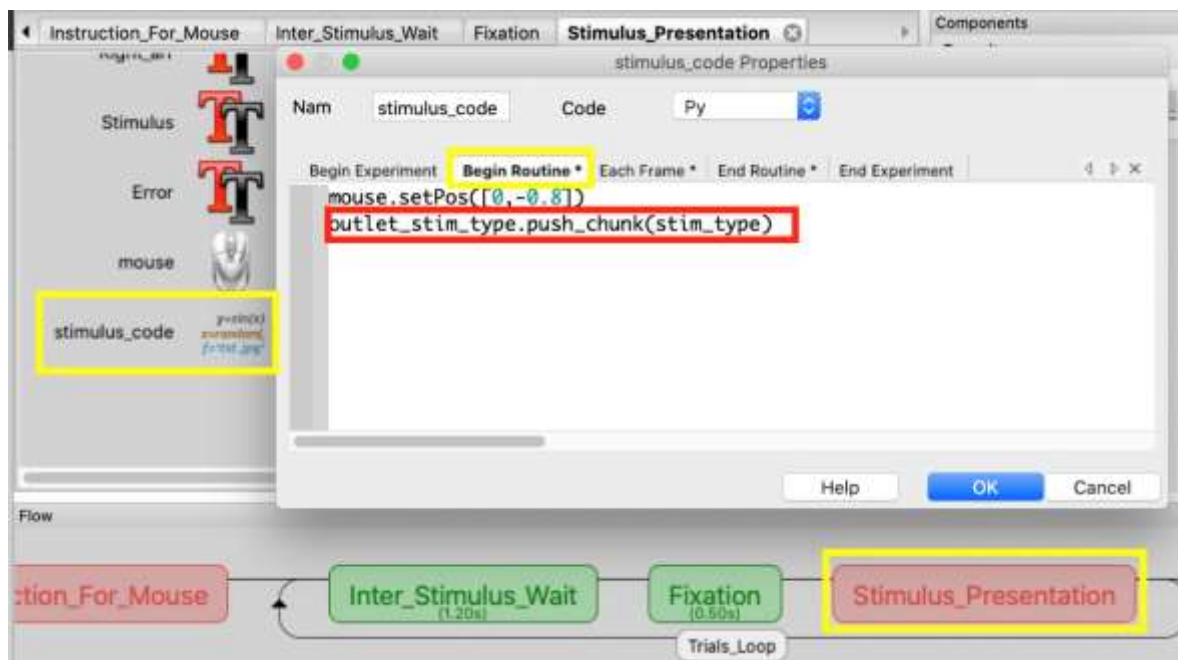
Figure 16. Sending the type of stimulus to **LSL** at the onset of stimulus presentation on the screen
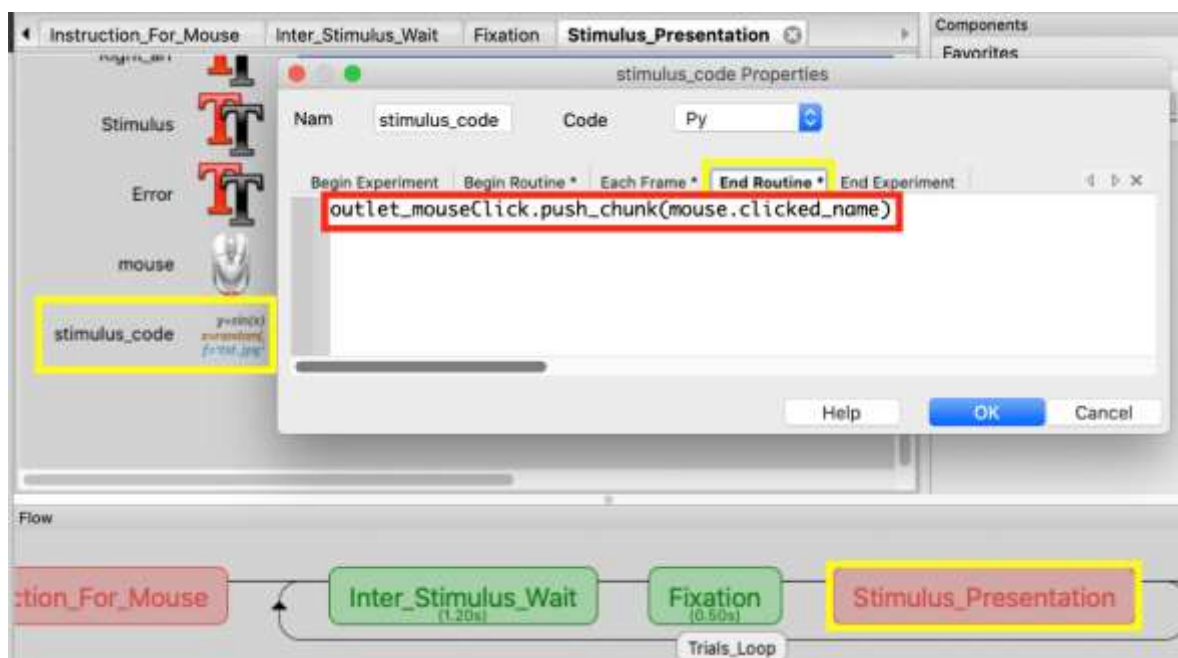
Figure 17. Sending the user response data (whether the user clicked on the left/right box) to **LSL** at the moment he clicks on the left/right box.
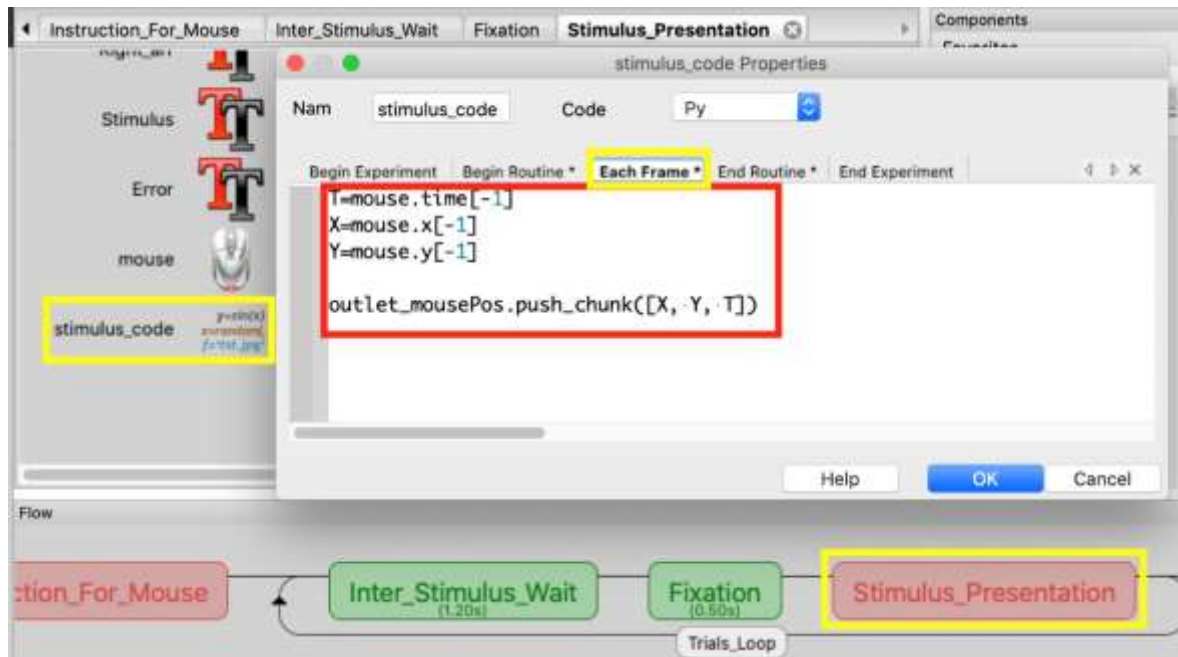
Figure 18. Sending mouse coordinates in each refresh of the monitor screen to **LSL**

Features such as maximum velocity, maximum acceleration, total distance of the mouse movement, area under the curve, maximum absolute deviation from a straight line, etc. can be extracted easily from Mouse data by a package for R and Python called *mousetrap* (Kieslich 2017).

4.3.2   Mouse Data + Flanker task markers + EEG

Here we show how to add different EEG devices to the experiment.

- **g.tec Unicorn (8-channel EEG device)**

    We have developed a C++ program (using Unicorn SDK) to send the data from Unicorn device to **LSL**. You can download the application from our GitHub and just put the download folder inside the experiment *lib* folder. Then you can simply call the application from **PsychoPy** by adding the script shown in Figure 19 in the **Begin Experiment** tab of the **initialize_code** inside the **Initialize** routine. This will automatically send data from a paired Unicorn device to **LSL**.
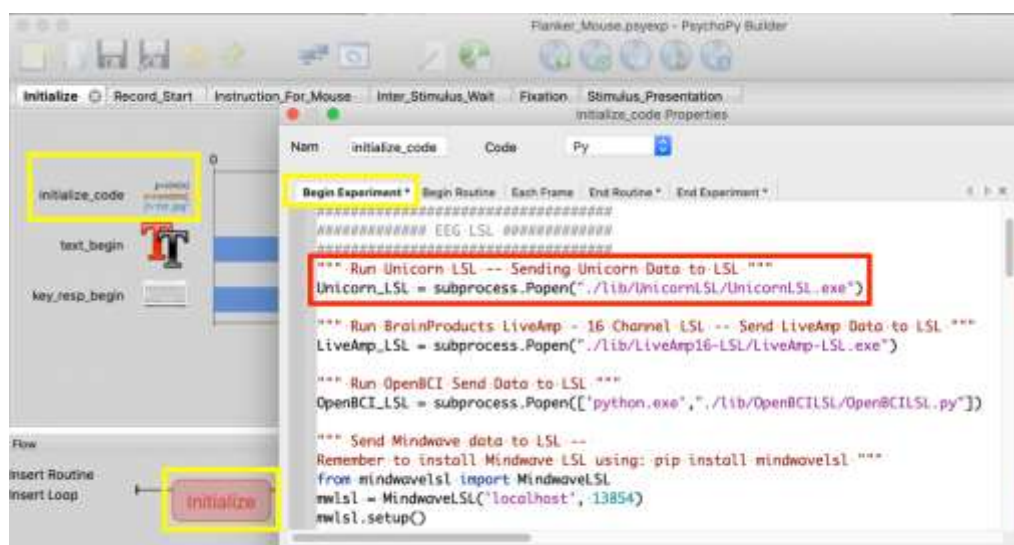
Figure 19. Running the application for sending g.tec Unicorn data to **LSL**

- **BrainProducts LiveAmp (16, 32 and 64-channel EEG device)**
  We have developed three C++ applications (using LiveAmp SDK) to send data from 16, 32 and 64-channel LiveAmp devices to **LSL**. You can download the application associated with your device from our GitHub and just put the download folder inside the experiment *lib* folder. Then you can simply call the application from **PsychoPy** by adding the script shown in Figure 20 in the **Begin Experiment** tab of the **initialize_code** which is inside the **Initialize** routine. This will automatically send data from a turned on LiveAmp device to **LSL**.
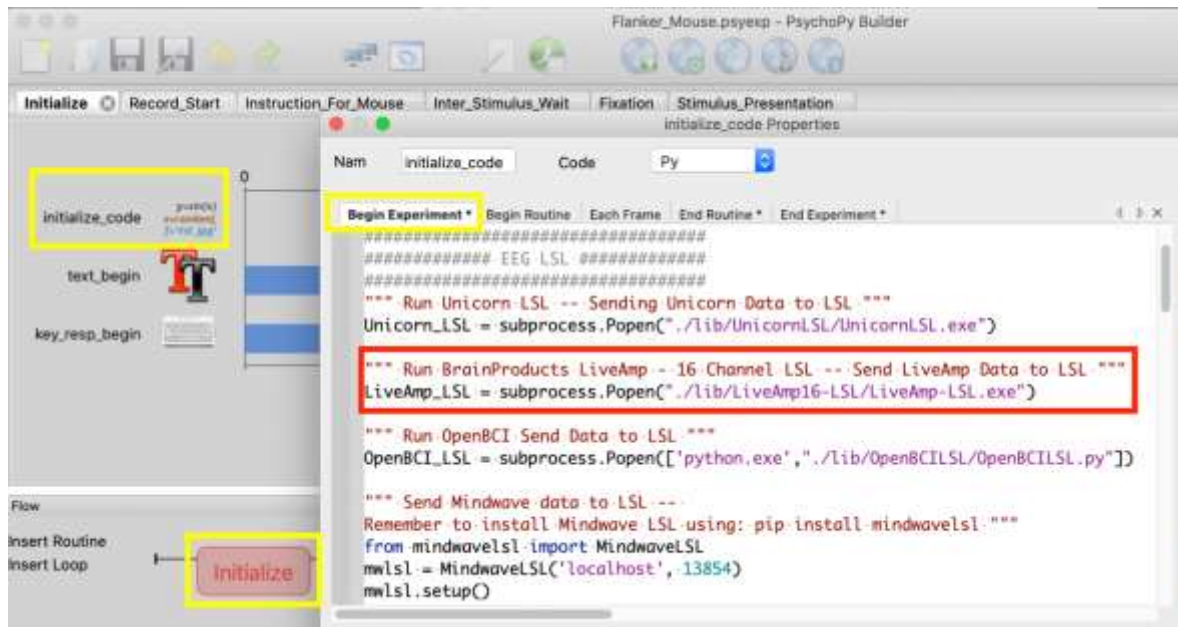
Figure 20. Running the application for sending BrainProducts LiveAmp data to **LSL**

