Constructing a Rodent Head-Fixed Lick Rig

Table of Contents

Introduction

This guide describes in detail the process for building a mouse head-fixed lick rig for studying mouse neurobiology via lingual kinematics. This rig is capable of collecting millisecond resolution lick and paw touch data, and lick-triggered high speed (1 kHz) video of simultaneous side and bottom views of the tongue as it licks within a flexible experimental paradigm that can include optogenetic inactivation. See Figure 1 for a diagram of the coordinate system used throughout the documentation. See Figure 2 for an overall diagram of the system. Some have been custom machined or 3D printed – the specs for these components are made available at the following URL: https://github.com/GoldbergLab. We built a single setup for taking high speed video (a "video box"), and several for simply training the mice without video. The instructions for creating a training box are a subset of the instructions for creating the video box.

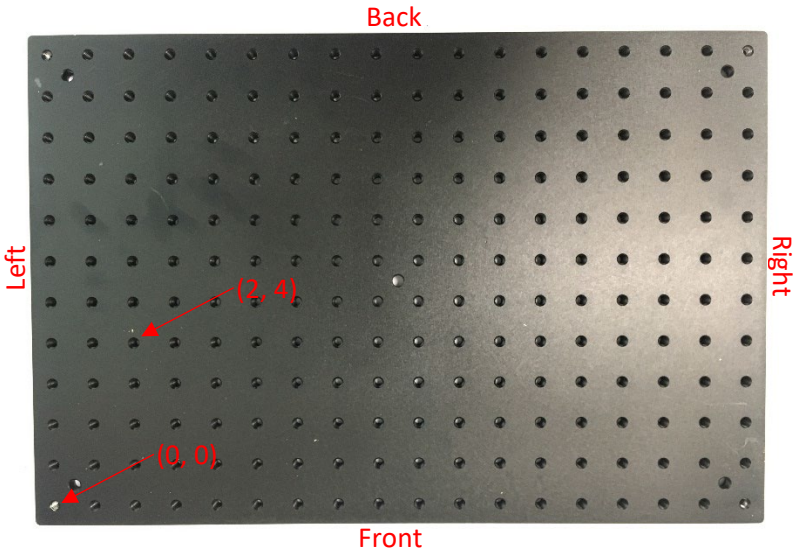

Figure 1 The coordinate system used throughout the documentation

Note that the StroboLED II IR strobe light that we obtained from AOS Technologies has been discontinued, so alternate high speed IR illumination will be needed for high speed video recording.

Note that while individual fasteners are detailed in each materials section, we recommend the Thorlabs 1/4"-20 Cap Screw and Hardware Kit (https://www.thorlabs.com/thorproduct.cfm?partnumber=HW-KIT2), as it is an easy way to get most of the fasteners you will need in one purchase.

Throughout this guide, a basic knowledge of soldering (including surface-mount soldering) is assumed, as are the required tools for soldering.

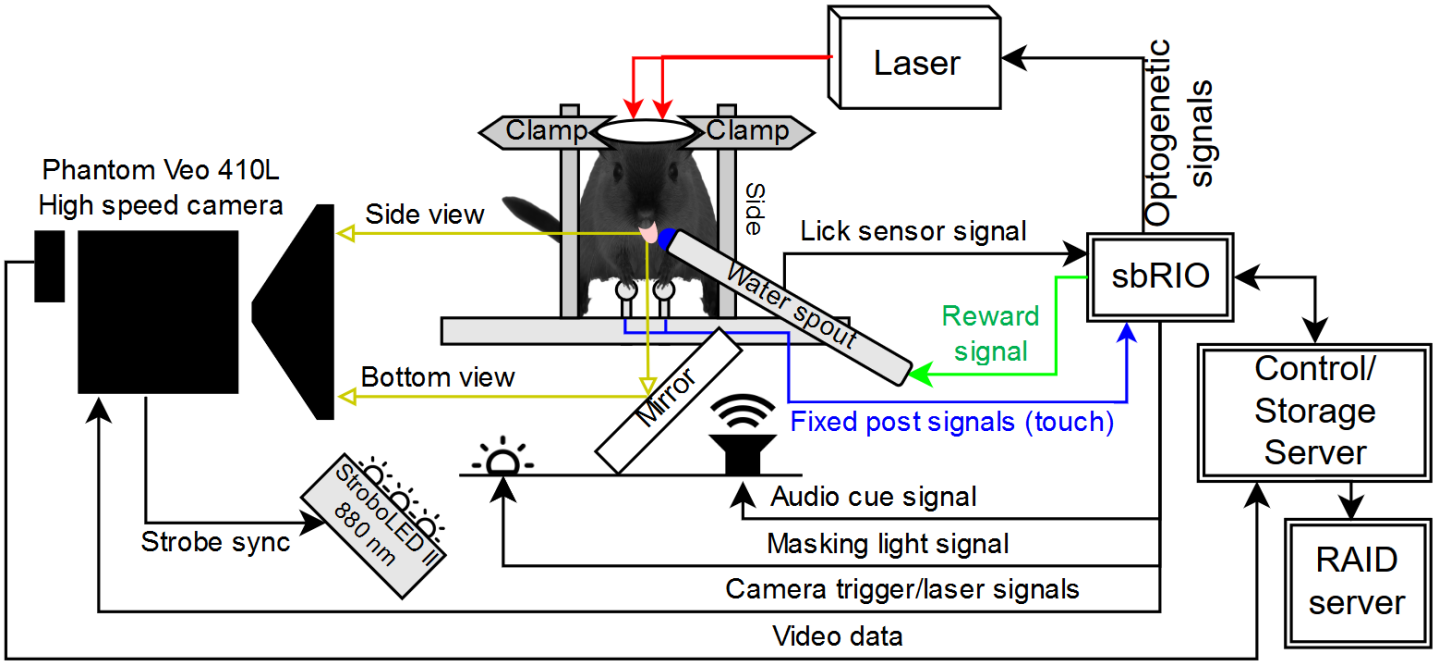

Figure 2 Overall system diagram

Part I: Constructing the rig base

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Aluminum Breadboard 12" x 18" x 1/2", 1/4"-20 Taps	Thorlabs	MB1218	https://www.thorlabs.com/thorproduct.cfm?partnumber=MB1218
2	1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 1"	Thorlabs	PH1	https://www.thorlabs.com/thorproduct.cfm?partnumber=PH1
3	1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 3" x3	Thorlabs	PH3	https://www.thorlabs.com/thorproduct.cfm?partnumber=PH3
4	1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 4" x4	Thorlabs	PH4	https://www.thorlabs.com/thorproduct.cfm?partnumber=PH4
5	1/2" Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 4" x4	Thorlabs	TR4	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR4
6	15" Long Construction Rail	Thorlabs	XE25L15	https://www.thorlabs.com/thorproduct.cfm?partnumber=XE25L15
7	Dovetail Optical Rail, 3", Imperial	Thorlabs	RLA0300	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0300
8	2" Manual Rotation Stage	Thorlabs	RP01	https://www.thorlabs.com/thorproduct.cfm?partnumber=RP01
9	Cap screw, 1/4”-20, 3/4” long x2	Thorlabs	SH25S075	https://www.thorlabs.com/thorproduct.cfm?partnumber=SH25S075
10	Cap screw, 1/4”-20, 5/8” long x2	Thorlabs	SH25S038	https://www.thorlabs.com/thorproduct.cfm?partnumber=SH25S038
11	Setscrew, 1/4”-20, ¾” long x11	Thorlabs	SS25S075	https://www.thorlabs.com/thorproduct.cfm?partnumber=SS25S075
12	Pan head screw, 8-32, 3/8” long x2	McMaster-Carr	91772A192	https://www.mcmaster.com/91772A192/
13	Acrylic platform	Laser cut from 1/8” acrylic	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/41a75cd7e26776ec9ef0e0aba1f082387032ecff/DesignFiles/Mouse%20platform

Building Instructions

General notes

The base of the rig consists of a Thorlabs optical breadboard with various posts attached to support the other components.

Recommended tools: 5/64” hex wrench, 3/16” hex wrench

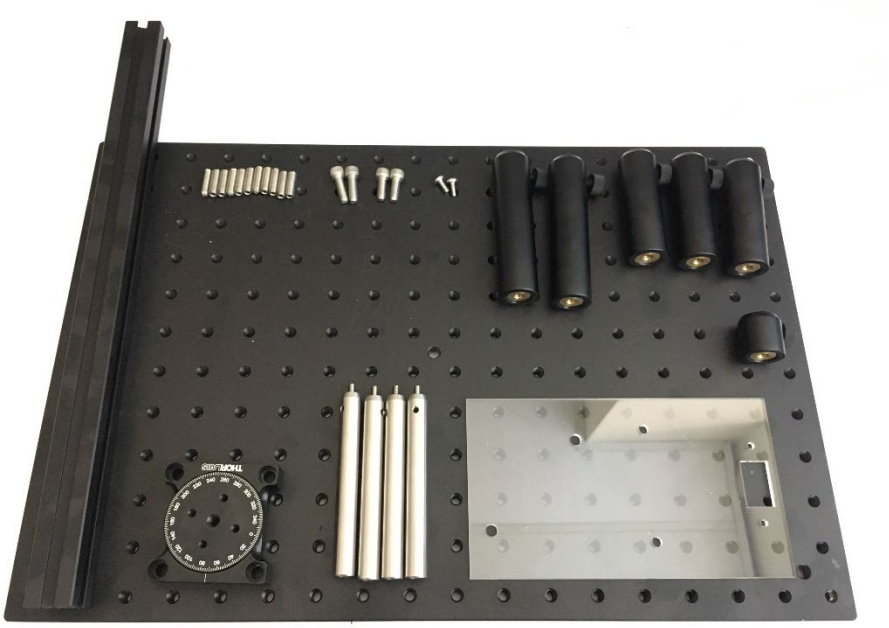

Figure 3 Materials for head-fixed rig base. Clockwise from top left: Construction rail, setscrews, 1/4"-20 screws (3/4” and 5/8”), 8-32 screws, PH4, PH3, PH1, acrylic platform, TR4, RP01. The components are sitting on the optical breadboard.

1. Remove the 8-32 setscrews from all the optical posts

- Use a 5/64” hex wrench to remove the 8-32 setscrews from the ends of the optical posts. They will not be needed.

2. Attach components to the optical breadboard

- Throughout the next steps, ensure that no screws are poking through the bottom of the optical breadboard – this will tilt the rig and interfere with alignment when the head-fixed rig is secured to the camera mount later.
- See Figure 1 for an explanation of the coordinate system used here.
- Screw setscrews all the way into the bottom of four 4” posts (TR4), then screw the post/setscrew assemblies in at (11, 5), (13, 5), (11, 10), and (13, 8).
- Screw ¼”-20x3/4” bolts partially in at (3, 0) and (17, 2). These will be used later to secure the head-fixed rig to the camera mount

Figure 4 Removing the 8-32 setscrews from the optical posts

- Screw a setscrew half in at (5, 0), and screw the 1” post holder (PH1) onto it. This will be used to mount the strobe light.
- Screw setscrews half in at (8, 7) and (16, 7), then screw a 4” post holder (PH4) onto each.
- Remove the thumbscrews from the sides of two 3” post holders (PH3) – they’ll get in the way in the next step.
- Screw setscrews half in at (7, 7) and (17, 7), then screw the two 3” post holders (sans thumb screws) onto them.
- If the holes are accessible, put the thumb screws back in. If not, adjust the bottom setscrews in the PH3s.
- *For centered spout:* Place the rotation stage (RP01) so it is centered at (12, 1), with the locking setscrew hole facing the front of the rig (see Figure 5), and screw it down using two 1/4"-20x5/8” screws. The RP01 can be shifted to the right or left to produce non-centered spout positions.

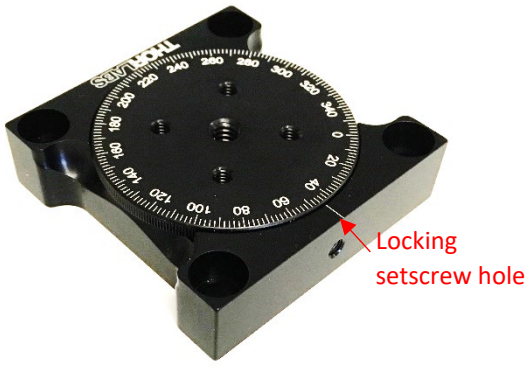

Figure 5 RP01 rotation stage.

- Screw a setscrew half in to the center of the RP01 rotation stage, then screw a 3” post holder (PH3) onto the setscrew.
- Screw a setscrew half in at (2, 9), and screw the 15” construction rail onto the setscrew.

3. Check for protruding setscrews

- Lift up the rig so you can see the underside of the breadboard. Check for any setscrews protruding out the bottom of the breadboard.
- Use a hex wrench as necessary to adjust the position of setscrews so the bottom of the breadboard has no protrusions.

4. Attach the platform

- Place the acrylic platform on the four optical posts so the rectangular cutout is facing forwards.
- Screw the platform down onto the back two optical posts, at (11, 10), and (13, 8) using two 8-32x3/8” screws.
- See Figure 6 for the completed head-fixed rig base.

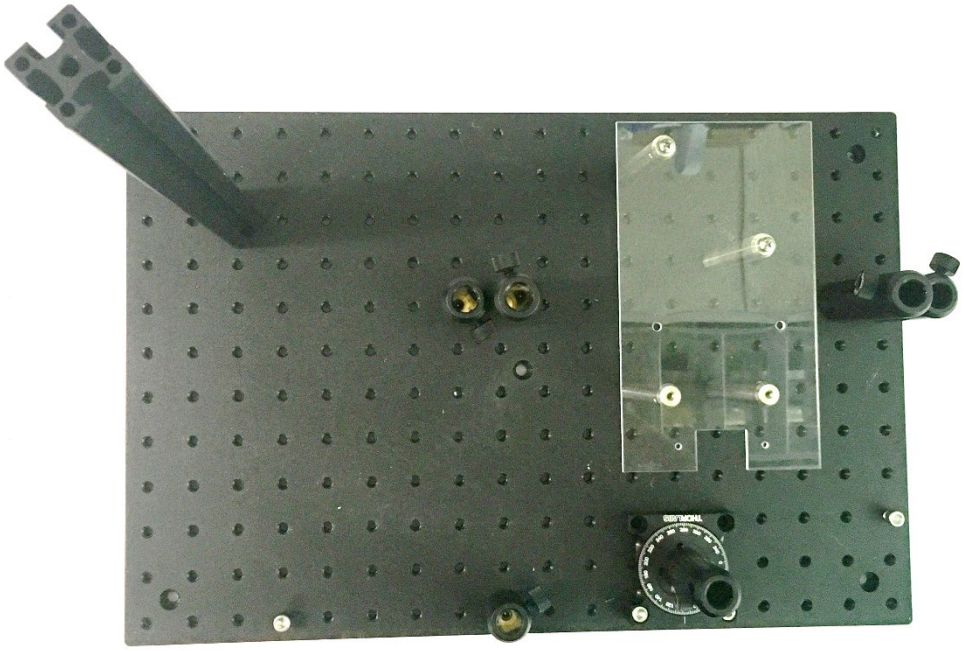

Figure 6 Completed head-fixed rig base

Part II: Constructing the head-fixing assemblies

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Head-plate clamp x2	3D printed	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/ba9c37c076680f8113f53b5dc9c8878031db508f/DesignFiles/Headplate%20clamp
2	1/2" Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 4" x2	Thorlabs	TR4	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR4
3	1/2" Graduated Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 3" x2	Thorlabs	TR3E	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR3E
4	Dovetail Rail Carrier, 2.00" x 1.00", 1/4" Counterbore, 8-32 Taps x2	Thorlabs	RC2	https://www.thorlabs.com/thorproduct.cfm?partnumber=RC2
5	Dovetail Optical Rail, 6", Imperial x6	Thorlabs	RLA0600	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0600
6	Dovetail Optical Rail, 3", Imperial x2	Thorlabs	RLA0300	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0300
7	Pan head screw, 8-32, 3/8” long x4			

Building Instructions

General notes

The head-fixing assemblies consist of two separate mirror-symmetric sides that fit into the pairs of post holders on the rig base. The instructions below describe building the left side. The right side is a reflection of the left side.

Recommended tools: 3/16” hex wrench, 1/4" or adjustable crescent wrench, screwdriver, bench-top vise (optional)

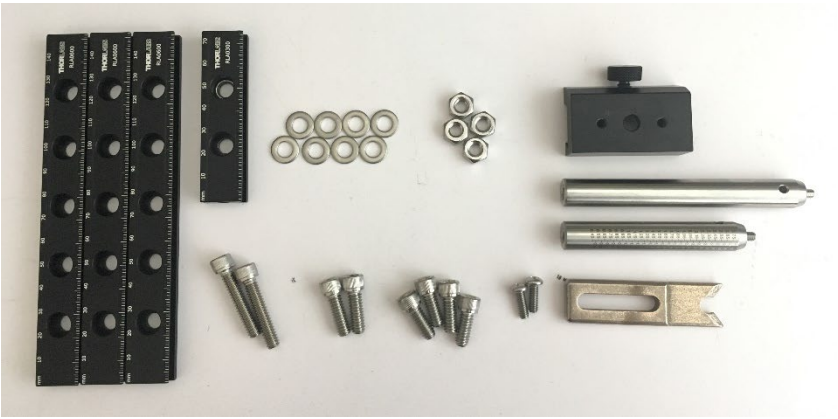

Figure 7 Head-fixing assembly materials (one side only - another set is needed for the other side)

1. Attach the dovetail rails together

- Lay two 6” rails beside each other, markings up.
- Lay a 3” rail across the two 6” rails, markings up. Line up the two holes on the 3” rail with the back two holes on the 6” rails.
- Insert a 1/4"-20x3/4” screw into each of the two 3” rail holes, and through the 6” rail holes. Add a washer and a nut to the other side of each screw, and loosely tighten them.

- Lay a 6” rail across the two connected 6” rails, markings **down**. For the left head-fixing assembly, align the new 6” rail so the second and third holes from the left align with the front two holes in the two 6” rails.
- Add a washer to two 1/4"-20x1 1/4" screws, then insert them into each of the two overlapping 6” rail holes. Add a washer and a nut to the other side of each screw, and loosely tighten them.
- Adjust the rails so they are all perpendicular to each other, forming a rectangle, rather than a general parallelogram, and tighten the screws/nuts. A vise can be useful to hold the rails in position while you tighten the screws. See Figure 8 for the results of this step.

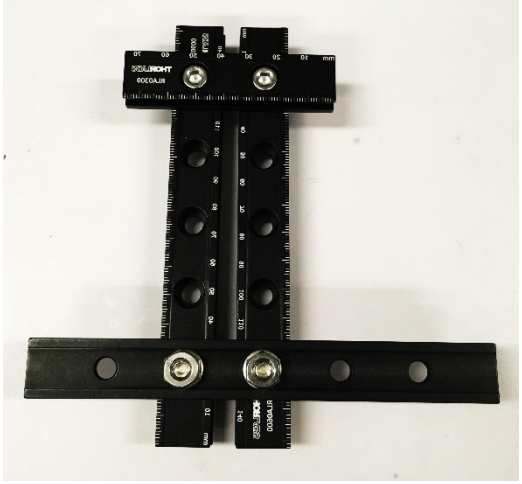

Figure 8 Head-fixing assembly dovetail rails connected together

2. Attach the head-fixing clamp to the rail carrier

- Lay the head-fixing clamp on top of the rail carrier so the slot in the clamp overlaps the two 8-32 holes in the carrier. For the left-hand head-fixing assembly, when viewed from the top of the rail carrier with the rail carrier thumbscrew facing away from you, the clamp should stick out to the right.
- Add washer to two 8-32x3/8” screws, and insert them through the clamp slot and into each of the two 8-32 holes in the carrier.
- Straighten the clamp so it is centered on and parallel to the edges of the rail carrier, and tighten the two 8-32 screws. See Figure 9 for the results of this step.

Figure 9 Rail carrier with clamp

3. Add the rail carrier onto the dovetail rails

- Slide the rail carrier onto the underside of the 6” rail that crosses the other two 6” rails. For the left head-fixing assembly, the carrier should slide onto the longer overhanging part of the 6” rail that protrudes to the right. The clamp should be facing to the right, and the thumbscrew should be facing forwards. See Figure 10 for the results of this step.

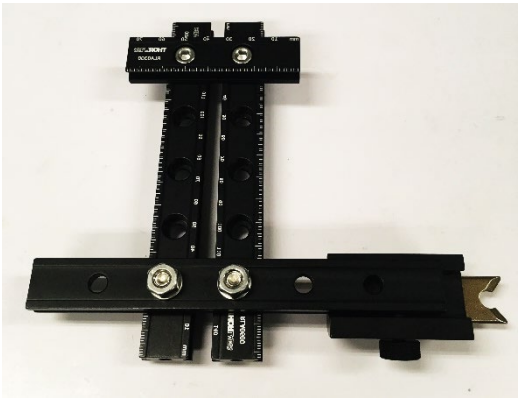

Figure 10 Dovetail rails with carrier installed

4. Connect the support posts

- Use a 5/64” hex wrench to remove the 8-32 setscrews from the ends of all the optical posts. They will not be needed.
- Attach the bottom (the end with the 1/4"-20 hole) of the 4” optical post to the left 6” rail using the hole closest to the 3” rail with a 1/4"-20x3/8” screw.
- Attach the bottom (the end with the 1/4"-20 hole) of the 3” graduated optical post to the right 6” rail using the hole closest to the 3” rail with a 1/4"-20x3/8” screw. See Figure 12 for the results of this step.

5. Insert the head-fixing assembly into the base

- Insert the two optical posts into the left-hand 3” and 4” post holders with the clamp side facing forwards. The thumbscrew on the 4” post holder can be used to set the height of the head-fixing assembly. See Figure 11 for the results of this step.

6. Repeat the above steps reflected to build the right head-fixing assembly

- Repeat the above steps in mirror-image to create the right head-fixing assembly.

7. Check clamp alignment

- Using the thumbscrews on the post holders, adjust the height of the left and right head-fixing assemblies so the left and right clamps are level with each other.
- Check that the left and right clamps are parallel and pointing directly at each other. If they aren't, adjust the alignment of the dovetail rails and/or the clamp/carrier connection.

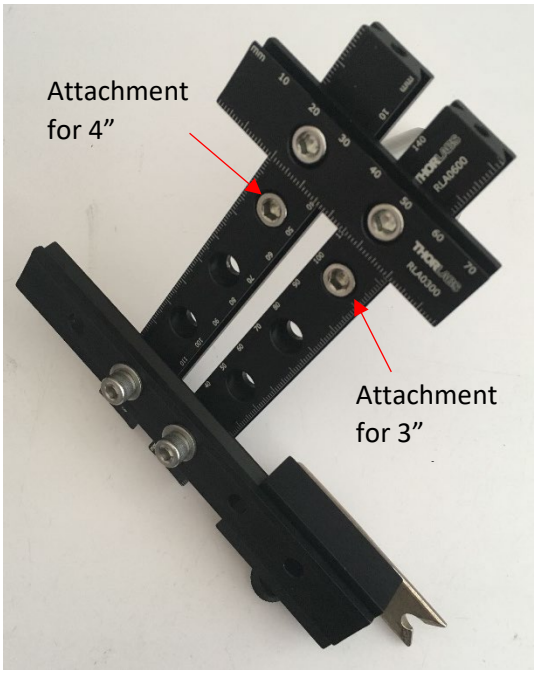

Figure 12 Head-fixing assembly with optical posts attached

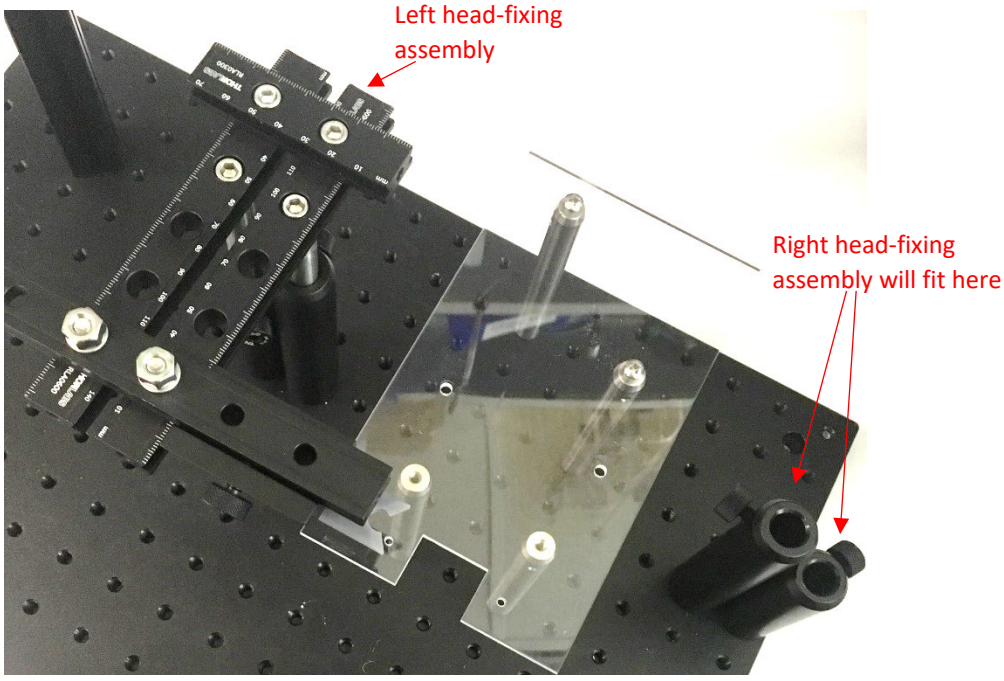

Figure 11 Base with left head-fixing assembly complete and installed

Part III: Constructing the touchposts and mirror mount

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Touchpost panel	3D printed	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/ba9c37c076680f8113f53b5dc9c8878031db508f/DesignFiles/Mirror%20mount
2	Ball bearing with machined hole	Custom made	Cornell machine shop	
3	2-pin receptacle x2	Hirose/Digikey	DF3-2S-2C	https://www.digikey.com/product-detail/en/DF3-2S-2C/H2083-ND/141479
4	Stranded, insulated wire, approximately 26 AWG, two different colors			
5	24 AWG Wire Wrap	Digikey	K517	https://www.digikey.com/product-detail/en/jonard-tools/R24R-0100/K517-ND/806200
6	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF
7	Dental Acrylic (Flow-It ALC Flowable Composite)	Pentron	N11H	http://www.pentron.com/products/product_detail/flow_it_alc_flowable_composite
8	Heatshrink wrap			

Building Instructions

General notes

The touchposts and mirror mount are 3D printed as one piece to ensure that they are aligned precisely, and, for multiple rigs, identically. The two touchposts allow detection of paw touches, and the 45° mirror mount allows a side-mounted camera to simultaneously view the side view of the head/tongue and the view from below.

