

Journal of Visualized Experiments

Activity of Posterior Lateral Line Afferent Neurons During Swimming in Zebrafish --Manuscript Draft--

Article Type:	Invited Methods Collection - JoVE Produced Video
Manuscript Number:	JoVE62233R1
Full Title:	Activity of Posterior Lateral Line Afferent Neurons During Swimming in Zebrafish
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Additional Information:	
Question	Response
Please specify the section of the submitted manuscript.	Neuroscience
Please indicate whether this article will be Standard Access or Open Access.	Standard Access (US\$2,400)
Please indicate the city, state/province, and country where this article will be filmed . Please do not use abbreviations.	Saint Augustine, Florida, United States of America
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1 TITLE:

2 Activity of Posterior Lateral Line Afferent Neurons During Swimming in Zebrafish

3

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16

17 KEYWORDS:

18 hair cell, electrophysiology, ventral root, efferent copy, corollary discharge

19

20 SUMMARY:

21 We describe a protocol to monitor changes in the afferent neuron activity during motor
22 commands in a model vertebrate hair cell system.

23

24 ABSTRACT:

25 Sensory systems gather cues essential for directing behavior, but animals must decipher what
26 information is biologically relevant. Locomotion generates reafferent cues that animals must
27 disentangle from relevant sensory cues of the surrounding environment. For example, when a
28 fish swims, flow generated from body undulations is detected by the mechanoreceptive
29 neuromasts, comprising hair cells, that compose the lateral line system. The hair cells then
30 transmit fluid motion information from the sensor to the brain via the sensory afferent neurons.
31 Concurrently, corollary discharge of the motor command is relayed to hair cells to prevent
32 sensory overload. Accounting for the inhibitory effect of predictive motor signals during
33 locomotion is, therefore, critical when evaluating the sensitivity of the lateral line system. We
34 have developed an *in vivo* electrophysiological approach to simultaneously monitor posterior
35 lateral line afferent neuron and ventral motor root activity in zebrafish larvae (4–7 days post
36 fertilization) that can last for several hours. Extracellular recordings of afferent neurons are
37 achieved using the loose patch clamp technique, which can detect activity from single or multiple
38 neurons. Ventral root recordings are performed through the skin with glass electrodes to detect
39 motor neuron activity. Our experimental protocol provides the potential to monitor endogenous
40 or evoked changes in sensory input across motor behaviors in an intact, behaving vertebrate.

41

42 INTRODUCTION:

43 Afferent neurons of mechanosensory systems transmit information from hair cells to the brain
44 during hearing and balance. Electrophysiology can reveal the sensitivity of afferent neurons

45 through direct recordings. While whole cell patching from hair cells can be challenging, recording
46 from downstream afferent neurons is easier and allows assessment of action potentials in
47 response to controlled stimulations¹⁻³. Stimulating hair cells lead to their deflection, which
48 modifies mechanosensory structures, thus triggering an increase in action potentials (spikes) in
49 afferent neurons⁴⁻⁶. In the absence of external stimuli, afferent neurons also spike spontaneously
50 due to glutamate leak from the hair cells on to afferent post-synaptic terminals^{7,8}, and have been
51 shown to contribute toward maintaining sensitivity^{9,10}. Patch clamp recording of afferent activity
52 enables observation of hair cell sensitivity and signal dynamics that are not possible using
53 techniques with lower temporal resolution, such as in microphonics^{11,12} or functional calcium
54 imaging¹³⁻¹⁵. The following protocol will allow the recording of afferent activity concurrent with
55 motor commands to reveal instantaneous changes in hair cell sensitivity.

