Instructions for steering wheel setup

Version 0.9.3, 18 July 2017

Lauren E Wool and Matteo Carandini, Cortical Processing Laboratory, University College London

Table of Contents

Introduction

Stimulus computer

- Installing the video card
- Installing the DAQ device

Frame and components

- Assembling the frame
- Preparing the screens
- Attaching the Fresnel lenses
- Installing the screens
- Configuring the screens
- Assembling the mouse holder
- Assembling the water valve
- Connecting the rotary encoder
- Connecting the water-reward system
- Connecting the photodiode

Comments and suggestions

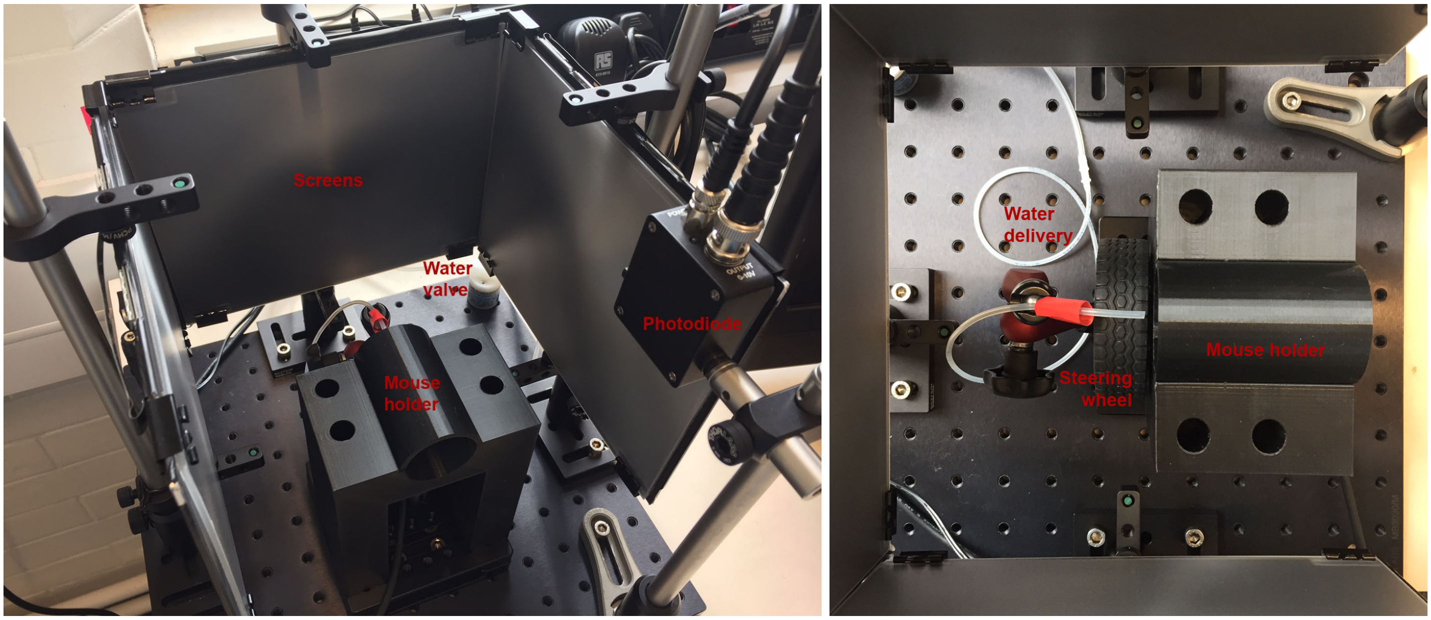
Introduction

This document gives instructions on how to build a basic version of the steering wheel setup to probe mouse behavior, introduced by Burgess et al (*bioRxiv* 2016), to be used in other laboratories such as those in the International Brain Laboratory. In this setup, we place a steering wheel under the front paws of a head-fixed mouse, and couple the wheel's rotation to the horizontal position of a visual stimulus on the screens (i.e., turning the wheel left or right accordingly moves the stimulus left or right). The mouse is then trained to decide whether a stimulus appeared to the left or the right of the central visual field. Using the wheel, the mouse indicates its choice by moving the stimulus to the center. A correct decision is rewarded with a drop of water and short intertrial interval, while an incorrect decision is penalized with a longer timeout and noise burst.

