TRIGGER HUB

USER MANUAL

Version 0.5

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1. DISCLAIMER

Wearable *Sensing*'s Trigger Hub system is a system designed for use in scientific and engineering research environments.

Wearable *Sensing*'s Trigger Hub was designed, constructed and preliminarily tested for performance and safety. However, this is a research instrument, and **Wearable** *Sensing* makes no warrantee concerning its safety. It should only be used by knowledgeable individuals at their own risk.

The **Wearable** *Sensing* Trigger Hub system is designed to consolidate trigger signals (< 20 V) from multiple sources into a single input for **Wearable** *Sensing*'s Dry Sensor Interface (DSI) hardware, as well as distribute multiple trigger signals to multiple devices that can accept digital signals (0-5 V). Any other information gathered from this device, either implied or otherwise, is not the intent purpose of this instrument and is therefore not the responsibility of **Wearable** *Sensing* or its subsidiaries.

Any usage of this instrument except for the specific purpose outlined above is strictly prohibited and voids all **Wearable** *Sensing* assurances of the system's durability or functionality except those strictly expressed in this Operation Manual.

The specifications, information and performance of the **Wearable** *Sensing* Trigger Hub system may be changed without notice. Since the use of this information and the conditions in which the system is used are beyond the control of **Wearable** *Sensing* and its subsidiaries, it is the obligation of the customer and/or the equipment operator to determine the correct and safe selection and settings and conditions of use of the device.

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2. System Overview

Wearable *Sensing*'s Trigger Hub system is an electronic hub that is intended to receive input signals from a number of upstream systems and distribute event markers to downstream devices. It is designed to simplify the process of consolidating up to 8 trigger sources into a single multi-channel output as an input to **Wearable** *Sensing*'s Dry System Interface (DSI) hardware. The use of standardized input connectors (BNC connectors, 3.5mm sockets, DB-25 D-subminiature connector) allows a wide range of devices to be connected to the Trigger Hub using standard cables.

An additional benefit of the Trigger Hub design is that it allows synchronization across multiple data sources that are distributed across multiple systems, each of which running at its own clock rate. One such case commonly experienced in EEG experiments involves synchronization of EEG and Eye Tracking measurements, where the inevitable clock drift that arises between two systems during extended measurements creates difficulty in aligning data to events across the two systems.

One approach to synchronization of devices is to distribute triggers from a single source amongst multiple devices. In this way, trigger events can be used for time synchronization across systems. A specific feature addressing the issue of synchronization is the Trigger Hub's AutoTrigger function, an internally generated 1 Hz trigger signal that can be distributed to all outputs, which can act as a signal used for timing alignment between multiple acquisition systems.

There are dedicated inputs on the Trigger Hub for 4 different types of inputs:

1. Signals between 0 and 20 V
2. Line-level audio
3. Switch inputs
4. Output from a PC's parallel port.

Input voltages that drive a trigger event can be selected via a thresholding circuit on each signal. The threshold level is common to all inputs, and can be adjusted between 0.6 V and 6 V by the user. The resulting triggers are consolidated on an output parallel port that can be connected to **Wearable** *Sensing* EEG headset with a cable. In addition, triggers from the input parallel port are distributed across the connectors on the output panel. The trigger output voltage is 0-5V, which is sufficient to drive the trigger inputs of common devices.

A trigger cable supplied with the Trigger Hub system is used to transfer trigger signals from the Hub to a headset. Also provided is a wireless receiver that can be plugged into a **Wearable** *Sensing* EEG headset and receive multi-channel trigger information encoded into a byte of digital information.

This User Manual has been divided into the following main sections:

3. System Components

4. System Description
5. System Operation
6. Specifications

2.1 Related Manuals

These other manuals are available for **Wearable** *Sensing*'s hardware and software:

- DSI-24 User Manual
- DSI-7 User Manual
- DSI-Streamer software User Manual

3. System Components

The Trigger Hub system is shown in the below photograph.

A number of cables and accessories are included with the Trigger Hub. These are shown below:

Power Supply Components

Power cable and Adapter
(USB to micro-USB)

USB wall charger

Wireless Components

Wireless receiver

Wireless repeater

Trigger Cables

Push-button trigger cable
(3.5mm stereo phone connector)

Photodetector cable
(3.5mm stereo phone connector)

Trigger cable
(DB-25 to Hirose LX40-12P 12-pin)

Stereo cable
(male-male 3.5mm stereo cable)

4. System Description

4.1 Equipment Overview

The Trigger Hub front panel (outputs) and rear panel (inputs) are shown in Figure 1 and Figure 2. The trigger cable, wireless receiver and wireless repeater are shown in Figure 3.

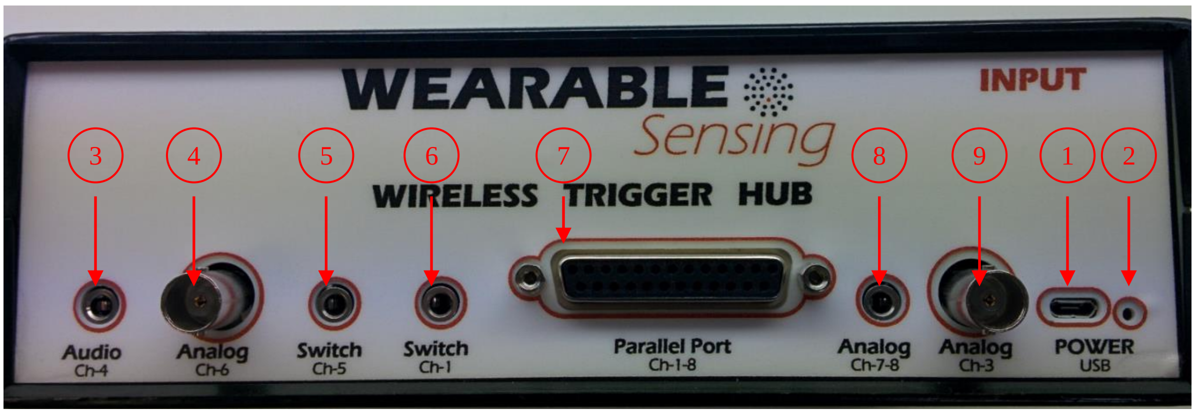

Figure 1. Rear (input) panel of Trigger Hub.