Note that in recent iterations, we eliminated the touch-sensitive touchposts in favor of a non-sensing paw “perch”. In that case, you can skip to step 5.

Recommended tools: Soldering microscope, soldering iron, wire strippers, needle-nose pliers UV curing light, tweezers, clips/helping hands, power drill, Form 2 3D printer

Figure 13 Materials for constructing the touchposts and mirror mount. Clockwise from top left: Solid wire, two colors of stranded wire, epoxy, dental acrylic, heatshrink tubing, receptacles, crimp terminals, touchpost & mirror mount. Not pictured: magnets

1. Connect the capacitive ball electrode to leads

- Cut a 2.5” piece of wire wrap wire
- Strip last 1/16” of insulation from one end of the wire
- Clamp the capacitive ball in place under a microscope with the machined hole facing in an easily accessible direction

- Dab a little flux in the machined hole on the capacitive ball. Avoid getting flux elsewhere on the ball.
- Insert the solder wire into the machined hole
- Heat the capacitive ball by touching the soldering iron to the back until the solder melts into the hole. A small amount in the hole is ideal. Too much solder will lead to inconvenient bulges of solder out of the hole.
- Heat the ball again to re-melt the solder as you insert the stripped end of the wire into the capacitive ball hole. Remove the soldering iron heat while holding the wire in place, until the solder cools and solidifies
- Clean off any excess flux and solder
- Tug on the wire gently to confirm that the ball is firmly soldered in the hole.
- Strip about 1/4" of insulation off the other end of the wire.
- See Figure 14 for an illustration of this process.
- Repeat the above steps for the other electrode. See Figure 15 for the results of this step.

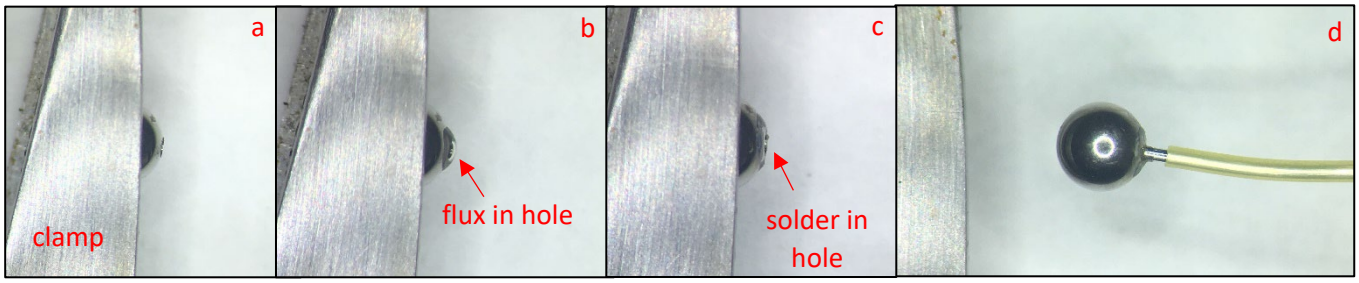

Figure 14 Steps for connecting a wire lead to the ball electrode: a) clamp the ball in place with hole accessible b) add a dab of flux onto the hole in the ball c) melt solder into the hole in the ball d) remelt solder and insert wire

2. Insert ball electrode leads into touchposts.

- Insert each ball electrode lead into one of the 3D printed touchposts. Ensure that each ball can sit centered on top of its post.
- Lift the ball up and spread a thin layer of epoxy below it on the wire lead, then push the ball back down. Carefully remove any excess epoxy that squishes out around the ball – ensure that no epoxy gets on the upper hemisphere of the ball.
- Liberally epoxy the area on the other side where the wire leads come out to protect the ball/wire joint from strain.
- Suspend the touchposts in their proper orientation so the epoxy doesn't drip off to the side as it cures (5 min).

Figure 15 Completed ball electrodes with wire leads

3. Create the connecting wires

- Cut four lengths of wire approximately 2 feet long each
- Twist them into two twisted pairs of wire
- Strip one end of each wire to about 1/4", and the other end of each wire to about 1/16". See Figure 16 for the results of this step.
- Using needle-nose pliers, crimp the tabs of a crimp terminal onto the 1/16" stripped side of each wire, so the middle tabs hold the bare metal of the wire, and the back tabs hold the insulation. *Note: If the back tabs are flattened too much or too little, they may not fit in the receptacle, and adjustment will be necessary.*
- Insert the crimp terminals at the ends of each pair of wires into the 2-pin receptacles. See Figure 17 for an illustration of this process.
- Add some dental acrylic to the back of the receptacles to ensure the wires don't pop out under stress.

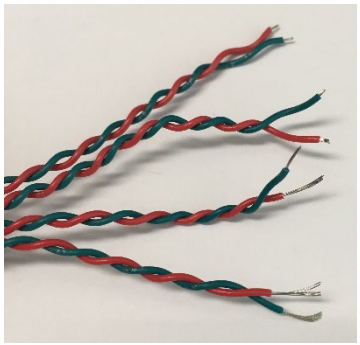

Figure 16 Four connecting wires in two twisted pairs, showing the eight ends appropriately stripped

- Slip on a piece of heatshrink tubing onto the other end of each pair of wires in preparation for the next step.

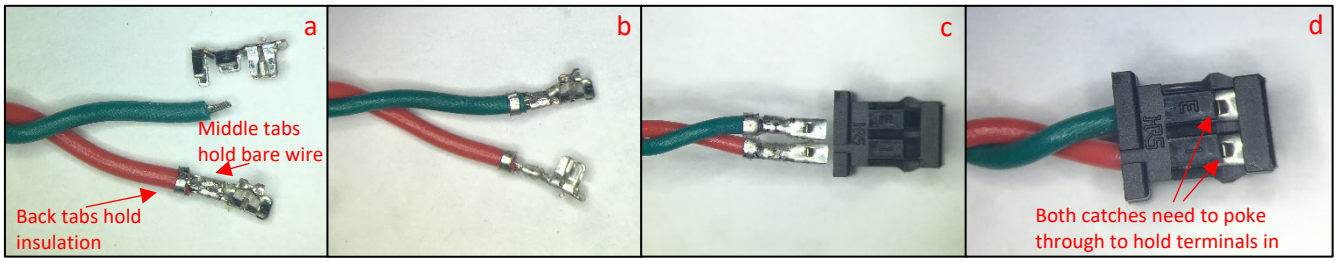

Figure 17 Process for attaching wires to receptacles: a) crimp middle tabs onto stripped wire, back tabs onto insulation b) repeat for other wire c) insert into receptacle in the orientation shown d) push in until catch pokes out into hole

4. Solder the connecting wires to the capacitive ball electrode leads

- Solder each pair of wires together to one of the ball leads.
- Slide the heatshrink tubing over the solder joint and use a heat gun to shrink it onto the joint. See Figure 18 for the results of this step.

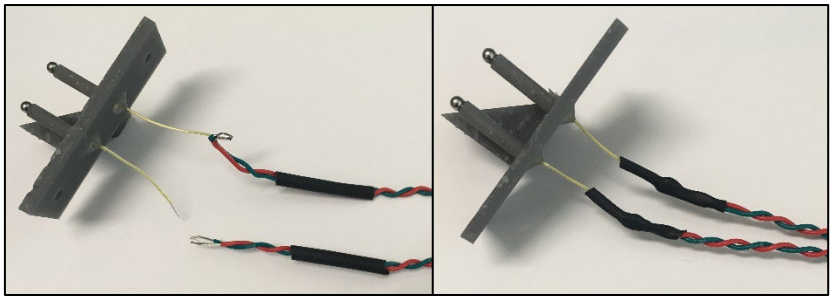

Figure 18 Soldering connecting wires to the electrode leads. Left, one pair of connecting wires is soldered on. Right, both pairs soldered with heatshrink tubing applied.

5. Add magnets to the back of the mirror mount

- Take two pairs of magnets and insert them into the two holes in the back of the mirror mount – make sure their “north” sides are facing the same way. These magnets will hold the mirror in place during camera recording.
- Careful use of a vise or clamp can help to pop the magnets into place if the fit is tight.
- Add a small amount of superglue to secure them in place.

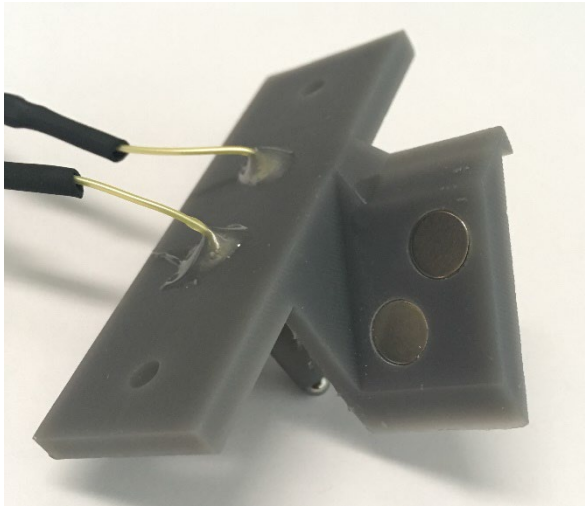

Figure 19 Two pairs of magnets inserted into magnet holes

Part IV: Constructing the water reservoir

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Lixit Flat sided water bottle	Lixit	QLCSA-5	http://www.lixit.com/node/653
2	Plastic Quick-Turn Cap	McMaster-Carr	51525K311	https://www.mcmaster.com/51525k311
3	Luer lock female x female connector x3	Cole-Parmer	EW-45502-22	https://www.coleparmer.com/i/cole-parmer-female-luer-x-female-luer-adapter-nylon-25-pk/4550222
4	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF

Building Instructions

General notes

The water reservoir is a modified consumer rodent water bottle. The reservoir has a Luer lock port at the bottom to connect to the lick spout intake tube. It also has two Luer lock ports – one for filling on top, and one optional one for draining to a pre-set level for use with an automatic watering system. These can be filled manually or connected to an automatic water system to easily maintain the appropriate water height in each bottle, and therefore maintain a constant dispense volume at the lick spout. The constant dispense volume can be calibrated by adjusting the duration of solenoid valve opening.

Figure 20 Reservoir materials. Clockwise from top left: Water bottle, FxF Luer lock connectors x3, Luer lock caps x3, epoxy

1. Disassemble the bottle

- Remove the bottle from its packaging
- Unscrew the cap, separate the rubber seal and the metal spout. Discard the spout.

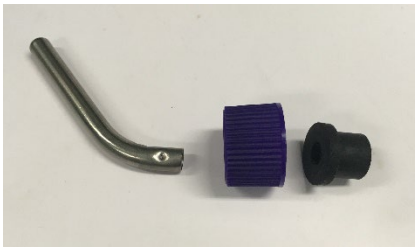

Figure 21 Reservoir cap disassembled. The metal spout can be discarded.

2. Install bottom outlet adapter

- Apply liberal amounts of epoxy around the outside of a one end of a female x female Luer lock connector to ensure water doesn't leak between the cap and the adapter.
- Quickly insert the epoxied end of the connector into the wide end of the rubber seal up to the middle connector flange.
- Using a swab, clean off excess epoxy that comes out of the rubber seal.
- Allow epoxy to harden (5+ minutes)
- Slightly widen the hole in the bottle cap to approximately 7/16 inches, to allow the Luer lock flange to fit.
- As an optional backup to prevent leaks, add more epoxy around the Luer lock flange.
- See Figure 22 for a depiction of this process.

3. Add fill and drain ports

- Drill a 1/4” hole in the top and flat side of the bottle. The optional side drain hole should be approximately 1 cm below the top surface of the bottle.
- Insert female x female Luer lock connectors into the two holes.
- Use a generous amount of epoxy between the bottle and the Luer lock connectors and around the lip of the connectors to make a watertight seal.
- See Figure 25 for this process

4. Add pressure relief hole

- Drill a 1/16” hole somewhere on the top surface of the reservoir to relieve pressure during operation.

5. Screw cap back on and test seals

- Screw the cap back on
- Test to make sure the three ports are watertight by filling the bottle with water, capping the ports, and check for drips after a while
- Make sure there are no plastic fragments left in the reservoir that could clog up the ports or tubing.
- See Figure 24 for the completed water reservoir.

Figure 22 Process of making bottom water outlet. A) Mix epoxy and slather generous amounts on one side of male adapter B) Insert male adapter into the wide end of the rubber seal up to the flange C) Wipe excess epoxy away D) allow to harden, and insert in cap

Figure 25 Luer lock fill and drain ports inserted and epoxied

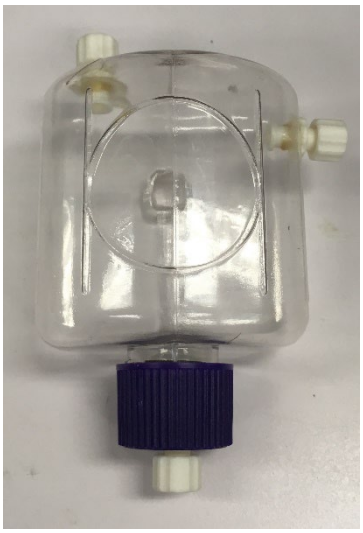

Figure 24 Completed water reservoir

Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer /Supplier Part Number	Datasheet/Drawing/Modification
1	Stainless Steel 304 Hypodermic Tubing, 14 Gauge, 0.083" OD, 0.072" ID, 0.0055" Wall, 36" Length	Amazon	B004WPPVYE	https://www.amazon.com/dp/B004WPPVYE
2	Lick spout mount	Custom made		
3	Tygon PVC Tubing for Food, Beverage, and Dairy, 1/16" ID	McMaster-Carr	6546T33	https://www.mcmaster.com/#6546t33
4	1/16” barbed plug	VWR	P0-1NK	https://us.vwr.com/store/product/14459897/barbed-plugs-eldon-james
5	Male Luer x 1/16” hose barb	Cole-Parmer	EW-45518-00	https://www.coleparmer.com/i/cole-parmer-male-luer-with-lock-ring-x-1-16-hose-barb-pp-25-pk/4551800
6	Solenoid valve	The Lee Company	LHDA2433215H	http://www.theleeco.com/electro-fluidic-systems/solenoid-valves/lhd/3-port-ported-style.cfm
7	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
8	Stranded, insulated wire, ~26 AWG, four colors			
9	2-pin receptacle	Hirose/Digikey	DF3-2S-2C	https://www.digikey.com/product-detail/en/DF3-2S-2C/H2083-ND/141479
10	3-pin receptacle x3	Hirose/Digikey	DF3-3S-2C	http://www.digikey.com/product-detail/en/DF3-3S-2C/H2084-ND/141482
11	Heatshrink tubing			
12	Capacitive lick sensor board			
13	2-pin header	Hirose/Digikey	DF3A-2P-2DSA	http://www.digikey.com/product-detail/en/DF3A-2P-2DSA/H2094-ND/141512
14	3-pin header	Hirose/Digikey	DF3A-3P-2DSA	http://www.digikey.com/product-detail/en/DF3A-3P-2DSA/H2095-ND/141515
15	R1 = 1 kΩ resistor, SMT	For example, Yageo AC0603JR-071KL		https://www.digikey.com/product-detail/en/yageo/AC0603JR-071KL/YAG3646TR-ND/5896388
16	C1 = 3.3 nF capacitor (value may vary by application), SMT	Samsung CL21B332KBANNNC		https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL21B332KBANNNC/1276-1260-1-ND/3889346
17	C2 = 0.47 uF capacitor, SMT	For example, Samsung CL10B474KO8NNNC		https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B474KO8NNNC/1276-1062-2-ND/3886720
18	C3 = 10 pF capacitor, SMT	For example, Samsung CL10C100JB8NNNC		https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C100JB8NNNC/1276-1027-2-ND/3886685
19	U1 = Atmel Touch sensor IC, SMT	AT42QT1011		http://ww1.microchip.com/downloads/en/DeviceDoc/40001947A.pdf

#	Part Description	Manufacturer/ Supplier	Manufacturer /Supplier Part Number	Datasheet/Drawing/Modification
20	Translucent scotch tape			
21*	Dovetail Rail Carrier, 1.00" x 1.00", 1/4" Counterbore	Thorlabs	RC1	https://www.thorlabs.com/thorproduct.cfm?partnumber=RC1
22*	1/4"-20x5/8” screw	Thorlabs	SH25S063	https://www.thorlabs.com/thorproduct.cfm?partnumber=SH25S063
23*	1/4"-20 washer	Thorlabs	W25S050	https://www.thorlabs.com/thorproduct.cfm?partnumber=W25S050
24*	1/4"-20 nut	Thorlabs	N25S044	https://www.thorlabs.com/thorproduct.cfm?partnumber=N25S044
25*	1/2" Graduated Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 3"	Thorlabs	TR3E	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR3E
26*	Dovetail Optical Rail, 3", Imperial	Thorlabs	RLA0300	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0300

* = not required for 1D or 2D positionable spout

Building Instructions

General notes

The lick port consists of a water spout, which both dispenses water and serves as a capacitive touch sensor electrode to detect licks, a solenoid valve, a capacitive touch sensor PCB, and connecting wires.

Recommended tools: Soldering iron, wire strippers, needlenose pliers, Dremel with cutting wheel, fine small file, heat gun

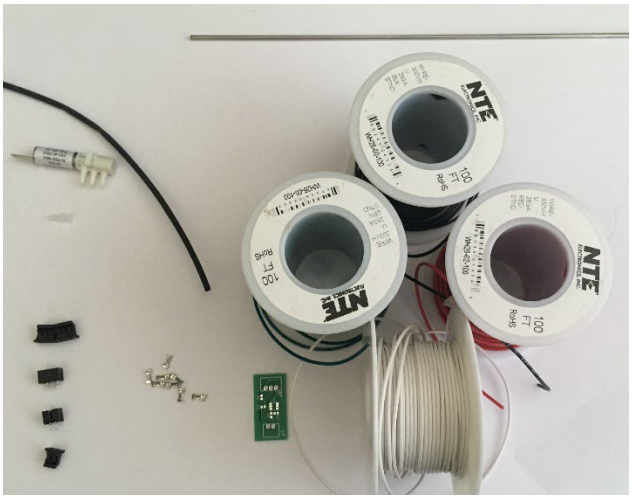

Figure 26 Materials for lick spout. Clockwise from top left: heatshrink tubing, steel tube, wire, lick sensor PCB, crimp terminals, headers and receptacles, 1/16" plug, solenoid valve. Not pictured: lick spout mount, rail carrier, screw, nut, and washer.

1. Create connector cable between capacitive lick sensor PCB and joystick PCB

- Cut three electrode wires, a ground wire (black), a 5V wire (red), and a lick signal wire (white), about 1 foot long. Color coding is recommended.
- Braid the wires together
- Strip the both ends of the wires to about 1/16”, and add crimp terminals to both ends.
- Insert the three crimp terminals on each end into 3-pin receptacles in the order shown in Figure 27.
- Add dental acrylic to the back side of the receptacle to secure the wires, and cure.

Figure 27 Lick spout PCB connector cable. Left: Completed cable. Right: close-up of receptacle wire order (same for both ends)

2. Create the lick spout

- Use a Dremel with a cutting wheel or a hacksaw to cut the steel tubing to 2 1/16” long. It’s easier to cut it accurately if you leave a little extra, then

grind it down to the right length with a Dremel or other tool. Note: The ends of the tube need to be flat (perpendicular to the tube), rather than angled/pointed.

- Use a fine file to smooth the ends of the tube. Any burrs or sharp edges may cut the mouse's tongue. Checking the end for sharp parts under a microscope is recommended. See Figure 28 for the results of this step.

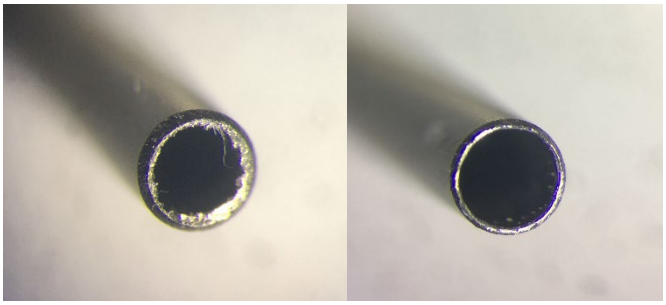

Figure 28 Lick spout end under a microscope. Left: before filing off burs and sharp edges. Right: After filing

3. Attach the lick spout tube to the mount

- Mark the spout tube 1.5" from one end with a fine marker.
- Use the mark to position the spout tube on the mount so 1.5" of the tube stick out from the mount.
- Fill the space between the tube and the mount with dental acrylic **only** along the triangular recess, **not** in the deeper cylindrical recess (the tubing will need to fit in that space).
- Position the spout precisely, and use scotch tape to hold it firmly in place.
- Cure the dental acrylic through the scotch tape, then remove the tape.
- Add extra dental acrylic to increase the strength of the joint, being careful not to add any in the cylindrical recess, and cure.
- See Figure 29 for a depiction of this process.

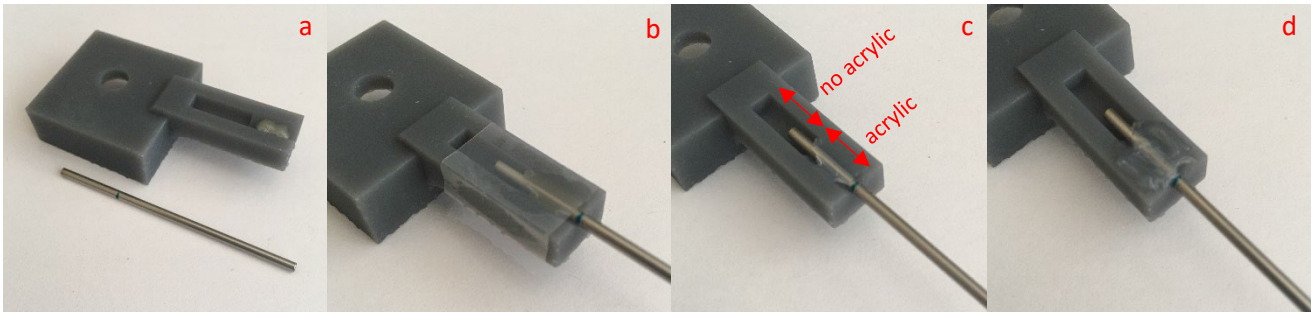

Figure 29 Attaching the spout tube to the mount. a) mark tube at 1.5" b) fill triangular area with dental acrylic, insert tube at 1.5", and cover with tape c) cure and remove tape d) add extra dental acrylic and cure

4. Create electrode leads for the water spout

- The water spout, which also serves as the touch sensitive electrode, will be connected to two wires, which will lead to the PCB.
- Cut two wires, about 3" long each. This may need to be longer depending on the details of how your rig is set up, but the shorter they are, the better the sensor will work, since the entire length of the cable will also be touch sensitive. Additionally, the spout will be less sensitive if the cables are longer.