We use this steering wheel setup throughout our laboratory, and deploy it in two kinds of rigs: training rigs and experimental rigs. Training rigs are used to train head-fixed mice on the steering-wheel task and acquire behavioral data. Experimental rigs have additional apparatus to collect electrophysiological and imaging data, measure eye movements and licking activity, provide optogenetic perturbations, and so on

Up until recently, constructing these setups required a machine shop that could provide custom-made components. However, for the purposes of spreading this setup to other laboratories, we here describe a new version that does not require any machined parts: all components are off-the-shelf or 3D-printable. For now, this is only a basic version: most notably absent are (1) a device for holding the head of the mouse (which for now does require a machine shop); (2) cameras to look at the mouse's eyes and face.

This document gives instructions for building such a basic version. The instructions will change over time as we perfect the setup (and we will have different version numbers) so please do help us by providing comments.



A basic behavioral setup with three iPad screens (with Fresnel lenses), a mouse holder (with steering wheel), a water-delivery system, and a photodiode.

The main components of the behavioral setup are a mouse holder with steering wheel encoder, a water-delivery system, three iPad screens for stimulus presentation. These and other components are held together by a "frame". In addition, , a "stimulus computer" controls all this apparatus.

A detailed list of the components can be found in this spreadsheet. Note that this list was assembled in the UK; though we have aimed to use international vendors, you may need to pick different ones depending on your location (please let us know by adding comments). Place the orders as soon as possible, as some items will take time to arrive.

We start with the "stimulus computer" because it helps to have it in place first. This way you can use it to test other components as they arrive. Also, start planning how you will 3D-print the mouse holder.

Stimulus computer

The "stimulus computer" controls stimulus display and water delivery, and acquires the mouse's movements on the steering wheel and the output of a photodiode to synchronize stimulus output with other measurements. It runs Windows 10. The computer should be connected to the network, ideally through a high-speed connection (not WiFi).

Installing the video card

The required video card is the NVIDIA NVS 510. This card drives four monitors. We will use it to drive the main display monitor and the three iPad screens. Below are instructions for installing it (these are just regular instructions that would apply to any video card -- the instructions are just there in case you are not familiar with installing video cards).

1. Ensure your main monitor is connected to the onboard graphics card
2. If you are removing a currently graphics card, open 'Device Manager' and check the 'Display adapters' drill-down menu for the current graphics card
3. Double-click the graphics device: under the 'Driver' tab, select 'Uninstall' to remove any drivers associated with the current card.
4. After powering down and unplugging the computer, open the case and install the NVIDIA NVS 510 in the PCI slot. If you are replacing an existing card, remove it and replace it with the NVS 510.
5. Power up the computer and open 'Device Manager' and check that the 'Display adapters' drill-down menu shows a new object: 'Microsoft Basic Display Adapter,' or similar
6. Via your browser, find and download, then install, an appropriate driver for your new card. As of April 2017, the current driver for NVIDIA NVS 510 is the Quadro Desktop/Notebook Driver Release 375, Version R375 U6 (377.11).
7. Back in Device Manager, check that 'Microsoft Basic Display Adapter' has changed to the name of your GPU ('NVIDIA NVS 510').
8. Restart the computer for changes to take effect
9. Migrate the main display monitor to an NVS graphics card port using a suitable mini-DisplayPort cable, and confirm that you have visual output