56
57 Zebrafish (*Danio rerio*) use hair cells contained in neuromasts that compose the lateral line
58 system to detect water movement relative to their body, which is translated into neural signals
59 essential for navigation¹⁶⁻¹⁸, predator avoidance, prey capture^{19,20}, and schooling²¹. Water flow
60 can also be self-generated by the motions of swimming²²⁻²⁴, respiration^{22,25,26}, and feeding²⁷.
61 These behaviors comprise repetitive movements that can fatigue hair cells and impair sensing.
62 Therefore, it is critical that the lateral line system differentiates between external (exafferent)
63 and self-generated (reafferent) flow stimuli. A corollary discharge attenuates self-generated flow
64 signals during locomotion in zebrafish. This inhibitory predictive motor signal is relayed via
65 descending neurons to the sensory receptors to modify the input or interrupt the processing of
66 the reafferent feedback^{28,29}. Seminal work contributing to our early understanding of this
67 feedforward system relied on in vitro preparations where the connectivity and endogenous
68 activity of the neural circuit were not maintained^{28,30-35}. This protocol describes an approach to
69 preserving an intact neural circuit where endogenous feedback dynamics are maintained thus
70 enabling better understanding of the corollary discharge in vivo.

71
72 The protocol outlined here describes how to monitor posterior lateral line afferent neuron and
73 motor neuron activity simultaneously in larval zebrafish. Characterizing afferent signal dynamics
74 before, during, and after motor commands provides insights into real-time, endogenous
75 feedback from the central nervous system that modulates hair cell sensitivity during locomotion.
76 This protocol outlines what materials will need to be prepared prior to experiments and then
77 describes how to paralyze and prepare zebrafish larvae. The protocol will describe how to
78 establish a stable loose patch recording of afferent neurons and extracellular ventral root (VR)
79 recordings of motor neurons. Representative data that can be obtained using this protocol are
80 presented from an exemplar individual and analysis was performed on multiple replicates of the
81 experimental protocol. Pre-processing of data is performed using custom written scripts in
82 MATLAB. Overall, this in vivo experimental paradigm is poised to provide a better understanding
83 of sensory feedback during locomotion in a model vertebrate hair cell system.

84
85 **PROTOCOL:**

86 All animal care and experiments were performed in accordance with protocols approved by the
87 University of Florida's Institutional Animal Care and Use Committee.

88

89 **1. Preparation of materials for electrophysiological recordings**

90

91 **1.1 Make a silicone elastomer-bottomed recording dish.**

92

93 1.1.1 Dispense a thin layer of self-mixing silicone elastomer components (e.g., Sylgard) into a
94 cover glass bottomed tissue culture dish until it levels with the rim of shallow well. Approximately
95 0.5 mL is sufficient.

96

97 1.1.2 Cover and cure the dish for a minimum of 48 h at room temperature.

98

99 **1.2 Make dissection pins.**

100

101 1.2.1 Provide a negative charge (5 V) to a 100 mL beaker of etchant (3M KOH) using a DC power
102 supply and attach a tungsten wire (0.002 inch; 50.8 μm diameter) to the positively charged
103 output.

104

105 CAUTION: Negative and positive wires should not contact one another during this procedure as
106 you may run the risk of producing sparks, which could pose a potential fire hazard.

107

108 1.2.2 Etch tungsten wire by quickly and repeatedly dipping the tip of the wire into the etchant
109 bath until the tip narrows to a sharp point. Under a stereomicroscope, cut the wire approximately
110 1 mm from the tip with a straight edge razor blade. Repeat three more times and then insert pins
111 into cured recording dish using fine forceps.

112

113 **1.3 Prepare recording electrodes.**

114

115 1.3.1 Pull a borosilicate glass capillary tube (inner diameter: 0.86 mm, outer diameter: 1.50
116 mm) using a horizontal micropipette puller with box filament into electrodes with a 30 μm
117 diameter tip with slight taper (**Figure 1 Ai**) that will be used to record afferent neurons from the
118 posterior lateral line.

119

120 1.3.2 Pull an additional borosilicate glass capillary tube into a pair of electrodes with smaller tip
121 diameters (1–5 μm). Holding one electrode in each hand, gently run the tips across one another
122 to break them to a $\sim 30^\circ$ angle. Using a microforge, polish the beveled tip until smooth. The final
123 tip diameter should be between 30–50 μm and will be used as the ventral root (VR) recording
124 electrode (**Figure 1 Aii**).

125

126 1.3.3 Mark the side of the VR electrode with the leading edge with permanent ink to aid in
127 orienting the tip aperture downward when inserting the electrode into the pipette holder of the
128 headstage (step 3.2).