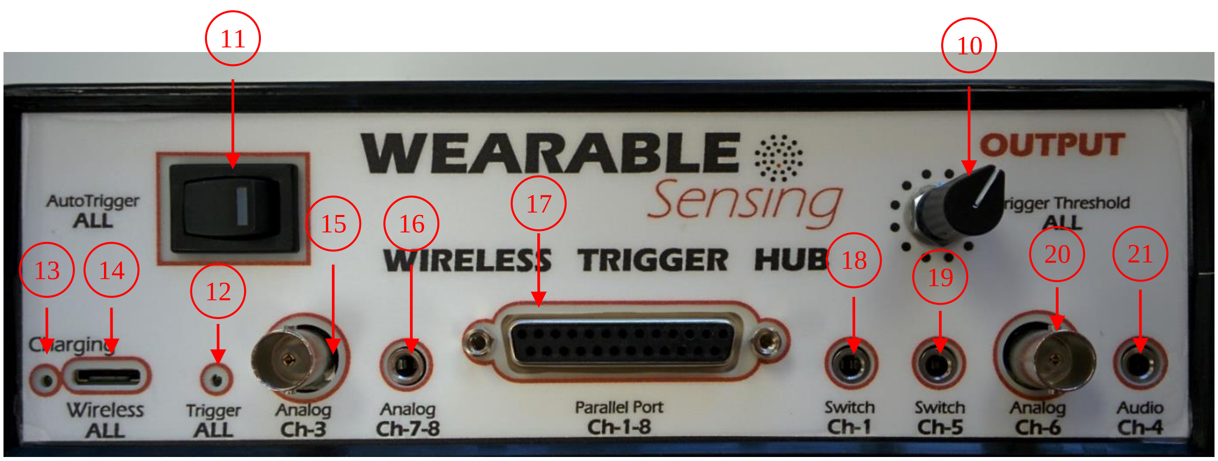

Figure 2. Front (output) panel of Trigger Hub.

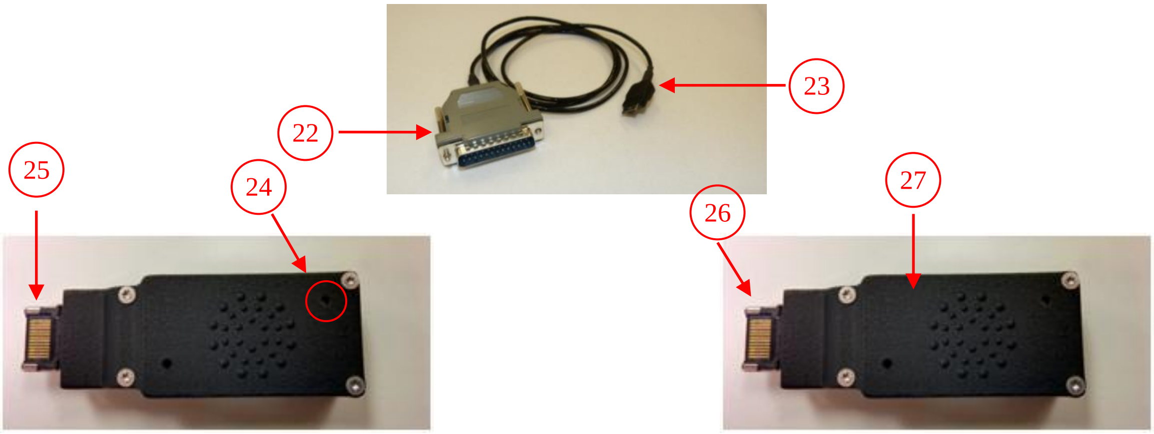

Figure 3. (top) Trigger cable. (lower left) Wireless receiver. (lower right) Wireless repeater.

Input Panel

1. POWER-in µUSB connector
2. POWER LED indicator
3. Audio input (Ch-4) 3.5mm connector
4. Analog input (Ch-6) BNC connector
5. Switch input (Ch-5) 3.5mm connector
6. Switch input (Ch-1) 3.5mm connector
7. Parallel Port input DB-25 connector
8. Analog input (Ch-7,8) 3.5mm connector
9. Analog input (Ch-3) BNC connector

Output Panel

10. Threshold selector switch
11. AutoTrigger switch
12. Trigger LED indicator
13. Charging LED indicator
14. Charging input for wireless receiver
15. Analog trigger output (Ch-3) BNC connector
16. Analog trigger output (Ch-7,8) 3.5mm connector
17. Parallel Port output DB-25 connector
18. Switch trigger output (Ch-1) 3.5mm connector
19. Switch trigger output (Ch-5) 3.5mm connector
20. Analog trigger output (Ch-6) BNC connector
21. Audio trigger output (Ch-4) 3.5mm connector

Trigger Cable

22. DB-25 connector
23. Plug compatible with **Wearable** *Sensing*'s EEG headsets

Wireless Receiver

24. Hole for pairing button
25. Plug compatible with **Wearable** *Sensing*'s EEG headsets

Wireless Repeater

26. USB connector
27. Pairing button

4.2 Device Description

The Trigger Hub has been designed to receive signals from a wide range of sources (via INPUTS) and to transmit triggers to multiple devices (OUTPUTS). Accordingly, it has numerous INPUT and OUTPUT ports, as outlined in Section 4.1. Specifically, there are 7 input connectors (2xBNC, 4x3.5mm sockets, 1xDB-25) on the input panel and a matching set of 7 output connectors on the output panel.

System power is provided via USB (the POWER USB input on the input panel), and can either be derived from a USB wall charger, or from a USB cable plugged into a PC.

The Trigger Hub possesses the additional capability to set triggering thresholds on each input via the threshold selector switch on the output panel. Note that the trigger threshold is applied uniformly across all inputs, so the threshold setting must be set to generate triggers for the input with the lowest maximum signal level.

In addition, the Trigger Hub can generate its own triggers (**AutoTrigger** function) to help in synchronization of multiple devices.

Triggers resulting from signals on a given output are passed to the corresponding output connector. In addition, signals on the BNC and 3.5mm input connectors are also consolidated onto the DB-25 output, while the DB-25 inputs are distributed to the BNC and 3.5mm output connectors, so that a single trigger can be shared with multiple devices. Therefore ***the user should be careful when using the DB-25 input and the BNC/3.5mm input connectors*** as triggers from both sources will appear on a single output. Details for the I/O functionality are presented in detail in Section 4.3.

In addition to the output trigger ports, the Trigger Hub consolidates all trigger sources into a single byte that is wirelessly transmitted to a wireless receiver that can be plugged into **Wearable** *Sensing*'s EEG hardware. Also included is a wireless repeater that improves the robustness of wireless communication, by eliminating the shadowing effect when the subject's body prevents line-of-sight communication between the Trigger Hub and the receiver.

4.3 Input-Output Functionality

Each connector is labeled according to the type of signal that can be applied as an input. These inputs are:

Switch Inputs: There are two "switch" inputs, which allow for user-generated triggers by closing a switch. The trigger is internally generated upon closing the switch, which allows flexibility for implementation of external triggers. Included with the Trigger Hub are two cables: one configured with a push button switch and a second with an integrated photodetector that can produce triggers derived from incident light level. Both are supplied with 3.5mm stereo plugs and can only be used with the switch inputs.

Warning: if an active source of trigger is connected to a "Switch" input, 5V from the trigger hub may damage the source device.