- **OpenBCI Cyton (8-channel) and OpenBCI Cyton + Daisy (16-channel EEG Device)**
  You first need to install pyOpenBCI using: **pip install pyOpenBCI**. Then you can download *OpenBCILSL* folder from our GitHub and copy it in the experiment *lib* folder. Then you can add the code shown in Figure 21 in **Begin Experiment** tab of the **initialize_code** inside the **Initialize** routine to send data from OpenBCI automatically to **LSL**. Based on whether you want to use the OpenBCI Daisy module (16-channel) or not (8-channel), in the *OpenBCILSL.py* file you can set **daisy = True/False** and set the number of channels in the **LSL** stream info to 16 (for Cyton + Daisy) or 8 (for Cyton) (Figure 22).
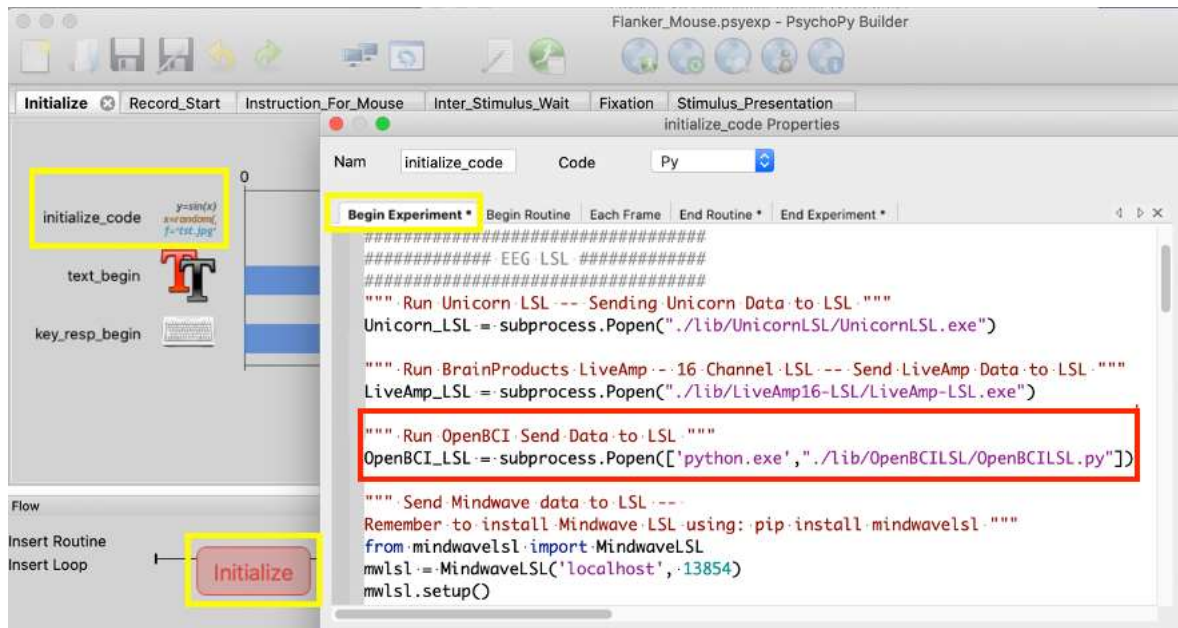
Figure 21. Calling the Python script for sending OpenBCI Cyton/OpenBCI Cyton + Daisy data to **LSL**
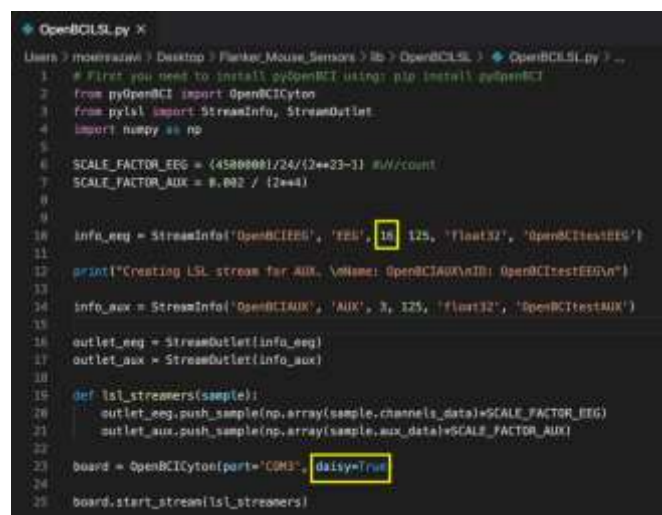
Figure 22. Python script for sending OpenBCI Cyton/OpenBCI Cyton + Daisy data to **LSL**

- **NeuroSky Mindwave (1-channel EEG device)**
  You first need to install **mindwavelsl** using the command **pip install mindwavelsl**. Then, you can add the lines of code shown in Figure 23 in the **Begin Experiment** tab of the **initialize_code,** which is inside the **Initialize** routine. This single electrode EEG device is surprisingly useful and versatile for self-paced learning tasks (e.g., classroom) [25].
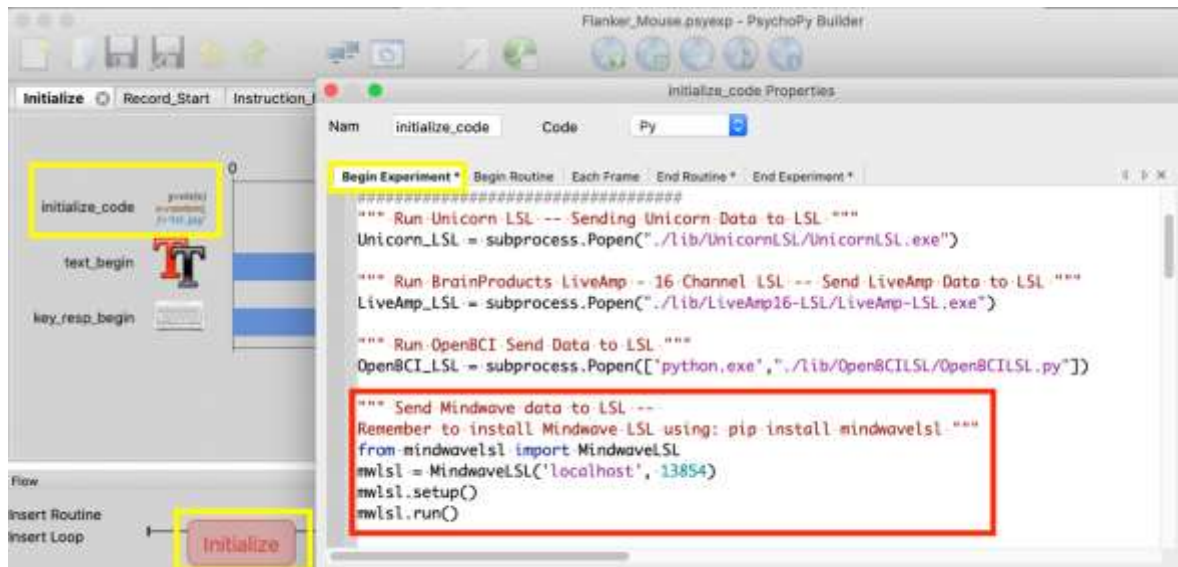
Figure 23. Sending NeuroSky Mindwave data to **LSL**

- **Muse (4-channel EEG device)**

    First, you need to download **BlueMuse from:**
    https://github.com/kowalej/BlueMuse/releases/download/v2.1/BlueMuse_2.1.0.0.zip   and
    install it as instructed in https://github.com/kowalej/BlueMuse. Then you need to install
    muselsl module using: **pip install muselsl.** To run **BlueMuse** automatically in the
    background when you run the experiment, you can add the lines shown in Figure 24 in the
    Begin Experiment tab of the **initialize_code** inside the **Initialize** routine.
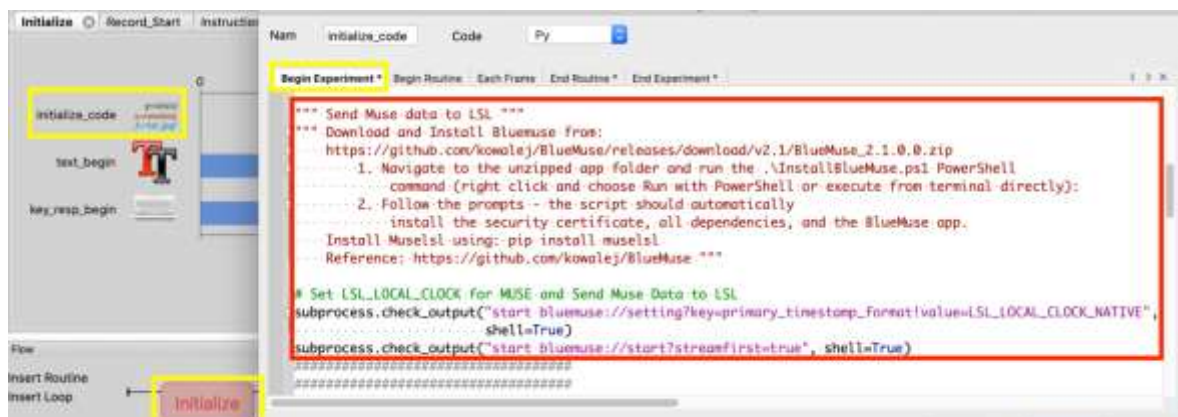
Figure 24. Sending Muse data to **LSL**

EEG   data   can   be   analyzed   in   **EEGLAB**   (MATLAB   Toolbox;
https://sccn.ucsd.edu/eeglab/index.php) and Python **MNE** module. In order to read the **XDF** files in
EEGLAB, you need to install **xdfimporter** extension for **EEGLAB**. To analyze data using Python
MNE, **pyxdf** module should be installed for Python.

4.3.3   Mouse Data + Flanker task markers + EEG + GSR (Arduino)

For GSR, we used 2 different devices, 1) eHealth Sensor v2.0 Arduino shield, and 2) Gazepoint
Biometrics kit. For eHealth Arduino shield, first, you need to add <eHealthDisplay.h> and
<eHealth.h> libraries to Arduino IDE. We can send the data from Arduino to **LSL** by sending its data
to Serial port by writing a script in Arduino IDE (https://www.arduino.cc/en/main/software) (Figure
25) and deploying this code on the Arduino device. Then, we use a separate Python script to receive
the data from the Serial port. This Python script which is named *Serial2LSL.py* can be downloaded

from our GitHub: https://github.com/moeinrazavi/eHealth-GSR-LSL; We need to change the Serial port name based on the name of the port that the Arduino is connected to (Figure 26). Then we can call the Python script *Serial2LSL.py* from **PsychoPy** as a subprocess (Figure 27). This will send the data from Arduino automatically to **LSL** when it is connected to the Serial port. You can find the so-called Arduino IDE and Python script examples in the *lib* folder.