129

130 NOTE: Mechanical modification of the VR recording electrode is imprecise and step 1.3.2 may
131 require multiple attempts until a suitable tip morphology is attained before polishing. VR
132 recording electrode is beveled to conform to the body curve of the larvae. Once fabricated, the

133 VR recording electrode can be used repeatedly as long as the tip remains clear and clean between
134 experiments.

135

136 1.4 Generate the protocol in electrophysiology recording programs.

137

138 1.4.1 Ensure the right headstage is connected to the **Channel 1** input in the back of the
139 microelectrode current and voltage clamp amplifier for the afferent neuron recordings and the
140 left headstage is connected to the **Channel 2** input for the VR recordings.

141

142 NOTE: Computer specifications for the current and voltage clamp amplifier minimally require 1
143 Ghz or a better processor, Windows XP Pro or Mac OS X 10.46.6, CD-ROM drive with 512 MB
144 RAM, 500 MB hard drive space, and 2 USB ports.

145

146 1.4.2 Open the computer-controlled amplifier software.

147

148 1.4.3 Set **Channel 1** and **Channel 2** to current clamp mode by clicking the **IC** button for each
149 channel.

150

151 1.4.4 Input the following parameters under both **I-Clamp 1** and **I-Clamp 2** tabs. **Primary Output:**
152 100x AC Membrane Potential (100,000 mV/mV), **Gain:** 1,000, **Bessel:** 1 kHz, **AC:** 300 Hz, **Scope:**
153 Bypass. **Secondary Output:** 100x AC Membrane Potential (100 mV/mV), **Gain:** 1, **Lowpass Filter:**
154 10 Hz.

155

156 1.4.5 Save channel parameters as **Ch1_Aff** and **Ch2_VR**.

157

158 1.4.6 Install and open the patch clamp electrophysiology software.

159

160 1.4.7 Click on **Configure** and select **Lab Bench** to set up the analog signals by adding **Ch1_Aff**
161 and **Ch2_Vr** to **Digitizer Channels** (e.g., **Analog IN #0** and **Analog IN #1**) that are connected, by
162 BNC coaxial cable, to the corresponding **Channel 1** and **Channel 2 Scaled Outputs** of the amplifier.
163 Click on **OK**.

164

165 NOTE: The minimum computer requirements for the digitizer are: a 1 Ghz or better processor,
166 Windows XP Pro or Mac OS X 10.46.6, CD-ROM drive 512 MB RAM, 500 MB hard drive space, and
167 2 USB ports.

168

169

170 1.4.8 Click on **Acquire** and select **New Protocol**.

171

172 1.4.9 In the **Mode/Rate** tab, select **Gap Free**; under **Acquisition Mode**, set **Trial Length** to either
173 **Use available disk space** (i.e., record until stopped) or a desired set **Duration (hh:mm:ss)**, and
174 then set the **Sampling rate per signal (Hz)** to **20,000** to maximize the resolution.

175

176 1.4.10 Under the **Inputs** tab, select the **Analog IN Channels** that were previously configured (in
177 step 1.4.6) and select **Ch1_Aff** and **Ch2_VR** for the corresponding channel.

178
179 1.4.11 Under the **Outputs** tab, select **Cmd 0** and **Cmd 1** for **Channel #0** and **Channel #1**,
180 respectively.

181
182 1.4.11.1 Connect Channel 1 Command on the amplifier to Analog Output 0 on the digitizer
183 via BNC coaxial cable and repeat for Channel 2 Command to Analog Output 1.

184
185 1.4.12 The remaining tabs can remain under default settings. Click on **OK** and save the protocol.
186

187 **2. Solution preparation**

188
189 2.1 Prepare Hank's solution: 137 mM NaCl, 5.4 mM KCl, 0.25 mM Na₂HPO₄, 0.44 mM KH₂PO₄,
190 1.3 mM CaCl₂, 1.0 mM MgSO₄, 4.2 mM NaHCO₃; pH 7.3. Dilute to 10% Hank's solution by adding
191 the appropriate volume of deionized water to the stock.