Analog Inputs: There are two BNC and one stereo 3.5mm socket Analog Input ports. These inputs operate with positive voltages up to 20V and will trigger when the threshold is crossed. These inputs are intended for use with square wave sources that do not meet the specifications for TTL of CMOS logic levels. (The use of the term "digital" has been avoided because of the implication of being constrained to the various standards for digital signals.) However, these inputs can also be used with analog waveforms. The minimum requirement for an analog waveform or square wave "high" voltage is that it exceeds 0.63 V.

Audio Input: The audio input accepts analog inputs that are consistent with line level audio signals. The trigger generated on this channel is derived from the envelope of one channel of a stereo audio signal. The default channel is the LEFT channel.

Parallel Port: The parallel port has been designed to detect triggers generated by a PC's parallel port. Up to 255 independent triggers can be supported using the parallel port. Additionally, the internal circuitry will also allow the Parallel Port inputs to accept signals equivalent to those that would generate a trigger on the "Analog" inputs. In this way, the user can produce custom cables to consolidate up to 8 independent trigger sources into the Parallel Port connector.

Specifics for each input, including pinouts, are presented in Section 5.7. Specifics for the outputs are presented in Section 5.8.

A channel number has been assigned to each connector. As can be seen in the photographs in Figure 1 and Figure 2, a total of 7 channels (Ch-1 and 3-8) are assigned to the BNC and 3.5mm audio connectors. Each channel corresponds to one of the eight data pins on the parallel port connector. The eighth channel (Ch-2) is taken by the AutoTrigger signal (see Section 0).

Input decoupling circuitry is present on each of the switch/analog/audio inputs and also on each of the data lines on the parallel port. This circuitry allows the threshold circuitry for an input and its corresponding pin on the parallel port to be shared: i.e. a simultaneous trigger on both will damage neither the Trigger Hub nor either of the two sources. For the case in which two sources are connected to the same channel via two connectors, a trigger from either or both sources will result in a trigger output.

The threshold selector switch sets the value of the threshold that is applied uniformly across all input signals. After thresholding, the resulting trigger signals for each channel are connected to their corresponding outputs – i.e. an audio signal input to the Ch-4 connector will generate a trigger on the Ch-4 output connector. (Additionally, the Ch-4 trigger output will also appear on the output parallel port on its 4th data pin.)

The I/O map is summarized in Table 1. Also included are the data lines when using the wireless receiver.

Table 1. Input/Output Map for Trigger Hub.

Input		**Outputs**				
		Wireless	Parallel	Switch	Analog	Audio
Parallel Port	D1	D1	D1	Ch-1		
Parallel Port	D2	D2	D2			
Parallel Port	D3	D3	D3		Ch-3	
Parallel Port	D4	D4	D4			Ch-4
Parallel Port	D5	D5	D5	Ch-5		
Parallel Port	D6	D6	D6		Ch-6	
Parallel Port	D7	D7	D7		Ch-7	
Parallel Port	D8	D8	D8		Ch-8	
Switch Ch-1		D1	D1	Ch-1		
Switch Ch-5		D5	D5	Ch-5		
Audio Ch-4		D4	D4			Ch-4
Analog Ch-3		D3	D3		Ch-3	
Analog Ch-6		D6	D6		Ch-6	
Analog Ch-7		D7	D7		Ch-7	
Analog Ch-8		D8	D8		Ch-8	
AutoTrigger		D2	D2	Ch-1, Ch-5	Ch-3, Ch-6, Ch-7, Ch-8	Ch-4

5. System Operation

The following sections describe the operation of the Trigger Hub, and gives details of the each input/output.

5.1 Powering the Trigger Hub

The Trigger Hub can be powered using a USB port on a PC, or using a USB power supply plugged into the wall. The input connector for the power on the Trigger Hub is a micro-USB connector.

A green POWER LED indicator shows Power status.

5.2 Wired Connection to Wearable *Sensing*'s EEG Hardware

The trigger cable provided with the Trigger Hub is compatible with **Wearable** *Sensing*'s EEG headsets. It is connected to the parallel port output on the Trigger Hub, as shown in Figure 4 (left). The other end is plugged into the trigger input port on the headset (Figure 4, right). The 8 data lines on the parallel port are wired to the 8 input pins for **Wearable** *Sensing*'s EEG headsets. The trigger output voltages of the Trigger Hub match the input requirements of trigger inputs for **Wearable** *Sensing*'s EEG headsets.

Figure 4. (left) Plugging the trigger cable into the parallel port output of the Trigger Hub. (right) Plugging the trigger cable into a Wearable *Sensing* DSI-24 EEG headset.

The DSI-24 headset is the only Wearable Sensing's headset that uses the full complement of 8 trigger inputs.
Wearable Sensing's DSI-7 headset only uses data lines D1-D4.

5.3 Wireless Connection to EEG Headset

Wireless Receiver

The Trigger Hub has an internal wireless transmitter that transmits trigger information whenever a trigger is received. Communication is one-way (from Hub to receiver), and occurs irrespective of whether a receiver is plugged into a nearby EEG headset.

The wireless receiver provided with the Trigger Hub has been designed for operation with **Wearable** *Sensing*'s EEG headsets. It has a rechargeable battery and is automatically turned on when the receiver is plugged into the trigger input port on the headset (Figure 5, left). The wireless receiver will light a RED LED when the battery level is low. The receiver is recharged by plugging into the charging input (Figure 5, right) on the Trigger Hub while the unit is powered. An orange LED indicates at the charging status (on when battery is charging and off when charging is complete)

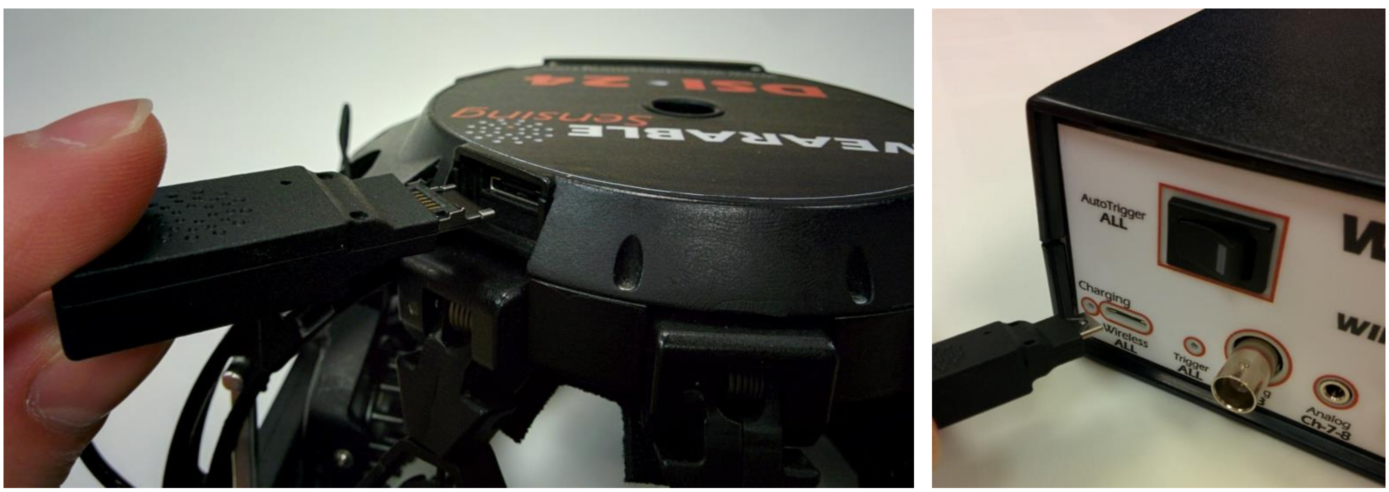

Figure 5. (left) Plugging the wireless receiver into a Wearable *Sensing* DSI-24 EEG headset. (right) Plugging the wireless receiver into the Trigger Hub for recharging.