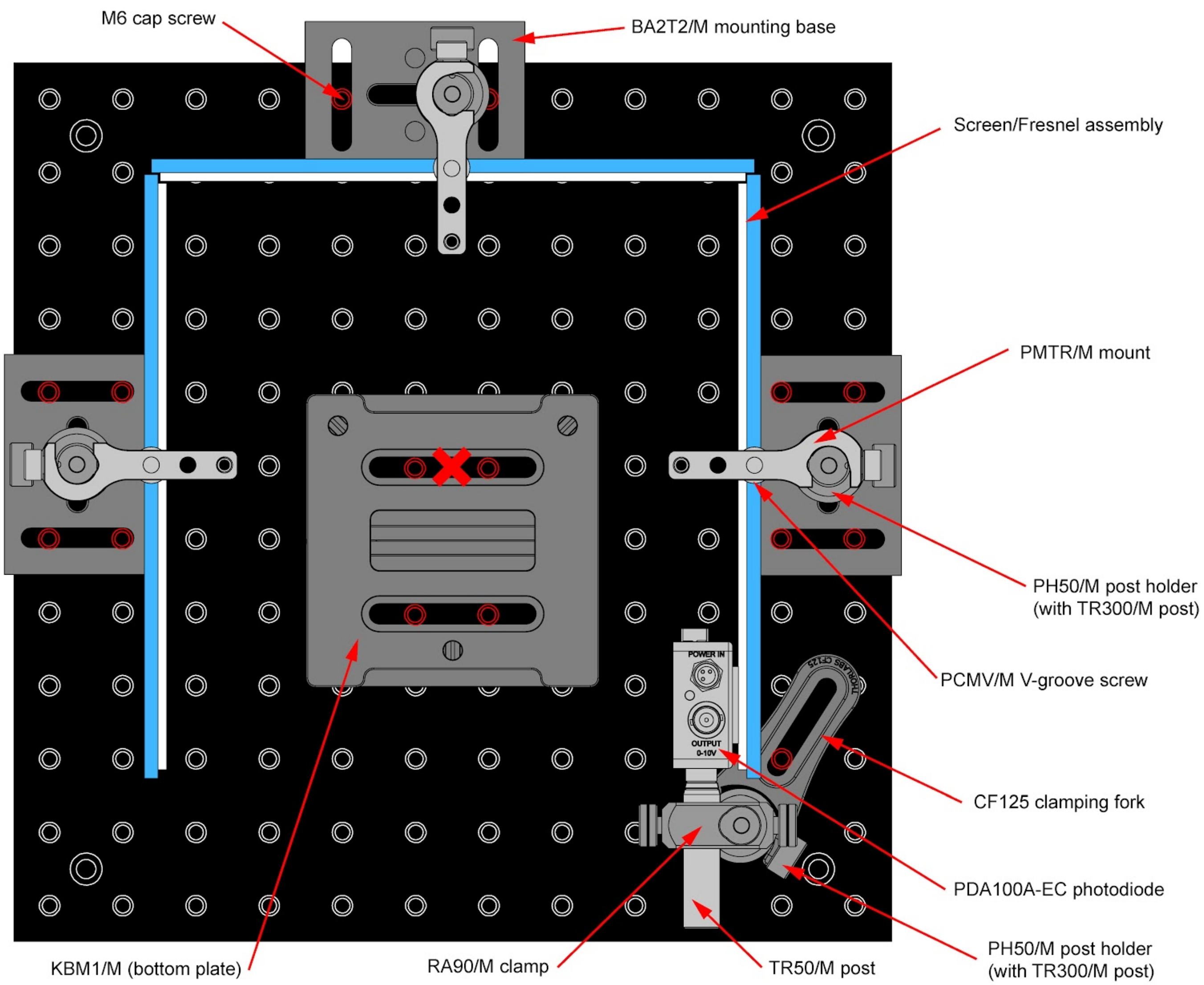
Installing the DAQ device

To acquire data from the steering wheel and from the photodiode and to deliver water rewards to the mouse, we use a DAQ (data acquisition) device, the NI-DAQ 6211.

1. Plug in the device to a powered USB port on the stimulus computer
2. Visit the Drivers page on the National Instruments website and select ‘NI DAQmx’ from the ‘Popular Drivers and Updates’ list, then download the latest version of the device driver (17.0.1, as of May 2017).
3. Once installation is complete, restart the computer.
4. Launch ‘NI Device Monitor’ from the System Tray. The program should recognize that the NI-DAQ 6211 is connected, and a green light on the DAQ should flash

Frame and components

The setup itself comprises three iPad screens installed on posts, a mouse holder with a steering wheel encoder, and a water-delivery system. Here we describe the assembly of the frame required to hold these and other components together.



The steering-wheel setup is contained entirely within a frame made of Thorlabs components, all seated on a 300mm x 300mm aluminium breadboard (MB3030/M). Components can be secured to the breadboard using 25mm M6 cap screws. The screen/Fresnel assemblies are seated between two grooved screws on clamps (one bottom, one top) that are attached to 300mm posts. The mouse itself is seated on a 3D-printed holder (not shown) that attaches to a magnetic plate in the center of the frame. In order for the Fresnel lenses to collimate light properly, the mouse's head position must be equidistant from the three screens (indicated by the red 'x'). This requirement is fulfilled with proper attachment of the holder to the magnetic plate (described below).

Assembling the frame

The frame is composed chiefly of Thorlabs components.

1. Assemble the three screen post mounts, by attaching each post holder (PH50/M) to a mounting base (BA2T2/M)
2. Attach the screen post mounts to breadboard (MB3030/M) in the positions shown in the diagram
3. Insert and secure 1 TR300/M post into each of the mounts
4. On each post, firmly secure 1 PMTR/M clamp 1 cm above the PH50/M. Each clamp arm should be perpendicular to its BA2T2/M plate and facing the center of the breadboard
5. In the first M6 tap on each PMTR/M clamp arm, insert 1 PCMV/M V-groove screw so that the groove is facing up and is parallel to the BA2T2/M plate. (Depending on the required orientation of the groove, the screw may not be completely tightened in the tap)
6. On each post, attach 1 PMTR/M clamp ~20 cm above the lower clamp, and facing the same direction. Tighten

just to secure, as this will be readjusted

7. In the first M6 tap on each PMTR/M clamp arm, insert 1 PCMV/M V-groove screw so that the groove is facing down and is parallel to the BA2T2/M plate. (Depending on the required orientation of the groove, the screw may not be completely tightened in the tap)