Figure 25. Arduino IDE script to send Arduino data to Serial port

Figure 26. Python script for receiving data from Serial port and sending it to **LSL**
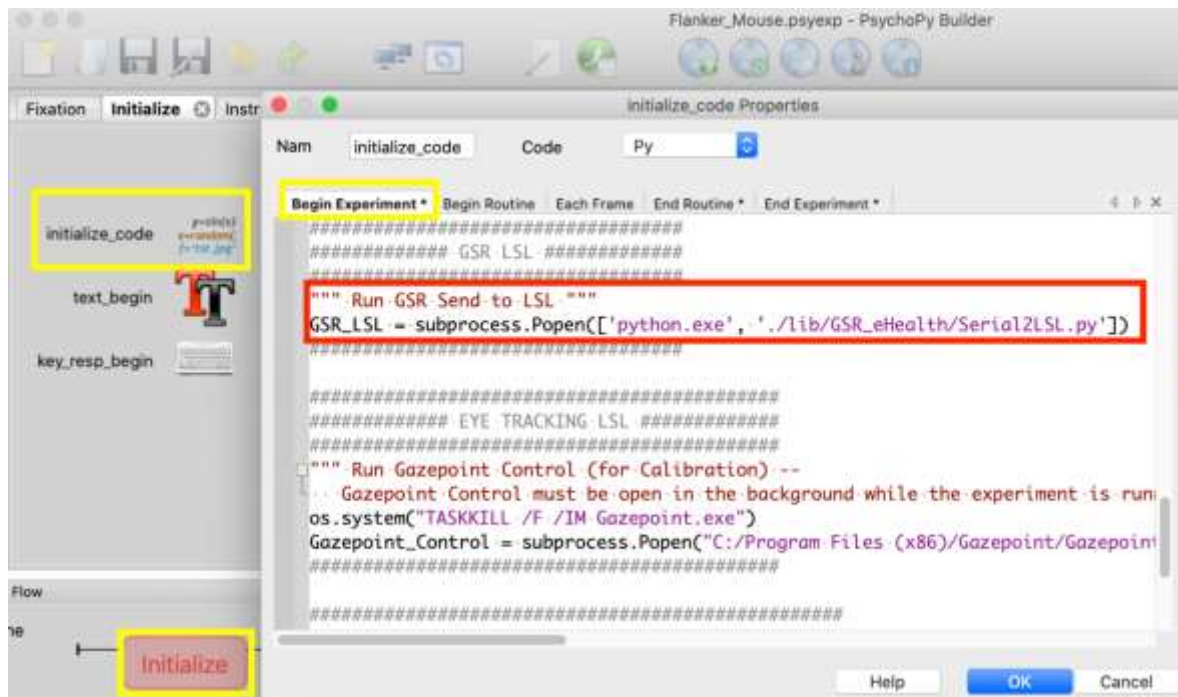
Figure 27. Calling the Python script for sending Arduino data to **LSL**

GSR data can be analyzed using **ledalab** (a MATLAB Toolbox). You can download **ledalab** from http://www.ledalab.de/**.** To analyze the data in **ledalab**, you need to open the *.xdf* file by calling the *load_xdf* function in MATLAB. In the next subsection, we will show how to send **GSR** data from the **Gazepoint Biometrics** kit (along with Gazepoint eyetracking data) to **LSL**.

4.3.4   Mouse Data + Flanker task markers + EEG + GSR + Eyetracking

First, download the Gazepoint installer from https://www.gazept.com/downloads/ to install the Gazepoint Control application. This application is used for eyetracking calibration and needs to be run in the background of the experiment while collecting the data from Gazepoint. We used Gazepoint SDK to develop a Python script to send eyetracking and biometrics data (GSR, heart-rate, etc.)   to   **LSL**.   This   Python   script   can   be   accessed   by   downloading   the   folder *Gazepoint(Eyetracking+Biometrics)-LSL*   from   our   GitHub: https://github.com/moeinrazavi/MultiModal_MultiSensory_Flanker_Task/tree/master/lib.   You should add that folder to the experiment **lib** folder. Then add the lines of code shown in Figures 28-30. The lines of code shown in Figure 28 are used to open Gazepoint Control. Then the code shown in Figure 29 is used to minimize the experiment screen to have access to Gazepoint Control for calibration. And finally, Figure 30 shows the code to check whether the Gazepoint Control is not closed by the user, and by running the *LSLGazepoint.py* as a subprocess, it starts sending data to **LSL**.
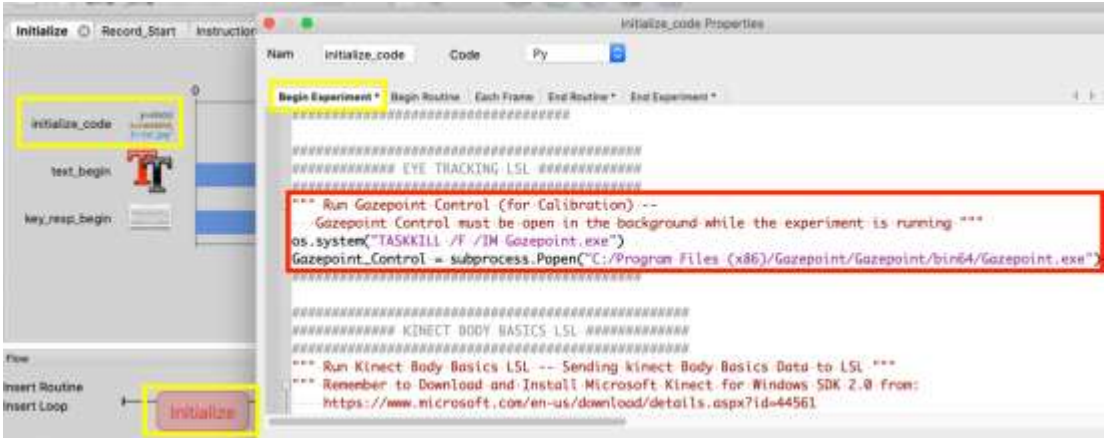
Figure 28. Script for running Gazepoint Control application.
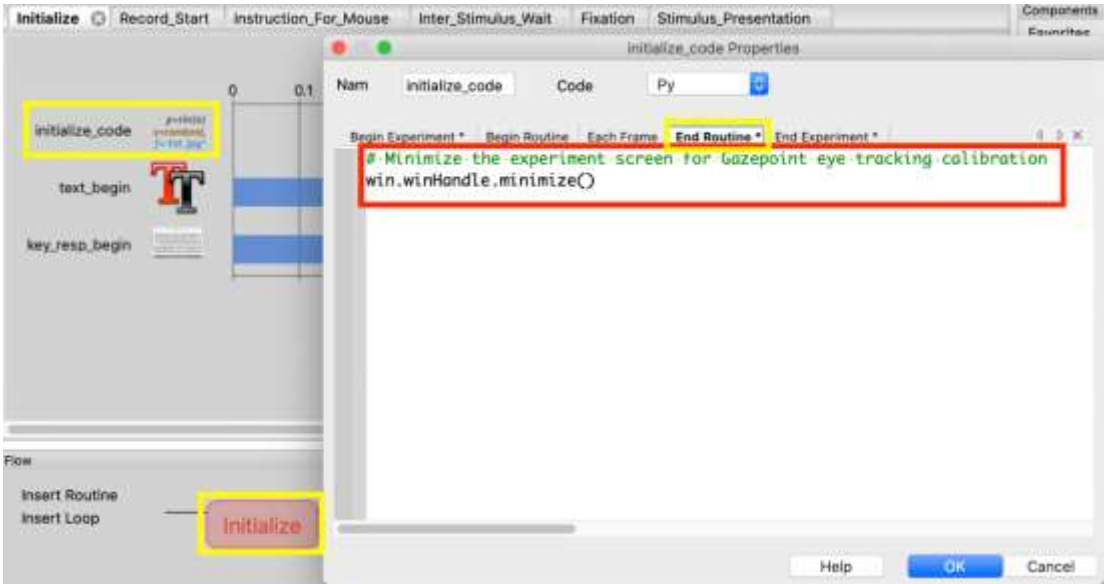
Figure 29. Script for minimizing the experiment screen to access the Gazepoint Control calibration
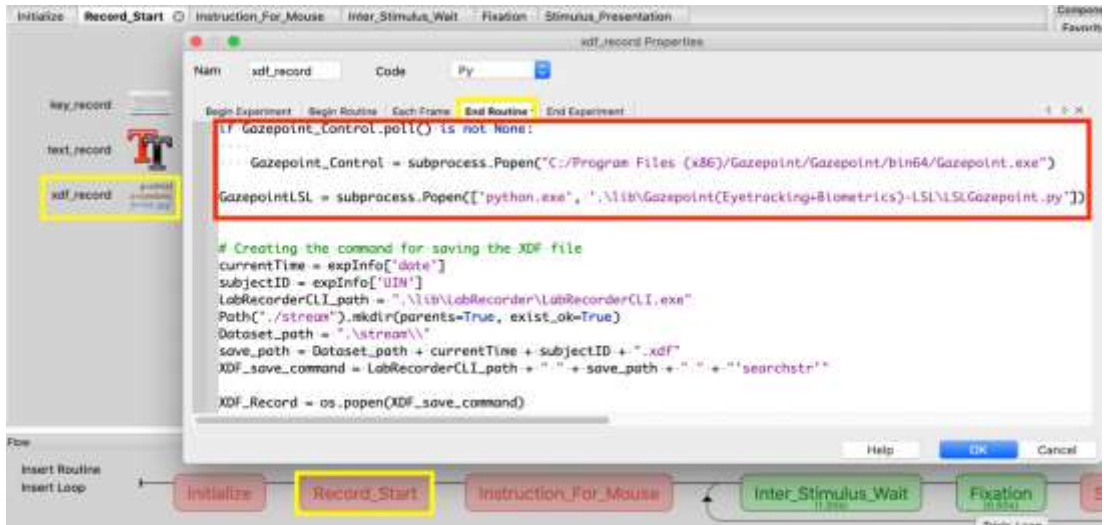
Figure 30. If Gazepoint Control closed by the user, run it again and send Gazepoint eyetracking (+ GSR and heartrate) to **LSL**

4.3.5   Mouse Data + Flanker task markers + EEG + GSR + Eyetracking + Body Motion

We used Kinect for Windows v2 to record body motion. First, install Microsoft Kinect for Windows SDK 2.0 from https://www.microsoft.com/en-us/download/details.aspx?id=44561. We developed a C++ application based on Kinect Body Basics SDK to send data from a connected Kinect device to **LSL**. This application can be accessed by downloading the folder *Kinect-BodyBasics-LSL* from our GitHub: https://github.com/moeinrazavi/Kinect-BodyBasics-LSL and copying this folder in the experiment *lib* folder. Then, add the lines of code shown in Figure 31 to the **Begin Experiment** tab of **initialize_code** in the **Initialize** routine.
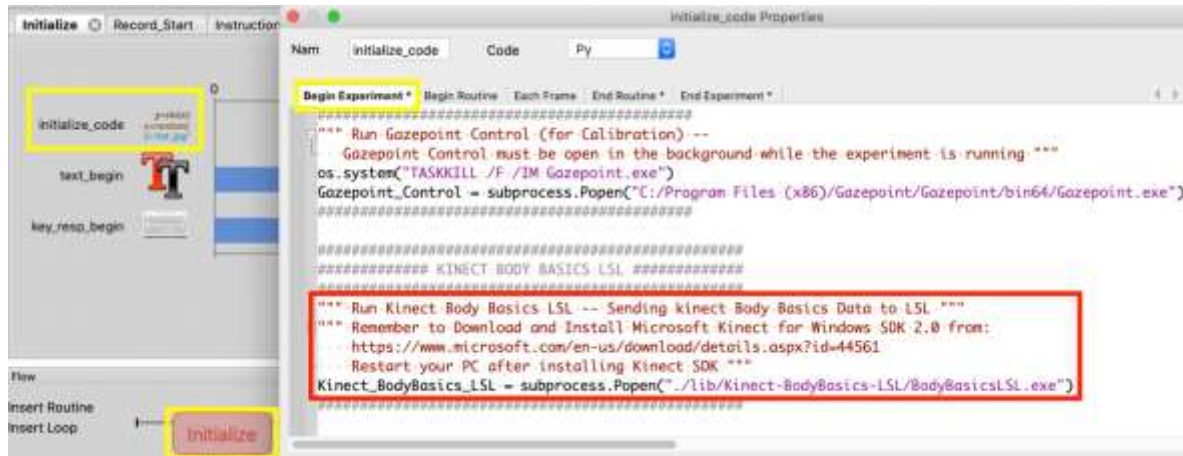
Figure 31. Running the application for sending Kinect body motion data to **LSL**