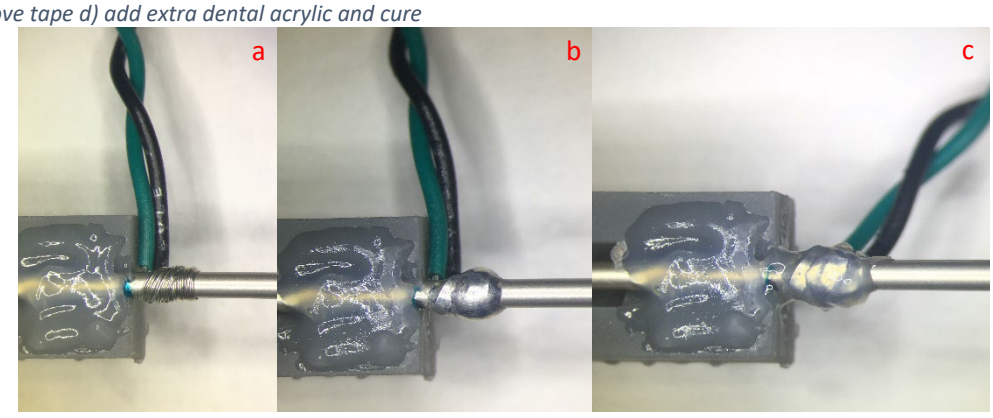

Figure 30 Attaching the electrode leads to the water spout. a) twist stripped ends of leads around spout b) using flux, solder wires onto spout c) add dental acrylic to solder joint

- Twist the two wires together.
- Strip the wires so one end of the wires is stripped to about 1/16”, and the other end is stripped to about 1/2".
- Wrap the bare wire ends of the 1/2" stripped side of the twisted pair around the lick spout tube right next to where it emerges from the mount.
- Paint some liquid flux over the area where the wires are wrapped around the tube.
- Apply a generous amount of solder to connect the twisted wire pair to the tube.
- Cover the wire/spout solder joint with dental acrylic or other adhesive to mechanically reinforce the connection.
- See Figure 30 for an illustration of this process.
- Add crimp terminals to the other ends of the twisted pair of electrode wires.
- Insert the crimped ends of the wires into the 2-pin receptacle (in any order).
- Add dental acrylic to the area where the wires enter the receptacle to provide extra mechanical strength.
- See Figure 17 for a depiction of the crimp terminal process.
- See Figure 31 for the finished water spout.
- N.B. It’s actually unnecessary to connect two separate wires to the spout – a single wire with the two pins shorted together at the connector or on the PCB itself is equivalent.

Figure 31 Finished mounted water spout. Note that ideally the length of the cable would be shorter than pictured – 2” or length is a good guideline

5. Add wires to solenoid valve

- Cut two wires to a length of approximately 1 foot each.
- Twist the wires together.
- Strip one side of the wires to about 1/4", and the other to about 1/16”
- Add a piece of heatshrink tubing to the 1/4" stripped end of each wire
- Solder the 1/4" stripped wires onto the solenoid valve. The solenoid valve is nonpolar, so the order of the wires is not important.
- Slide the heatshrink tubing over the solder joint, and shrink with a heat gun.
- See Figure 32 for an illustration of this process.
- Add crimp terminals to the other ends of the wire, and insert into the 3-pin receptacle as shown in Figure 32d. Note which receptacle slot is left empty (due to historical changes in design).
- See Figure 17 for a depiction of the crimp terminal process.
- See Figure 33 Solenoid valve with completed leads for the results of this step.

Figure 33 Solenoid valve with completed leads

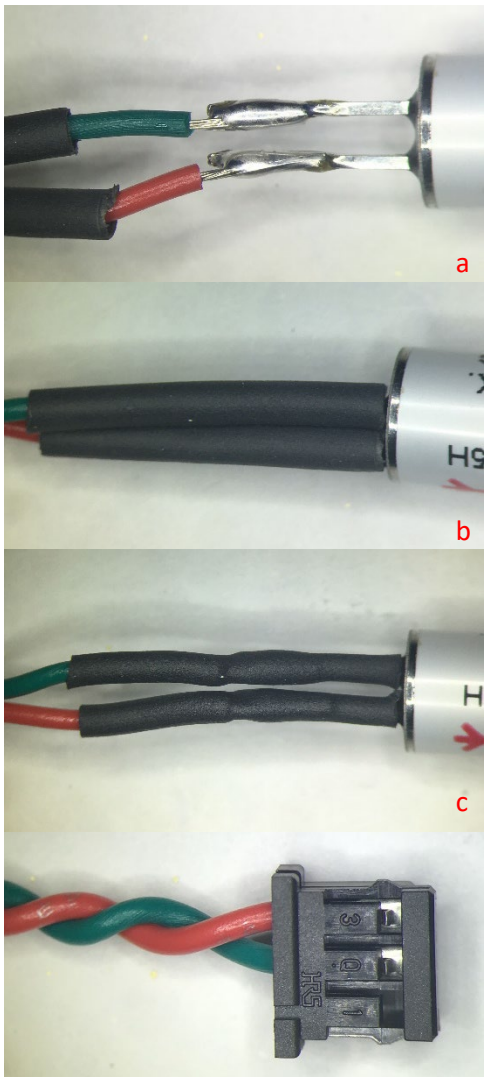

Figure 32 Adding leads to solenoid valve. a) solder b) slide on heatshrink c) shrink heatshrink d) insert receptacle - note which receptacle slot is empty

6. Add tubes to solenoid valve

- Cut an approximately 1” section of 1/16” tubing.
- Push the 1” piece of tubing onto the valve outlet closest to the wire terminals, then add a 1/16” plug to seal that outlet
- Cut two more lengths of tubing, one approximately 1 foot, the other approximately 2 feet.
- Push the two lengths of tubing onto the other two valve outlets (order doesn’t matter).
- To see the tubing connected to the solenoid valve, see Figure 36.

7. Connect the valve to the lick spout

- Push the free end of the 1-foot section of tubing from the valve onto the lick spout tube. Push the tubing as far on as possible.
- See Figure 34 for the results of this step

8. Add the connector for the reservoir

- Push the last free tube onto the female Luer x 1/16” hose barb adapter. This will connect to the bottom port on the water reservoir.

9. Solder components onto lick sensor board

- Solder the resistor, capacitors, IC chip, and headers onto the PCB
- See the parts list for the value of each labeled component on the PCB
- Note that the capacitor labeled C1 (referred to as the “sense capacitor” in the Atmel datasheet) controls the sensitivity of the lick sensor. We’ve found that 20 nF works well to accurately discriminate mouse tongue contact on the spout. If your application changes, C1 will need to be adjusted to fit the circumstances and desired sensor behavior. Higher values of C1 will result in a more sensitive electrode. With higher values of sensitivity, you may find the lick sensor registering a lick when the tongue passes nearby the electrode, even if it isn’t actually licking. With lower values of sensitivity, some licks may fail to register. It is fairly easy to desolder surface mount capacitors, so this value can be varied during calibration without remaking the entire PCB.
- See Figure 35 for the completed capacitive lick PCB.

10. Plug the electrode and the connector cable into the PCB

- Insert the electrode 2-pin receptacle into the 2-pin header on the PCB.
- Insert the 3-pin connector cable receptacle into the 3-pun header on the PCB.

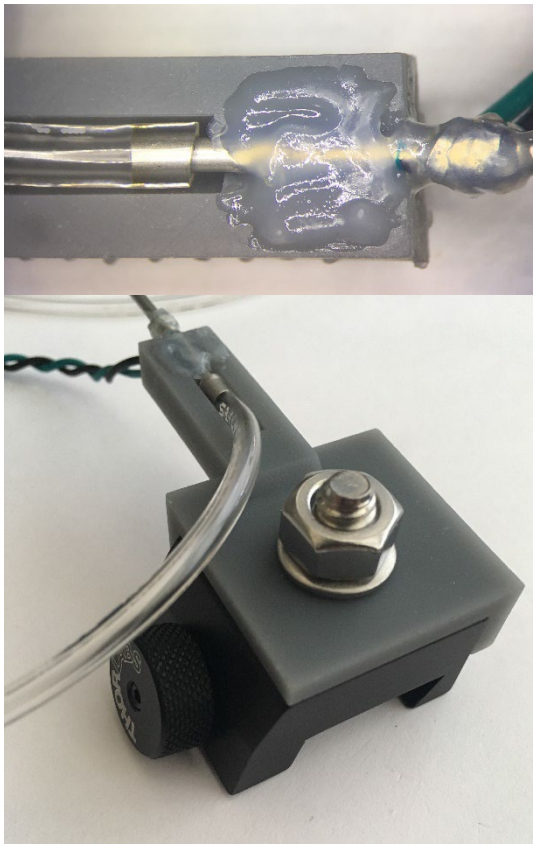

Figure 34 Tube connecting solenoid valve and lick spout. Top: Close-up of tube/spout connection

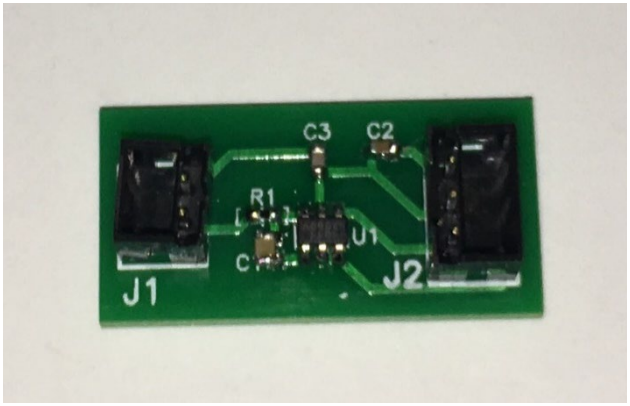

Figure 35 Lick sensor PCB with components soldered on.

11. Mount the lick spout on the rail carrier

- Place the lick spout mount on the rail carrier so the rail carrier is snug in the corner of the underside of the mount.
- Insert the 1/4"-20x5/8” screw into the underside of the rail carrier and through the hole in the mount, and secure with a washer and a nut.
- See Figure 36 for the finished lick spout, capacitive lick sensor, and solenoid valve.
- Note that this step and the next step are not relevant if you are constructing a 1D or 2D positionable spout – see “Part VI: **Error! Reference source not found.**” or “Part VIII: Constructing alternate 2D positionable spout mount for 2D double-step experiments”

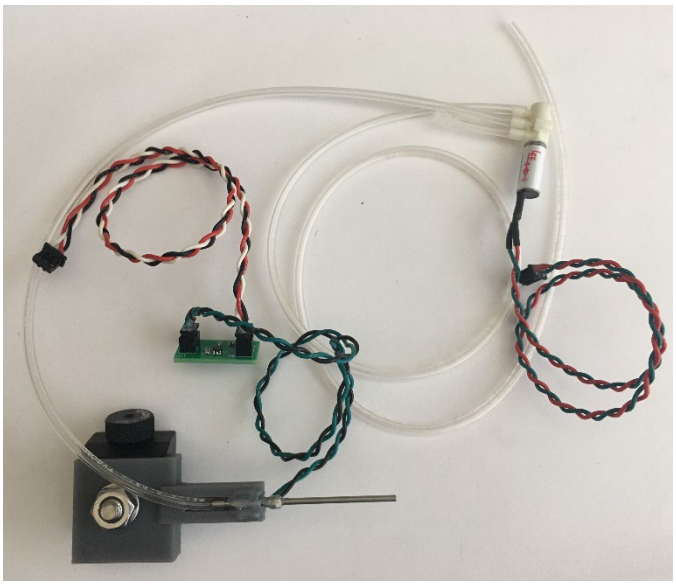

Figure 36 Completed lick spout, capacitive lick sensor, and solenoid valve, all connected. (male Luer

12. Add rail to mount lick spout

- Connect the bottom of the 3” graduated optical post to the 3” dovetail rail with a 1/4"-20x3/8” screw.
- See Figure 37 Lick spout mounting rail for the results of this step.
- Slide the lick spout rail carrier onto the 3” rail. Use the carrier thumbscrew to hold it in place.

Figure 37 Lick spout mounting rail

Part VI: Constructing an alternate electrophysiology-compatible analog lick sensor

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/ Supplier Part Number	Datasheet/Drawing/Modification
1	Op amp	Texas Instruments/Digikey	LM358ANNS	https://www.digikey.com/en/products/detail/texas-instruments/LM358AN-NOPB/54928
2	Voltage regulator, 5V	Traco Power/Digikey	1951-2747	https://www.digikey.com/en/products/detail/traco-power/TSR-1-2450/9383780
3	1.6 kΩ resistor	Stackpole/Digikey	CF14JT1K60CT	https://www.digikey.com/en/products/detail/stackpole-electronics-inc/CF14JT1K60/1741251
4	2.4 kΩ resistor	Stackpole/Digikey	CF14JT2K40TR	https://www.digikey.com/en/products/detail/stackpole-electronics-inc/CF14JT2K40/1741327
5	Perma-proto board, ¼ size	Adafruit/Digikey	1528-1101	https://www.digikey.com/product-detail/en/adafruit-industries-llc/1608/1528-1101-ND/5154676
6	Copper sheet, ~0.1mm thick, at least 3”x3”	Amazon	B0CGXLL2JD	https://www.amazon.com/uxcell-Copper-Sheet-Metal-1000mm/dp/B0CGXLL2JD/ref=sr_1_4
7	Screw terminal, 2 position	Digikey	ED10561	https://www.digikey.com/en/products/detail/on-shore-technology-inc/OSTVN02A150/1588862
8	Screw terminal, 3 position	Digikey	ED10562	https://www.digikey.com/en/products/detail/on-shore-technology-inc/OSTVN03A150/1588863
9	Spectra 360 Electrode Gel	Parker Laboratories/Amazon	B00AMGV010	https://www.amazon.com/Spectra-360-Electrode-Gel-Laboratories/dp/B00AMGV010
10	Solid jumper wire (~22 AWG)			

Building Instructions

General notes

The capacitive lick sensor described in “Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve” is not ideal for electrophysiology experiments, because it tends to cause large artifacts in the recordings when the mouse’s tongue contacts the spout.

These instructions are for building an alternate lick sensor which produces very little electrical interference for electrophysiology experiments. It is somewhat more difficult to use, since it requires the mouse to be well-grounded to a copper pad; they can replace Part V: 9 and 10.

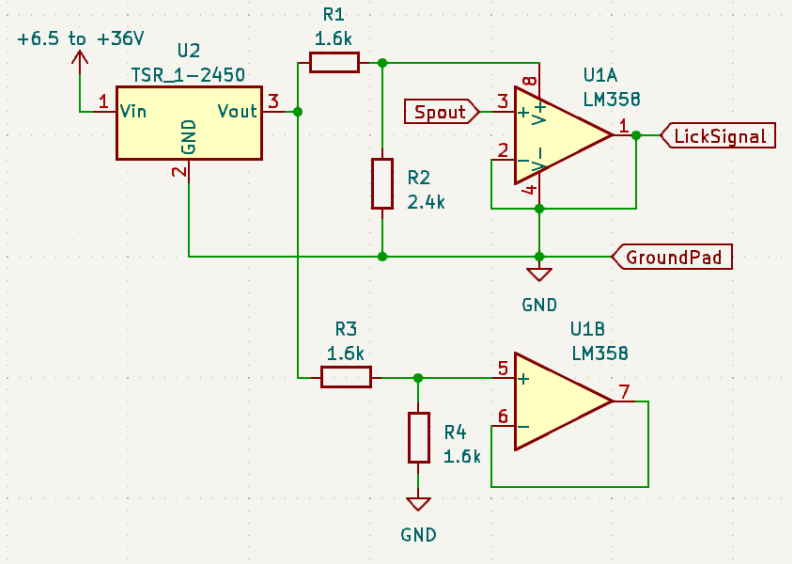

Figure 38 Schematic for electrophysiology-compatible analog lick sensor. Note that U1A and U1B are the two circuits in the dual op amp IC. The U1B circuit is not used, and is properly terminated.

The principle of operation is this: the mouse is held at 0 V by the copper ground pad. The spout is held at the supply voltage of the op amp by the input bias current from the op amp’s non-inverting input. When the mouse’s tongue touches the spout, it temporarily brings the spout voltage down closer to 0 V, then when the tongue withdraws,

the spout charges back up to the supply voltage. The supply voltage is set at the lowest possible value for the LM358, which is 3 V, so the electrical recording artifact is as small as possible.

Note that this lick sensor needs “debouncing”, meaning at each lick onset and offset there are often spurious onsets and offsets. A simple remedy for this is to, for example, ignore onsets that arrive unreasonably soon after the last offset.

Note also that an improved version of this sensor is currently being tested using a MOSFET op amp, which has almost no leakage current, and a reverse-biased Zener diode to charge the spout to an even lower voltage.

Finally note that it would be simpler and similarly effective to use a regulator that steps directly down to ~3V (such as Traco power TSR 1-2433), rather than use a voltage divider to further reduce the voltage to ~3V. We happened to have 5V regulators on hand, so to preserve fidelity to what we actually did, that is what is documented here.

Recommended tools: Soldering iron, wire strippers, sand paper

1. Solder together components onto proto board
   - See Figure 39
2. Solder a lead onto the copper ground pad
   - Cut a piece of wire to approximately 8” long; it needs to reach from the mouse to wherever the lick sensor board will be on the rig, and strip both ends.
   - Somewhere in the back corner of the copper sheet, where it won’t interfere with the mouse, choose a spot to solder on a wire lead
   - Clean, then rough up the spot with sandpaper to remove any dirt, oils, and corrosion
   - Using a generous amount of flux, solder one end of the wire to the copper sheet
   - See Figure 40
3. Tape the copper pad onto the acrylic platform between the restraint walls
   - Make sure the tape won’t prevent the mouse from making good contact with the copper sheet.
   - See Figure 41
4. Connect components electrically
   - Using the screw terminals, connect the copper ground pad lead, the + and - power inputs, the spout wire, and the lick signal output to the circuit board.

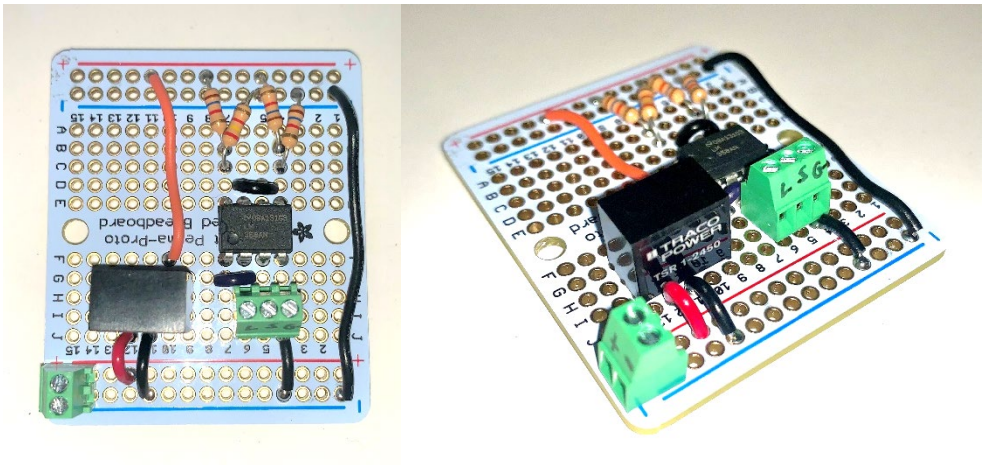

Figure 39 Ephys compatible lick sensor circuit board

Figure 40 Copper ground pad with soldered lead

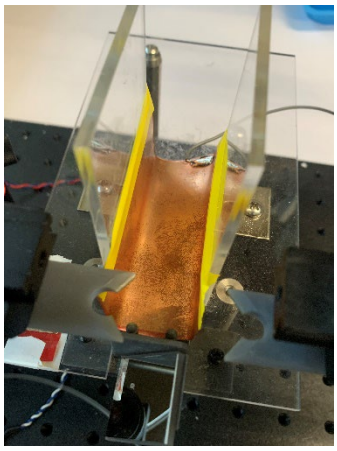

Figure 41 Ground pad installed on the rig

Part VII: Constructing alternate 1D positionable spout mount for 1D double-step experiments

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer /Supplier Part Number	Datasheet/Drawing/Modification
1	Linear motor mount	3D printed	N/A (Custom made)	
2	Positionable lick spout mount	3D printed	N/A (Custom made)	
3	1/2" Graduated Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 3"	Thorlabs	TR3E	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR3E
4	8-32x3/8” screw			
5	Linear DC Servomotor	Faulhaber / Micromo	LM0830-015-01	https://www.faulhaber.com/en/products/series/lm-083001/
6	Linear Motor Controller	Faulhaber / Micromo	MCLM3006 S RS	https://www.faulhaber.com/en/products/series/mclm-3006-s/
7	LM0830 flexboard adapter	Micromo	6501.00117	
8	LM0830 flexboard adapter cable	Micromo	6501.00118	
9	DC power supply (12V – 30V, 5+ A)			
10	M1.2 x 3mm screw, non-magnetic recommended x4			
11	M1.6 x 5mm screw, non-magnetic recommended			
12	M1.6 x 3mm screw, non-magnetic recommended			
13	Small washer, non-magnetic (approximately M1.6)			
14	M3 x 5mm screw x4			
15	Guide rail (with included fasteners)	McMaster-Carr	6725K43	https://www.mcmaster.com/6725K43-6725K31/
16	Guide rail carriage	McMaster-Carr	8438K3	https://www.mcmaster.com/8438K3/
17	M3 hex nut			
18	M3 x 10 mm screw (optional)			
19	Stranded, insulated wire, approximately 26 AWG, two different colors			
20	BNC female x solder cup connector	Amphenol / Digikey	ARFX1905	https://www.digikey.com/product-detail/en/amphenol-rf-division/031-10-RFXG1/ARFX1905-ND/2643384
21	BNC male x male connector	Amphenol / Digikey	ARFX1070	https://www.digikey.com/product-detail/en/amphenol-rf-division/31-218-RFX/ARFX1070-ND/160252
22	Heatshrink tubing			

Building Instructions

General notes

This section describes the construction of an alternate motorized 1-dimensional linear positioning spout mounting system for double-step experiments. This section replaces parts of "Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve" if a linearly positionable spout is needed instead of a static one. This section does not describe how to construct or connect the solenoid valve or lick sensor, as the process is essentially identical. Refer to the other section for that information.

Figure 42 Spout mount with spout attached

Caution: Never allow the actuator shaft to come out of the linear motor housing – doing so may release the bearings and destroy the motor. Never allow the carriage to come off of the guide rail – doing so likewise may release the bearings.

Recommended tools: Very fine flathead screw driver (~1.4mm)

1. Create the lick spout

- Refer to the procedure in "Part V: 2. Create the lick spout"

2. Attach the lick spout to the mount

- Refer to the procedure in "Part V: 3. Attach the lick spout tube to the mount", using the positionable spout mount instead of the regular spout mount.
- See Figure 42 for the results of this step.

Figure 43 Motor mount with optical post attached

3. Attach the optical post to the linear motor mount

- Insert the 8-32 screw into one of the motor mount mounting holes.
- Screw the optical post onto the threaded end of the screw protruding below the motor mount.
- See Figure 43 for the results of this step.

4. Mount the guide rail onto the motor mount

- Slide the guide rail into the slot in the motor mount until the end mounting hole lines up with the small hole on the motor mount. You may need to clear 3D printing blemishes from the motor mount using a file or flush cutters. Try to keep the guide rail clean and clear of dust and debris.
- Insert one of the included guide rail screws into the end hole in the guide rail, so it protrudes through the small hole on the motor mount, and screw on the M3 hex nut onto the protruding end and tighten.

Figure 44 Motor mount with guide rail installed. Left: Top view. Right: Bottom view.

Note that the included guide rail fasteners are just barely long enough – it may be helpful, though not necessary, to purchase a slightly longer M3 x 10 mm screw.

- See Figure 44 for the results of this step.

5. Mount the linear motor on the motor mount

- Hold the flat side of the linear motor up to the mounting panel on the motor mount, so the four mounting holes line up, and the flex cable is pointing backwards (away from the motor mount).
- Screw the four M1.2 screws through the four mounting holes on the mounting panel into the linear motor and tighten.
- Carefully remove the plastic cap on the back side of the linear motor shaft – DO NOT ALLOW THE SHAFT TO COME OUT OF THE MOTOR HOUSING.
- Insert the M1.6 x 3mm screw into the small washer, then screw it into the back of the linear motor shaft. This will prevent the shaft from accidentally exiting the motor housing in one direction.
- See Figure 45 for the results of this step.

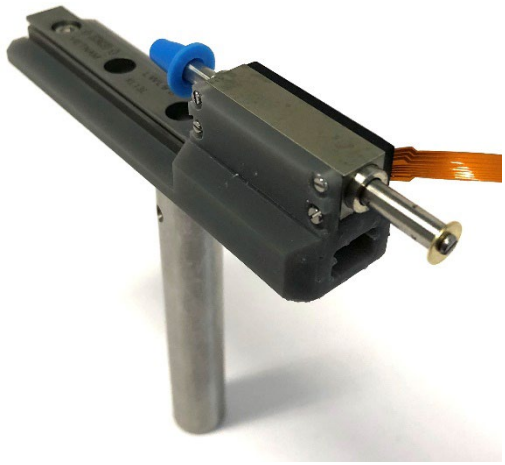

Figure 45 Motor mount with motor installed.

6. Attach the spout mount onto the guide rail carriage

- Unwrap the carriage, but DO NOT remove the plastic guide rail – doing so may release the bearings from the carriage.
- Hold the spout mount onto the carriage so the four mounting holes line up.
- Screw at least two M3 x 5mm into the mounting holes and tighten.
- See Figure 46 for the results of this step.

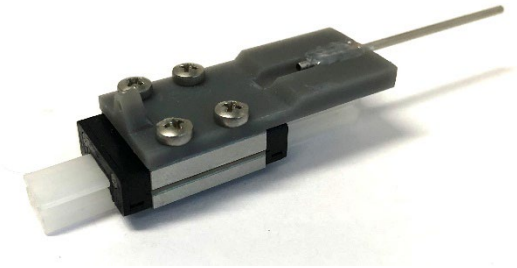

Figure 46 Spout mount attached to guide rail carriage

7. Install the carriage onto the guide rail and motor shaft

- Match the end of the plastic placeholder rail (which the carriage is packaged on) up to the guide rail on the motor mount, so the two guide rails are collinear.
- Carefully slide the carriage off the plastic guide rail and onto the metal guide rail with the spout pointing away from the motor – make sure not to allow the bearings to escape the carriage while transferring it from the plastic guide rail to the metal guide rail.
- Insert the M1.6 x 5mm screw into the shaft mounting hole on the spout mount, and screw it firmly into the end of the motor shaft, securing the carriage to the motor shaft.
- See Figure 47 for the results of this step.