192
193 2.2 Prepare extracellular solution: 134 mM NaCl, 2.9 mM KCl, 1.2 mM MgCl₂, 2.1 mM CaCl₂,
194 10 mM glucose, 10 mM HEPES buffer; pH 7.8 adjusted with NaOH. Vacuum filter extracellular
195 solution through the filter with 0.22 µm pore size.

196
197 2.3 Prepare α-bungarotoxin: Dissolve 1 mg of lyophilized α-bungarotoxin in 10 mL
198 extracellular solution to produce 0.1% dilution.

199
200 2.4 Prepare Euthanasia solution: 50% (mg/L) buffered pharmaceutical-grade MS-222 in 10%
201 Hank's solution.

202
203 CAUTION: α-bungarotoxin is a potent neurotoxin that paralyzes muscles by blocking cholinergic
204 receptors. Gloves are required and eye protection is recommended while handling the paralytic.

205 206 **3. Preparation of larvae for electrophysiological recordings**

207
208 **3.1 Immobilize zebrafish larvae.**

209
210 **3.1.1** Use larvae from the laboratory-bred population of zebrafish (*Danio rerio*; 4–7 days post
211 fertilization) and house in embryo solution (10% Hank's solution) at 27 °C.

212
213 **3.1.2** Transfer larva from housing into a small Petri dish (35 mm) using a large-tipped transfer
214 pipette and remove as much of the surrounding solution as possible.

215
216 NOTE: Removal of the embryo solution prevents dilution of the paralytic and increases its
217 efficacy. The corner of a task wipe can be used to wick away the remaining embryo solution, and
218 it is critical not to contact the larvae or leave larvae exposed to air.

219

220 3.1.3 Immerse larvae in 10 μ L of 0.1% α -bungarotoxin for approximately 5 min.

221

222 NOTE: The time necessary to immobilize larvae varies between preparations. A healthy
223 preparation depends on closely monitoring sustained fast blood flow and decreased motor
224 responses. Brief overexposure to the paralytic can lead to a slow decline in overall health of the
225 preparation even after a thorough washout. It is best to apply a wash before the larva is
226 completely immobilized while it still shows signs of subtle muscle vibrations.

227

228 3.1.4 Wash paralyzed larva with extracellular solution and bathe for 10 min.

229

230 NOTE: The washout allows for the larva to transition from subtle muscle vibrations to complete
231 paralysis. Also, α -bungarotoxin is an antagonist of the nicotinic acetylcholine receptor (nAChR)
232 α 9-subunit, which is a critical component of the endogenous feedback circuit this protocol
233 observes; however, this effect has been shown to be reversible in *Xenopus* and zebrafish hair
234 cells after a 10 min washout^{36,29}.

235

236 3.2 Pin fish in the recording dish.

237

238 NOTE: Anesthesia (e.g., MS-222, Tricaine) is not required while preparing larval zebrafish (4–7
239 dpf) as it interferes with animal health. In fact, larval zebrafish are exempt from certain
240 vertebrate protocols.

241

242 3.2.1 Using transfer pipette, move the larva from the extracellular solution bath to the silicone-
243 bottomed recording dish. Fill the remainder of the dish with extracellular solution.

244

245 3.2.2 Under a stereomicroscope, gently position the larvae with fine-tipped forceps above the
246 center of the silicone mat, lateral side up, with the body's anterior and posterior ends running
247 left to right, respectively. Then grasp an etched pin from the silicone mat using fine-tipped
248 forceps and insert the pin, orthogonally to the silicone, through the dorsal notochord of the
249 larvae directly dorsal to the anus. Insert the second pin through the notochord near the end of
250 the tail and insert the third pin through the notochord dorsal of the gas bladder (**Figure 1B**).

251

252 NOTE: While inserting pins, it is important to target the center of the notochord width to prevent
253 impinging blood flow or damaging surrounding musculature. The notochord is dorsal to the
254 posterior lateral line nerve, so with proper pinning, no damage is expected to the lateral line
255 sensory neurons. Insert after first contact as to not disturb the surrounding tissue. Ideally, the
256 diameter of the pin is less than half the width of the notochord to ensure clean insertion. If the
257 pins exceed this width, repeat step 1.2 until the desired pin width is attained. If the blood flow
258 slows after pinning, repeat from step 1.3 onward with a new specimen.