At the end of experiment, in order to stop recording, the lines of code shown in Figure 32 can be added to the **End Experiment** tab.
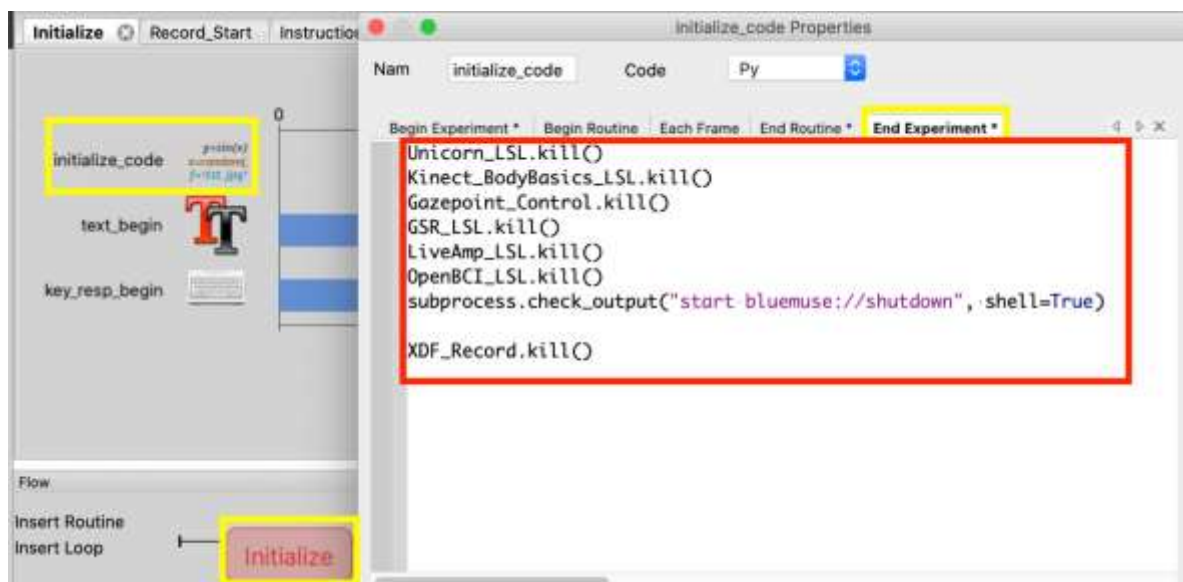
Figure 32. Script for stop recording the data from all the devices

5. Building a Multisensory Virtual Reality (VR) Experiment (Unity)

In this section, we first show how to create simple interactable game objects in a **VR** environment using **Unity**. Then, we provide a tutorial on how to synchronize **VR** environment data (e.g., objects positions and orientations), user data (i.e., marker for pressing HTC VIVE controller trigger, positions of player and controllers), and data from multiple devices such as EEG (g.tec Unicorn, Muse, Neurosky Mindwave, BrainProducts LiveAmp, OpenBCI Cyton and OpenBCI Cyton + Daisy), GSR (e-Health Sensor Platform v2.0 for Arduino), Eyetracking (HTC VIVE Pro with Tobii Eyetracking),

and Body Motion (Kinect) together by **LSL**. Finally, we explain how to use **LabRecorder** to save data automatically to disk by embedding it in **Unity**.

5. 1. Software and Plugin Installation

In order to design a **VR** environment, you need to install **Unity** (https://unity3d.com/get-unity/download) and Steam (https://store.steampowered.com/about/), which are available to download for free.

5. 2. Create simple interactable objects in VR environment

After installing **Unity** and Steam, in order to create a **VR** environment in Unity, you should create a new 3D project from Projects part in Unity Hub (Figure 33)
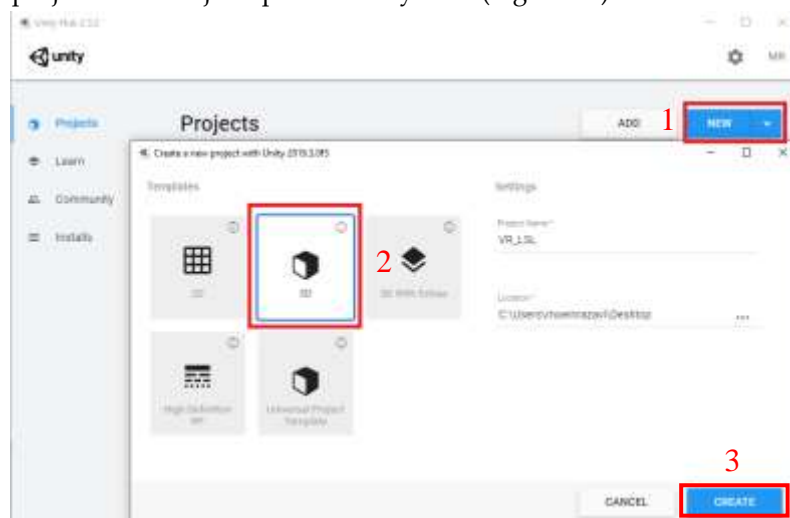
Figure 33. Create a new 3D project in **Unity**

After creating the project, there is a Main Camera object in **Unity** SampleScene which is fixed to the environment and useless for **VR** purposes (Figure 34). We will show later how to attach a camera object to the player that can move with it.
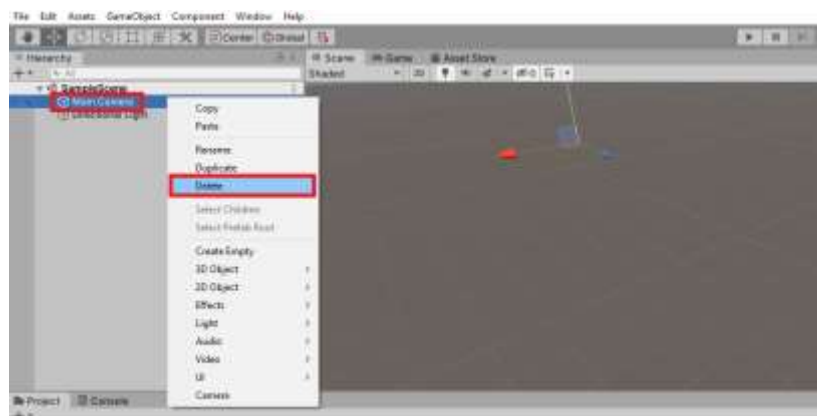
Figure 34. Delete Main Camera object from the Scene

To utilize **VR** properties and functions, you should import the SteamVR Plugin to our project. SteamVR Plugin can be downloaded and imported from Asset Store in **Unity**. In the pop-up window that appears after importing SteamVR Plugin, click on import (Figure 35.a). After that, you will see another pop-up window in which you should click on Accept All (Figure 35.b).

Figure 35. a. Import SteamVR Plugin

Figure 35. b. Import SteamVR Plugin

Next, we added simple objects (e.g., Plane and Cube) to the Scene (Figure 36). To make the objects interactable with the user, we first added **Interactable** and then **Throwable** features to the **Cube** object (Figure 37). By doing this, the user can move and throw the Cube object.
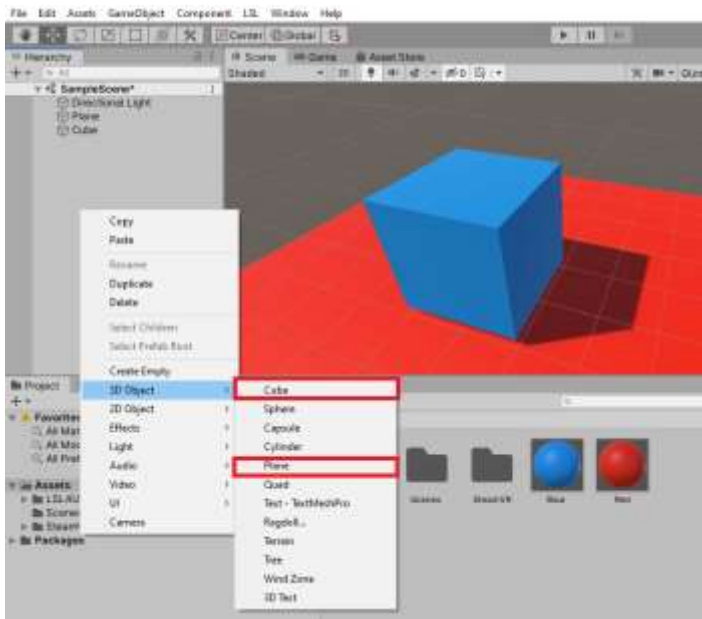
Figure 36. Add Plane and Cube objects to the Scene
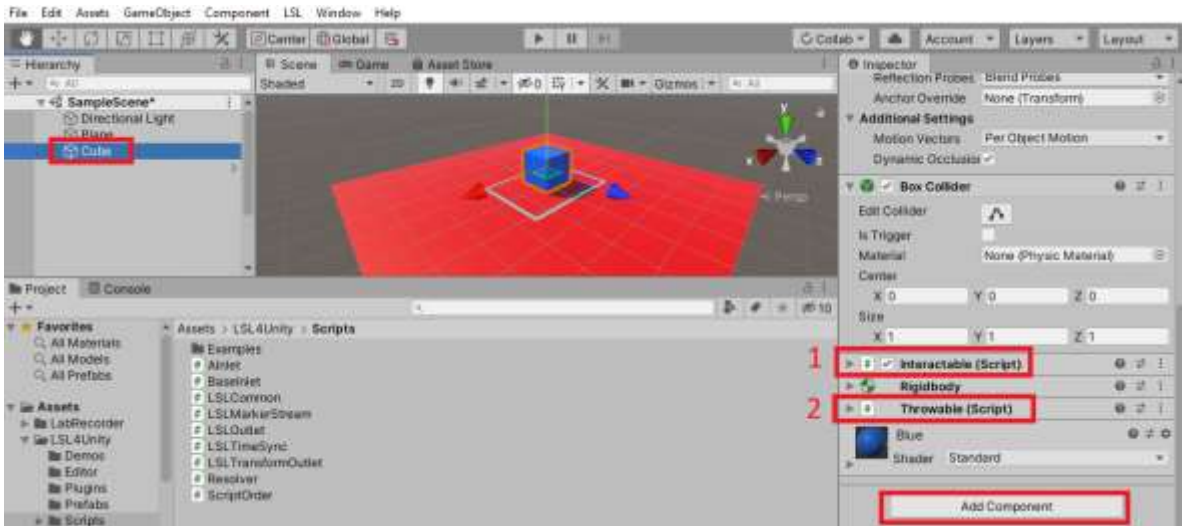
Figure 37. Add **Interactable** and then **Throwable** components to the **Cube**