Preparing the screens

To protect the screens from damage, keep the plastic film on until you are ready to attach the Fresnel lenses

1. On a soft surface, turn the iPad over so that the back is facing up and the input cable is running along the top
2. Check that the cable input on the driver board has its locking mechanism (black plastic bar) pressed up
3. Carefully connect a driver board to the input cable. There will be ~1mm of gold contacts left visible. DO NOT FORCE THE CABLE.
4. Attach the driver to the back of the screen with a small piece of Velcro or double-sided tape, positioning it so the cable is not bending or shearing
5. Check that each driver board switch is set to 'OFF'

Attaching the Fresnel lenses

The purpose of the Fresnel lenses is to ensure that the intensity is homogeneous across the screen when viewed from a specific location (marked by a cross in the figure above).

1. Ensure the smooth side of each Fresnel lens is clean and dry, with no fingerprints (use an air duster if needed to remove debris)
2. Lay the lens on a bed of paper towels, smooth-side up with the short edge nearest
3. Cut a piece of window film that is slightly larger than the fresnel lens (~2 cm border)
4. Carefully peel back the adhesive and lay the window film next to the lens, adhesive-side up with the short edge nearest
5. Generously spray both the lens and the film with soap/water solution
6. Lift the window film from a short edge, letting it hang orthogonally to the surface of the fresnel lens
7. Slowly lower the film to the lens surface, allowing the bottommost short edges to begin contacting each other
8. Continue lowering to make contact with the lens, meanwhile using the squeegee to press out extra bubbles and solution to the sides
9. Continue working away from the bottom edge, lowering the film and using the squeegee to remove bubbles and solution
10. Lifting the lens/film, replace the wet paper towels with some new dry ones
11. Carefully flip the lens/film over so that the ridged side is now facing up
12. Trim the film edges with a razor or scalpel blade
13. Flip the lens over to remove any remaining bubbles with a squeegee, and further trim edges with a blade as needed
14. To the rough side of the lens, carefully attach four small pieces of clear double-sided tape (3 mm x 25 mm) to each corner, with the long dimension of the tape running along the lens's horizontal edges. Do not remove the backing film from the tape.
15. Carefully remove the plastic protective film from the iPad screen
16. Center the fresnel lens over the screen, taking care to align the tape 'pads' with the screen bezel (i.e., the tape should not touch the viewable part of the screen).
17. Using four binder clips, clip the screen/Fresnel assembly together at each corner (two clips on the top and two clips on the bottom). Ensure that the clips do not intrude on the viewable area of the screen, but only grip along the bezel.

Installing the screens

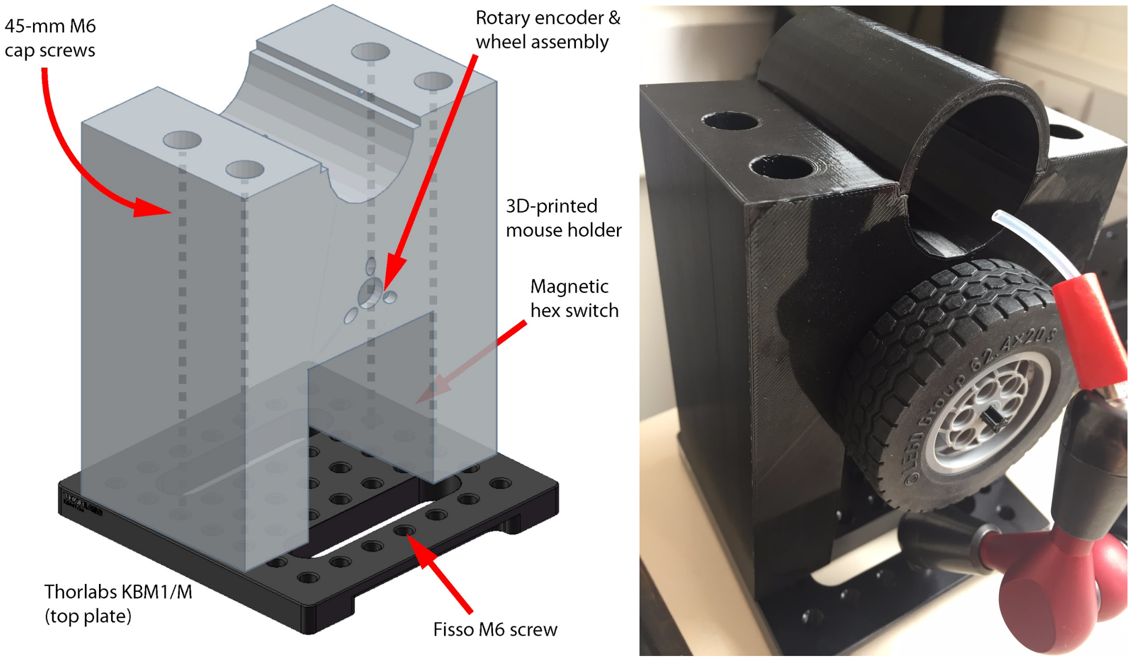
If you haven't already done so, ensure that the main monitor is connected to the NVIDIA video card via a mini-DisplayPort cable, at port 4.