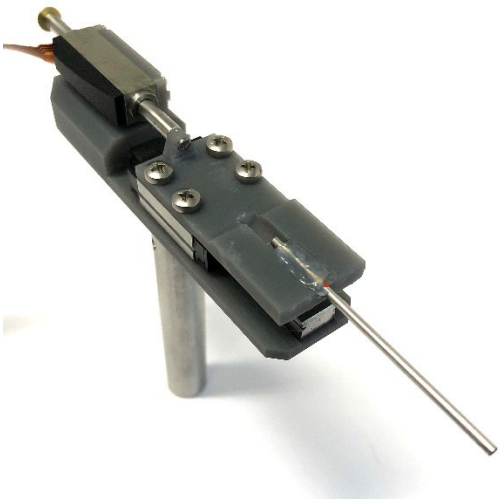

Figure 47 Carriage installed on guide rail and attached to motor shaft

8. Connect the motor controller to the motor

- Gently insert the “flexboard” (the orange flat flexible connector on the motor) into the flexboard adapter by pulling the compression collar out, inserting the end of the flexboard into the collar, and pushing the compression collar back in. Make sure the bare metal contacts on the flexboard are facing down towards the green PCB when inserting.

- Plug the black receptacle on one end of the flexboard adapter cable onto the pins on the adapter board. Make sure the small key on the black receptacle is facing away from the green PCB (compare the colored wire positions in Figure 48 to confirm correct orientation)
- Insert the free ends of the colored wires of the flexboard adapter cable into the screw terminals on the motor controller. It is very important that the correct color wires go into the correct screw terminals on the motor controller. Connecting them incorrectly may damage the motor or controller. See Figure 48 for the correct order.
- See Figure 48 for the results of this step.

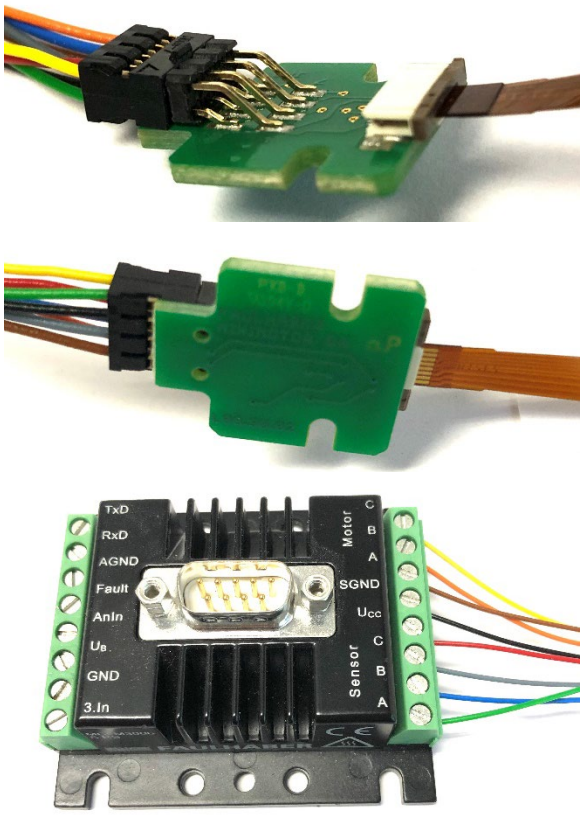

Figure 48 Top to bottom: Flexboard adapter top view, bottom view, and motor controller connections

9. Connect the motor controller to power and control signal source

- The motor controller has screw terminals labeled “GND” and “U_B”. Connect these to the ground and positive connections respectively on an appropriate power supply (as per the MCLM 3006 technical manual, 12V – 30V, 5A or higher)
- The motor controller has screw terminals labeled “GND” and “AnIn”. When assembling the entire system, connect the FPGA analog output (the BNC output) to the GND and AnIn screw terminals on the motor controller to allow the FPGA to send an analog control signal to the motor controller.
- Use the BNC solder cup, the BNC M x M connector, stranded insulated wire, and heatshrink tubing to make a cable that can connect from the FPGA BNC output to the motor controller screw terminals.

10. Complete the rest of the steps to build and attach the lick sensor and solenoid valve.

- See “Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve”, steps 1, 4, 5, 6, 7, 8, 9, and 10.

Part VIII: Constructing alternate 2D positionable spout mount for 2D double-step experiments

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer /Supplier Part Number	Datasheet/Drawing/Modification
1	Linear motor mount x2	3D printed	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/ba9c37c076680f8113f53b5dc9c8878031db508f/DesignFiles/Positionable%20spout%20-%201D
2	Cross motor mount connector	3D printed	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/ba9c37c076680f8113f53b5dc9c8878031db508f/DesignFiles/Positionable%20spout%20-%202D
3	Positionable lick spout mount	3D printed	N/A (Custom made)	https://github.com/GoldbergLab/HeadFixedLickHardware/tree/ba9c37c076680f8113f53b5dc9c8878031db508f/DesignFiles/Positionable%20spout%20-%201D
4	1/2" Graduated Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 3"	Thorlabs	TR3E	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR3E
5	8-32x3/8” screw			
6	Linear DC Servomotor x2	Faulhaber / Micromo	LM0830-015-01	https://www.faulhaber.com/en/products/series/lm-083001/
7	Linear Motor Controller x2	Faulhaber / Micromo	MCLM3006 S RS	https://www.faulhaber.com/en/products/series/mclm-3006-s/
8	LM0830 flexboard adapter x2	Micromo	6501.00117	
9	LM0830 flexboard adapter cable x2	Micromo	6501.00118	
10	DC power supply (12V – 30V, 5+ A)			
11	M1.2 x 3mm screw, non-magnetic recommended x8			
12	M1.6 x 5mm screw, non-magnetic recommended x2			
13	M1.6 x 3mm screw, non-magnetic recommended x2			
14	Small washer, non-magnetic (approximately M1.6) x2			
15	M3 x 5mm screw x6			
16	M3 x 18mm screw x2			
17	Guide rail (with included fasteners) x2	McMaster-Carr	6725K43	https://www.mcmaster.com/6725K43-6725K31/
18	Guide rail carriage x2	McMaster-Carr	8438K3	https://www.mcmaster.com/8438K3/
19	M3 hex nut x2			
20	M3 x 10 mm screw (optional) x2			
21	Stranded, insulated wire, approximately 26 AWG, two different colors			
22	BNC female x solder cup connector x2	Amphenol / Digikey	ARFX1905	https://www.digikey.com/product-detail/en/amphenol-rf-division/031-10-RFXG1/ARFX1905-ND/2643384

#	Part Description	Manufacturer/ Supplier	Manufacturer /Supplier Part Number	Datasheet/Drawing/Modification
23	BNC male x male connector x2	Amphenol / Digikey	ARFX1070	https://www.digikey.com/product-detail/en/amphenol-rf-division/31-218-RFX/ARFX1070-ND/160252
24	Heatshrink tubing			

Building Instructions

General notes

This section describes the construction of an alternate motorized 2-dimensional linear positioning spout mounting system for double-step experiments. This section replaces parts of "Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve", if a 2-dimensional linearly positionable spout is needed instead of a static or 1D one. It is based on the instructions in "Part VI: Constructing an alternate electrophysiology-compatible analog lick sensor". This section does not describe how to construct or connect the solenoid valve or lick sensor, as the process is essentially identical, and it does not describe how to mount the motor, rail, or carriage. Please refer to the other sections for that information.

In this section we will create two motor mounts, one to control motion in the medial-lateral (ML) direction, and one to control motion in the anterior-posterior (AP) direction. The AP motor mount will be mounted on top of the ML motor mount, and they will be connected by the 3D printed cross motor mount connector.

Recommended tools: Very fine flathead screw driver (~1.4mm)

1. Create the lick spout

- Refer to the procedure in "Part VI: 2. Create the lick spout"

2. Assemble the ML motor mount with the optical post

- See Part VI: 3, 4, and 5.
- Do not attach the spout mount.

3. Attach the cross motor mount connector to the carriage, and install the carriage on the guide rail and motor shaft

- Refer to Part VI: 7 for general instructions for installing the carriage.

4. Attach the second linear motor mount to the top of the cross motor mount connector

- The second (AP) motor mount will be at a right angle to the first (ML) motor mount.

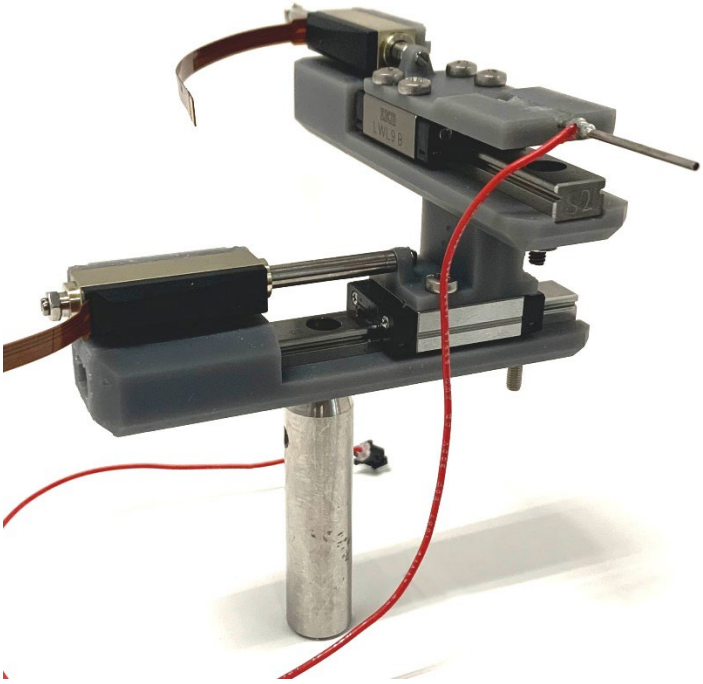

Figure 49 Completed 2D positionable spout

- Use the two M3 x 18mm screws to fasten the AP motor mount through the cross motor mount connector down into the ML carriage.

5. Mount the guide rail and motor to the AP motor mount
   - See Part VI: 4 and 5.
6. Attach the lick spout to the carriage, and install the carriage on the AP guide rail and motor shaft.
   - See Part VI: 6 and 7.
   - See Figure 49 for an image of the assembled 2D spout mount
7. Connect the two motor controllers to the two motors and connect each controller to power and control signal source
   - Refer to Part VI: 8 and 9 for instructions
8. Complete the rest of the steps to build and attach the lick sensor and solenoid valve.
   - See “Part V: Constructing the lick spout with capacitive lick sensor and solenoid valve”, steps 1, 4, 5, 6, 7, 8, 9, and 10.

Part IX: Assembling the underside viewing mirror

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	High-Permeability Magnetic Shielding Foil	Thorlabs	MSFHP	https://www.thorlabs.com/thorproduct.cfm?partnumber=MSFHP
2	1" x 1" Protected Silver Mirror	Thorlabs	PFSQ10-03-P01	https://www.thorlabs.com/thorproduct.cfm?partnumber=PFSQ10-03-P01

Building Instructions

General notes

The underside viewing mirror is a mirror that can be placed on the mirror mount to allow a side-mounted camera to see both the side view of the mouse's head and tongue and, simultaneously, the view from underneath. Because typically only one rig can be in the camera at a time, but many rigs can be training mice at the same time, the mirror was designed to be detachable. The mirror easily attaches to the rig with magnets when recording video.

Figure 50 Completed mirror, showing the back side with the magnetic foil applied.

Recommended tools: Scissors, bench-top vise

1. Prepare the magnetic backing

- Cut an approximately 0.75" x 0.75" square of magnetic shielding foil.
- Sandwich the foil between two flat pieces of metal, and press in a vise to completely flatten it. *Note: any bumps or bends in the foil will cause the mirror angle to differ from 45°, changing the underside view angle.*
- Peel off the backing – avoid bending the foil.
- Stick the backing onto the non-reflective back of the mirror. The foil should not stick out on any edge of the mirror.
- See Figure 50 for the results of this step.

2. Install mirror

- When recording video, the mirror can by placed and positioned by simply putting it on the mirror mount. The magnets embedded in the mirror mount will hold the foil in place.

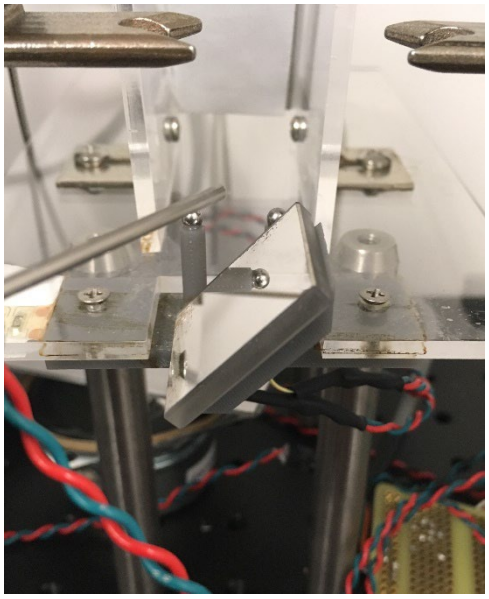

Figure 51 Mirror placed on mirror mount on head-fixed rig

Part X: Building the masking light

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	LED light strip	Amazon	B01980IN56	https://www.amazon.com/KAPATA-Waterproof-Superbright-100cm-Strip/dp/B01980IN56/
	LED light strip (alternate equivalent product)	Amazon	B08LR6PQK8	https://www.amazon.com/KXZM-Flexible-Brightness-460-465nm-No-Waterproof/dp/B08LR6PQK8/ref=sr_1_1_sspa
2	2-pin receptacle	Hirose/Digikey	DF3-2S-2C	https://www.digikey.com/product-detail/en/DF3-2S-2C/H2083-ND/141479
3	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
4	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF
5	Stranded, insulated wire, ~26 AWG			

Building Instructions

General notes

The masking light is an LED with wires and a 2-pin connector. It plugs into the joystick board and will be attached to the homecage above the lick port. Its purpose is to prevent mice from visually discriminating between trials when the optogenetic laser is on or off due to laser light leaking from the cannula.

Recommended tools: soldering iron, wire strippers, needlenose pliers, knife

Figure 52 Materials for masking light. Clockwise from top left: wire, heatshrink tubing, crimp terminals, 2-pin receptacle, LED light strip

1. Cut one LED unit off of the strip

- Cut one of the LED units off of the strip along the printed divider lines.
- Peel and cut away the tiny bit of the plastic coating on the edge of the LED unit that covers the copper terminals marked “+” and “-“.
- See Figure 54 for the results of this step.

2. Solder wires onto the LED

- Cut, twist together, and strip two wires approximately 18” long each
- Solder one end of each wire onto the exposed terminals on the LED unit marked “+” and “-”. Color coding is recommended. See Figure 55.
- Coat the exposed junction with epoxy or dental acrylic to insulate and strengthen the joint.
- See Figure 55 for the results of this step.

3. Add receptacle

- Add crimp terminals to the two stripped ends of the wires
- Insert the crimped ends of the wires into the 2-pin receptacle in the order shown in Figure 56.

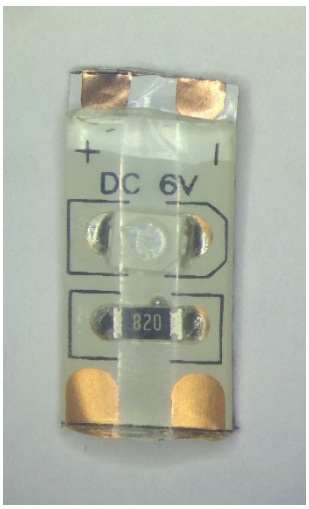

Figure 54 LED unit cut from strip, with terminals exposed

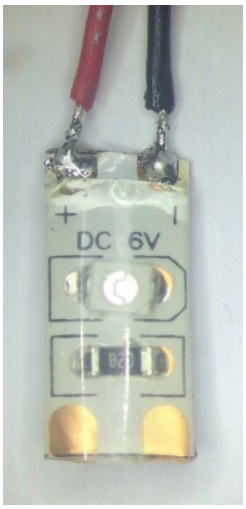

Figure 53 LED with wires soldered onto terminals. Note that the terminals are marked "+" and "-" to indicate 5V and GND.

Figure 55 LED with terminals coated

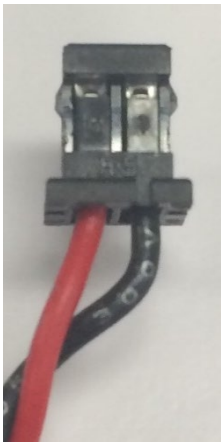

Figure 56 Receptacle for LED

Figure 57 Completed masking light

Part XI: Constructing the audio cue system

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Speaker for Classic Mouse Chamber	Med Associates Inc.	ENV-324M	https://www.med-associates.com/product/cage-speaker-for-classic-mouse-chamber/
2	Multiple Tone Generator	Med Associates Inc.	ENV-223	https://www.med-associates.com/product/multiple-tone-generator/
3	1/4 Sized Perma-Proto Breadboard	Adafruit	1608	https://www.adafruit.com/product/1608
4	NPN Transistor	Micro Commercial Co/Digikey	2N3904	https://www.digikey.com/product-detail/en/micro-commercial-co/2N3904-AP/2N3904-APCT-ND/950591?utm_adgroup=Semiconductor%20Modules&gclid=EAIaIQobChMIpO3hideR2gIVFFcNCh0mPwH6EAAYASAAEgIVBvD_BwE
5	2 kΩ resistor, axial lead	Stackpole Electronics Inc./Digikey	CF14JT2K00TR	https://www.digikey.com/product-detail/en/stackpole-electronics-inc/CF14JT2K00/CF14JT2K00TR-ND/1741368
6	3-pin receptacle	Hirose/Digikey	DF3-3S-2C	http://www.digikey.com/product-detail/en/DF3-3S-2C/H2084-ND/141482
7	Small jumper wire			

Building Instructions

General notes

The audio cue system provides an audible tone to cue the mouse that the lick spout is active. A simple transistor circuit allows the DAQ to switch the audio tone on and off. See Figure 61 for a schematic of this circuit.

Recommended tools: Wire stripper, soldering iron, needlenose pliers

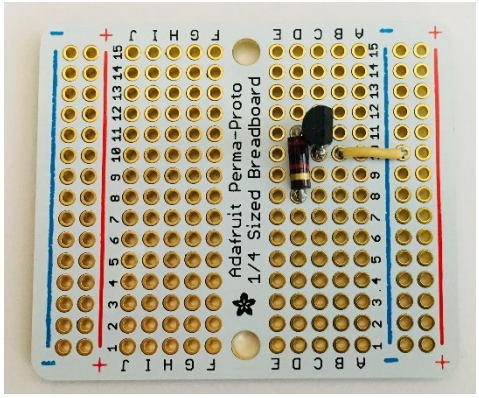

Figure 58 Breadboard with resistor, transistor, and jumper wire soldered

1. Solder the resistor, transistor, and jumper wire

- Solder the jumper wire into the negative bus and row 10
- On the breadboard, solder the transistor emitter (left pin if the flat side faces you) into row 10, the base (center pin) into row 11, and the collector (right pin) into row 12.
- Solder the resistor into pins 8 and 11
- Trim the excess wire from the underside. See Figure 58 for the results of this step.

2. Create a connector cable

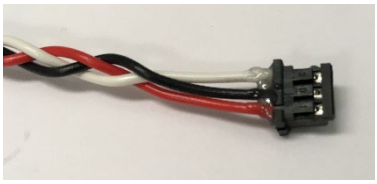

Figure 59 Connector cable end. Note the order of the wires in the receptacle.

- Cut three wires about 6” long. Color coding is recommended – red=5V, black=ground, white=signal.
- Braid three wires together
- Strip one end of each wire to about 1/4", and the other end to about 1/16”
- Solder the longer stripped side of the cables into the breadboard, red wire onto the positive bus row, black wire onto the negative bus row, and white wire onto row 8
- Add crimp terminals to the other end of each of the three wires
- Insert the crimp terminals into the 3-pin receptacle in the order shown in Figure 59.
- Add some dental acrylic to the back of the receptacle to secure the terminals in place.

3. Solder the tone generator leads onto the breadboard

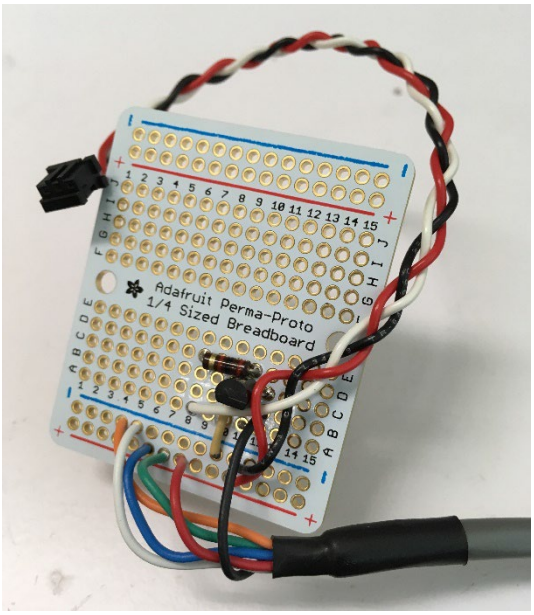

Figure 60 Completed breadboard for audio cue system

- Cut off any connectors at the end of the cable coming out of the tone generator, removing as little wire as possible, so there is plenty to work with.
- The blue, green, orange, and white wires can each be connected to ground or 5V to control the frequency of the tone generated. The combination described below should generate a 3.5 kHz tone. See the ENV-223 manual for other combinations.
- The wires are color coded. Solder them as follows:
    - Black wire onto row 12
    - Red, green, and blue wires onto positive bus row
    - Orange and white wires onto negative bus row
- See Figure 60 for the results of this step.

4. Plug in the speaker

- The speaker has an audio plug – insert it into the audio jack on the tone generator
- Note that the volume can be adjusted with a small flathead screwdriver.
- See Figure 62 for the completed audio cue system.