Then we added a Player object to the Scene by dragging it to the Scene (Figure 38). The Player object will define the position of the user in the **VR** environment. After that, we added [CameraRig] object to the Player by dragging it to the Player (Figure 39). This will attach the **VR** camera and controllers (here HTC VIVE Pro camera and controllers) to the Player object.
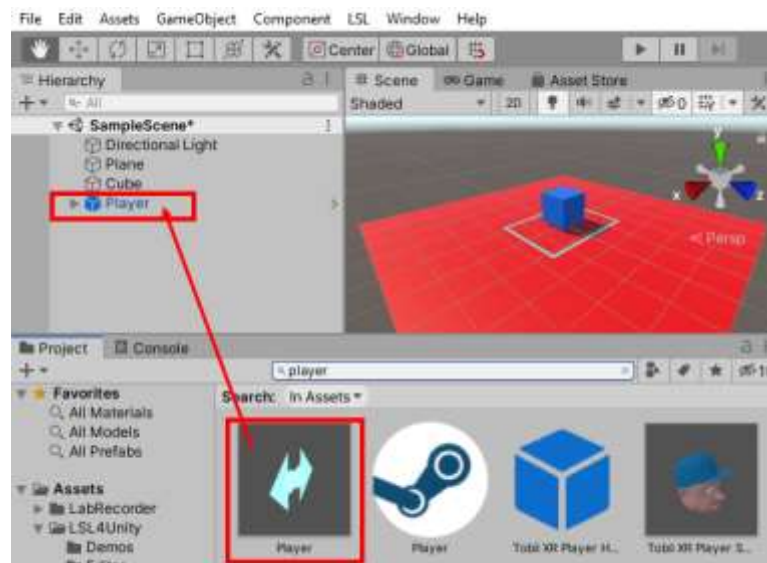
Figure 38. Add Player object to the Scene
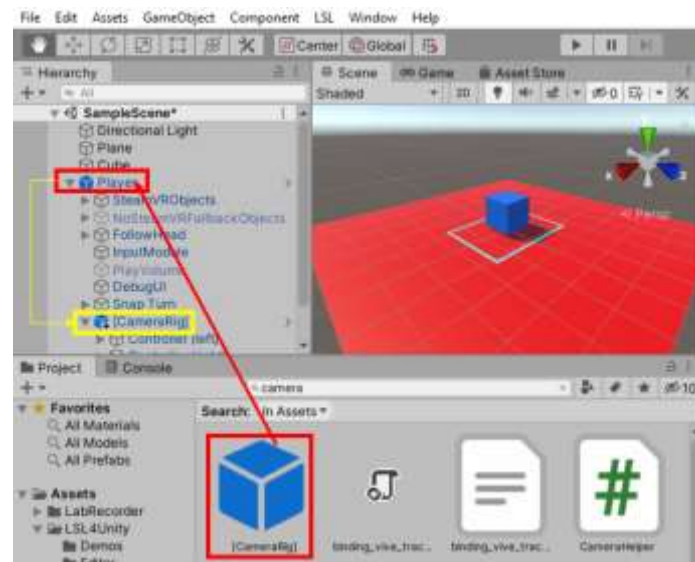
Figure 39. Add [CameraRig] object to the Player

In the following, we show how to synchronize the data from the **VR** environment, user and different devices using **LSL**.

*5. 3. Synchronize data from **VR**, user and different devices by **LSL***

In this step, to use **LSL** features, you should add **LSL4Unity** plugin to the *Assets* folder in the main project folder (here **VR_LSL**). In addition, to send HTC VIVE eyetracking and controller trigger press data to **LSL**, we developed two C# scripts which should also be added to the *Assets* folder (Figure 40). The **LSL4Unity** plugin and these scripts can be accessed from our GitHub: https://github.com/moeinrazavi/VR_LSL.
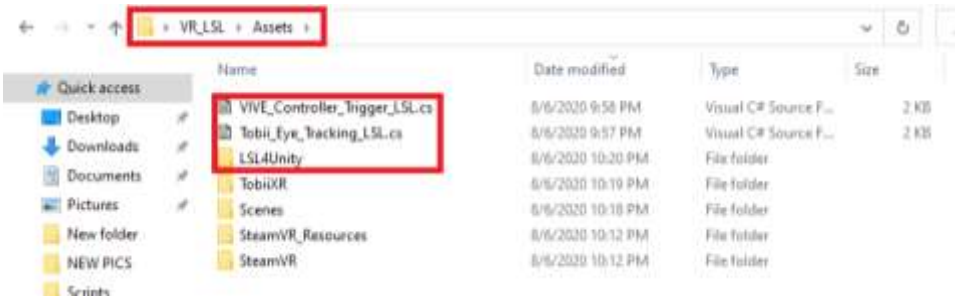
Figure 40. Add **LSL4Unity** plugin and developed scripts for sending HTC VIVE eyetracking and controller trigger press data to **LSL** in the project's *Assets* folder.

5.3.1   Send **VR** objects data to **LSL**

Each object in **Unity** has a component named Transform which defines the Position and Rotation of that object in the environment (Figure 41). The LSLTransformOutlet function in **LSL4Unity** plugin can be attached to each object and send data from its Transform component to **LSL**. In Figure 42, we showed how to add this function to the Cube object by dragging the function to the object. We should set the Sample Source field of this function to the object that we want to send its Transform data to **LSL** (Figure 42). The LSLTransformOutlet function provides up to 3 types of data to be sent to **LSL**. The first type contains 4 channels that send the rotation data in the Quaternion system (angles with x,y,z and w axes); the next one has 3 channels that are associated with the rotation data in the Euler system (angles with x,y and z axes). The last one includes 3 channels that send the position data (x, y and z coordinates) to **LSL** (Figure 43).
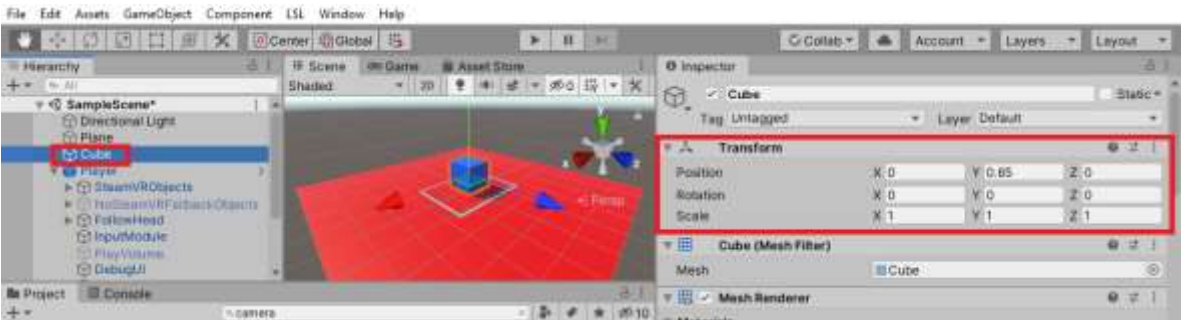
Figure 41. Transform component of an object
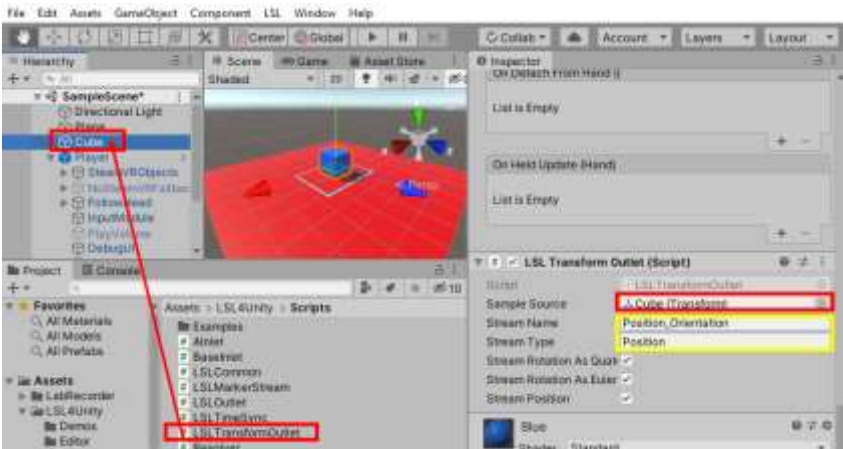
Figure 42. Add LSLTransformOutlet function to the Cube object
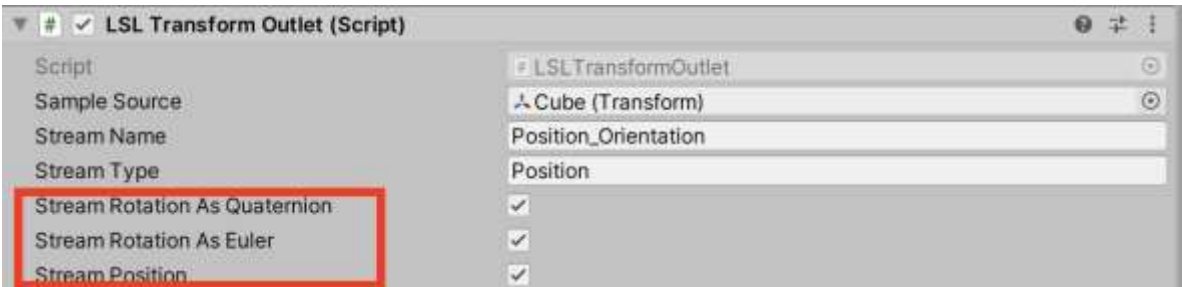
Figure 43. LSLTransformOutlet data streaming choices

5.3.2   Send **VR** objects data + user data to **LSL**

Here we show how to send the camera rotation, camera position coordinates and controller trigger press markers to **LSL**. The camera is attached to the Player object.

First, to send the camera rotation and position data to **LSL**, similar to the previous subsection, we attached the LSLTransformOutlet function to Camera object under the Player object and chose Camera as the Sample Source of this function (Figure 44). Similar to camera, you can easily send position and rotation of controllers by attaching LSLTransformOutlet function to the Transform component of each controller (not shown here for brevity).
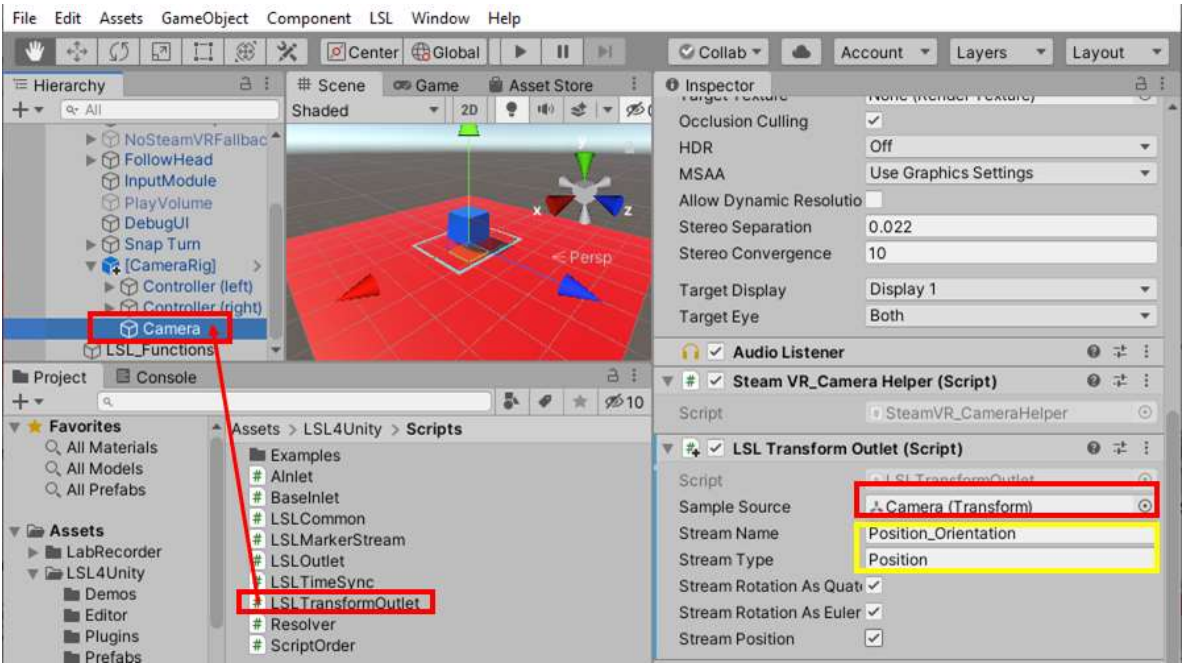
Figure 44. Add LSLTransformOutlet function to the Camera object