The suggested maximum range for wireless communication is 30'.

The wireless communication has a fixed latency of 12 ms ± 10 µs. This latency is adjusted for in software by selecting the Wireless Trigger Option

Wireless Repeater

The wireless receiver provided with the Trigger Hub has been designed for operation with **Wearable** *Sensing*'s EEG headsets. It has the form factor of a USB thumb drive and is powered by either:

- Plugging into a USB wall charger

- Plugging into a USB port on a computer

The repeater functions by receiving a wireless transmission from the Trigger Hub, and then immediately forwarding it on to the receiver plugged into the headset. Inside the wireless receiver, a logical OR function is applied between the trigger information received from the Trigger Hub and the trigger information received from the repeater. Thus if a trigger is received from **either** source, a trigger is registered by the headset.

The function of the repeater is to improve the robustness of wireless communication between the Trigger Hub and the headset, with respect to the following:

- Eliminating shadow effect

  For ambulatory EEG measurements, there will be times when there is no line-of-sight communication between the Trigger Hub and the wireless receiver. In these cases, the receiver lies in the shadow of the subject's body and successful reception of trigger information is only possible via reflections from nearby surfaces.

  Careful positioning the repeater will eliminate the shadow effect and trigger information will be received at from at least one source.

- Range of wireless communication

  Placing the repeater between the subject and the Trigger Hub effectively extends the range of wireless communication, provided that the shadow effect is minimal. Tests at **Wearable** *Sensing* have shown zero loss of triggers up to a distance of 60', with a repeater placed halfway between the Trigger Hub and the receiver.

Latency for wireless communication with the repeater is the same as that for the wireless receiver operating alone: 12 ms ± 10 µs.

Pairing Wireless Receiver With Trigger Hub

The receiver is paired with the Trigger Hub prior to shipping and cannot be used with any other Trigger Hub without performing a pairing operation. The button that controls the pairing status of the receiver is below the hole in the top panel of the receiver (Figure 6).

The pairing operation is performed via the following steps:

- Turn EEG headset ON
- Activate wireless communication from Trigger Hub via a series of triggers
  We recommend using the **AutoTrigger** function
- Insert paperclip into pairing hole and press a button inside to begin pairing (Figure 6)
- A red LED inside the receiver will turn on to indicate that pairing button is pressed and receiver is ready to pair with a Trigger Hub
- As soon as a trigger signal from transmitter is received the red LED will blink several times to indicate that pairing is complete

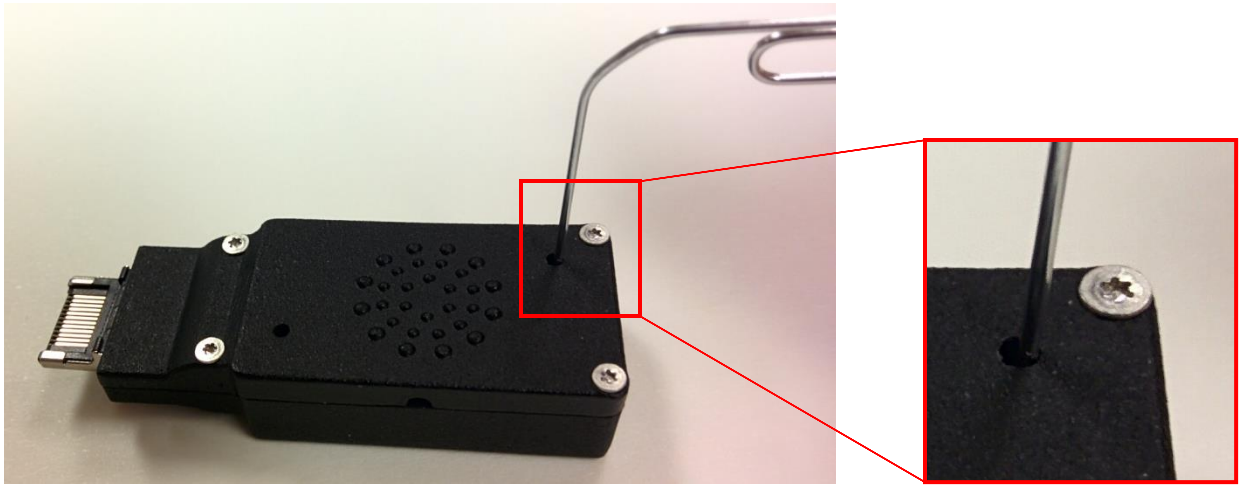

Figure 6. Insert paperclip into pairing hole to press button to pair receiver with Trigger Hub.

It is possible to pair more than one receiver to a single Trigger Hub.
Since the communication is one-way (Hub to receiver), multiple receivers will not disrupt communication.
It is NOT possible to pair two Trigger Hubs to a single receiver.

Pairing Wireless Repeater With Trigger Hub

The repeater is paired with the Trigger Hub prior to shipping and cannot be used with any other Trigger Hub without performing a pairing operation. The button that controls the pairing status of the receiver is shown in Figure 7.

Pairing Button

Figure 7. Button for pairing repeater with Trigger Hub.

The pairing operation is performed via the following steps:

- Remove lid from repeater
- Plug repeater into USB wall charger or USB port on computer
- Press button to begin pairing (Figure 7)
- A LED inside the repeater will turn on to indicate that receiver is ready to pair with a Trigger Hub
- Activate wireless communication from Trigger Hub via a series of triggers
  We recommend using the **AutoTrigger** function
- The LED will blink several times to indicate that pairing is complete

DO NOT attempt to pair multiple repeaters with a single Trigger Hub.
The wireless receiver is designed to receive trigger information from no more than 2 sources.

5.4 Triggers Appearing in Wearable *Sensing*'s Data Acquisition Software

Triggers received by **Wearable** *Sensing*'s EEG headsets are coded as 8-bit unsigned integers, in which the least significant bit (LSB) is data line D1 on the parallel port. Values reported on-screen in DSI-Streamer or written to file are the corresponding decimal number. The decimal values for each data line are shown in Table 2.