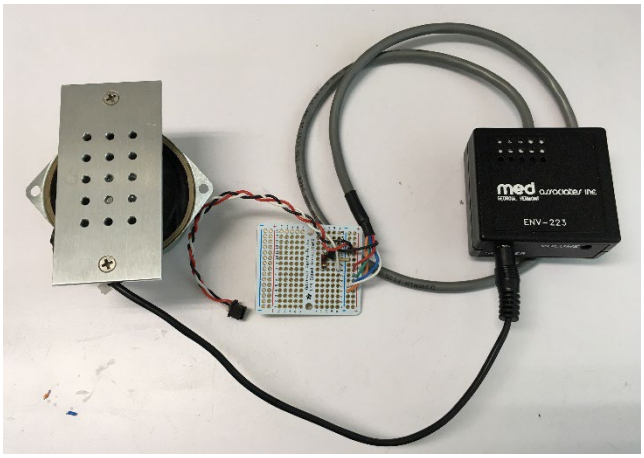

Figure 62 Completed audio cue system

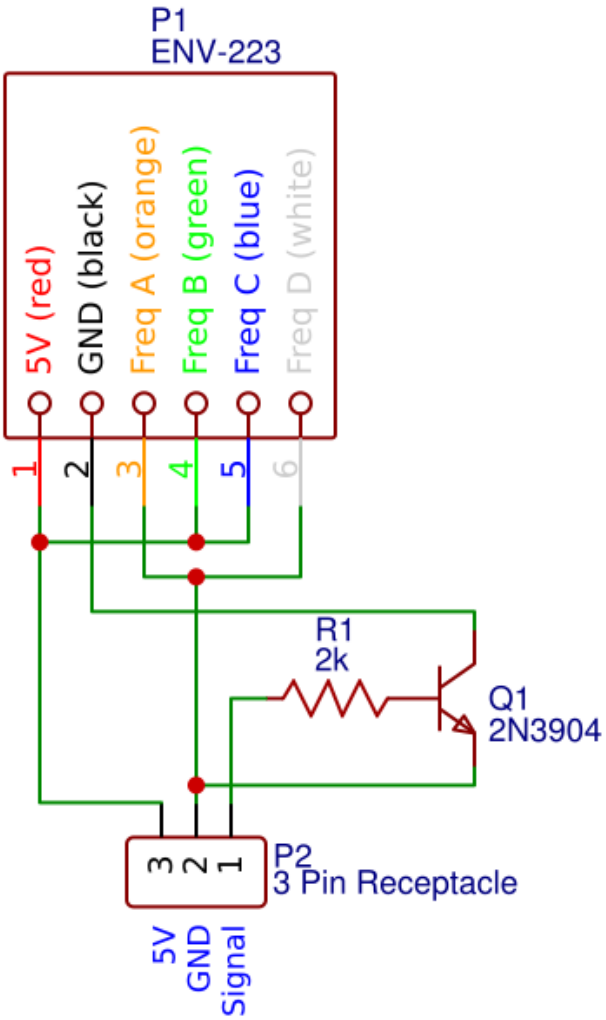

Figure 61 Schematic for audio cue circuit

Part XII: Building a joystick board

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Joystick PCB	Custom made using Pad2Pad	N.A. (Custom made)	
2	Capacitor, 10 pF, SMT x2	Samsung/Digikey	1276-2154-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C100JB8NCNC/1276-2154-1-ND/3890240
3	Capacitor, 1 nF, 0603 case x3	Samsung/Digikey	1276-1091-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C102JB8NNNC/1276-1091-1-ND/3889177
4	Capacitor, 10 nF, SMT x4	Samsung/Digikey	1276-1103-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B103JB8NNNC/1276-1103-1-ND/3889189
5	Capacitor, 0. 1 µF (100 nF), 0603 case	Samsung/Digikey	1276-6998-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B104KO8ZW6C/1276-6998-1-ND/7320640
6	Capacitor, 0.22 µF, radial leads	Samsung/Digikey	1276-1996-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B223JB8NNNC/1276-1996-1-ND/3890082
7	Capacitor, 0.47 µF, 0402 case x2	Samsung/Digikey	1276-2082-1-ND	https://www.digikey.com/en/supplier-centers/s/samsung-electro-mechanics-america
8	Resistor, 160 Ω, 0402 case	Vishay-Dale/Digikey	541-160YCT	https://www.digikey.com/product-detail/en/vishay-dale/CRCW0402160RFKEDHP/541-160YCT-ND/2825954
9	Resistor, 1 kΩ, 0402 case x5	Panasonic/Digikey	P1.00KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF1001X/P1.00KLCT-ND/97341
10	Resistor, 2.6 kΩ, 0402 case	Panasonic/Digikey	P2.61KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF2611X/P2.61KLCT-ND/194243
11	Resistor, 3.3 kΩ, 0402 case x2	Rohm/Digikey	RHM3.3KCDCT	http://www.digikey.com/product-detail/en/MCR01MRTF3301/RHM3.3KCDCT-ND/4083740
12	Resistor, 9 kΩ, 0402 case	Panasonic/Digikey	P9.10KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF9101X/P9.10KLCT-ND/17467224

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
13	Resistor, 22 kΩ, 0402 case	Panasonic/Digikey	P22KJCT	http://www.digikey.com/product-detail/en/ERJ-2GEJ223X/P22KJCT-ND/146939
14	Op Amp IC, SMT	TI/Digikey	LM358	https://www.digikey.com/product-detail/en/texas-instruments/LM358DR/296-1014-1-ND/404838
15	Voltage regulator	STMicroelectronics/ Digikey	L7805CV	https://www.digikey.com/product-detail/en/stmicroelectronics/L7805CV/497-1443-5-ND/585964
16	Touch sensor IC, SMT x2	Atmel/Digikey	AT42QT1011	http://www.atmel.com/images/Atmel-9542-AT42-QTouch-BSW-AT42QT1011_Datasheet.pdf
17	Transistor x2	Micro Commercial Co/Digikey	2N3904	https://www.digikey.com/product-detail/en/micro-commercial-co/2N3904-AP/2N3904-APCT-ND/950591?utm_adgroup=Semiconductor%20Modules&gclid=EAIaIQobChMIpO3hideR2gIVFFcNCh0mPwH6EAAYASAAEgIVBvD_BwE
18	2-pin header x4	Hirose Electric/Digikey	DF3A-2P-2DSA	http://www.digikey.com/product-detail/en/DF3A-2P-2DSA/H2094-ND/141512
19	3-pin header x2	Hirose Electric/Digikey	DF3A-3P-2DSA	http://www.digikey.com/product-detail/en/DF3A-3P-2DSA/H2095-ND/141515
20	4-pin header	Hirose Electric/Digikey	DF3A-4P-2DSA	http://www.digikey.com/product-detail/en/DF3A-4P-2DSA/H2096-ND/141518
21	DB-9 connector, male, through hole	Amphenol/Digikey	A34064-ND	https://www.digikey.com/product-detail/en/te-connectivity-amp-connectors/5747871-2/A34064-ND/1123840
22	DB-15 connector, female, RA through hole	Amphenol/Digikey	17EBH-015-S-AM-0-10	https://www.digikey.com/product-detail/en/amphenol-commercial-products/17EBH-015-S-AM-0-10/17EBH-015-S-AM-0-10-ND/1242549
23	Heat sink	Wakefield-Vette/Digikey	345-1022	https://www.digikey.com/product-detail/en/wakefield-vette/273-AB/345-1022-ND/340320
24	Heat sink compound, Silicone (type Z9)	GC Electronics	10-8109	http://www.gcelectronics.com/order/DataSheets/10-8109%2010-8108%2010-8107-10%2010-8107-100%2010-8106%20Silicone%20(Z9).pdf
25	Screw, 4-40x3/8” with nut			

Building Instructions

General notes

The joystick board collects and conditions the signals from the various sensors, and passes the resulting signals to the DAQ. The board was developed for an experiment involving a rodent joystick, and although this setup does not involve a rodent joystick, most of the other sensors are the same, so the same board can be used.

If soldering, especially surface mount soldering, is new to you, there are many guides available on the internet.

Recommended tools: Soldering iron, helping hands

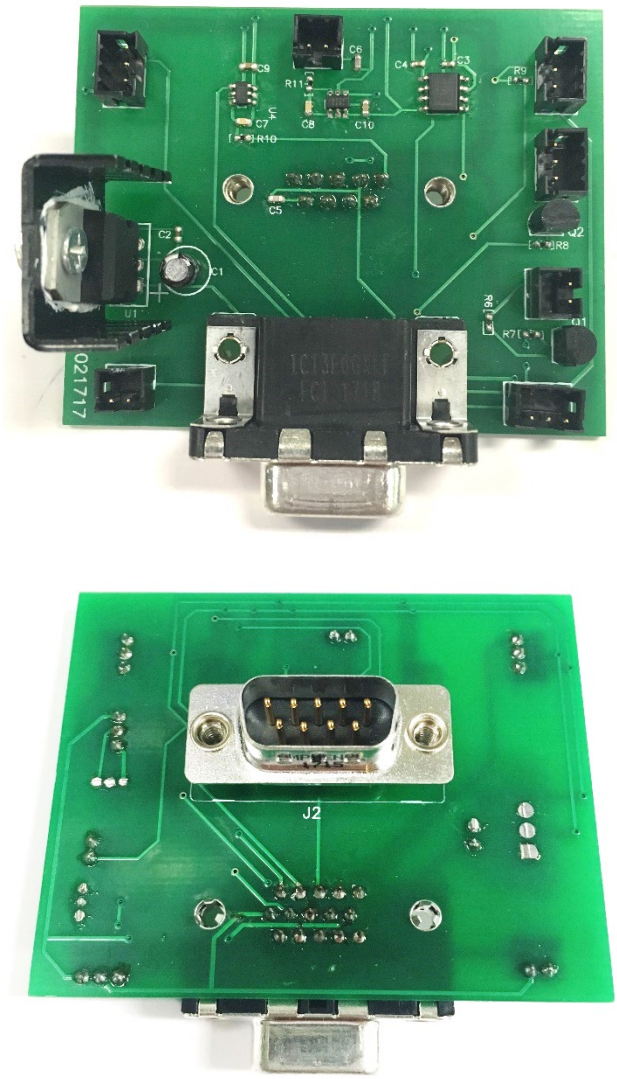

Figure 63 Completed joystick board. Top: Front side. Bottom: Back side.

1. Soldering the SMT components

- C2 = 0.1 uF
- C3 = 1 nF
- C4 = 1 nF
- C5 = 10 pF
- C6 = 10 pF
- C7 = 10 nF
- C8 = 10 nF
- C9 = 0.47 uF
- C10 = 0.47 uF
- R6 = 3.3 kΩ
- R7 = 1 kΩ
- R8 = 1 kΩ
- R10 = 1 kΩ
- R11 = 1 kΩ
- R9 = 22 kΩ
- U2 = Op amp IC – *note: the orientation is important here!*
- U4 = Touch sensor IC – *note: the orientation is important here!*
- U5 = Touch sensor IC – *note: the orientation is important here!*

2. Soldering the through-hole components

- C1 = 0.22 uF – *note: the orientation is important here!*
- U1 = Voltage regulator – *note: the orientation is important here!*
- Q1 = Q2 = Transistor – *note: the orientation is important here!*
- J5 = J7 = J9 = 2-pin header
- J3 = J4 = J6 = J8 = 3-pin header
- J2 = DB-9 connector (solder on **back** of board)
- J1 = DB-15 connector

3. Add heatsink

- Dab a small amount of heatsink compound onto the heatsink.
- Using a 4-40 screw and nut, firmly attach the heatsink to the voltage regulator using the hole on the regulator chassis.
- See Figure 63 for the completed joystick board.

Part XIII: Building an adapter for the joystick board

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	DB-9 Female Receptacle Solder Cup	Norcomp/Digikey	209FE-ND	https://www.digikey.com/product-detail/en/norcomp-inc/171-009-203L001/209FE-ND/858108
2	Heatshrink tubing			
3	Stranded, insulated wire, ~26 AWG			
4	2-pin header	Hirose Electric/Digikey	DF3A-2P-2DSA	http://www.digikey.com/product-detail/en/DF3A-2P-2DSA/H2094-ND/141512

Building Instructions

General notes

Note that this step is only necessary if your rig will use touch-sensitive posts as paw-rests for the mouse. If you are omitting them, then you can skip this step (see Constructing the touchposts and mirror mount)

Since the joystick board was originally designed to attach to a rodent joystick with a capacitive ball touch sensor, but this setup does not include a joystick, we will need a small adapter to connect the second capacitive ball electrode to the joystick board. The joystick board could be redesigned to accommodate two touch posts, which would obviate the need for this adapter.

Recommended tools: Soldering iron, heat gun, needlenose pliers, helping hands

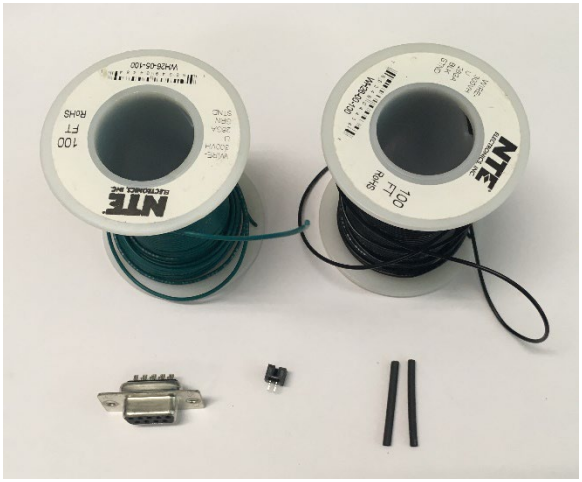

Figure 64 Materials for joystick board adapter. Clockwise from top left: Wire, heatshrink tubing, 2-pin header, female to solder cup DB-9 connector

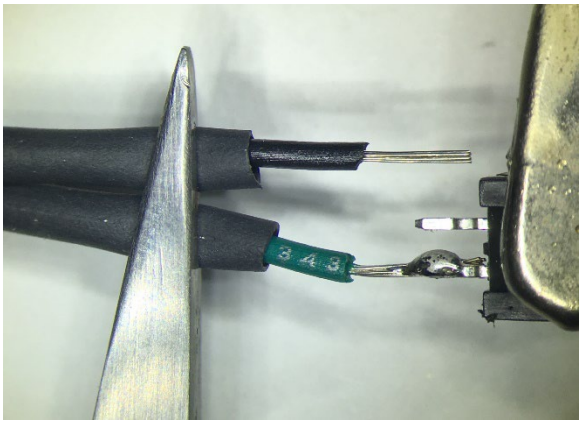

Figure 65 Soldering wires to 2-pin header

1. Prepare the leads

- Cut two wires about 6” long
- Twist them together and strip the ends, about 1/8” on both sides
- Slide a piece of heatshrink tubing onto each of the ends on one side of the wires in preparation for the next step

2. Connect the header

- Solder the heatshrink-side of each of the wires onto each of the two header pins. *Note: the plastic housing the header pins tends to melt if exposed to soldering iron heat for extended periods of time.*
- Slide the heatshrink tubing over the solder joint and shrink with a heat gun.
- See Figure 65 for an illustration of this process

3. Connect the DB9

- Add a piece of heatshrink tubing to the other end of each wire
- Fill the solder cups #1 and #9 on the DB9 connector (if you look closely, you can see pin numbers next to the cups)
- Remelt the solder and insert the two wires into solder cups #1 and #9
- Push the heatshrink tubing over the solder cup and shrink with a heat gun
- See Figure 67 for the finished adapter.

Figure 66 Header connected to wire leads

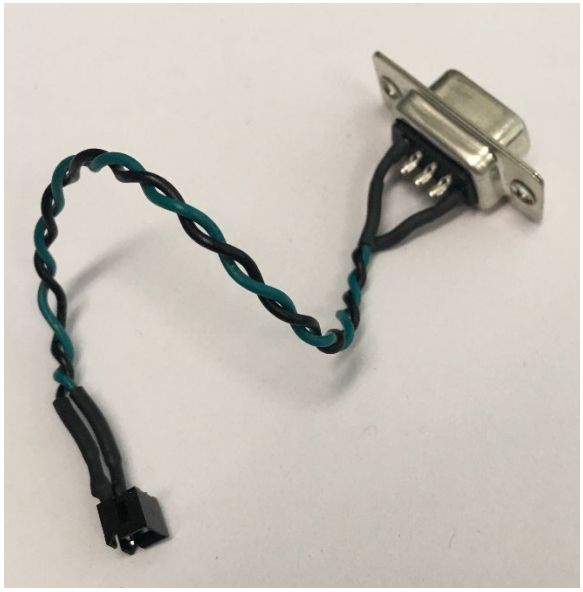

Figure 67 Completed joystick board adapter for second touch post

Part XIV: Building restraint walls and back support

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	White fun foam 9" X 12" X 1/16" thick	Cleverbrand Inc./Amazon	4336848947 / B01HIMLUGA	https://www.amazon.com/WHITE-FUN-FOAM-THICK-PACK/dp/B01HIMLUGA/ref=asc_df_B01HIMLUGA/
2	Acrylic wall panels x2	Custom made with laser cutter (see Figure 71)	N/A (Custom made)	N/A
3	Aluminum back support (rectangular, 1” x 1 5/8” x 1/4")	Custom made – any rigid material should work	N/A	N/A
4	Metal brackets x2	McMaster-Carr	15275A51	https://www.mcmaster.com/15275A51/
5	4-40x3/8” screws x2			
6	4-40 nuts x2			
7	Superglue (Loctite 401)	Loctite	401	http://www.loctite.sg/sea/content_data/93806_NEWCA401EN.pdf

Building Instructions

General notes

To maintain the mouse’s body orientation during head-fixing, two side walls are mounted on top of the platform on either side of the mouse, and a back support fits between them.

Recommended tools: Screwdriver, adjustable crescent wrench, scissors

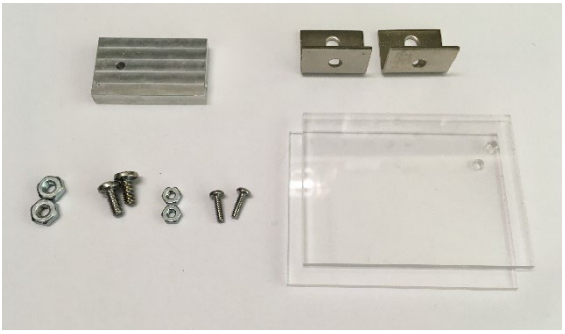

Figure 68 Materials for restraint walls and back support. Clockwise from top left: aluminum back support, brackets, side wall panels, 4-40x3/8” screws, 4-40 nuts, 8-32x3/8” screws, 8-32 nuts. Not pictured: Foam sheet

4. Attach brackets to the side walls

- Attach the hole side (as opposed to slot side) of one of the brackets to the hole in one of the side walls. See Figure 70 for the correct orientation.
- Attach the other bracket to the other wall oriented in mirror image to the other wall.

5. Construct the back support

- Cut pieces of foam sheet the same size as the front, back, and two long edges of the back support rectangle.
- Use superglue to affix the foam to the rectangle.
- The foam makes the back support more comfortable for the mouse, and also makes it possible to wedge the back support firmly between the walls.
- See Figure 69 for the results of this step.

Figure 69 Completed back support

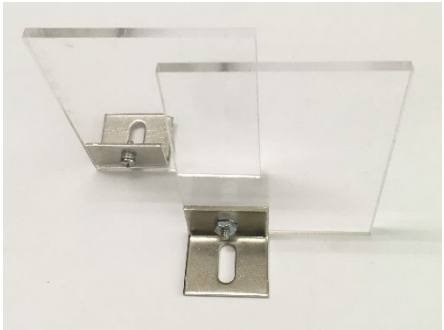

Figure 70 Side walls with brackets attached. Note that the long dimension of the wall is vertical, that the slot side of the bracket is down, and that the two walls are mirror images of each other.

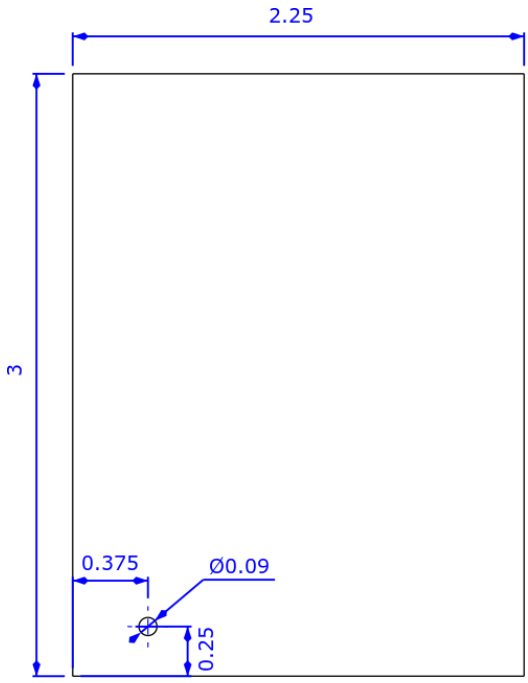

Figure 71 Wall dimensions, in inches

Part XV: Final assembly of the rig

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Head-fixed rig base			See Constructing the rig base
2	Head-fixing assemblies (left and right)			See Constructing the head-fixing assemblies
3	Touchposts and mirror mount			See Constructing the touchposts and mirror mount
4	Water reservoir			See Constructing the water reservoir
5	Lick spout, lick sensor, and solenoid valve			See Constructing the lick spout
6	Mirror with magnet mount			
7	Masking light			See Building the masking light
8	Audio cue system			See Constructing the audio cue system
9	Joystick board			See Building a joystick board
10	Joystick board adapter for second touchpost			See Building an adapter for the joystick board
11	Side walls and back support			See Building restraint walls and back support
12	1/2" Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 2"	Thorlabs	TR2	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR2
13	8-32x3/8” screws x5			
14	8-32 nuts x5			
15	4-40x3/8” screws x2			
16	4-40 nuts x2			
17	1/4"-20x3/8” screw			
18	Tape			

Building Instructions

General notes

See Figure 77 for a diagram of where all the components plug into the joystick board.

9. Mount restraint walls

- Set the two restraint walls with brackets so the bracket slots are over the two mounting holes in the platform and the brackets face outwards.
- Insert 8-32x3/8” screws into the bracket slots and the platform holes.
- Add 8-32 nuts loosely onto the 8-32x3/8” screws.
- Position the walls so they are centered on the platform, and the back support fits snugly between them, then tighten the 8-32 screws.
- The walls must be positioned so the back support can just be wedged between them.

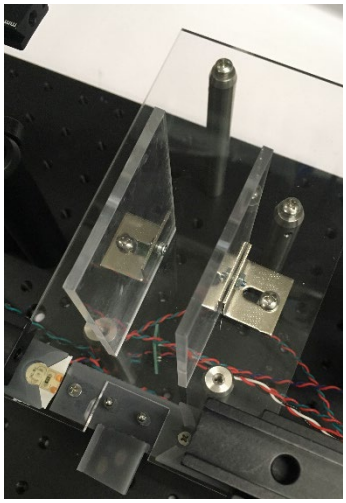

Figure 72 Side walls installed on platform

10. Mount touchposts and mirror mount on platform

- Use 4-40x3/8” screws and nuts to mount the touchposts and mirror platform in the rectangular cutout in the front of the platform. The touchpost panel should be mounted **below** the platform.
- Plug the joystick board adapter into the DB-9 connector in the back of the board.
- Plug one of the touchposts into the adapter, and the other into the joystick board. See Figure 77 for the correct positions on the joystick board.
- See Figure 74 for the results of this step.

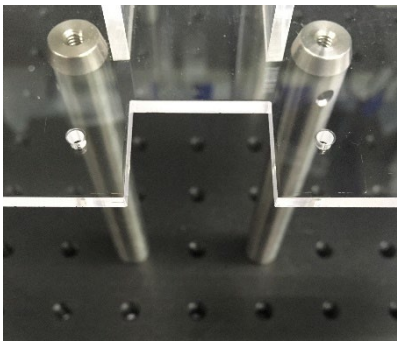

Figure 73 Platform ready for touchposts and mirror mount platform

11. Mount water reservoir

- Remove the screw and backing for the water reservoir mounting mechanism that comes with the water bottle. They won’t be used.
- Insert an 8-32x3/8” screw into the water reservoir mount, and start an 8-32 nut on the screw, but leave it at the end of the screw – do not tighten it.
- Slide the nut into the front-facing slot on the construction rail.
- Position the mount at the top of the rail, and tighten the screw firmly to hold the mount in place.
- Insert the water reservoir into the mount and lock it in.
- See Figure 75 for the results of this step.

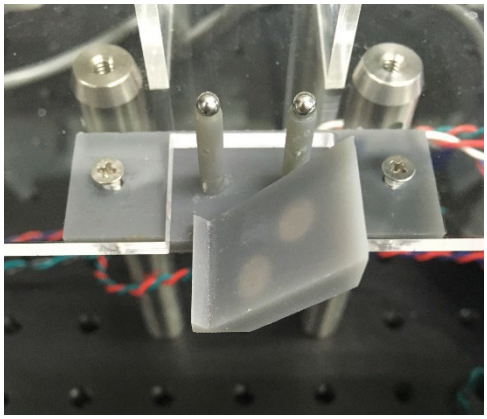

Figure 74 Touchposts and mirror mount installed

12. Install and connect lick spout assembly

- Insert the end of the lick spout optical post into the 3” post holder on the rotation stage on the rig base. Use the thumbscrew to hold the post in place.
- Plug the lick sensor connector cable into the joystick board. See Figure 77 for the correct position on the joystick board.

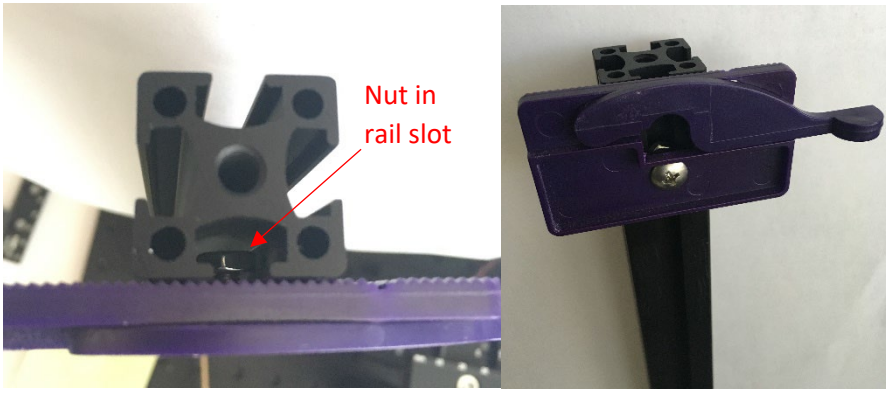

Figure 75 Water reservoir mount attached to construction rail

13. Add audio system

- Place the speaker on the rig base breadboard near the platform. Put the tone generator and circuit board out of the way on the back area of the rig base, and run the connector cable around the back.
- Connect the connector cable to the joystick board. See Figure 77 for the correct position on the joystick board.

14. Connect lick spout to water reservoir and joystick board

- Plug the solenoid connector cable into the joystick board. See Figure 77 for the correct position on the joystick board.
- Slide the unconnected end of the tube from the solenoid valve onto the bottom outlet of the water reservoir.

15. Connect the masking light

- Tape the masking light onto the underside of the platform right next to the touchpost panel. The light needs to be easily visible from the mouse's point of view.
- Plug the masking light cable into the joystick board. See Figure 77 for the correct position on the joystick board.