Then, to have access to controllers, we need to generate SteamVR Input by clicking on SteamVR Input in Window tab. Click on **Yes** on every pop-up window that appears, and finally click on **Save and generate** button in the last pop-up window (Figure 45). The SteamVR Input makes controller button actions accessible.
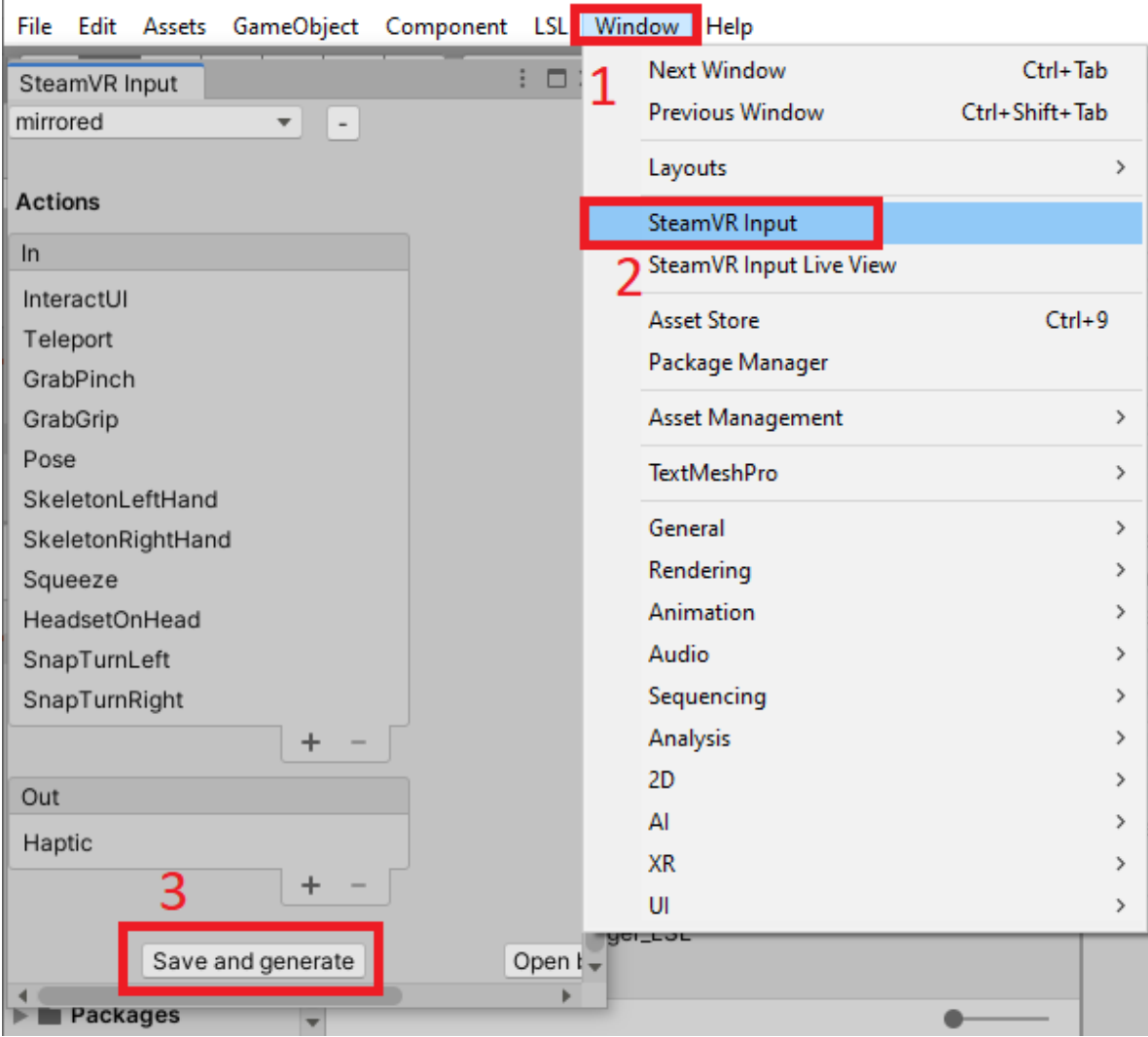
Figure 45. Generate SteamVR Input

5.3.3   Send **VR** objects data + user data + data from different devices to **LSL**

In order to send data from controllers, eyetracking and other devices, we created an empty GameObject; we added this object to LSL_Functions (Figure 46).
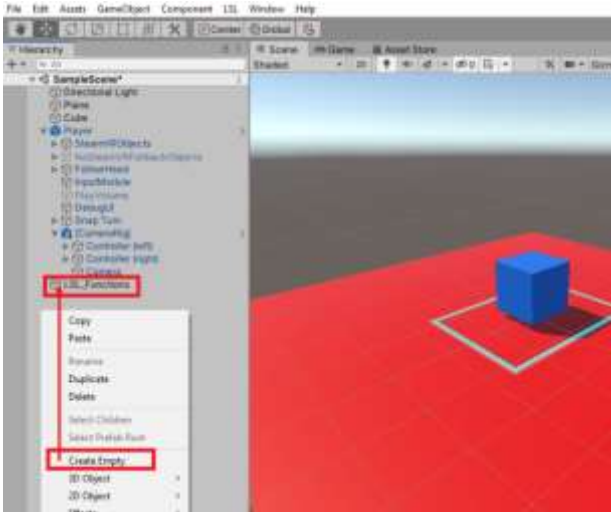
Figure 46. Create an empty GameObject (here renamed to LSL_Functions)

In the following, we added the scripts which send data from different devices to **LSL** to LSL_Functions object, step by step. We provided a brief explanation for some of the scripts.

- **Sending controller trigger press marker to LSL**

To send the controller trigger press markers to **LSL**, we first needed to add the **Steam VR_Activate Action Set On Load** function to LSL_Functions object. This function allows access to controller button actions. The Action Set in this function must be set to \actions\default. Then we added **VIVE_Controller_Trigger_LSL** that we have developed with C# and **LSL Marker Stream** functions to LSL_Functions. The **VIVE_Controller_Trigger_LSL** function uses **LSL Marker Stream** to send controller trigger press data to **LSL** (Figure 47). In VIVE_Controller_Trigger_LSL panel, you need to set the Trigger_Data on \actions\default\in\GrabPinch; This will assign the action of sending data to **LSL** to the controller trigger. You also need to choose whether you want the right hand controller or the left one to send data to **LSL** by choosing Right Hand/Left Hand for the Hand Type.
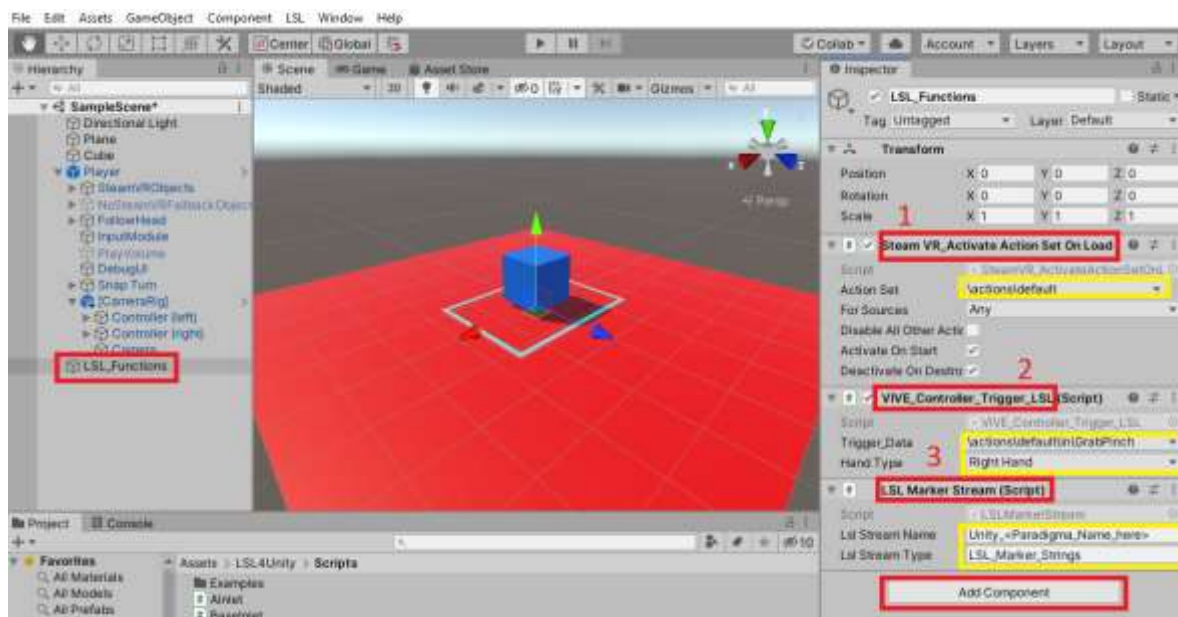
Figure 47. Add the scripts to send controller trigger press data to **LSL**

- **Sending Eyetracking data to LSL**

In order to send the Eyetracking (HTC VIVE Pro with Tobii Eyetracking) data to **LSL**, first, you need to download Tobii XR SDK for **Unity** from https://vr.tobii.com/sdk/downloads/. Then, while the project is open, double click on the downloaded file and it will start importing the required libraries for Tobii eyetracking in **Unity**.

Then you need to add the **Tobii_Eye_Tracking_LSL** function that we developed with C# to the LSL_functions object (Figure 48).
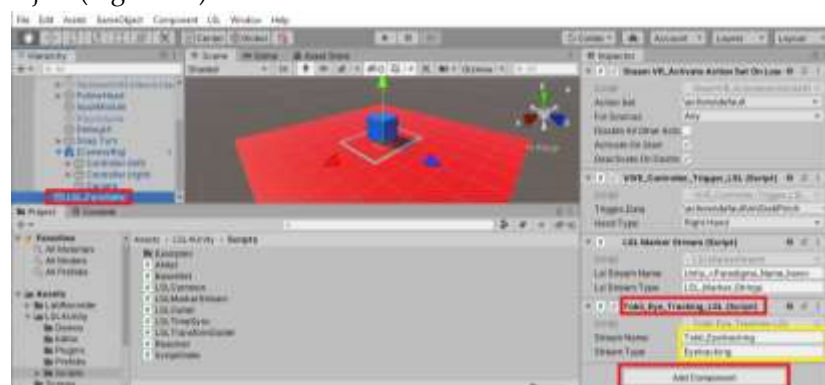
Figure 48. Add the script to send eyetracking data to **LSL**