259

260 3.2.3 Insert the fourth pin through the otic vesicle while providing slight rotation as the pin
261 inserts into the encapsulant (**Figure 1B**). As a slight rotation is applied, watch for the tissue
262 between the cleithrum and otic vesicle to reveal the cluster of afferent somata.

263

264 NOTE: Angled insertion of the fourth pin is to ensure the exposure of the posterior lateral line
265 afferent ganglion, which is otherwise obstructed by the large otic vesicle.

266

267 4. Ventral root recording

268

269 4.1 Place pinned larva under the 10x water immersion objective on a fixed stage differential
270 interference contrast (DIC) upright microscope and orient the myoseptal clefts of the muscle
271 blocks parallel to the left headstage approach vector (**Figure 1B**).

272

273 4.1.1 A fixed stage DIC microscope floated on an optical air table works best to prevent
274 vibrations from interfering with the recordings. Using a motorized positioner, the microscope can
275 then move freely around the fixed stage in which the preparation and headstages are mounted
276 (**Figure 1C**).

277

278 4.1.2 Place the ground wire into the bath solution and ensure that it is connected to the left
279 headstage.

280

281 4.2 Fill the VR recording electrode with 30 μ L of extracellular solution using a flexible gel-
282 loading pipette tip and insert into the left headstage pipette holder.

283

284 4.3 Lower the recording pipette into the dish solution with a micromanipulator while applying
285 positive pressure (1–2 mmHg) produced by a pneumatic transducer. Under 10x magnification,
286 confirm the orientation of the tip aperture is facing downward.

287

288 4.3.1 The pneumatic transducer should be connected to the pipette holder port via silicone
289 tubing.

290

291 4.4 Place the VR electrode onto the myoseptum

292

293 4.4.1 Using the micromanipulator again, lower the VR electrode tip until it is holding position
294 above the larva. Increase the magnification to 40x immersion.

295

296 4.4.2 Bring the electrode tip over a myoseptum between two myomeres ventral to the lateral
297 line until the cleft is centered in the VR electrode tip aperture (**Figure 1D**).

298

299 4.4.3 Lower the pipette until the lagging edge of the tip aperture gently contacts the
300 epithelium. After initial contact, maneuver the pipette diagonally to ensure the leading edge
301 makes contact and can generate a seal.

302

303 4.4.4 Apply negative pressure (~100 mm Hg) with the pneumatic transducer and hold.

304

305 NOTE: Proper orientation of the VR pipette relative to the myoseptum and continuous negative
306 pressure optimizes detecting motor neuron activity with a high signal-to-noise ratio through the
307 skin.

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4.5 Detect motor neuron activity.

4.5.1 The left headstage should be connected to the amplifier, which relays the amplified signal into a digitizer that outputs the said signal into the patch clamp electrophysiology software to be monitored on an adjacent computer (see section 1.4).

4.5.2 In the patch clamp software, click on the **Play** button on the tool bar to monitor the VR signal (**Figure 1E**).

4.5.3 Ensure that the VR recording is being achieved once motor neuron activity with well-stereotyped burst signal dynamics are observed^{29,37} (**Figure 1E**).

NOTE: Fictive swim bouts are the activity patterns of the VR motor neurons that continue to transmit despite the preparation being paralyzed. Therefore, fictive swims are an accessible means of determining the behavioral state of the animal and measuring locomotor parameters while simultaneously performing afferent neuron recordings that require an immobilized preparation. In our hands, once a VR recording is achieved, a healthy preparation will elicit voluntary fictive swim bouts every few seconds. Remember, a healthy preparation has sustained fast blood flow. Be advised, obtaining a sufficient VR signal may take several minutes and the signal-to-noise ratio may improve after initial detection. In the interest of time, it is acceptable to move on to section 5.

4.5.4 If a VR recording is still not achieved after completing section 5, release negative pressure, raise the electrode, and repeat from step 4.4.2 onward on a different myoseptum if the larva health is still optimal.