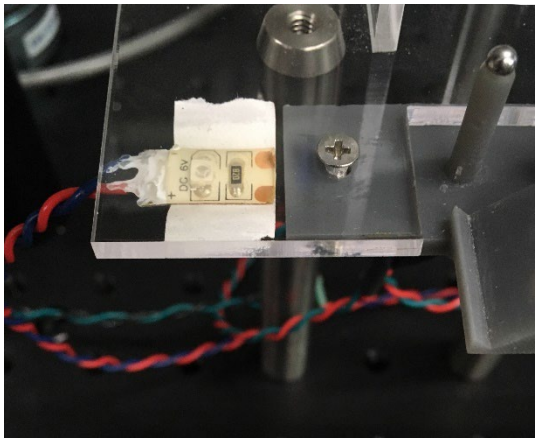

Figure 76 Masking light installed

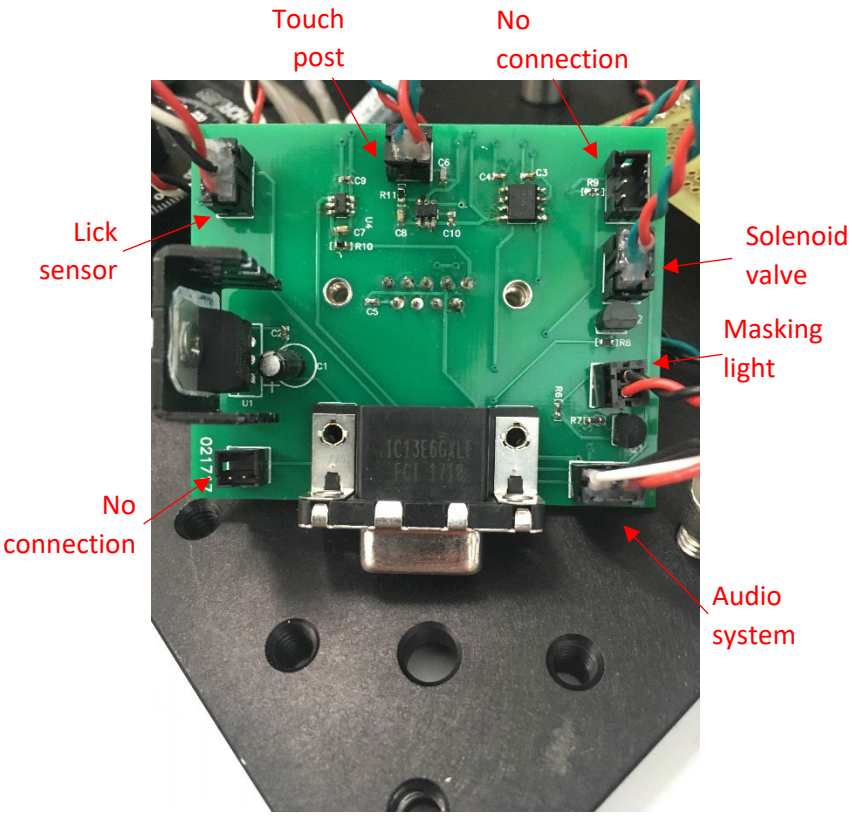

Figure 77 Joystick board connections for the head-fixed rig. The second touchpost connects to the DB-9 adapter cable, which attaches in the back of the joystick board.

Part XVI: Building the optogenetic system

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Doric Laser Diode Fiber Light Source, 2 channel, 450 nm	Doric	LDFLS_450/075_450/075	http://doriclenses.com/life-sciences/laser-diode-fiber-light-sources/910-laser-diode-fiber-light-source-2-channel-model.html#/ld_wavelengths-450_nm_75_mw/ld_wavelengths_2-450_nm_75_mw
2	Fiber commutator	Doric	FRJ_1x2i_FC-2FC	http://doriclenses.com/life-sciences/fiber-optic-rotary-joints/809-1x2-fiber-optic-rotary-joints-intensity-division.html
3	Mounting plate for commutators	Custom made with laser cutter	N.A. (Custom made)	
4	Fiber optic cable, male to male SMA	Thorlabs	FG200UCC 200um 0.22NA	https://www.thorlabs.com/thorproduct.cfm?partnumber=FG200UCC
5	Fiber optic cable, male SMA to ferrule insert			
6	Commutator mounting bracket	Doric	Holder_FRJ_large	http://doriclenses.com/life-sciences/holders-for-rotary-joints/819-holder-for-frj1x2-frj1x4-erj-aerj-hrj-oe-and-ledfrj-1ch.html
7	1/4”-20 x 1” screws			
8	1/4”-20 nuts			

Building Instructions

General notes

The optogenetic system consists of a laser light source, optical fibers, and a commutator/splitter. The light is sent via fiber optic cable to one or two fiber optic cranial implants on a mouse. Although the mouse is head-fixed and does not need to be able to rotate, the commutator doubles as a laser light splitter, allowing us to illuminate two brain regions simultaneously; since we already use the commutators in freely moving experiments it’s easy for us to use them for head-fixed experiments as well. It would work just as well to use a cheaper light splitter instead of a commutator. The commutator mounts on a custom plate that sits in the rack above each homecage.

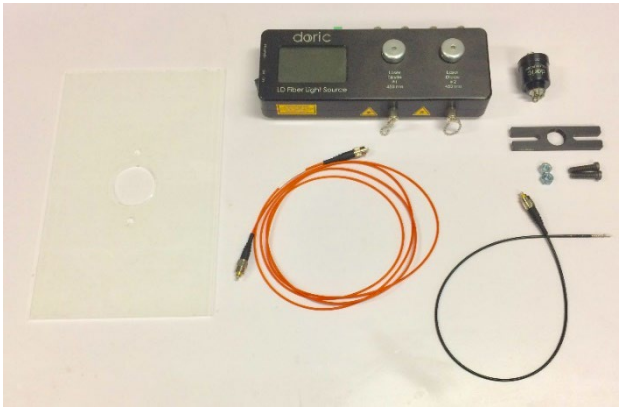

Figure 78 Optogenetic system materials. Clockwise from top left: Custom mounting plate, laser light source, commutator, commutation mounting bracket, 1/4"x20 bolts and nuts, fiber optic cable (black, male SMA to ferrule), fiber optic cable (orange, male to male)

1. Screw commutator into mounting bracket

- See Figure 79 for the results of this step.

2. Bolt bracket to custom mounting plate

- Use the 1/4"x20 bolts and nuts to fix the commutator roughly in the middle of the opening in the plate.
- Note that the bracket should go on top, so in the unlikely event that the screws loosen and come out, the commutator will not fall.

- See Figure 80 for the results of this step.

3. Connect the fiber optic cables.

- The male-male cable should go on top (the non-rotating port). The other end of this cable will connect to the laser light source.
- The male-ferrule cable should go on the bottom (the rotating port). The other end of this cable will connect to the implant.
- See Figure 82 for the results of this step.

Figure 79 Commutator screwed into bracket

4. Use tape to hold excess cable in place

- Take the extra fiber optic cable that connects the laser to the commutator and coil it on the top of the mounting plate.
- Use tape to fix the coil in position so it won't shift during the experiment.
- Note that changes in the radius of curvature of the fiber optic cable during the experiment will cause the light power level reaching the implant to change.
- See Figure 81 for the results of this step.

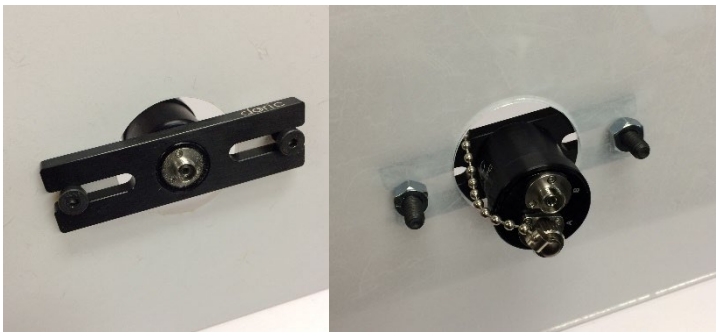

Figure 80 Commutator and bracket mounted to custom plate. Left: View from top. Right: View from bottom

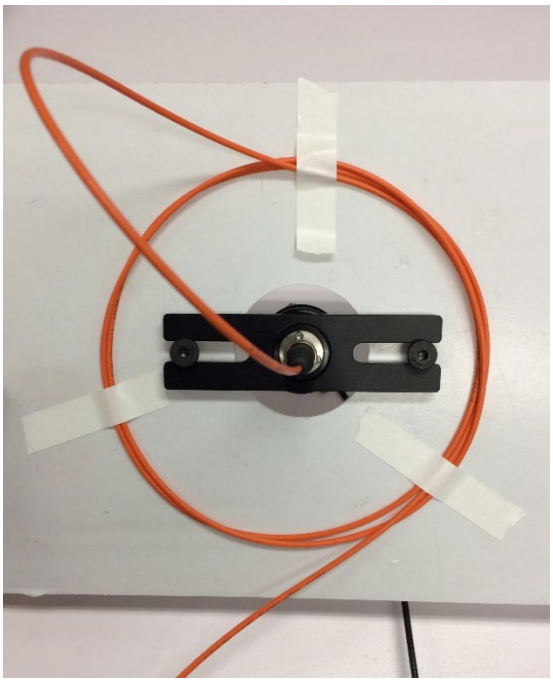

Figure 81 Cable management

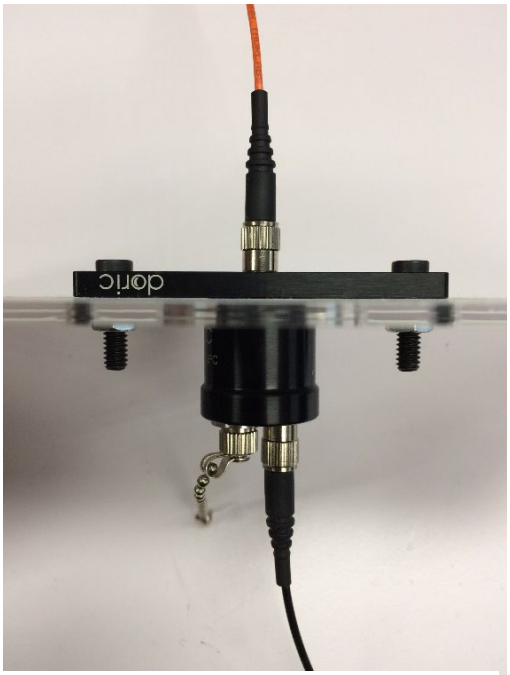

Figure 82 Fiber optic cables connected

Part XVII: Building the RIO breakout board

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	RIO breakout board		N.A. (Custom Made)	
2	15 Position D-Sub, High Density Plug, Male Pins Connector x4	Digikey	181-215RME	https://www.digikey.com/product-detail/en/norcomp-inc/181-015-113R561/181-215RME-ND/1767724
3	BNC Connector Jack, Female Socket 50 Ohm Panel Mount, Through Hole, Right Angle Solder x4	Digikey	ARF1065	https://www.digikey.com/product-detail/en/amphenol-rf-division/31-5431/ARF1065-ND/80179
4	Thermistors, surface mount x28	Digikey	PRF18BB471QB5RB	https://www.digikey.com/product-detail/en/murata-electronics-north-america/PRF18BB471QB5RB/490-8499-1-ND/4380762
5	Schottke Diodes, surface mount x28	Digikey	TBAT54S	https://www.digikey.com/product-detail/en/toshiba-semiconductor-and-storage/TBAT54SLM/TBAT54SLMCT-ND/6109133
6	50 pin ribbon cable header x2			
7	20-22 AWG wires for power x2			

Building Instructions

General notes

The RIO breakout board is a component of the DAQ system. It plays two roles – protecting the analog and digital IO ports of the expensive sbRIO board, and routes the sbRIO IO channels into four groups and connects them to DB-15 and BNC receptacles so they can be easily connected to the homecages and laser light sources. Each RIO breakout board services a single sbRIO board, and supports up to four homecages.

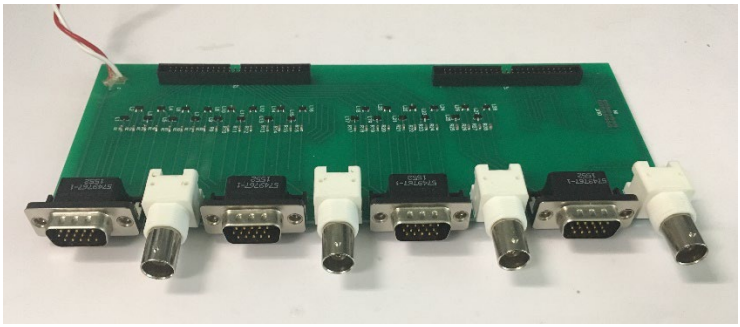

Figure 83 Completed RIO breakout board

1. Solder the SMT components
2. Solder the through-hole components
3. Cut and strip power wires
   - Cut and strip two wires, about 1 foot each.
   - Color coding is recommended – color scheme used here: red=high, white=low
   - Solder into power connection through holes in RIO breakout board.
   - See Figure 83 for the completed breakout board.

Part XVIII: Building the data acquisition system (DAQ)

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Single board RIO		sbRIO-9636	http://sine.ni.com/nips/cds/view/p/lang/en/nid/210421
2	Completed RIO breakout board		N.A. (Custom Made)	
3	50-pin IDC ribbon cables x2	National Instruments		
4	RIO power connector (NI Minfit Pigtail 2C 12 inches)		152834A01	
5	Wire, 18-22 AWG			
6	4-40x3/8” screws x49			
7	4-40x1/4” screws x3			
8	4-40 nuts x8			
9	4-40 x 1/2" spacers x3			
10	4-40 x 1” spacers x3			
11	Heatshrink tubing			
12	Enclosure (Rackmount Chassis 19" 2U 84HP 340MM) with custom front panel openings		20860127	https://www.digikey.com/product-detail/en/schroff/20860127/1439-1130-ND/4209859
13	Power supply		P37-15T	http://www.polytrondevices.com/products/power-modules/linear-encapsulated-power-modules
14	Universal power cord x2		03130	https://www.cablestogo.com/product/03130/6ft-18-awg-universal-power-cord-nema-5-15p-to-iec320c13-taa-compliant
15	Panel mount power receptacle with switch		76400003	http://www.qualtekusa.com/images/AC_Receptacles/pdfs/76400003.pdf
16	Panel mount Ethernet receptacle			
17	DB-15 cables, CNC Tech x4		731-10061-00200	https://www.digikey.com/product-detail/en/cnc-tech/731-10061-00200/1175-1157-ND/3064888
18	Completed homecage x4			
19	Control & storage computer			
20	Ethernet cable, ~1 foot			
21	Ethernet cable, long enough to reach network access point			
22	LabVIEW 2013			
23	Rodent VI LabVIEW software			

Building Instructions

General notes

The data acquisition system consists of single-board RIO DAQ from National Instruments, which has a large array of digital and analog input/output (IO) channels, a custom PCB that protects and distributes those channels, an enclosure for the DAQ, DB-15 cables to connect the DAQ to each homecage, and a control/storage computer which controls the DAQ via LabVIEW software, and stores the sensor data it receives. Each DAQ system can host up to eight head-fixed rigs, or two high speed video head-fixed rigs. See Figure 84 for the training rig schematic, and Figure 85 for the video rig schematic.

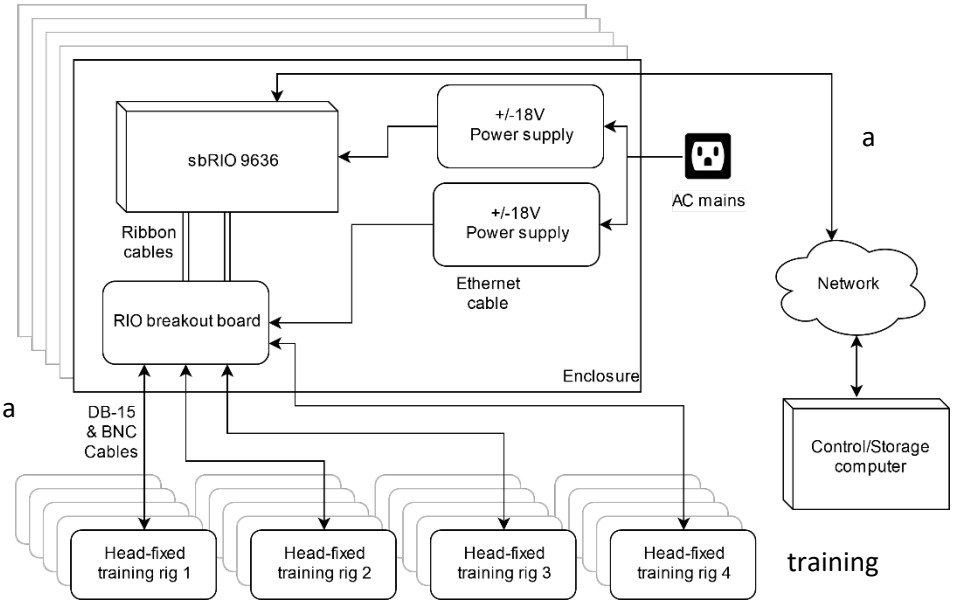

Figure 84 DAQ system schematic for head-fixed training (not video) rigs, showing half of what can fit in one enclosure

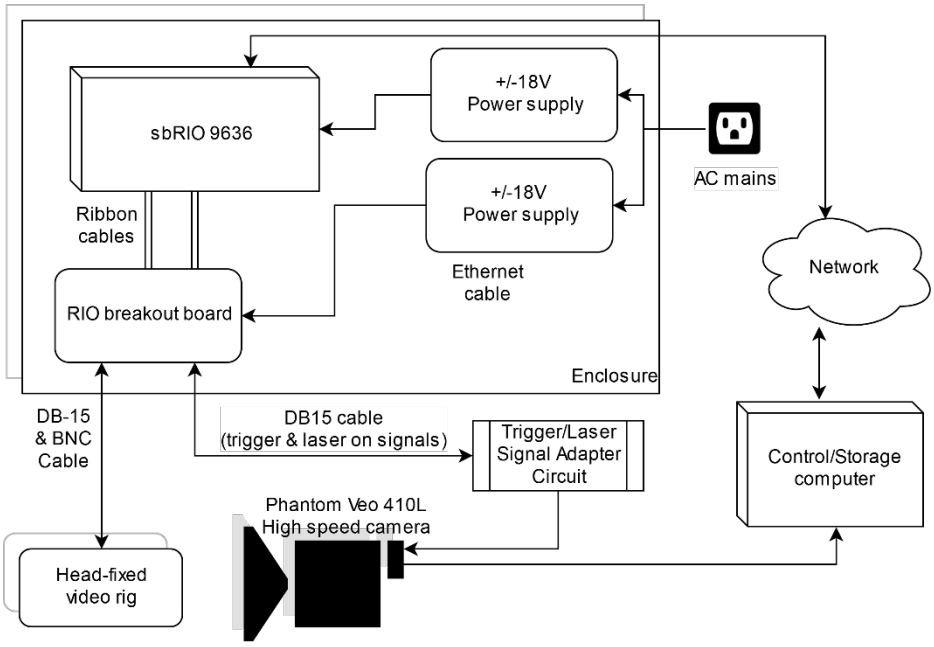

Figure 85 DAQ system schematic for head-fixed video rig, showing half of what can fit in one enclosure

Figure 90 sbRIO supplies. Clockwise from top left: sbRIO-9636 x2, NI Minifit Pigtail x2, NI 50 pin ribbon cable x2, mounting hardware (not used)

Figure 88 Required cords: 2 short Ethernet cords, 2 power cords

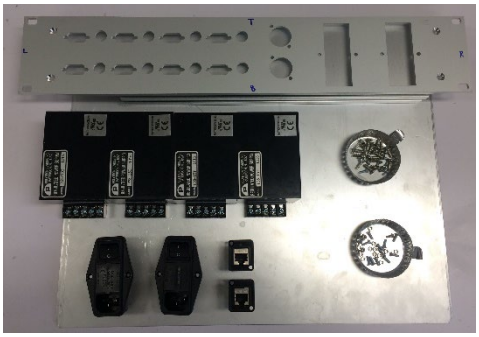

Figure 89 Enclosure materials. Clockwise from top left: custom cut front, sides, and back panels, enclosure hardware, 4-40 screws and nuts, Ethernet jacks x2, power jacks x2, power supplies x4

1. Assemble base and sides of enclosure

- See manufacturer instructions

2. Mount power supplies on enclosure base

- Each power supply has four 4-40 mounting holes.
- Drill four mounting holes (1/8”) for each power supply along the right side of the base plate of the enclosure.
- Screw each power supply in using 4-40x1/4” screws.
- See Figure 86 and Figure 87 for the results of this step.

Figure 87 Four power supplies mounted

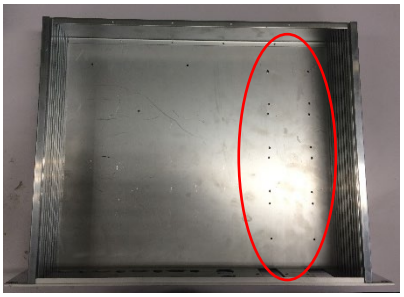

Figure 86 Enclosure base plate with power supply mounting holes drilled

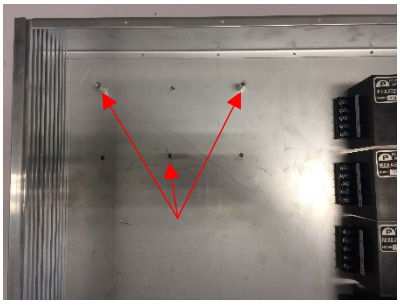

Figure 93 Baseplate with three standoffs installed. Note that the image shows the other three holes drilled - these will be unused and unnecessary.

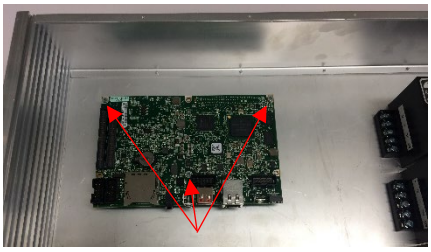

Figure 92 sbRIO #1 installed on standoffs

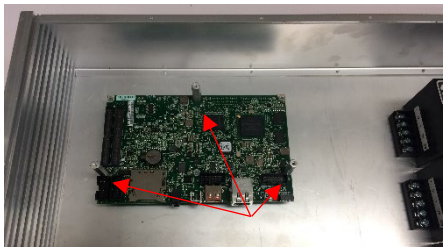

Figure 91 2nd layer of standoffs installed

3. Mount sbRIOs on enclosure base

- Drill mounting holes (1/8”) for three of the six mounting holes in the sbRIO board. See Figure 93.
- Note that the mounting standoffs provided by National Instruments do not provide enough clearance for the ribbon cables when mounting two sbRIOs on top of each other.
- Note that unless you have male to female standoffs, you can only use three mounting holes for each sbRIO.
- Screw the shorter three standoffs into the enclosure base.
- Mount an sbRIO on top of the three standoffs. See Figure 92.

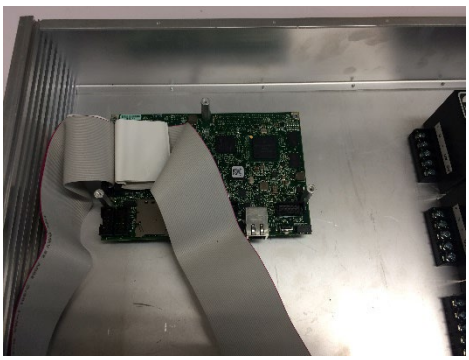

Figure 97 sbRIO #1 installed with ribbon cables

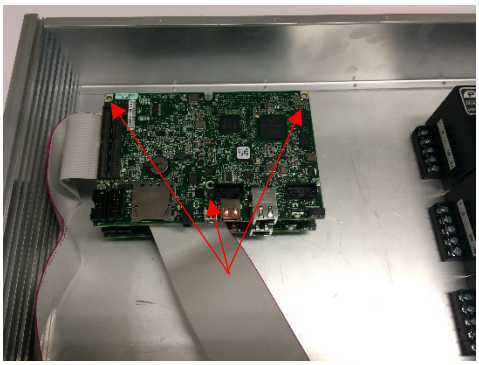

Figure 96 sbRIO #2 installed

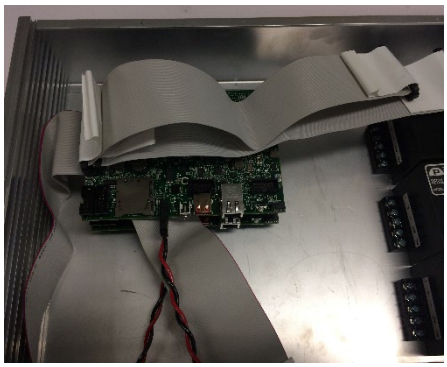

Figure 95 sbRIO #2 ribbon cables plugged in

- Screw the longer three standoffs into the three unused mounting holes on the first sbRIO. See Figure 91.
- Plug two ribbon cables into the two 50-pin headers on the sbRIO board. These cables carry the DIO and AIO channels to and from the sbRIO. Make sure the side of the ribbon marked red is on the side of the header with channel #1. See Figure 97.
- Screw the 2nd sbRIO onto the 2nd layer of standoffs. Take care that the ribbon cables from the first sbRIO are neatly exiting the space between the sbRIOs. See Figure 96.
- Plug the other two ribbon cables into sbRIO #2. Again take care that the orientation is correct. See Figure 95.

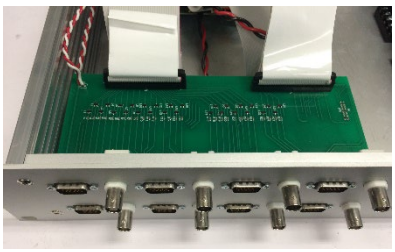

Figure 94 Two RIO breakout boards installed with ribbon cables.