- **Send data from other devices to LSL**

Here we show how to send data from other devices (EEG (g.tec Unicorn, Muse, Neurosky Mindwave, BrainProducts LiveAmp, OpenBCI Cyton and OpenBCI Cyton + Daisy), GSR (e-Health Sensor Platform v2.0 for Arduino), and Body Motion (Kinect)) to **LSL**. To do that, first, download the required folders from our GitHub and copy them in the *Assets* folder (Figure 49). Also, download the **Multiple_Devices_LSL** script that we developed in C# and copy it in the *Assets* folder (Figure 50). This script uses Windows Command Prompt to automatically send data from the devices mentioned above to **LSL** (Figure 51).
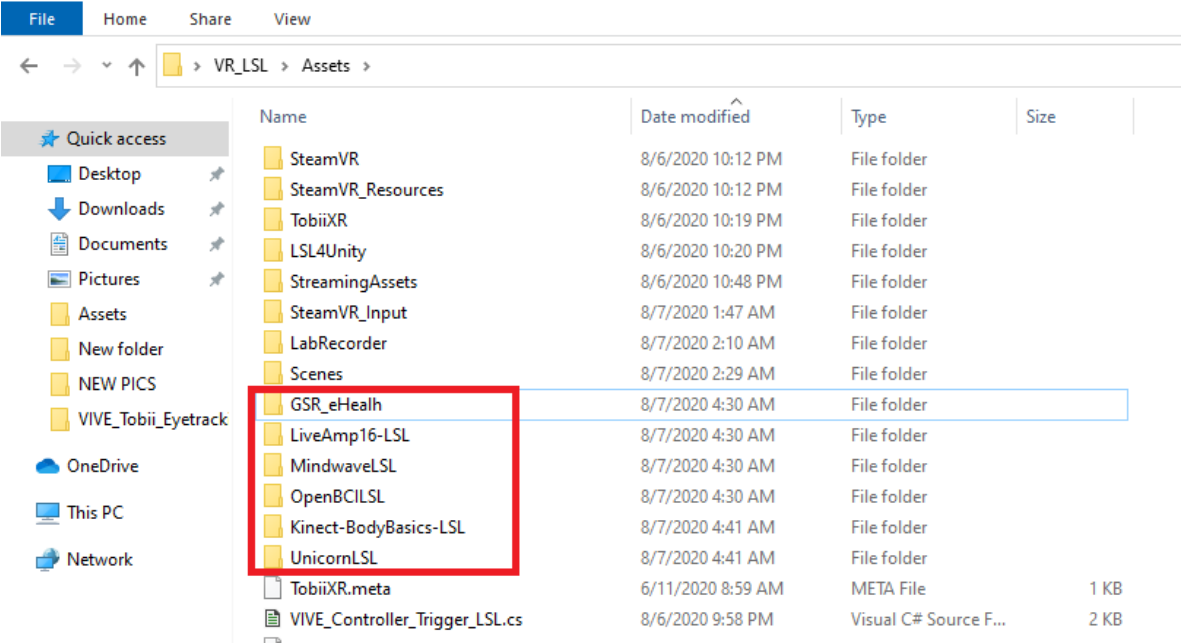
Figure 49. Add files associated with different devices to the *Assets* folder
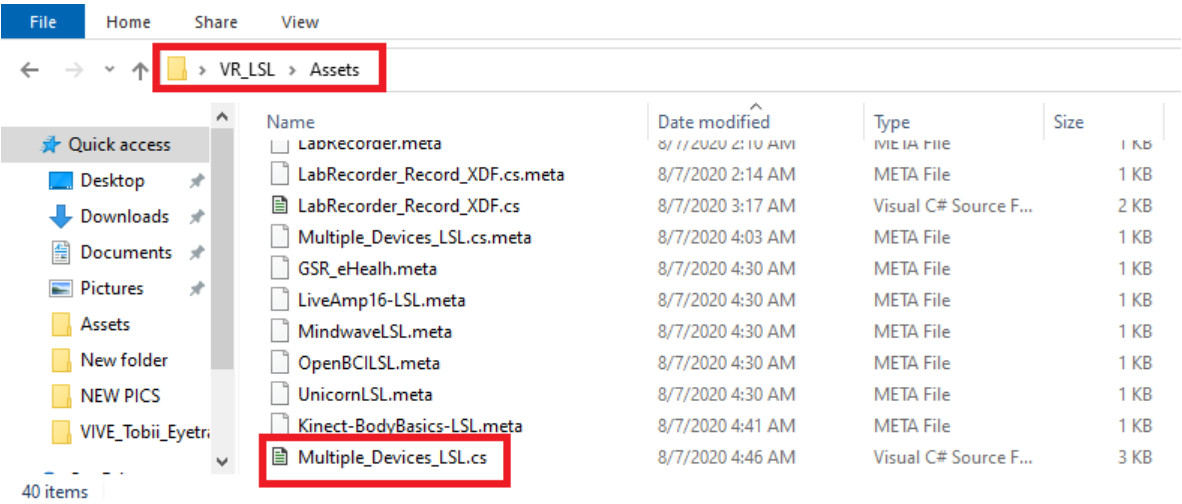
Figure 50. Add the Multiple_Devices_LSL script to *Assets* folder
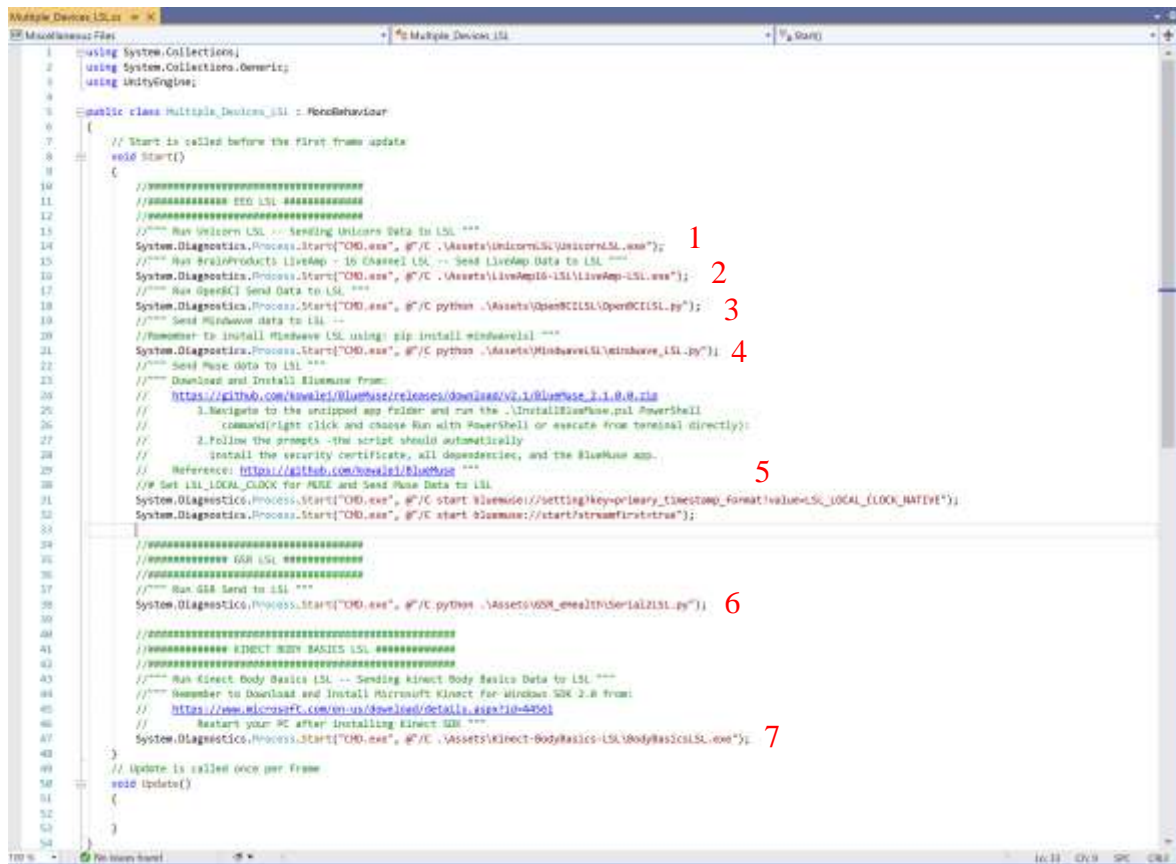
Figure 51. Multiple_Devices_LSL script: Send data from 1) g.tec Unicorn, 2) BrainProducts LiveAmp, 3) OpenBCI, 4) NeuroSky Mindwave, 5) Muse, 6) eHealth v2 GSR sensor and 7) Kinect to **LSL**

In Figure 52, we show how to add Multiple_Devices_LSL script to LSL_Functions object in **Unity**.
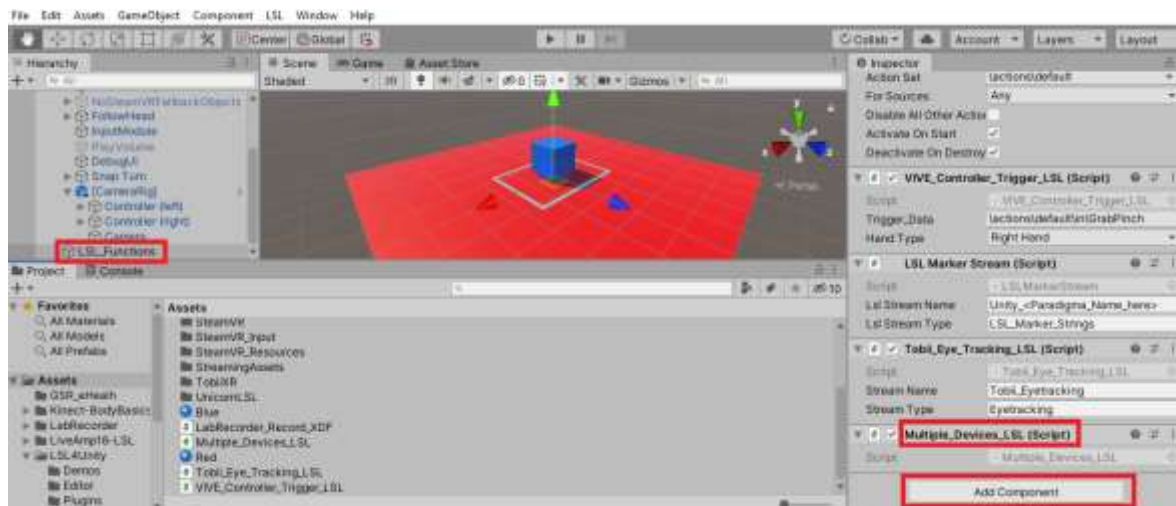
Figure 52. Add the Multiple_Devices_LSL script to LSL_Functions object

In the following, we show how to call **LabRecorder** to start recording the data available on **LSL** automatically by embedding **LabRecorder** in **Unity**.

First, we added the *LabRecorder* folder available on our GitHub (https://github.com/moeinrazavi/VR_LSL/tree/master/Assets/LabRecorder) to the *Assets* folder (Figure 53). We also added the script **LabRecorder_Record_XDF** that we developed in C# to the *Assets* folder (Figure 54). Then we added the **LabRecorder_Record_XDF** script to the LSL_Functions

object (Figure 55). By doing this, when you press the Play button in **Unity**, all the data sent to **LSL** will start being recorded automatically.
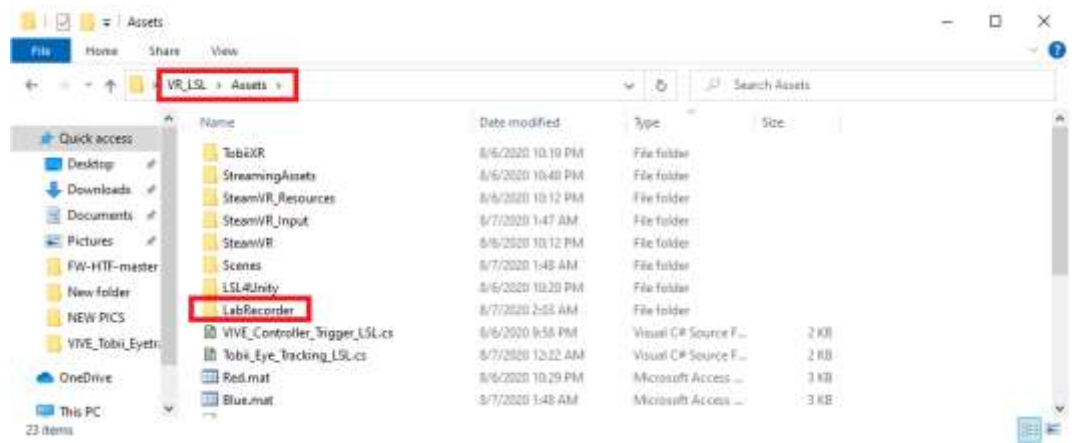
Figure 53. Add the **LabRecorder** file to *Assets* folder
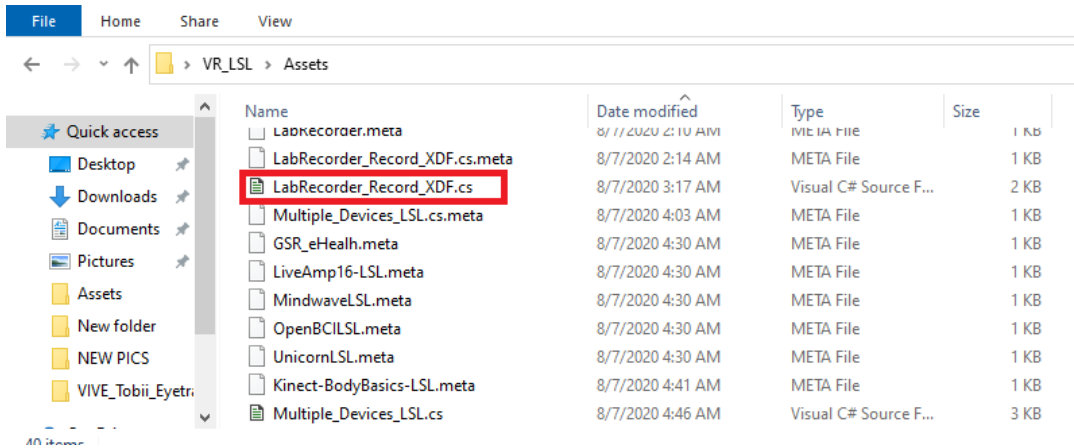
Figure 54. Add the LabRecorder_Record_XDF script to *Assets* folder
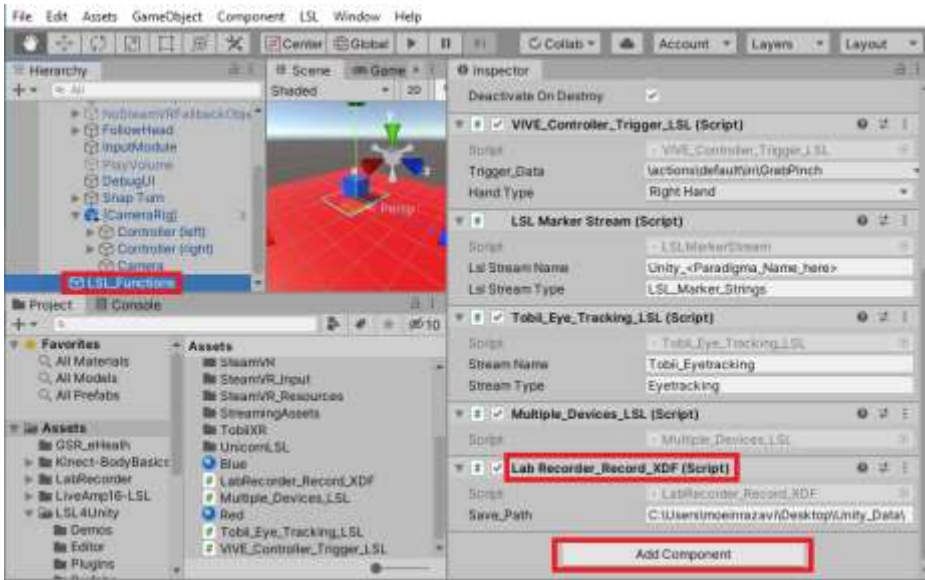
Figure 55. Add the LabRecorder_Record_XDF script to LSL_Functions object