5. Afferent neuron recording

5.1 Fill the afferent recording electrode with 30 μ L of extracellular solution; insert into the right headstage pipette holder (**Figure 1B,C**), and lower into the dish solution while applying positive pressure (1–2 mm Hg) produced by a pneumatic transducer.

5.2 Locate and loosely attach to posterior lateral line afferent ganglion.

5.2.1 Using a micromanipulator, lower the afferent electrode tip until it is holding position above the cleithrum.

5.2.2 Increase the magnification to 40x immersion and locate the intersection of the posterior lateral line nerve and cleithrum. Follow the lateral line nerve anterior from the cleithrum to where the fibers innervate the posterior lateral line afferent ganglion, distinguishable by the discrete cluster of soma (**Figure 1F**).

351 5.2.3 Bring the electrode tip over the afferent ganglion and lower the pipette until the tip
352 contacts the epithelium. Gently, maneuver the electrode so that the entire tip circumference
353 contacts the afferent ganglion.

354
355 5.2.4 Apply negative pressure (20–50 mm Hg) with the pneumatic transducer and hold.

356
357 NOTE: The negative pressure applied to the afferent ganglion is gentler than the suction applied
358 during the ventral root recording. Increasing negative pressure can improve signal-to-noise, but
359 afferent neuron health declines under sustained aggressive suction, which decreases the
360 probability of a successful recording.

361
362 5.3 Record afferent neuron activity.

363
364 5.3.1 Ensure that the right headstage is connected in a similar sequence as described in step
365 4.5.1.

366
367 5.3.2 In pClamp10, click on the **Play** button on the tool bar to monitor afferent neuron and VR
368 signal simultaneously.

369
370 5.3.3 Ensure that the whole cell, loose patch recording of afferent neurons is achieved once
371 spikes occur spontaneously, roughly every 100–200 ms^{1,29} (**Figure 1E**).

372
373 5.3.4 Gradually, increase the afferent neuron recording electrode pressure back to atmospheric
374 (0 mm Hg) and hold for the remainder of the recording.

375
376 **6. Data acquisition**

377
378 6.1 Simultaneous recording.

379
380 6.1.1 Once afferent neuron and motor neuron activity are both detected, click on the **Record**
381 button on the tool bar in pClamp10 to capture simultaneous gap free recordings in both the
382 channels.

383
384 6.1.2 Record for the desired duration (**Figure 1E**).

385
386 NOTE: A recording in a healthy preparation can last for many hours and remain responsive to
387 external stimuli.

388
389 6.1.3 Save the recording as a supported file type (.abf, pClamp10) to preserve metadata such
390 as acquisition parameters.

391
392 **7. Euthanasia**

393

394 7.1 Apply positive pressure (10 mm Hg) to both afferent and VR recording electrodes using
395 pneumatic transducers and raise the electrodes from the recording dish using the
396 micromanipulators.

397

398 7.2 Transfer the recording dish from the fixed stage DIC microscope to the dissection
399 stereomicroscope.

400

401 7.3 Using fine tip forceps, remove tungsten pins from notochord and otic capsule, and
402 transfer the larvae using a transfer pipette into a Petri dish (35 mm) containing 5 mL of euthanasia
403 solution for a minimum of 5 min.

404

405 **8. Pre-processing and data-analysis**

406

407 NOTE: Data pre-processing and analysis will require a basic understanding of command line
408 coding.

409

410 8.1 Convert the recording file for pre-processing.

411

412 8.1.1 Install the Matlab software.

413

414 8.1.2 Download the custom written script, `abfload.m`³⁸ and save the file into the same folder
415 that stores the raw recording file.

416

417 8.1.3 In the **Matlab Editor** window, open `abfload.m` and click on **Run** on the tool bar. Select
418 **Change Folder**, if prompted.

419

420 8.1.4 Execute the function in the **Command Window** with the raw recording file as the input,

421

```
422 > [d,si,h] = abfload('[raw recording file name].abf')
```

423

424 and save the output workspace with a file name that includes larva designation, age, and
425 experimental date such as [specimen number]_[age in dpf]_[raw recording file name (includes
426 experimental date by default)].