4. Mount RIO breakout boards on enclosure faceplate

- Insert the RIO breakout board DB-9 and BNC ports into the faceplate cutouts.
- Secure the RIO breakout boards with 4-40x3/8” screws on either side of each DB-9 port.
- Plug the four ribbon cables into the RIO breakout boards. In the orientation shown, the left ribbon cables from the sbRIOs go into the left headers on the RIO breakout boards. Pin #1 goes on the right.
- See Figure 94 for the results of this step.

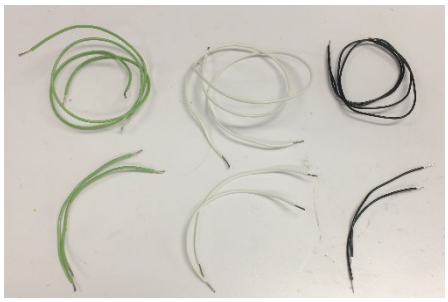

Figure 98 Power supply wires, cut and stripped

5. Cut and strip power wires

- Cut three pairs of 12” wires (two each for AC hot, neutral, and ground), and three pairs of 6” wires (two each for AC hot, neutral, and ground). Color coding is recommended – the color scheme used here is
  - AC hot = black
  - AC neutral = white
  - AC ground = green
- See Figure 98 for the results of this step.

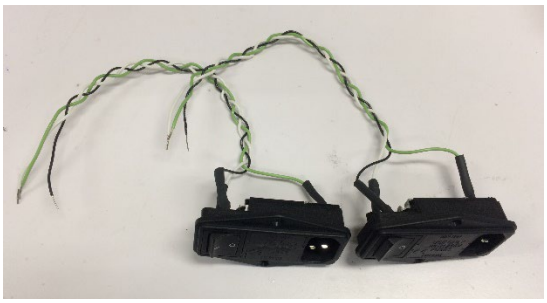

Figure 99 AC power receptacles

6. Solder wires onto power receptacles, and mount on faceplate

- Solder the longer wires onto the two power receptacles. Use heatshrink tubing to protect the solder joint.

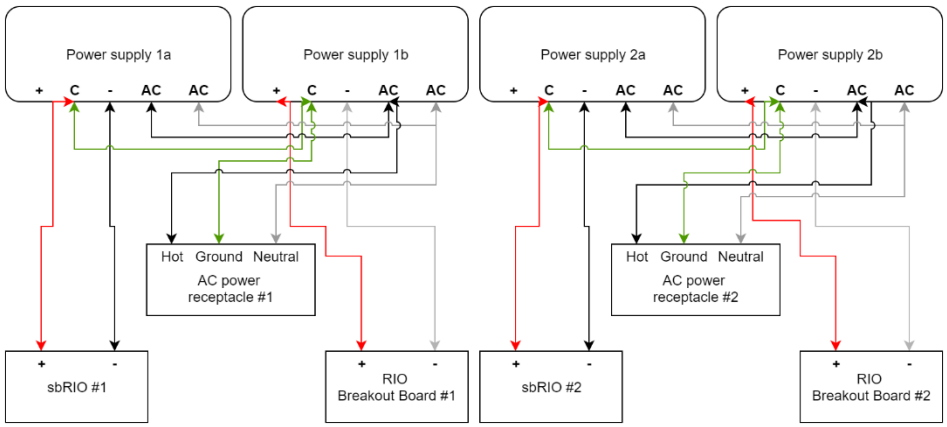

Figure 102 Power supply connection schematic. Compare to corresponding photo.

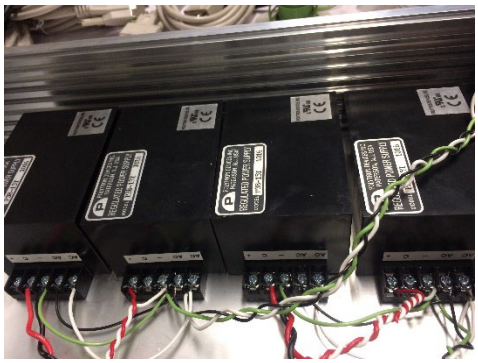

Figure 101 Power supply connection photo

- Use 4-40 screws and nuts to mount each receptacle on the faceplate.
- See Figure 99 for the results of this step.

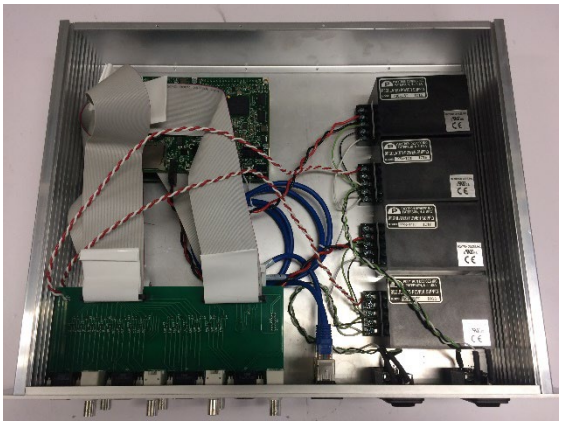

Figure 100 Completed DAQ system

7. Connect power wires to power supplies.

- Connect the wires to the screw terminals on the power supplies as shown in Figure 102 and Figure 101.

8. Connect sbRIO and RIO breakout board power cables

- Plug minfit power connectors into each sbRIO power jack.
- Connect bare wire ends of the sbRIO power cables and the RIO breakout board power cables to power supplies as shown in Figure 102 and Figure 101.

9. Mount Ethernet jacks in enclosure, and connect to sbRIO boards

- Mount Ethernet jacks on faceplate with 4-40 screws and nuts.
- Connect each sbRIO Ethernet jack to the panel-mounted jack using the short Ethernet cables.

10. Optional: close enclosure with lid.

11. Connect to sbRIO using LabVIEW, and compile software onto FPGA.

Part XIX: Building the camera trigger adapter

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	BNC female x solder cup connector x2	Amphenol/Digikey	ARFX1905	https://www.digikey.com/product-detail/en/amphenol-rf-division/031-10-RFXG1/ARFX1905-ND/2643384
2	DB-15 high density female x solder cup connector	Amphenol/Digikey	609-4045	https://www.digikey.com/product-detail/en/amphenol-icc-fci/10090770-S154ALF/609-4045-ND/2350291
3	2N3904 transistor x2	ON/Digikey	2N3904TFCT	https://www.digikey.com/product-detail/en/fairchild-on-semiconductor/2N3904TF/2N3904TFCT-ND/1626126
4	Perma-proto board	Adafruit/Digikey	1528-1101	https://www.digikey.com/product-detail/en/adafruit-industries-llc/1608/1528-1101-ND/5154676
5	1kΩ resistor x2			
6	Hookup wire			
7	Heatshrink tubing			

Building Instructions

General notes

The high speed camera must be able to record only when the mouse is licking, otherwise the amount of extraneous data generated for processing and storage would be prohibitively large. This section describes how to build a simple adapter circuit that allows the DAQ to send a trigger pulse to the camera, telling it when to record.

This circuit also allows the DAQ to send a separate signal to the camera indicating that the optogenetic laser is active during a particular recording. This causes the camera to mark the recording metadata with this information so it can be used later for analysis.

Both of those two parts of the circuit are identical – when the DAQ sends a logical high voltage pulse to one of the two halves of the circuit, it either triggers a recording or causes the camera to record the laser on condition.

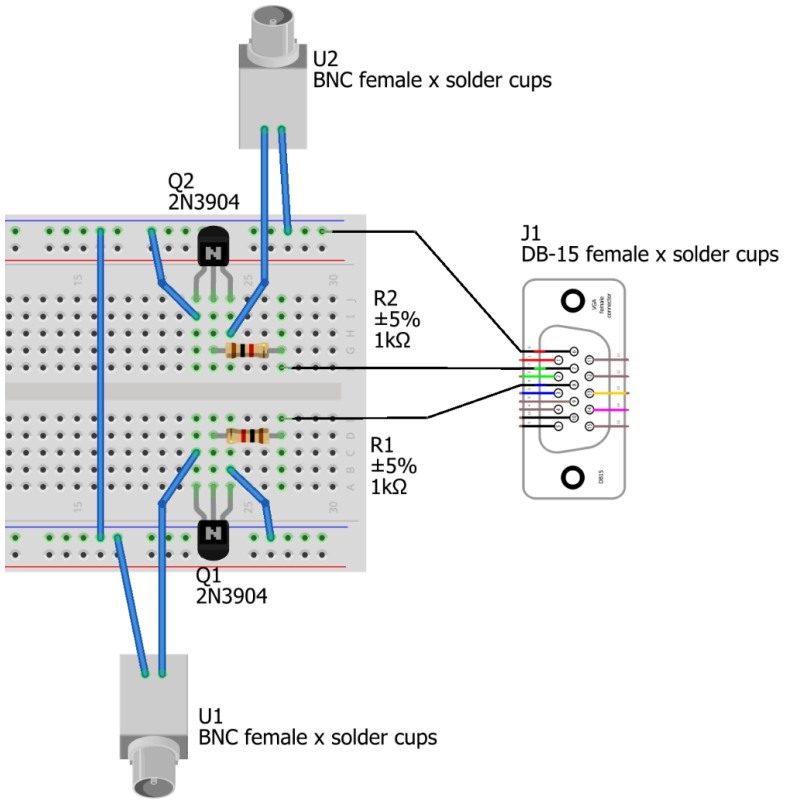

Figure 103 Camera trigger adapter circuit diagram

Recommended tools: Soldering iron, heat gun, flush cutters

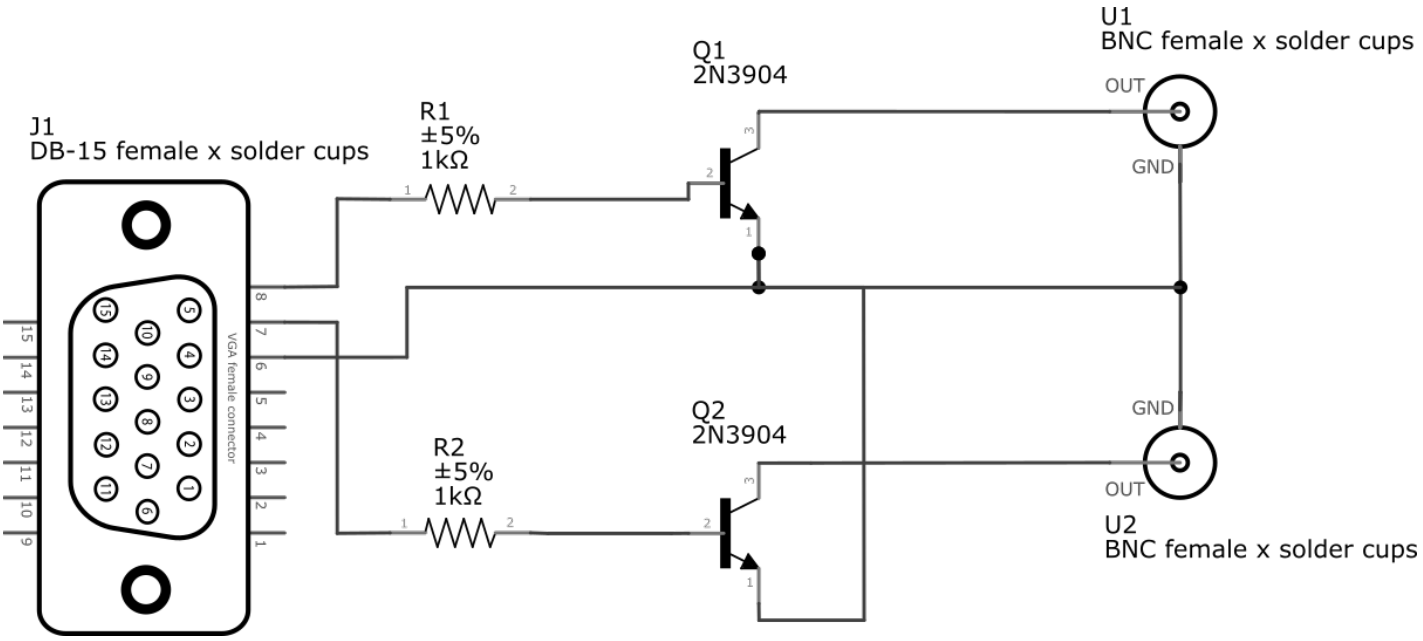

Figure 104 Camera trigger adapter circuit schematic. The U1 connector transmits the signal to indicate whether the optogenetic laser is on. The U2 connector transmits the trigger signal to start recording.

1. Cut and strip wire leads

- Cut seven wire leads and strip the ends.

2. Solder wires into connectors

- Solder wires into both solder cups on each BNC connectors, and into the solder cups for pins 6, 7, and 8 on the DB-15 connector.
- Add a piece of heatshrink tubing over each solder joint and shrink with the heat gun.

3. Solder components onto protoboard

- Solder the transistors, resistors, and connector leads onto the protoboard as shown in Figure 104 and Figure 103, and as also described in the net list below. See Figure 105 for the finished product.
- Part list:
    - U1, U2 = BNC female x solder cups connectors
    - Q1, Q2 = 2N3904 transistors
    - R1, R2 = 1 kΩ resistors
    - J1 = DB-15 female x solder cups connector
- Net list:
    - Ground net – U1 GND, U2 GND, Q1 pin 1, Q2 pin 1, DB-15 pin 6
    - Laser signal in net – DB-15 pin 8, R1 pin 1
    - Trigger signal in net – DB-15 pin 7, R2 pin 1
    - Laser base net – R1 pin 2, Q1 pin 2
    - Trigger base net – R2 pin 2, Q2 pin 2
    - Laser signal out net – Q1 pin 3, U1 OUT
    - Trigger signal out net – Q2 pin 3, U2 OUT

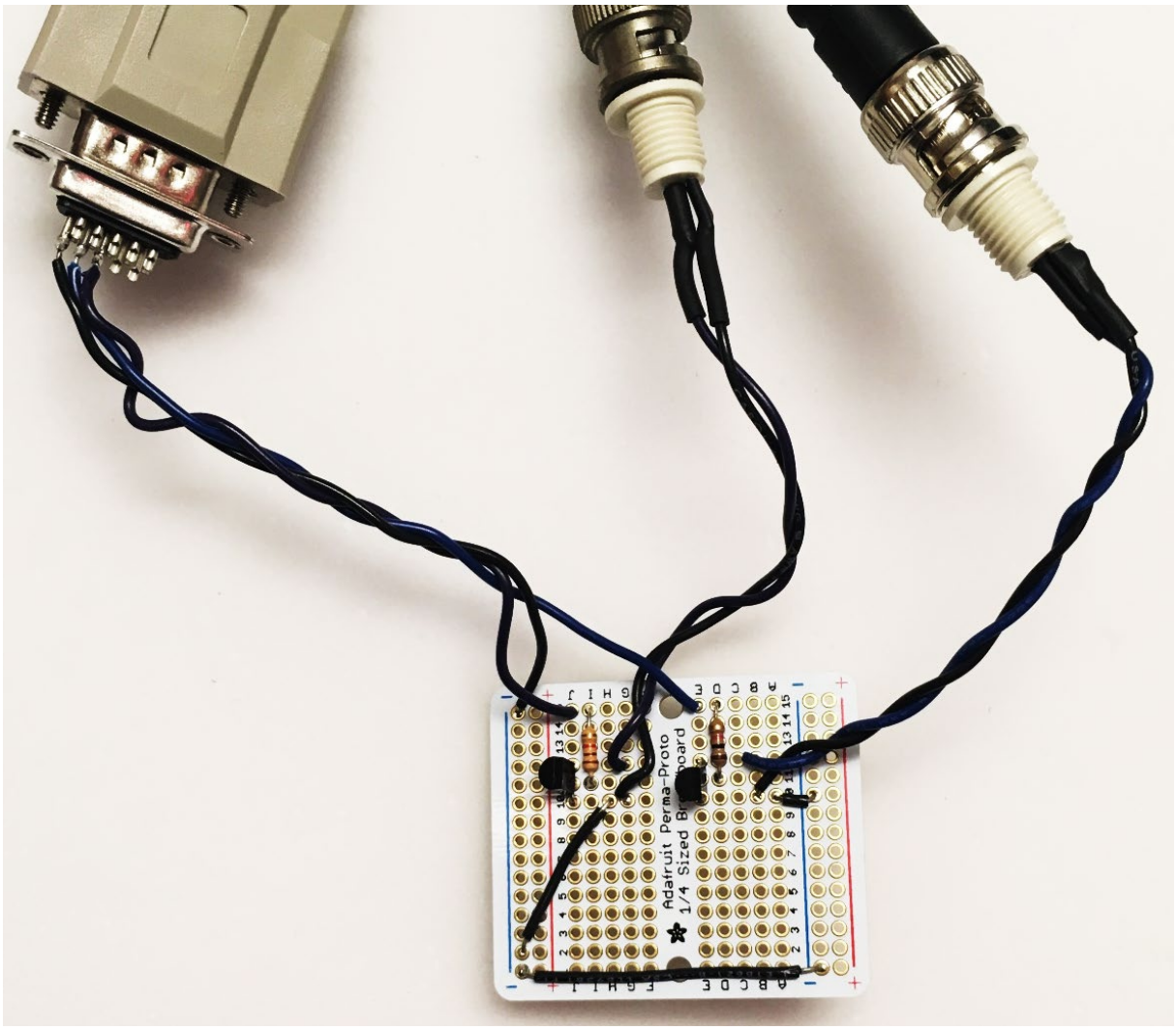

Figure 105 Camera trigger adapter circuit, with cables attached

Part XX: Constructing the high speed camera box

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Isolation box (Extra Tall Expanded PVC Sound Attenuation Cubicle)	Med Associates Inc.	ENV-018V	https://www.med-associates.com/product/extra-tall-expanded-pvc-sound-attenuating-cubicle/
2	Aluminum Breadboard 6" x 36" x 1/2" 1/4"-20 Taps	Thorlabs	MB636	https://www.thorlabs.com/thorproduct.cfm?partnumber=MB636
3	Aluminum Breadboard 4" x 6" x 1/2", 1/4"-20 Taps, x2	Thorlabs	MB4	https://www.thorlabs.com/thorproduct.cfm?partnumber=MB4
4	Dovetail Rail Carrier, 2.00" x 1.00", 1/4" Counterbore, 8-32 Taps, x2	Thorlabs	RC2	https://www.thorlabs.com/thorproduct.cfm?partnumber=RC2
5	Dovetail Optical Rail, 3", Imperial	Thorlabs	RLA0300	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0300
6	Dovetail Optical Rail, 6", Imperial	Thorlabs	RLA0600	https://www.thorlabs.com/thorproduct.cfm?partnumber=RLA0600
7	Ø1" Post Holder with Flexure Lock, 1/4"-20 Tap, L = 1.5", x2	Thorlabs	RSHT1.5	https://www.thorlabs.com/thorproduct.cfm?partnumber=RSHT1.5
8	1/4"-20 Stainless Steel Cap Screw, 3/4" Long x4	Thorlabs	SH25S075	https://www.thorlabs.com/thorproduct.cfm?partnumber=SH25S075
9	1/4"-20 Stainless Steel Socket Head Screw, 1-1/2" Long x2	McMaster-Carr	92196A706	https://www.mcmaster.com/92196a706
10	8-32 pan head screw, 3/4" long x4	McMaster-Carr	91772A197	https://www.mcmaster.com/91772a197
11	1/4"-20 Stainless Steel Setscrew, 1/2" Long x2	Thorlabs	SS25S050	https://www.thorlabs.com/thorproduct.cfm?partnumber=SS25S050
12	8-32 pan head screw, 2” long	McMaster-Carr	91772A205	https://www.mcmaster.com/91772a205
13	1/4"-20 nut x2	McMaster-Carr	92673A113	https://www.mcmaster.com/92673a113
14	8-32 nut	McMaster-Carr	91841A009	https://www.mcmaster.com/91841a009
15	1/4" Washer, M6 Compatible, Stainless Steel x2	Thorlabs	W25S050	https://www.thorlabs.com/thorproduct.cfm?partnumber=W25S050
16	8-32 oversized washer	McMaster-Carr	90313A302	https://www.mcmaster.com/90313a302
17	Sonex mini acoustic foam, 2’ x 4’ x 1.5”	Acoustical Solutions	FOMSONMIN242WHT	https://acousticalsolutions.com/product/sonex-mini-acoustic-foam/

Building Instructions

General notes

The head-fixed rig is designed to be able to be accurately and quickly mounted within a high speed video box. This way, multiple head-fixed rigs can be used for training mice concurrently, and can be swapped in and out of the high speed video box when video is needed. The camera and the head-fixed rig are positioned relative to each other using a Thorlabs optical breadboard, which makes the video scene highly constant between video sessions, facilitating automatic segmentation of the video with a machine learning algorithm.

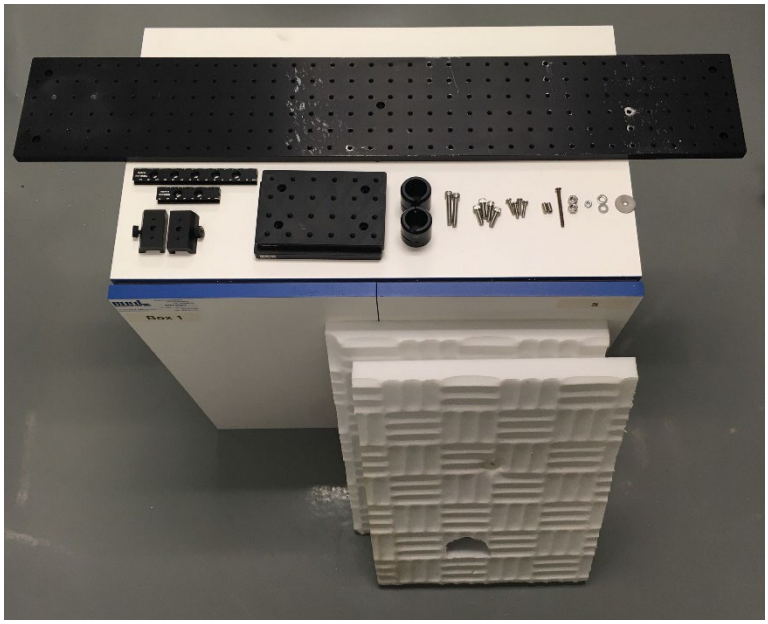

Figure 106 Materials for constructing high speed camera box. Clockwise from top: 36" breadboard, 8-32 oversized washer, 1/4"-20 washers, 8-32 nut, 1/4"-20 nuts, 8-32x2” screw, 1/4"-20x1/2” setscrews, 8-32x3/4” screws, 1/4"-20x3/4” screws, 1/4"-20x1.5” screws, 1” post holders, 4”x6” breadboards, rail carriers, dovetail optical rails. Bottom: Med Associates Inc. Sound Attenuation Cubicle, acoustic foam

Both the training box and the video box consist of a modified “sound attenuation cubicle” from Med Associates Inc. The video box has hardware added to allow for mounting the camera and the head-fixed rig accurately. The training box does not require the camera mounting hardware, and the only modification needed is the top hole for optogenetic equipment; as there is no camera to position relative to, the head-fixed rig can sit directly on the floor of the box. The instructions below are for constructing the video box. The instructions for constructing a training box is a subset of these instructions.

Recommended tools: Jigsaw (or router if available), drill, hole saw bit, hex wrench set, screw driver, box cutter

Step 1 – Modifying the box

1. Cut rectangular slot in box for breadboard

- Turn the box so its left side is facing upwards.
- Measure and mark a rectangle 1/2" x 6” with its bottom left corner 6.75” from the back of the box and 0.75” from the bottom of the box.
- This step is only for the video box, not the training box.
- See Figure 107 for the results of this step.

2. Cut side hole for camera view

- Using a 2.5” hole saw, cut a hole centered at 9.25” from the back of the box and 6.125” from the bottom.
- This step is only for the video box, not the training box.
- See Figure 107 for the results of this step.

3. Add anchor holes for breadboard

- We will use the two countersunk holes on the right side of the camera mounting breadboard to anchor the breadboard to the box
- Turn the box back right side up.
- Slide the breadboard into the box.
- Position the two countersunk holes so that their centers are approximately 1.25” from the right wall of the box
- Mark the location of the two countersunk holes
- Remove the breadboard from the box
- Drill a 1/4" through the bottom of the box at each mark
- This step is only for the video box, not the training box
- See Figure 108 for the results of this step.