6. Results

After the experiment is finished, for both **PsychoPy** and **Unity** projects, all the streams will be saved with their associated timestamps in a single *.xdf* file. Each stream can be easily accessed with the assigned **name**, **type** and **source_id** inside the Python script, MATLAB script or **EEGLAB** toolbox. Ojeda et al. (2014) created an open-source **EEGLAB** toolbox, **MoBILab**, for analyzing data from multiple sensors at the same time (EEG, body motion, eye movement, etc.) [26].

In order to open *.xdf* file using Python, see Appendix.

7. Discussion

The ability to use multiple measures that are synchronized together to distinguish factors affecting behavior and brain functionality is getting more attention. Previous works have mostly used one or a couple of measures to study the human mind and behavior. Some studies showed that using various measures (multimodal experiments) can improve the accuracy and the confidence for interpretation of the results. That said, an accurate and easy to use system to integrate and synchronize multiple measures with different sampling rates is often lacking. In this paper, we provided a practical and comprehensive method on integrating and synchronizing multiple different measures together. We developed some applications that make the integration process easier and accessible for different devices. Once the experiment is created and all the streams are defined, it is straightforward for the experimenter to run the experiment for each subject as everything starts being recorded and saved on the disk automatically. It is also very time-saving in preparing the system for the multisensory experiments. We expect that for future works, adding stimuli from multiple sources that involve different human senses (e.g., tactile, hear, smell, taste, etc.) can result in higher accuracy and new findings. For instance, Marsja et al. (2019) found that changes in bimodal stimuli (both visual and auditory) conveyed a shift in the performance of spatial and verbal short-term memory tasks while changes in visual or auditory stimuli individually did not lead to a significant shift in the performance of the mentioned tasks [27]. This can be easily achieved by the aid of our proposed system, by sending the markers indicating the onset, offset, and other information related to multiple stimuli in different streams simultaneously. As multimodal behavioral data are interwoven, using methods that enable the fusion of multimodal data would obtain a wide range of new findings in the human brain and behavior research that have never been found before. For this purpose, the state-of-the-art deep learning models are powerful tools that have recently been used for combining and analyzing data from multiple sources together. Gao et al. 2020 conducted a survey study on using deep learning technics for multimodal data fusion and how they can help find new interpretations of the data [28]. Thus, we predict that these deep learning models can be beneficial for multimodal data obtained from human studies as well.

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Appendix

Install PsychoPy and pylsl

On windows, you need to install the standalone version of **PsychoPy** from https://www.psychopy.org/download.html.

Install pylsl module on PsychoPy

In order to install **pylsl** (version≥1.13) on PsychoPy using pip. To install **pylsl** on **PsychoPy** use the command: "C:\Program Files\PsychoPy3\python.exe" -m pip install pylsl --user in Windows command line.

Opening .xdf file in Python

In order to open .xdf file in Python, first you need to install pyxdf in python using pip in command line: pip install pyxdf. Then you can use the *.py* example from the link: <u>pyxdf_example</u>. We recommend using **Spyder** (<u>https://docs.spyder-ide.org/installation.html</u>) for the Python platform to open the .xdf file, since **Spyder** has the Variable Explorer panel which allows to track the variables.

References

1. Otto, T.U.; Dassy, B.; Mamassian, P. Principles of multisensory behavior. *J. Neurosci.* **2013**, *33*, 7463–7474, doi:10.1523/JNEUROSCI.4678-12.2013.

2. Critchley, H.D.; Mathias, C.J.; Josephs, O.; O'Doherty, J.; Zanini, S.; Dewar, B.K.; Cipolotti, L.; Shallice, T.; Dolan, R.J. Human cingulate cortex and autonomic control: Converging neuroimaging and clinical evidence. *Brain* **2003**, *126*, 2139–2152, doi:10.1093/brain/awg216.

3. Höchenberger, R.; Busch, N.A.; Ohla, K. Nonlinear response speedup in bimodal visual-olfactory object identification. *Front. Psychol.* **2015**, *6*, 1–11, doi:10.3389/fpsyg.2015.01477.

4. Kittler, J.; Hatef, M.; Duin, R.P.W.; Matas, J. On combining classifiers. *IEEE Trans. Pattern Anal. Mach. Intell.* **1998**, *20*, 226–239, doi:10.1109/34.667881.

5. Stevenson, R.A.; Ghose, D.; Fister, J.K.; Sarko, D.K.; Altieri, N.A.; Nidiffer, A.R.; Kurela, L.A.R.; Siemann, J.K.; James, T.W.; Wallace, M.T. Identifying and Quantifying Multisensory Integration: A Tutorial Review. *Brain Topogr.* **2014**, *27*, 707–730, doi:10.1007/s10548-014-0365-7.

6. Reeves, L.M.; Schmorrow, D.D.; Stanney, K.M. Augmented cognition and cognitive state assessment technology - Near-term, mid-term, and long-term research objectives. *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)* **2007**, *4565 LNAI*, 220–228.

7. Jimenez-Molina, A.; Retamal, C.; Lira, H. Using psychophysiological sensors to assess mental workload during web browsing. *Sensors (Switzerland)* **2018**, *18*, 1–26, doi:10.3390/s18020458.

8. Born, J.; Ramachandran, B.R.N.; Romero Pinto, S.A.; Winkler, S.; Ratnam, R. Multimodal study of the effects of varying task load utilizing EEG, GSR and eye-tracking. *bioRxiv* **2019**, 798496, doi:10.1101/798496.

9. Leontyev, A.; Yamauchi, T.; Razavi, M. Machine Learning Stop Signal Test (ML-SST): ML-based Mouse Tracking Enhances Adult ADHD Diagnosis. In Proceedings of the 2019 8th International Conference on Affective Computing and Intelligent Interaction Workshops and Demos, ACIIW 2019; Institute of Electrical and Electronics Engineers Inc., 2019; pp. 248–252.

10. Leontyev, A.; Sun, S.; Wolfe, M.; Yamauchi, T. Augmented Go/No-Go Task: Mouse Cursor Motion Measures Improve ADHD Symptom Assessment in Healthy College Students. *Front. Psychol.* **2018**, *9*, 496, doi:10.3389/fpsyg.2018.00496.

11. Leontyev, A.; Yamauchi, T. Mouse movement measures enhance the stop-signal task in adult ADHD assessment. *PLoS One* **2019**, *14*, e0225437, doi:10.1371/journal.pone.0225437.

12. Yamauchi, T.; Xiao, K. Reading Emotion From Mouse Cursor Motions: Affective Computing Approach. *Cogn. Sci.* **2018**, *42*, 771–819, doi:10.1111/cogs.12557.

13. Yamauchi, T.; Seo, H.; Choe, Y.; Bowman, C.; Xiao, K. *Assessing Emotions by Cursor Motions: An Affective Computing Approach*;

14. Yamauchi, T.; Leontyev, A.; Razavi, M. Assessing Emotion by Mouse-cursor Tracking: Theoretical and Empirical Rationales. In Proceedings of the 2019 8th International Conference on Affective Computing and Intelligent Interaction, ACII 2019; Institute of Electrical and Electronics Engineers Inc., 2019; pp. 89–95.

15. Yamauchi, T.; Leontyev, A.; Razavi, M. Mouse Tracking Measures Reveal Cognitive Conflicts Better than Response Time and Accuracy Measures. **2019**, 3150–3156.

16. Yamauchi, T.; Seo, J.; Sungkajun, A. Interactive Plants: Multisensory Visual-Tactile Interaction Enhances Emotional Experience. *Mathematics* **2018**, *6*, 225, doi:10.3390/math6110225.

17. Chen, F.; Ruiz, N.; Choi, E.; Epps, J.; Khawaja, M.A.; Taib, R.; Yin, B.; Wang, Y. Multimodal behavior and interaction as indicators of cognitive load. *ACM Trans. Interact. Intell. Syst.* **2012**, *2*, doi:10.1145/2395123.2395127.

18. Lazzeri, N.; Mazzei, D.; De Rossi, D. Development and Testing of a Multimodal Acquisition Platform for Human-Robot Interaction Affective Studies. *J. Human-Robot Interact.* **2014**, *3*, 1, doi:10.5898/jhri.3.2.lazzeri.

19. Charles, R.L.; Nixon, J. Measuring mental workload using physiological measures: A systematic review. *Appl. Ergon.* 2019, *74*, 221–232.

20. Lohani, M.; Payne, B.R.; Strayer, D.L. A review of psychophysiological measures to assess cognitive states in real-world driving. *Front. Hum. Neurosci.* **2019**, *13*, 1–27, doi:10.3389/fnhum.2019.00057.

21. Gibson, B.E.; King, G.; Kushki, A.; Mistry, B.; Thompson, L.; Teachman, G.; Batorowicz, B.; McMain-Klein, M. A multi-method approach to studying activity setting participation: Integrating standardized questionnaires, qualitative methods and physiological measures. *Disabil. Rehabil.* **2014**, *36*, 1652–1660, doi:10.3109/09638288.2013.863393.

22. Sciarini, L.W.; Nicholson, D. Assessing cognitive state with multiple physiological measures: A modular approach. *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)* **2009**, *5638 LNAI*, 533–542, doi:10.1007/978-3-642-02812-0_62.

23. Peirce, J.W. PsychoPy-Psychophysics software in Python. *J. Neurosci. Methods* **2007**, *162*, 8–13, doi:10.1016/j.jneumeth.2006.11.017.

24. Peirce, J.W. Generating stimuli for neuroscience using PsychoPy. *Front. Neuroinform.* **2009**, *2*, doi:10.3389/neuro.11.010.2008.

25. Yamauchi, T.; Xiao, K.; Bowman, C.; Mueen, A. Dynamic time warping: A single dry electrode EEG study in a self-paced learning task. In Proceedings of the 2015 International Conference on Affective Computing and Intelligent Interaction, ACII 2015; Institute of Electrical and Electronics Engineers Inc., 2015; pp. 56–62.

26. Ojeda, A.; Bigdely-Shamlo, N.; Makeig, S. MoBILAB: An open source toolbox for analysis and visualization of mobile brain/body imaging data. *Front. Hum. Neurosci.* **2014**, *8*, 1–9, doi:10.3389/fnhum.2014.00121.

27. Marsja, E.; Marsh, J.E.; Hansson, P.; Neely, G. Examining the role of spatial changes in bimodal and uni-modal to-be-ignored stimuli and how they affect short-term memory processes. *Front. Psychol.* **2019**, *10*, 1–8, doi:10.3389/fpsyg.2019.00299.

28. Gao, J.; Li, P.; Chen, Z.; Zhang, J. A survey on deep learning for multimodal data fusion. *Neural Comput.* **2020**, *32*, 829–864, doi:10.1162/neco_a_01273.