Table 2. Decimal values assigned to each data line in DSI-Streamer

Data Line	D8	D7	D6	D5	D4	D3	D2	D1
Value	128	64	32	16	8	4	2	1

DSI-Streamer also includes diamonds as a visual representation of trigger activity in the lower left corner of the screen (Figure 8). The data lines are shown in order D1 through D8 from left to right.

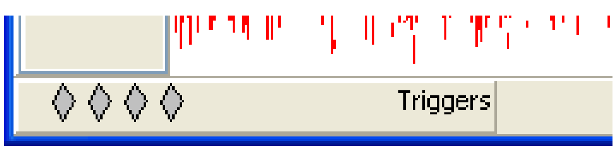

Figure 8. DSI-Streamer interface, with diamonds as a visual representation of trigger activity.

5.5 Thresholding

All signals input to the Trigger Hub, are passed through thresholding circuitry to provide noise immunity to the input signals. For the audio input, the threshold is applied after the audio signal is converted to the *envelope* of the audio signal. The threshold voltages for the different settings are summarized in the table below.

Table 3. Threshold voltages for corresponding threshold switch positions

Switch Position	1	2	3	4	5	6	7	8	9	10
Threshold Voltage	0.63 V	1.0 V	1.5 V	2.0 V	2.5 V	3.0 V	3.5 V	4.0 V	4.5 V	5.8 V

The internal voltage rail for the Trigger Hub is 5 V, which means that position #10 is the only position for which a switch input will **not** produce a trigger. In the photograph in Figure 9, the trigger threshold switch is shown in Position #10, where the dial is in the 12 o'clock position.

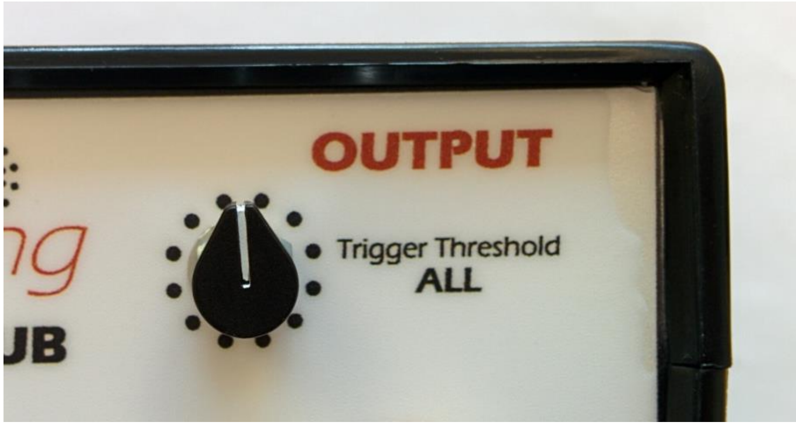

Figure 9. Trigger threshold switch in Position #10.

Thresholding is applied to each of channels 1-8. There is, however, no individual threshold setting for each channel – i.e. the threshold value specified by the threshold selector switch on the front panel is applied to all channels.

5.6 AutoTrigger Function

The AutoTrigger function is activated with the AutoTrigger switch. The switch's internal LED will light up to show that the AutoTrigger function is active.

The AutoTrigger function outputs a 1 Hz square wave to all of the switch/analog/audio output connectors, as well as the Data 2 line on the parallel port output connector.

Thresholding is not applied to the AutoTrigger.

Careful attention to INPUT pin assignment should be given if simultaneously using the AutoTrigger function with a parallel port INPUT, as both could generate outputs on the D2 pin of the OUTPUT parallel port, potentially leading to confusion.

The AutoTrigger function should NOT be used when triggers are input to any of the switch/analog/audio inputs on the Trigger Hub. To do so would result in confusion between AutoTriggers and triggers from the inputs.

5.7 Inputs

The following discussion presents the functionality of the Trigger Hub's inputs. The functionality of the individual inputs is summarized below:

Parallel Port

The input parallel port is a standard DB-25 connector configured to accept signals from a PC's parallel port. The pinouts of a parallel port are shown in Figure 10 below.

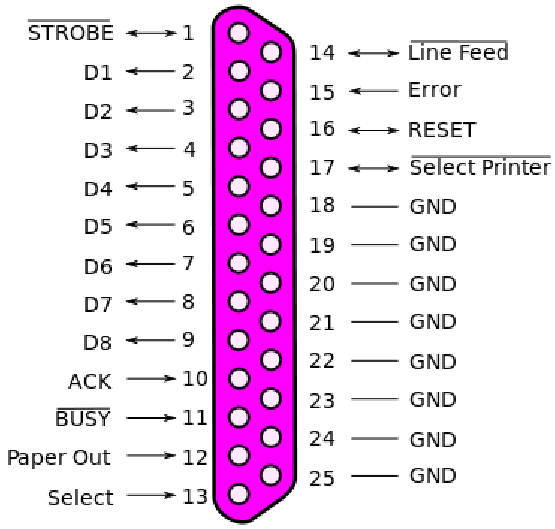

Figure 10. Parallel port connections.

The trigger signals from a PC's parallel port appear on the data pins (D1 through D8). The only pins on the Trigger Hub's parallel port that are connected internally are the data lines (D1-D8) and the GND pins.

Signals that exceed the threshold on any of the data pins are output on the corresponding pins on the output parallel port. Similarly, they are also shared with the individual output connectors on the Output panel, as per Table 4.

Table 4. Channel Mapping of Input Parallel Port Data Lines to Output Ports.

Data Line	Shared Output
D1	Switch Ch-1 output (Tip & Ring)
D2	*N/A*
D3	Analog Ch-3 output
D4	Audio Ch-4 output
D5	Switch Ch-5 output (Tip & Ring)
D6	Analog Ch-6 output
D7	Tip connection of Ch-7,8 3.5mm stereo socket
D8	Ring connection of Ch-7,8 3.5mm stereo socket

For computer generated triggers, the 8 data lines provide up to 255 independent triggers.

However, the thresholding circuitry connected to the parallel port inputs are identical that for the analog inputs. Therefore it is possible to prepare a custom cable using the pinouts in Figure 10 that uses up to 8 analog signals as inputs.

Careful attention to INPUT pin assignment should be given if simultaneously using the Parallel Port INPUT with other INPUT ports, as both could generate outputs on same pins. This will not damage the device, but may lead to confusion if two inputs are activated simultaneously.

Switch Inputs: Ch-1, Ch-5

The switch inputs (Ch-1 and Ch-5) use 3.5mm stereo phone sockets. Both inputs can be used with either the supplied switch cable or photodetector cable.

The required connector for using the switch inputs is a 3.5mm stereo plug, such as that shown in shown in Figure 11. The connections for a 3.5mm socket are shown to the left in the Figure. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND. The switch and photodetector cables are configured to make a connection between the TIP and RING connections.