1. For each screen, center the bottom edge into the V-groove screw of the lower PMTR/M clamp. The output cable and driver board should be at the top of the screen on the back
2. While holding the screen assembly in place, lower the upper PMTR/M clamp down the post until its V-groove screw holds the top edge of the screen assembly, and then firmly secure its position with the thumbscrew
3. After each screen assembly has been attached to a post, make minor adjustments at each BA2T2/M plate to ensure that the screens are perpendicular to each other and that the edges of the fresnel lenses are flush
4. Once the screens are firmly in place and all connection points are secured tightly to the breadboard, plug in the AC power cable to each. Use twist-ties to secure these cables to the optical posts
5. Connect each screen to the remaining NVS ports via the miniDP-to-DP display cables. Facing the screens, the leftmost screen should connect to port 1, the center to port 2, and the rightmost to port 3. The main monitor should connect to port 4. Use twist-ties to secure the iPad cables to their optical posts.
6. Turn the driver board switches to 'ON'
7. Check that visual output appears onscreen. It is possible that the screens are out of order or the 'main display' option defaults away from your main monitor.

Configuring the screens

The three iPad screens must be designated as a single viewable output, separate from the main monitor. This is accomplished using the NVIDIA Control Panel.

1. Launch the NVIDIA Control Panel
2. In the left panel, select ‘Select a task…’ > ‘Workstation’ > ‘Set up Mosaic’
3. Click ‘Create new configuration’
4. Under the ‘1. Select topology’ tab, select ‘Number of displays’ as 3 and choose a 1 x 3 topology with landscape orientation. (They mean “topography”, not “topology”, but never mind).
5. Check the box ‘I am using recommended connections for the selected topology’ and then click ‘Enable Mosaic’
6. Under the ‘2. Select displays’ tab, check the three iPad screens. These should be numbered 1 (0,0), 2 (0,1), and 3 (0,2). If they are not, rearrange the connections at the ports until this is satisfied.
7. Assign ‘Resolution per display’ to 1280 x 1024. If they are not already in the ‘Selected display sources’ box, drag them there and then click ‘Next’
8. Under the ‘3. Arrange displays’ tab, arrange the screen configuration so that 1-3 are arranged left to right. Apply the changes and select ‘yes’ to the dialog box prompting to save. Note: The main monitor will switch off and your working window will move to the 3-screen arrangement. Click ‘Finish’ (overlap and bezel correction is not required).
9. Return to the main control panel, this time choosing ‘Select a task…’ > ‘Displays’ > ‘Set up multiple displays’
10. Of the available displays, check the remaining box corresponding to the main monitor. In addition to the mosaic screens (labeled ‘3’), it will appear in the configuration window next to the 3-screen mosaic (display ‘3’) as display ‘4.’
11. Rearrange the screens in the preferred configuration, then right-click screen 4 and choose ‘make primary’. Apply and accept changes. The main monitor should now reactivate.
12. Launch Windows 10 > Settings > Display
13. For each of the displays, ensure that ‘Change the size of text, apps and other items’ is set to 100%



The mouse holder, seen from the front. The hole in the center will accommodate the rotary encoder and wheel assembly.