4. Cut top hole for optogenetics and strobe cables

- In the center of the top of the box, use a hole saw to drill a 2” hole
- This hole will allow the strobe trigger signal, power, and optogenetic cables to enter the box.
- See Figure 109 for the results of this step

5. Drill side hole for anchoring acoustic foam (optional)

- The acoustic foam provides extra sound isolation to prevent sounds from interfering with the experiment, and to prevent the audio cue from the experiment from interfering with other concurrent experiments.
- To prevent the acoustic foam from shifting and blocking the camera, we will anchor the left-hand foam sheet to the side of the box with a bolt.
- Approximately in the center of the box side, drill a 3/16” hole for the foam anchoring bolt
- See Figure 107 for the results of this step

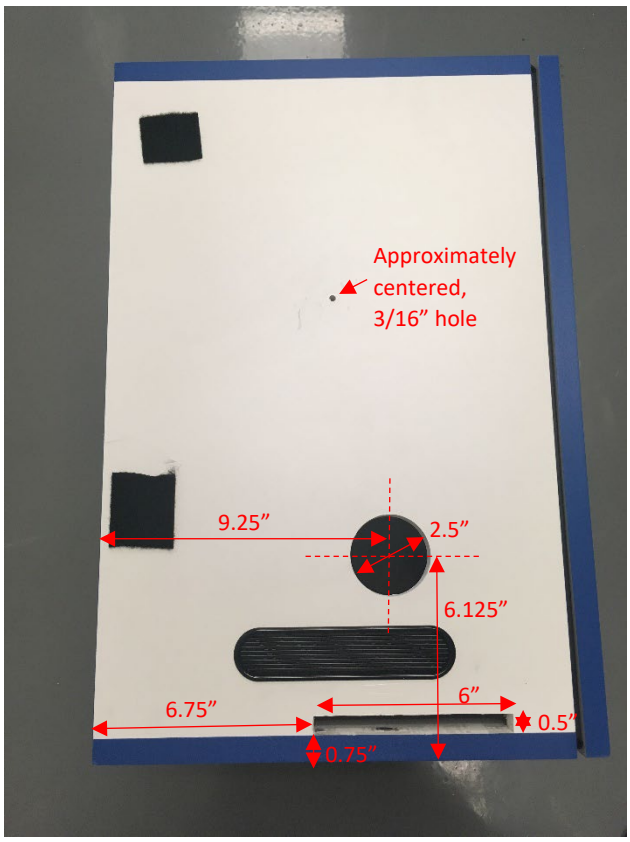

Figure 107 Modifications to the side of the box for the camera, the mounting breadboard, and the foam anchor bolt.

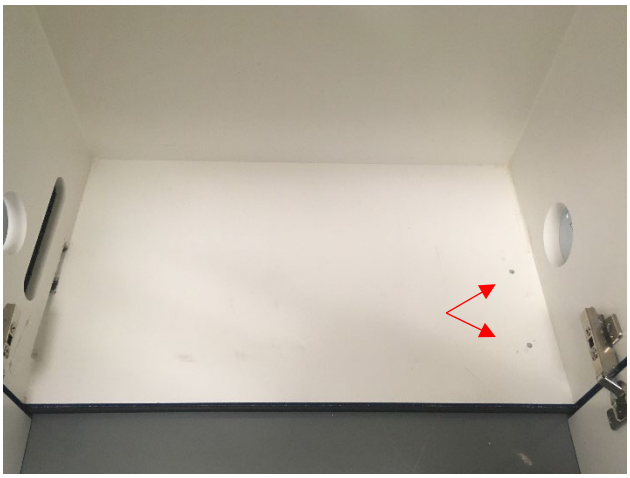

Figure 108 Breadboard anchoring holes

6. Cut acoustic foam panels (optional)

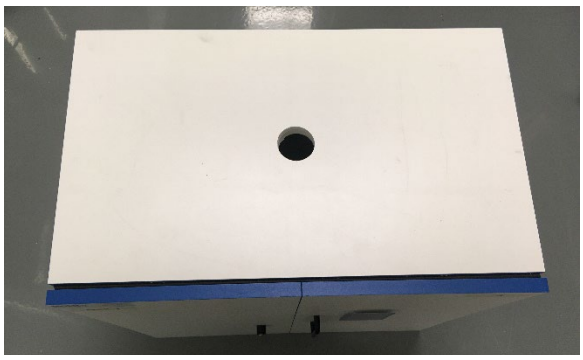

Figure 109 Top hole for optogenetics and strobe cables

- Mark a 14”x21” rectangle, and a 14”x21.5” rectangle on the acoustic foam sheet.
- Cut out the rectangles with a box cutter.
- The longer rectangle goes on the right side of the box interior; the shorter rectangle goes on the left.
- Position the longer rectangle on the right side of the box 1/2" above the bottom, and make ad-hoc cuts so it fits around the door hinges and lays flat against the right side.
- Position the shorter rectangle on the left side of the box 1” above the bottom, and make ad-hoc cuts to fit around the hinges.
- Poke a hole that matches the acoustic foam anchoring hole.
- Cut a slit in the right side foam piece where the lower factory-cut hole is; this is how the DB-15 cable will enter the box.
- Insert the 8-32 x 2” screw with a washer into the foam hole, into the side of the box, and out. Use the nut on the outside to secure the screw and foam.
- From the left outside of the box, trace the camera hole outline on the foam.
- Remove the foam and cut out the camera hole outline with a box cutter
- Re-install the foam.

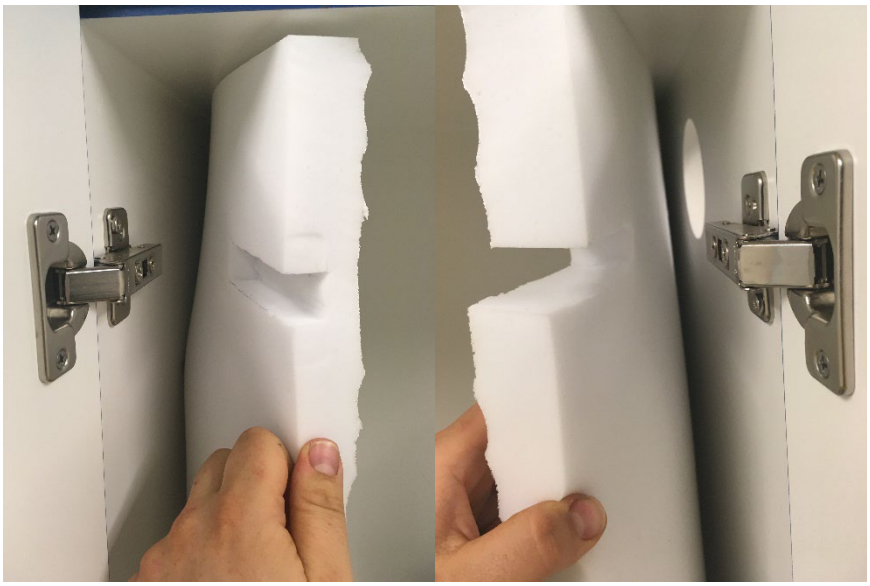

Figure 110 Foam with example cutouts to fit around hinges

Step 2 – Building and installing camera mount

The camera mount consists of a long breadboard that fixes the relative position of the camera and the head-fixed rig, allowing for repeatable video framing.

1. Add positioning rails

- Mount the 6” and 3” dovetail optical rails using the 1/4"-20x3/4" long bolts. The bolts should go in positions (0, 1), (0, 5), (4, 3), and (4, 4). See Figure 1 for a description of the coordinate system.
- See Figure 111 for the results of this step.

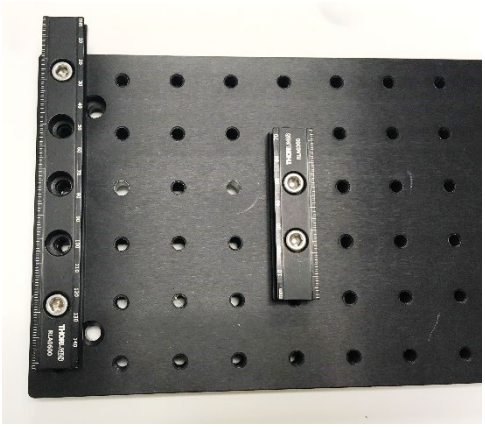

Figure 111 Camera positioning rails installed

2. Add rail carriers

- Slide a rail carrier on each optical rail with the locking thumbscrews pointing outwards.
- Line up the carriers with each other on their dovetail rails
- See Figure 112 for the results of this step.

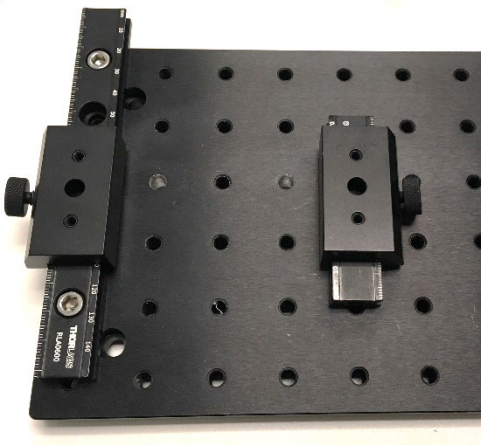

Figure 112 Rail carriers installed

3. Add camera platform

- Place the 4”x6” breadboard (the camera platform) on top of the two rail carriers.
- In the coordinate system of the 4”x6” breadboard, align holes (1, 1), (1, 2), (5, 1), and (5,2) with the two 8-32 holes on top of the rail carriers.
- Use the 8-32x3/4” screws to fasten the camera platform breadboard to the rail carriers using the holes at the above coordinates.
- See Figure 113 for the results of this step

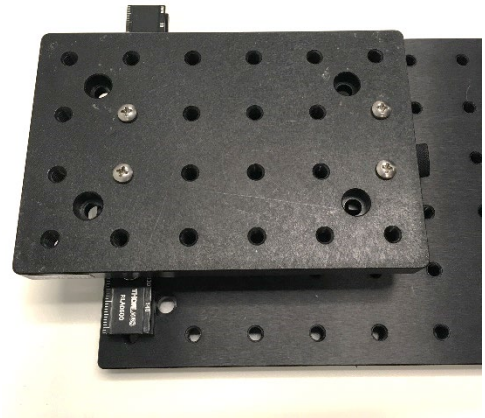

Figure 113 Camera platform installed

4. Add camera mounting feet receptacles

- Screw two 1/4"-20x1/2” setscrews halfway into the camera platform at positions (2, 2) and (4, 2).
- See Figure 114 for the results of this step.
- Screw the two 1” post holders down onto the setscrews.
- Check if the setscrews are protruding up above the inside bottom of the post holders. If they are, correct it with a hex wrench until they do not.
- See Figure 115 for a depiction of the setscrew correction
- See Figure 116 for the finished camera platform.

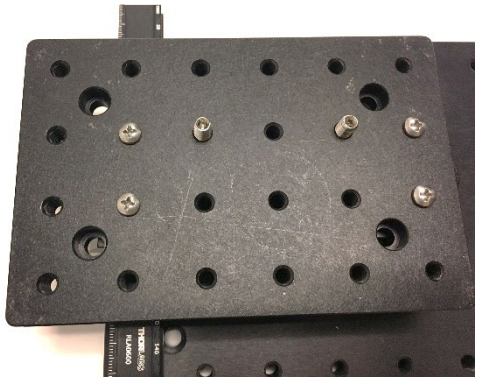

Figure 114 Camera mounting feet receptacle setscrews installed

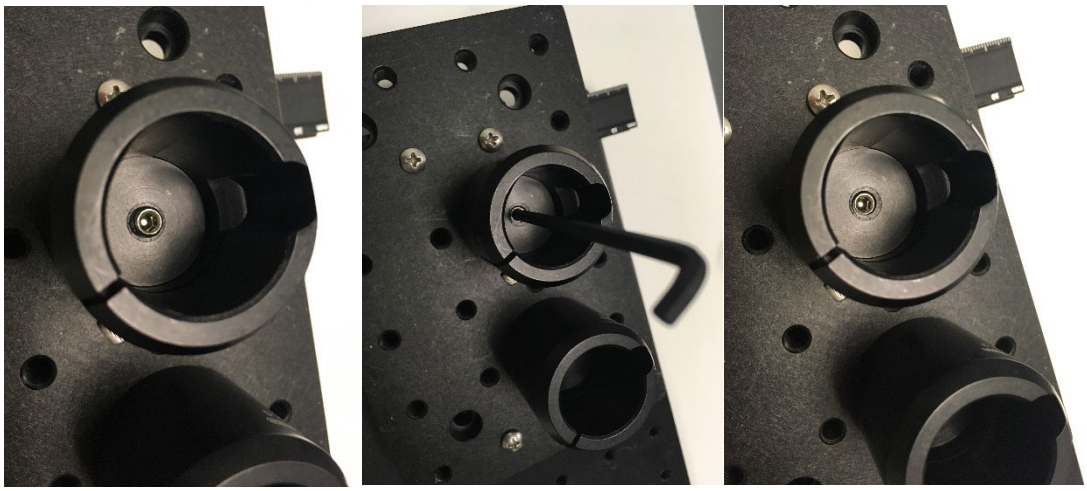

Figure 115 Adjusting the set screws so they don't protrude into the space where the camera feet need to sit. Left: protruding setscrew. Middle: fixing protruding setscrew with hex wrench. Right: correctly positioned setscrew

5. Insert camera mount into box

- Place the camera box up onto a wire rack shelf.
- Slide the entire camera mount into the rectangular slot cut into the left side of the camera box
- Line up the countersunk holes on the right side of the camera mount with the holes cut into the bottom of the camera box.
- Insert 1/4"-20x1.5” screws into the two countersunk holes on the right side of the camera mount breadboard, and through the holes in the bottom of the box.
- Use washers and nuts to secure the screws to the bottom of the box. See Figure 118 for the installed mounting screws
- Place the other 4”x6” breadboard in the box behind the camera mount. It can just sit on the bottom, and does not need to be mounted. This will provide support for the back of the head-fixed rig.

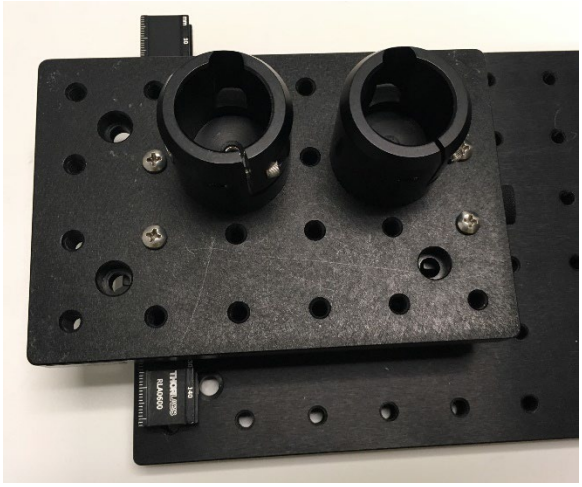

Figure 116 Finished camera platform

Figure 117 Box on a wire rack

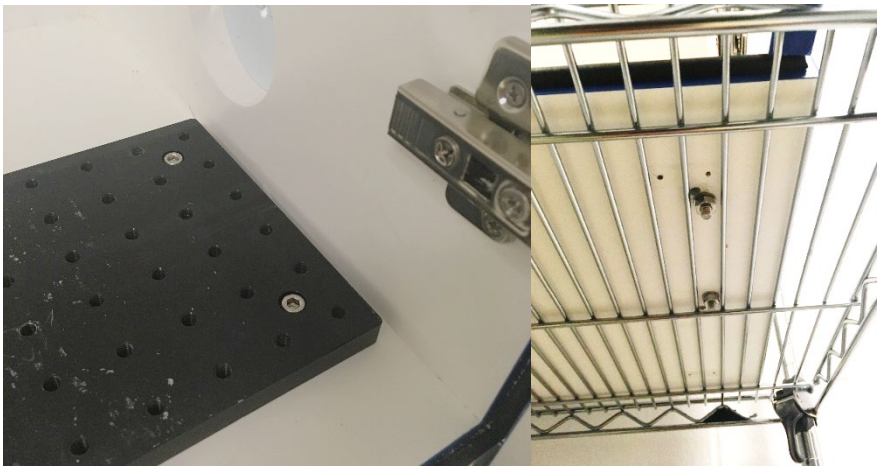

Figure 118 Screws fixing the camera mount to the box seen from the top (left) and from the bottom (right)

Figure 120 Camera mounting system installed in the box (without foam or the rear head-fixed rig support breadboard)

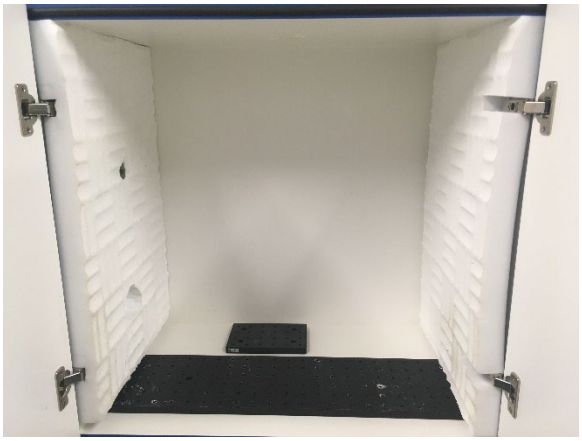

Figure 119 Camera mounting system installed in box with foam and rear head-fixed rig support breadboard.

Part XXI: Assembling entire system

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Phantom VEO 410L High speed camera	Vision Research	Phantom VEO 410L	https://www.phantomhighspeed.com/products/cameras/veo/veo410
2	Completed high speed camera box with camera mount		Custom made	
3	Completed optogenetic system		Custom made	
4	Completed DAQ		Custom made	
5	Completed camera trigger adapter circuit		Custom made	
6	Completed head-fixed rig		Custom made	
7	Control/storage server			
8	LabVIEW 2017			
9	LabVIEW control software			
10	Phantom Camera Control (PCC) software		Vision Research Inc.	https://www.phantomhighspeed.com/resourcesandsupport/phantomresources/pccsoftware
11	1" Pillar Posts, 0.75" long x2	Thorlabs	RS075	https://www.thorlabs.com/thorproduct.cfm?partnumber=RS075
12	1" Pillar Posts, 0.5" long x2	Thorlabs	RS05	https://www.thorlabs.com/thorproduct.cfm?partnumber=RS05
13	Ø25 mm Post Spacer, Thickness = 1 mm x2	Thorlabs	RS1M	https://www.thorlabs.com/thorproduct.cfm?partnumber=RS1M
14	1/4"-20 Stainless Steel Setscrew, 3/4" Long x5	Thorlabs	SS25S075	https://www.thorlabs.com/thorproduct.cfm?partnumber=SS25S075
15	IR LED strobe light	AOS Technologies	StroboLED II - 880 nm (Discontinued by manufacturer)	https://www.aostechnologies.com/fileadmin/user_upload/PDFs/Process_Monitoring/StroboLED_ProductLeaflet_en.pdf
16	1/2" Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 2"	Thorlabs	PH1	https://www.thorlabs.com/thorproduct.cfm?partnumber=TR2
17	BNC cables x			
18	DB-15 cables x2			
19	Ethernet cable x2			

Building Instructions

General notes

It may be helpful to refer to Figure 2 to visualize the connections needed.

Figure 122 Camera mounting feet parts

1. Assemble camera mounting feet

- Screw a 1/4"-20x3/4" setscrew into the 0.5” long pillar post so it only protrudes from one end. Stack the 1mm post spacer onto the protruding setscrew, and screw the 0.75” long pillar on top of the spacer. Make sure the setscrew does NOT stick out the bottom of the camera foot, or the camera will not mount properly.

Figure 121 Two completed camera mounting feet. From bottom to top: 1/2" pillar post, 1mm spacer, 3/4" pillar post, protruding setscrew.

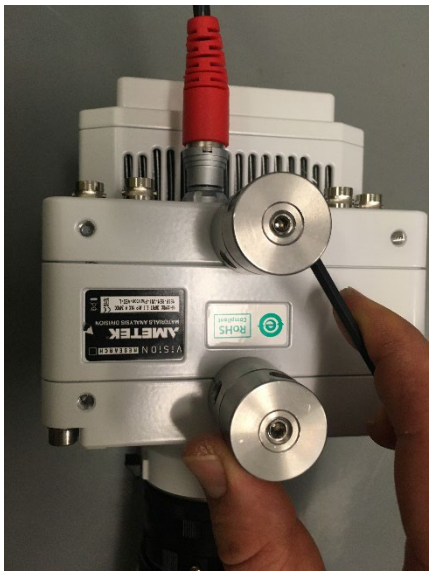

Figure 123 Camera mounting feet installed on the bottom of the Phantom VEO 410L, showing the process of tightening them on with a hex wrench.

- Screw another setscrew into the 0.75” long pillar so it does protrude out.
- Repeat the above steps to make a second mounting foot
- Screw the two mounting feet into two bottom mounting holes on the Phantom VEO 410L camera. Use a hex wrench in the side holes of the pillar posts to tighten it securely on.
- See Figure 121 for the completed feet, and Figure 123 for the feet installed on the camera bottom.

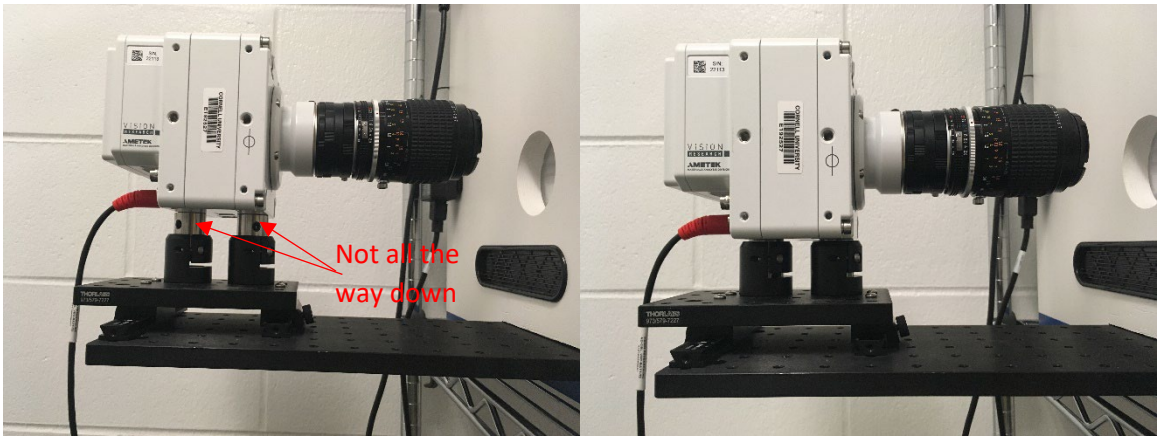

Figure 124 Installing the camera on the camera mounting platform. Left: Camera not completely seated. Right: Camera correctly seated.

2. Mounting the camera

- Gently, carefully insert the camera mounting feet into the post holders on the camera mounting platform. Make sure the mounting feet slide all the way down to the bottom of the post holders.
- See Figure 124 for the camera mounting process.

3. Install head-fixed rig

- Slide completed head-fixed rig into the back left corner of the box
- There should be two screws in the head-fixed rig base at (3, 0) and (17, 2). Turn the screws so they stick out slightly on the bottom, and align them with the nearest hole in the breadboard below the head-fixed rig. Screw them in further to connect the head-fixed rig breadboard to the camera mount breadboard. You may not be able to screw them all the way in, but they are only to ensure alignment, so that isn't a problem.

4. Install strobe light

Figure 125 Strobe light with mounting post on the bottom.

- Using a 1/4"-20x3/4" setscrew and a 2" optical post, add a mounting post to the strobe light.
- Slide the strobe light mounting post into the 1" post holder.
- The strobe can be positioned using the locking thumbscrew later for optimum illumination.
- Connect a BNC cable to the trigger BNC port on the back
- Connect the power adapter to the power port on the back of the strobe light (or prepare to – leaving it plugged in when not in use is not recommended)
- Run both the BNC and power adapter cables up through the top hole in the box. Use tape if necessary to keep the cables from dangling into the camera's field of view.
- Plug the other end of the power adapter into a power outlet
- Plug the other end of the BNC cable into the port on the back of the camera marked "5 I/O". This will transmit the sync signal from the camera to the strobe that will make the strobe flash in sync with the camera shutter.

5. Install optogenetic system

- Set the laser diode module on top of the wire rack above the rack. Plug in its power cord.
- Set the commutator in the hole on top of the box so the two optical connectors face downwards.
- Optional – add a cushion of acoustic foam under the commutator mounting panel to improve sound isolation
- Connect an optical fiber from the top of the commutator to one of the outputs of the laser diode module.

6. Install camera trigger adapter circuit

- The trigger adapter circuit has two BNC outputs, and one DB-15 input. The BNC output associated with the DB-15 pin 7 (U2 in Figure 104) transmits the trigger signal to the camera. The BNC output associated with the DB-15 pin 8 (U1 in Figure 104) transmits the laser on signal to the camera.
- Use a BNC cable to connect U2 in the adapter to the BNC port on the back of the camera marked "1 TRIGGER"
- Use a BNC cable to connect U1 in the adapter to the BNC port on the back of the camera marked "3 I/O"
- Use a DB-15 cable to connect the DB-15 connector (J1) to the Box 3 DB-15 port on the RIO

7. Set up control/storage server

- The control server that runs the LabVIEW code and the server that receives and stores the video data can be separate, or the same server, as long as the server has the resources to both store high throughput data and run the LabVIEW code at the same time.
- The Phantom VEO 410L is available with an optional 10 Gb Ethernet connection. This can allow for recordings that are larger or more frequent, as it allows data to offload from the camera RAM to the storage server more quickly. This also requires a 10 Gb Ethernet card in the storage server.
- The control server needs LabVIEW 2017 or later, and the custom LabVIEW control software.
- The storage server needs the free Vision Research camera capture software “Phantom Camera Control” (PCC).

8. Make RIO connections

- Run a BNC cable from the Box 1 (leftmost) BNC port on the RIO to the BNC port on the laser diode corresponding to the optical fiber output that is connected to the commutator
- Run a DB-15 cable from the Box 1 DB-15 port on the RIO through the right side factory-cut hole in the box, through the slit in the acoustic foam, to the DB-15 connector on the joystick board.
- Run an Ethernet cable from the Ethernet port on the RIO to the Ethernet port on the control server.

Table of Figures