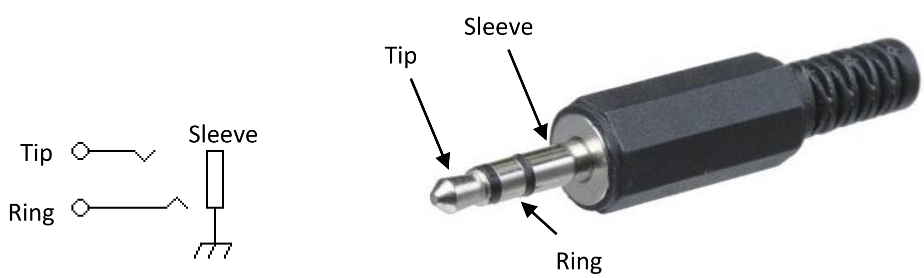

Figure 11. Stereo plug for use with switch inputs Ch-1, Ch-5.
This plug connector is also required for use with audio input Ch-4 and Ch-7,8 analog input.

A stereo 3.5mm connector IS NECESSARY to use this input. A mono connector will not generate triggers for either switch or photodetector inputs.

If a user wishes to manufacture their own switch cable, it is imperative that, when closed, the switch makes a connection between the TIP and the RING of the stereo plug.

The circuitry connected to these connectors has been designed to generate a trigger when a switch is closed. Internally, the Trigger Hub's 5V voltage rail is connected to one terminal of the socket, and the threshold circuitry is connected to other terminal. Thus closing a switch will generate a trigger for **ALL** threshold settings with the exception of setting #10 for the threshold selector switch. (The reader is referred to Table 3.)

The photodetector uses a phototransistor sensing element. In effect, the sensing element acts as a resistor whose impedance depends upon the incident light level. The Trigger Hub's 5V voltage rail is shared between the phototransistor and an internal pull-up resistor. Thus the photodetector will generate an analog voltage that varies with incident light level, and to which a threshold may be applied.

Signals that exceed the threshold on Ch-1 generate triggers that are output on both the TIP and RING connections for the Ch-1 output socket connector, and on D1 of the output parallel port.

Similarly, signals that exceed the threshold on Ch-5 generate triggers that are output on both the TIP and RING connections for the Ch-5 output socket connector, and on D5 of the output parallel port.

Audio Input: Ch-4

The audio input Ch-4 is a 3.5mm stereo phone socket.

The required connector for using the switch inputs is a 3.5mm stereo plug, such as that shown in shown in Figure 12. The connections for a 3.5mm socket are shown to the left in the Figure. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND.

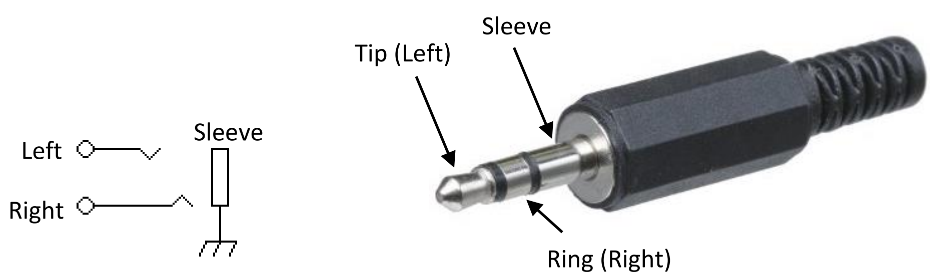

Figure 12. Stereo plug for use with audio input Ch-4.

A stereo 3.5mm connector is recommended for this input.
However, a mono connector may be used.
This will bypass audio channel selection internal to the Trigger Hub.

The audio input accepts line level audio signals and generates a trigger based on the envelope of the audio signal. The TIP connection of the stereo plug corresponds to the LEFT audio channel, and the RING connection of the stereo plug corresponds to the RIGHT audio channel. The GND for the audio signals must be connected to the sleeve.

Triggers are generated from one channel of the audio signal – i.e. Left or Right only. An internal switch in the Trigger Hub (S1) determines which audio channel is used for generating a trigger. The default audio channel for the Trigger Hub is LEFT.

Internally, the audio signal is filtered to a bandwidth of 40 Hz to 20 kHz (-3dB). The combination of filtering and the process of extracting the envelope of the audio signal prevents a simple relationship between instantaneous line out voltages and trigger thresholds. Therefore Table 5 has been provided as a guide. Entries in the table indicate discrete amplitudes/frequencies tested for which triggers occurred, and are not meant to be the actual threshold amplitudes or frequencies.

Table 5. Measured sine wave amplitudes & frequencies for which triggers began to be detected for corresponding threshold switch positions.

Switch Position	Threshold Voltage @ 1kHz	Frequency @ 200mVpp
1	40 mVpp	7 Hz
2	60 mVpp	10 Hz
3	80 mVpp	13 Hz
4	100 mVpp	17 Hz
5	110 mVpp	21 Hz
6	130 mVpp	26 Hz
7	150 mVpp	32 Hz
8	170 mVpp	40 Hz
9	190 mVpp	52 Hz
10	N/A	N/A

The middle column presents the lowest sine wave amplitudes (@ 1 kHz) for which a trigger was observed for each Threshold selector switch setting. The dynamic range of the audio signal over which the threshold may be adjusted is less than 20dB.

The right column presents the minimum frequency (at a fixed sine wave amplitude of 200mVpp) for which a trigger was observed for each Threshold selector switch setting.

The output of the circuitry generating the audio envelope is driven by the Trigger Hub's 5V voltage rail, which is why no trigger is detected in the final threshold switch position.

Audio signals that exceed the threshold on Ch-4 generate triggers that are output on both the left and right channels of the Ch-4 output socket connector, and on D4 of the output parallel port.

The threshold for audio inputs is not intended to provide discrimination between audio signals that are less than -33 dBV. Rather, it is intended to detect the presence of signals that can be characterized, and for which a suitable threshold may be set.

Analog Inputs: Ch-3, Ch-6

The analog inputs Ch-3 & Ch-6 are BNC connectors, which are ideal for connecting signals from function generators.

These inputs operate with **positive** voltages up to 20V and will trigger when the threshold is crossed. These inputs are intended for use with square wave sources that do not meet the specifications for TTL of CMOS logic levels. However, these inputs can also be used with analog waveforms (e.g. analog voltage from a joystick). The minimum requirement for the analog or square wave "high" voltage is that it exceeds 0.63 V.

Signals that exceed the threshold on Ch-3 or Ch-6 generate triggers that are output on the BNC output connectors for Ch-3 or Ch-6, and on D3 or D6 of the output parallel port, respectively.

Analog Inputs: Ch-7,8

The analog inputs Ch-7 & Ch-8 are on a single 3.5mm stereo phone socket.

The required connector for using the switch inputs is a 3.5mm stereo plug, such as that shown in shown earlier in Figure 11. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND.

Specifically, Ch-7 is the TIP connection of the stereo plug, and Ch-8 is the RING connection. The GND for the analog signals must be connected to the sleeve.