Assembling the mouse holder

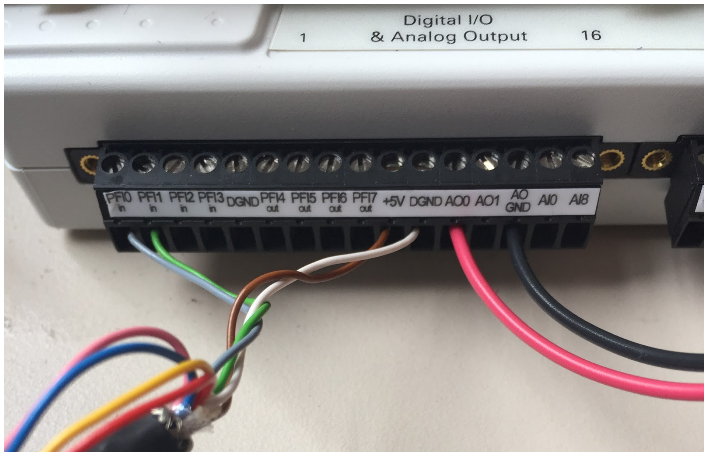
The mouse holder comprises seating for the mouse, a steering wheel/encoder assembly, and an articulated arm for delivering water rewards.

1. 3D-print the (a) mouse holder, (b) mouse cover, and (c) wheel coupler designs. This can be done in-house or can be outsourced to third parties. Use PLA plastic for best results.
2. Connect the wheel coupler to the shaft of the rotary encoder. It should attach securely with a just strong push
3. Feed the rotary encoder through the large center bore on the front plate of the mouse holder, so that the coupler is facing outward and the encoder body is housed on the underside of the mouse holder. The encoder cable should be oriented downward
4. Feed three 5-mm M3 cap screws through the small bores on the front plate and screw them into the threaded holes on the face of the encoder
5. To the top plate of the two-piece KBM1/M kinematic breadboard, the front center hole of the KBM1/M, attach the Fisso articulated arm to the front center hole of the KBM1/M, and secure tightly with a wrench
6. Connect the 3d-printed mouse holder to the KBM1/M top plate using four 45-mm M6 cap screws. The front face of the holder should be seated one row of M6 taps behind the Fisso arm. Ensure that the magnetic hex switch is oriented to one side for accessibility
7. Rotate the KBM1/M hex screw to release the bottom plate from the mouse holder assembly
8. Attach the KBM1/M bottom plate to the MB3030/M breadboard, then attach the holder assembly to the plate via the magnetic switch. (To avoid damage or injury, always make sure the magnetic switch is OFF before attempting to add or remove the top plate.)
9. Once the mouse holder is in position, assemble the Lego wheel and hub, then gently secure it to the front cross of the coupler. There should be 1-2 mm of space between the wheel and the front face of the mouse holder

Assembling the water valve

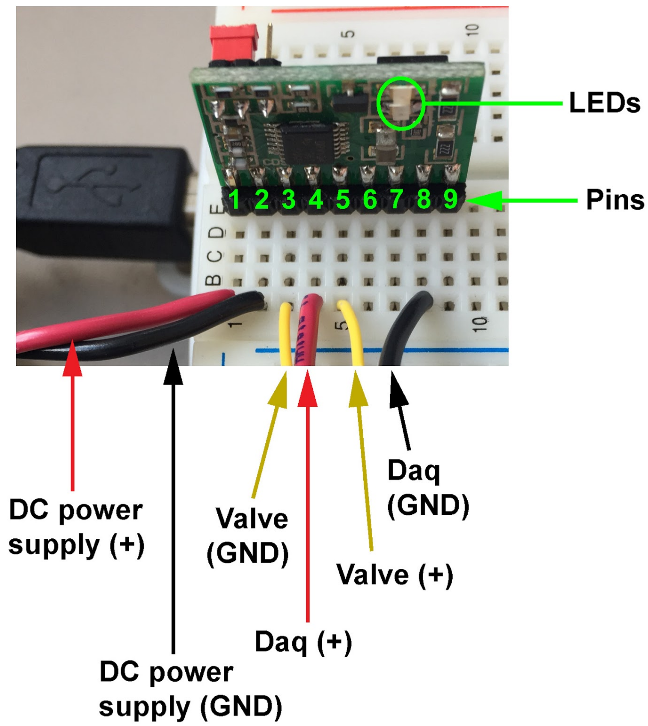
1. Position the water valve on one corner of the MB3030/M breadboard. Secure the valve wires to one of the nearby posts with a twist tie
2. On each end of the tubing already in the pinch valve, connect the larger end of a 3/32" x 1/16 barbed reducing connector

3. Cut 50 cm of 1/32" ID x 3/32" OD tubing, and attach one end to one of the barbed connectors
4. Feed the tubing up along the back of the Fisso arm, and gently attach the free end of tubing to the the screw tip of the Fisso with a piece of laboratory tape. Don't tape too tightly to ensure water can flow through this
5. Gently adjust the tubing so that ~2 cm extends beyond the screw tip
6. Adjust the Fisso arm so that the tube tip is centered in the bore of the mouse holder, and so that the Fisso does not obstruct free movement of the wheel
7. Additional 1/32" ID x 3/32" OD tubing will connect to the other barbed connector. This length should be cut in order to reach a nearby water reservoir (use a graduated cylinder or other vessel with millilitre precision)