A stereo 3.5mm connector IS NECESSARY to use this input.
A mono connector will create a short between the Ch-7 and Ch-8 inputs and generate triggers in both channels.

Signals that exceed the threshold on Ch-7 generate triggers that are output on the TIP connection for the Ch-7,8 output socket connector, and on D7 of the output parallel port.

Signals that exceed the threshold on Ch-8 generate triggers that are output on the RING connection for the Ch-7,8 output socket connector, and on D8 of the output parallel port.

5.8 Outputs

The output levels on **ALL** trigger outputs are 0 V (low, no trigger), and +5 V (high, trigger).

The following discussion presents the functionality of the outputs of the Trigger Hub. For the purposes of this discussion, it is assumed that the input signals have exceeded the threshold.

Parallel Port (Ch1-8)

The OUTPUT parallel port is a standard DB-25 connector configured to output triggers on the parallel port's data pins (D1 through D8). The only pins on the output parallel port that are connected internally are the data lines (D1-D8) and the parallel port GND pins (see Figure 10).

As noted in Sections 4.2 & 4.3, triggers on the output parallel port can be either due to signals appearing on the input parallel port's data lines (e.g. from a PC's parallel port), or due to signals appearing on one of the connectors on the input panel. This feature provides the functionality of consolidating triggers from multiple sources into a single output that can be plugged into **Wearable** *Sensing*'s EEG hardware. The reader is referred to Table 4 for the I/O mapping between input connectors and the output parallel port's data lines.

Switch Outputs: Ch-1, Ch-5

The switch outputs (Ch-1 and Ch-5) are 3.5mm stereo phone sockets.

The required connector for using the switch inputs is a 3.5mm stereo plug, as shown in Figure 11. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND.

Triggers appearing on Ch-1 are output on both the TIP and RING connections for the Ch-1 output socket connector. They are also output on D1 of the output parallel port.

Similarly, triggers appearing on Ch-5 are output on both the TIP and RING connections for the Ch-5 output socket connector. They are also output on D5 of the output parallel port.

A stereo 3.5mm connector is NOT necessary to use this input.
A mono connector can be used, since the trigger is output to both the Tip and Ring connections, and the output is therefore effectively a mono signal.

<u>Audio Output: Ch-4</u>

The audio output Ch-4 is a 3.5mm stereo phone socket.

The required connector for using the switch inputs is a 3.5mm stereo plug, as shown in Figure 12. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND.

Triggers appearing on Ch-4 are output on both the TIP and RING connections for the Ch-4 output socket connector. They are also output on D4 of the output parallel port.

A stereo 3.5mm connector is NOT necessary to use this input.
A mono connector can be used, since the trigger is output to both the Tip and Ring connections, and the output is therefore effectively a mono signal.

<u>Analog Outputs: Ch-3, Ch-6</u>

The analog outputs Ch-3 & Ch-6 are BNC connectors, which are ideal for connecting signals to data acquisition systems.

Triggers appearing on Ch-3 and Ch-6 are output on the Ch-3 and Ch-6 output BNC connectors, respectively. They are also output on D3 and D6 of the output parallel port, respectively.

<u>Analog Output: Ch-7,8</u>

The analog outputs Ch-7 & Ch-8 are on a single 3.5mm stereo phone socket.

The required connector for using the switch inputs is a 3.5mm stereo plug, such as that shown in shown in Figure 11. The Trigger Hub follows conventional wiring for stereo plugs by connecting the Sleeve to GND.

Triggers appearing on Ch-7 are output on the TIP connection for the Ch-7,8 output socket connector. They are also output on D7 of the output parallel port.

Triggers appearing on Ch-8 are output on the RING connection for the Ch-7,8 output socket connector. They are also output on D8 of the output parallel port.

A stereo 3.5mm connector IS NECESSARY for this input.
A mono connector would effectively render this two channel output to a single output by shorting Ch-7 and Ch-8 together.

5.9 Operational Examples

The following sections present specific experimental configurations that illustrate the functionality of the Trigger Hub.

i. Synchronization of EEG with Eye Tracking

In this example, the intent is to provide a mechanism for providing synchronization between an EEG system and Eye Tracking hardware. These two pieces of hardware are invariably independent and operate using different clocks. Over the course of extended measurements, drift between the clocks of both systems will inevitably become significant.

The two cases illustrated in Figure 13 indicate how to use **Wearable** *Sensing*'s Trigger Hub system to provide synchronization between two systems. In the example on the left, a trigger signal relating to the experiment is used to synchronize the two systems. This configuration uses the assumption that the trigger is frequent, or that the only EEG/Eye motion signals of interest temporally coincide with a trigger. The trigger is input to one of the Ch-N input connectors. The output trigger appears on the Ch-N output connector (which is connected to the Eye Tracking hardware) and also on the parallel port's Data N line, which is connected to the EEG hardware.

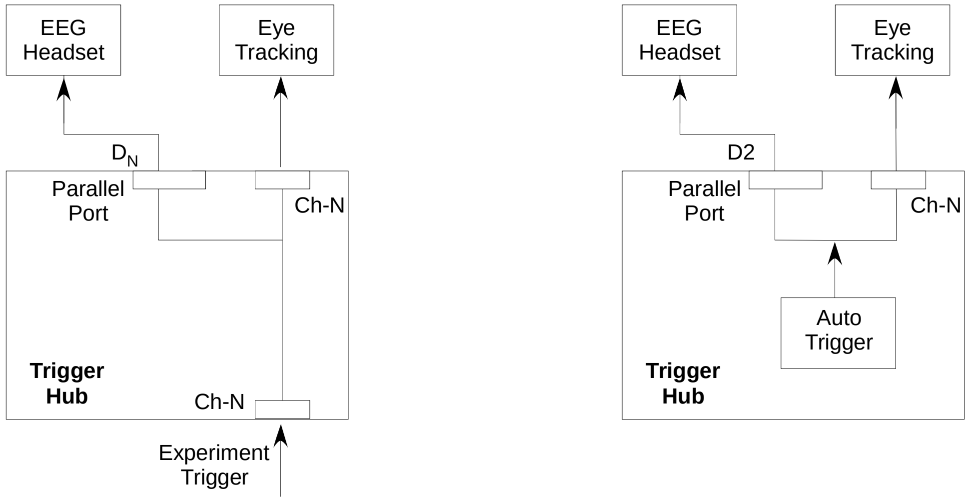

Figure 13. Example configurations for synchronization between EEG headset and Eye Tracking hardware. (left) Using external triggers. (right) Using AutoTrigger function.

In the example on the right, there are no trigger signals. Synchronization is provided by the **AutoTrigger** function, which produces a 1 Hz square wave that is output to all output connectors (Ch-N) and to the Data 2 line of the output parallel port. As in the first example, Ch-N output is connected to the Eye Tracing hardware, and the parallel port is connected to the EEG hardware. The result is two data streams containing 1 Hz square waves that can be used to provide time alignment between two data streams with different clock rates.