Connecting the rotary encoder

1. Isolate the gray, green, brown, and white wires in the cable output of the rotary encoder.
2. Connect the wires to the NI DAQ 6211 at positions PFI0 (gray), PFI1 (green), +5V (brown), GND (white) by inserting the exposed wire into the correct DAQ socket and securing it with a 2-mm flathead screwdriver until tight
3. To test for encoder function, launch 'NI Device Monitor' from the System Tray.
4. Select the 'NI USB-6211:Dev1' icon, and then select 'Test this device'
5. In the Test Panels dialog box, migrate to the 'Counter I/O' tab, then select 'Mode: Edge Counting' and 'Pulse Terminal: /Dev1/PF10'
6. Click the Start button, then manually spin the wheel on the mouse holder. If the encoder is working properly, the counter value will increase quickly, irrespective of wheel direction.

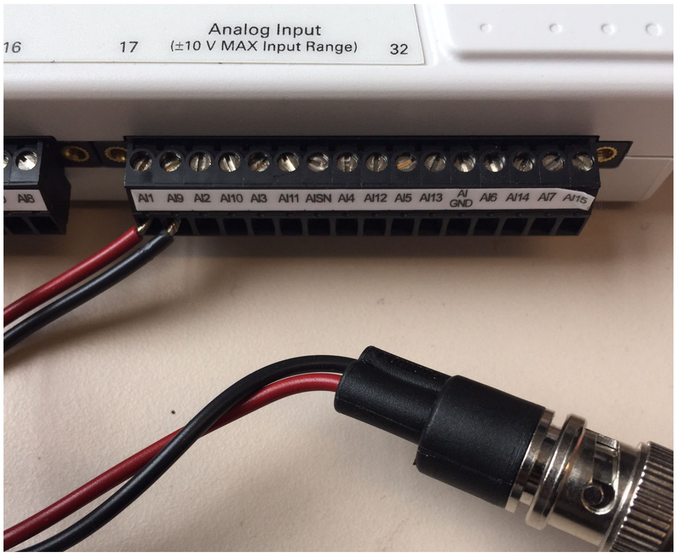


Connecting the water-reward system

Before troubleshooting, always power off the valve system by unplugging the power supply directly.

1. Cut two lengths each of red and black hookup wire. One red/black pair will connect the power supply and the other the DAQ board, so cut the lengths accordingly.
2. Strip 5mm of insulation from both ends of each wire
3. Connect the DC cable mount to the red/black wire pair that will supply power. Insert the red wire into the '+' terminal and the black wire into the '-' terminal. Secure the wires in the terminals by using a screwdriver to tighten the set screws. Ensure that no exposed wire is outside the mount housing.
4. Insert the CoolDrive valve controller driver into the prototyping mini-breadboard, so that its pins span multiple rows, not columns (i.e., the driver should run parallel to the center dividing well on the breadboard). The orientation of the driver is reversible, and pin information is twinned at each end (i.e., position 1 = position 9; position 2 = position 8, etc.). However, there is a LED trigger indicator on the driver, so consider its visibility when installing.
5. Connect the red (+) and black (GND) power-supply wires at position 1 and 2 on the breadboard, respectively.
6. Connect the two wires of the valve at position 3 and 5. Note that these leads are interchangeable.
7. Connect the red (+) and black (GND) DAQ wires at positions 4 and 8, respectively.
8. Using a piece of electrical tape, tape over all the breadboard connections to avoid short-circuiting or injury.
9. On the back of the power-supply plug, adjust the voltage of the power supply to the 12V by rotating the switch position with a flathead screwdriver
10. Connect the 5.5mm DC (male) plug to the two-pin output of the power-supply lead. Ensure the correct polarity by matching up the '+' symbols between the plug and the lead
11. Connect the red DAQ (+) wire at position 4 to the NI DAQ 6211 at port 'AO0.' Insert the wire into the port, and using a 2-mm flathead screwdriver, tighten the port's set screw until the wire is secure
12. Connect the black DAQ (GND) wire at position 8 to the NI DAQ 6211 at port 'AOGND.' Insert the wire into the port, and using a 2-mm flathead screwdriver, tighten the port's set screw until the wire is secure
13. Connect the male and female DC connectors for the power supply
14. Power the breadboard by plugging in the power supply to the wall socket

15. To test for valve function, launch 'NI Device Monitor' from the System Tray on the stimulus computer. The program should recognize the NI-6211, and a green light on the DAQ should flash
16. Select the 'NI USB-6211:Dev1' icon, and then select 'Test this device'
17. In the Test Panels dialog box, migrate to the 'Analog Output' tab, then select 'Mode: Voltage DC'
18. Alternate the 'Output Value' between (+) and (-) 5 V in the right pane, clicking the Update button each time.
19. The state of the valve (open or closed) will itself alternate with the alternating +/- 5V outputs—this will be evidenced by a small click and illumination of the green LED light on the driver board.



Connecting the photodiode

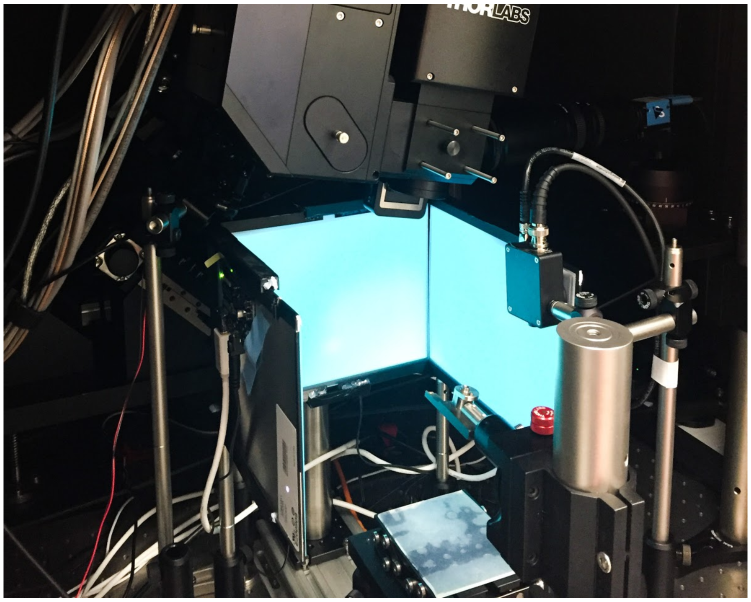
A photodiode is critical for gamma-correcting the luminance output of the screens, and is important for measuring stimulus timing.

1. Attach the photodiode horizontally to the TR50/M post via the M4 screw
2. Insert the TR300/M post into the PH50/M post holder
3. Place the PH50/M on the breadboard so that the TR300/M post is near the rightmost edge of the right iPad screen
4. Mount the PH50/M to the breadboard using a CF175 clamping fork and M6 cap screw
5. Use the RA90/M right-angle clamp to connect the TR50/M and TR300/M post so that the photodiode lens is facing the iPad screen
6. Adjust the clamp and post positions so that the photodiode lens is flush with the iPad screen and as far into the top righthand corner of the screen as possible
7. Connect the photodiode's power supply and a male-male BNC coaxial cable to the photodiode output port.
8. Connect the open end of the coaxial cable to the female BNC socket with test leads
9. Strip 5mm of insulation from both ends of each wire
10. Connect the red BNC (+) wire to the NI DAQ 6211 at port 'AI1.' Insert the wire into the port, and using a 2-mm flathead screwdriver, tighten the port's set screw until the wire is secure
11. Connect the black BNC (GND) wire to the NI DAQ 6211 at port 'AI9.' Insert the wire into the port, and using a 2-mm flathead screwdriver, tighten the port's set screw until the wire is secure
12. Power on the photodiode (there are switches at both the photodiode housing and power supply)
13. To test for photodiode function, launch 'NI Device Monitor' from the System Tray on the stimulus computer. The program should recognize the NI-6211, and a green light on the DAQ should flash
14. Select the 'NI USB-6211:Dev1' icon, and then select 'Test this device'
15. In the Test Panels dialog box, migrate to the 'Analog Input' tab, then select Channel Name: Dev1/ai1,' 'Mode: On Demand,' and 'Input Configuration: Differential'

16. Click the ‘Start’ button.
17. Free the photodiode slightly from its position near the screen so the sensor is visible. Without touching the sensor, carefully use your hand or a piece of cardstock to perturb the amount of light reaching it. This will cause the voltage reading to fluctuate, which will be visible on the onscreen graph.

Comments and suggestions

Now that you have your behavioral setup you will want to place it in a sound insulation box or other quiet place to train your mice, or somewhere else in your lab, where you can acquire physiological data.



An example of a setup used in a 2-photon imaging setup

In following these instructions you certainly will find that parts of this document can be improved. By all means please make those improvement, by using the “suggest” feature if you are reading this in Google Docs, or by sending an email to Lauren or Matteo.