We suggest that the **AutoTrigger** function be started after data recording has begun on both systems. This avoids potential confusion regarding the 1st transition of the 1 Hz square wave in each data file: Is the first transition in the EEG file the same one as that in the eye tracking file? Is there a delay between pressing start and data recording for either system, and the latter system began recording 1 or 2 seconds before (or after) the EEG system began recording?

Note that the AutoTrigger function cannot be running at the beginning of recording data for either system.

ii. Evoked Response Potential (ERP) Measurements

In this example, the intent is to provide a mechanism for providing triggers for evoked potential measurements. In many cases, these experiments are conducted according to a pre-determined sequence of stimuli. Analysis of the results without knowledge of the sequence is pointless, because the response to one type of stimulus must be averaged and compared to the average responses of other stimuli in the sequence.

Another complication that arises is an assumption of timing. Specifically, some measurements present a stimulus sequence and the only timing information available is the start and finish times for the sequence, and not the timing of individual stimuli. The assumption is made that the timing for each stimulus in the EEG data stream can be inferred based on the clock of the system generating the stimuli (e.g. screen update rate for visual ERPs, computer clock rate for auditory ERPs[1]). Unfortunately, it is not uncommon for system delays to affect the timing of computer-generated sounds/visuals.

The following examples show how **Wearable** *Sensing*'s Trigger Hub system can be used to provide reliable timing information and identify multiple stimuli within a single experiment.

a) Visual ERPs

Images presented to the user can be designed such that their periphery is different to different types of images. In Figure 14, example images are presented for a visual oddball task. Both target landscape images have a white cutout in the upper left. The oddball image has white cutouts in both of the upper corners. The experiment would use a black (blank) screen between images.

[1] On one occasion, **Wearable** *Sensing* investigated a timing drift of 1 in 32768 between a **Wearable** *Sensing* EEG headset and computer generated triggers. Upon investigation, it was found that the EEG headset had timing drift less than 5 in 10^6 relative to GPS. The source of drift was the PC software generating triggers, which was counting only 32767 counts every 32768 clock cycles.

Figure 14. Example of tailoring images for P300 (Oddball) experiment. (left) Landscape target image #1. (middle) Landscape target image #2. (right) Oddball image.

This experimental configuration requires two photodetectors, which would be plugged into the Ch-1 and Ch-5 switch inputs of the Trigger Hub. A photodetector would be placed over each of the two upper corners of the screen, thus enabling unambiguous identification of a target image versus the oddball image, and furthermore provide timing for the presentation of each image, independent about assumptions about screen update rate.

b) Auditory ERPs

The sound for auditory stimuli can be tapped from the audio line-out signals and connected directly to the audio input connector **Wearable** *Sensing*'s Trigger Hub system. Thus the timing of auditory stimuli will be known to within the trigger delay for audio input signals, which is less than 0.5 ms.

c) Using PC Parallel Port to Categorize Stimuli

When ERP stimuli are being generated by a computer, it is possible to use the PC's parallel port to characterize the stimuli. Up to 255 different stimuli can be characterized.

The timing of triggers may drift relative to expectation due to clock drift or PC system delays, etc., particularly over the course of extended measurements. However, this configuration assumes that errors between stimulus presentation and trigger output will be minimized because the timing of presentation and the timing of the trigger output are closely related.

iii. <u>Using Push Button/Switch to Locate Events Within Data</u>

This example is provided as a caveat regarding (c) above. Although it is a reasonable expectation that the timings for presentation and trigger output are related, different computer subsystems are involved and timing differences may result due to the way the PC uses resources differently from each subsystem. This will manifest as a timing jitter between presentation and trigger, rather than a timing drift between the two trigger outputs.

Take as an example the timing of multiple *types* of images (i.e. more than 2) presented to the screen. With more than 2 types of images, the parallel port can be used to categorize stimuli. However, images are presented using the video card, whereas the trigger information is output via the parallel port.

In this case, a photodetector can be plugged into one of the Trigger Hub's switch inputs (Ch-1, say) to obtain accurate timing for the presentation of an image. Information about the image can be included in the corresponding parallel port output. The trigger information in the data file will then contain two sets of information: a list of times for presentation of the images (based upon the Ch-1 or D1 output), and a corresponding list identifying the image for each presentation.

We recommend either of the following two approaches for the trigger information:

a) Reduce the number of individual stimuli

Care must be taken not to encode image information using data line D1 on the parallel port, as this will create confusion with the timing of image presentation. Therefore, in this case the limit upon the number of different stimuli is reduced to 127.

Considering the data lines as a binary representation of a number, all odd numbers would be excluded in this example.

b) Offset the timing of the parallel port output

A delay can be introduced into the code that sends data to the parallel port. If the trigger information is only output during a period when the screen is blank (i.e. Ch-1 input is low), then up to 255 different stimuli can be characterized.

iv. Using Push Button/Switch to Locate Events Within Data

A button press during measurements can provide timing markers that appear in the data stream. For example, switch triggers in this configuration may correspond to the start and end of an experiment, where data acquisition was running freely during setup prior to the experiment. Alternatively, two switches, which would be plugged into the Ch-1 and Ch-5 switch inputs of the Trigger Hub, can be used in an experiment in which the subject performs multiple tasks: Ch-1 marks the beginning of a task and Ch-5 marks the end of a task.

6. Specifications

6.1 List of Specifications

Power Supply:

- USB 3.0 power standard

Inputs/Outputs:

- 8 Digital channels (via parallel port)
- 4 Analog inputs (via 2xBNC & 1x 3.5mm stereo connector)
- 1 Audio input (via 3.5mm stereo connector)
- 2 Switch inputs (via 2x3.5mm stereo connectors)
- 1 AutoTrigger function (output via parallel port D2, all other output connectors)

Analog/Parallel Port Input Specifications

- Input Voltage Range: 0 – 20 V (max.)

Audio Input Specifications

- Audio Input Connector Level: Line out (2Vpp)
- Min. Audio Signal Level (1kHz): 40 mVpp
- Audio Input Connector Bandwidth: 40Hz – 20kHz (-3dB)

Threshold Adjustment

- Number of settings: 10
- Range of Threshold Voltages Settings: 0.63V to 5.8V

Output Triggers

- Trigger Output Voltage: 0 – 5 V
- Trigger Output current: 100mA continuous and 200mA in impulse
- Min. Trigger pulse width: 20 ms
- Min. Intertrigger Interval (interval between trigger rising edges): 40 ms
- Latency: < 100 µs (digital/analog/switch inputs)
< 0.5 ms (audio input)
12 ms ± 10 µs (wireless transmission)

Wireless

- Maximum Range of Transmission: 30 feet (no repeater)
60 feet (with repeater)
- Encoding for wireless trigger byte corresponds to parallel port data lines D1-D8