427

428 NOTE: The converted file name should only include underscore delineated integers.

429

430 **8.2 Perform data pre-processing.**

431

432 8.2.1 Download Matlab script `AffVR_preprocess.m` and associated functions, custom written
433 by the authors.

434

435 8.2.2 In the **Editor** window, open `AffVR_preprocess.m`.

436

437 8.2.3 Under **Variables**, adjust lower bound spike detection thresholds for both afferent and VR
438 recordings (**spk_detect_lb** and **vr_detect_lb**, lines 8 and 14, respectively) depending on the
439 recording of the signal-to-noise ratio.

440
441 NOTE: Spike detection relies on manual thresholding to sort and isolate signals from more than
442 one afferent neuron by amplitude. Baseline noise and activity from other units are filtered out
443 by thresholding to only include spike amplitudes within a percent (e.g., **spk_detect_lb**) of the
444 maximum (e.g., **spk_detect_ub**). Thresholding also ensures accurate binning of motor activity
445 spikes into bursts and collective fictive swim bouts. Generally, start with a threshold lower bound
446 of 0.5, and gradually decrease until accurate detection is achieved. For example, setting
447 **spk_detect_lb** as 0.5 and **spk_detect_ub** as 1.0 will detect all spikes equal to or greater than 50%
448 of the spike amplitude maximum and exclude noise or additional neurons of lower spike
449 amplitudes (**Figure 2A**). Alternatively, one could also lower the **spk_detect_ub** from 1.0 to
450 exclude neurons of higher spike amplitudes in order to isolate the neurons of lower spike
451 amplitudes. Pre-processing figure outputs (see step 7.2.6) will inform whether adjustments and
452 repeating from step 7.2.2 is necessary.

453
454 8.2.4 In the **Editor** window, click on **Run** to execute **AffVR_preprocess.m**.

455
456 8.2.5 Navigate to the previously converted .mat data file (see step 7.1.3); select and click on
457 **Open** to begin automated preprocessing.

458
459 NOTE: While the custom script is running, outputs will appear in the **Command Window**
460 informing its progress through processing steps such as “filtering data ...”, “detecting ventral root
461 activity ...”, and “generating figures ...”.

462
463 8.2.6 Figures generated by **AffVR_preprocess.m** will visualize afferent spike and VR detection
464 and indicate whether any analysis variables should be adjusted (**Figure 2**).

465
466 8.2.7 Enter “Y” on the keyboard to save pre-processed metadata into a **preprocess_output**
467 folder.

468
469 8.2.8 Pre-processed data will automatically output as **data_out.xls**.

470
471 8.3 Analyze the pre-processed data as desired.

472 473 **REPRESENTATIVE RESULTS:**

474
475 After zebrafish larvae are properly immobilized and the posterior lateral line afferent ganglion
476 and VR recording is achieved, activity in both afferent and motor neurons can be measured
477 simultaneously. Recording channels are displayed using gap-free recording protocols (step 1.4)
478 for continuous monitoring of afferent and VR activity. In real-time, decreases in spontaneous
479 afferent spike rate can be observed concurrent with VR activity indicative of fictive swim bouts
480 (**Figure 1E**). We found that best results and accurate spike detection were products of recordings

481 that achieved a signal-to-noise ratio of at least 0.5. Custom written pre-processing scripts
482 generate plots to assist in visualization of afferent and VR spike detection. Spontaneous afferent
483 spikes are identified using a combination of spike parameters such as threshold, minimum
484 duration (0.01 ms), and minimum inter-spike interval (ISI; 1 ms). Increasing negative pressure
485 while establishing the recording often yields signal detection from multiple afferent units at once.
486 Filtering by amplitude allows for distinguishing between signal dynamics of independent
487 afferents. Isolating signals can be achieved by adjusting the lower-bound and upper-bound
488 detection variables in the pre-processing script (**Figure 2A**). Aggressive suction to achieve multi-
489 unit recordings can lead to unstable recordings, mechanical noise, degradation of afferent health,
490 and ultimately a loss of signal. Therefore, it is important to slowly dial back suction to
491 atmospheric pressure once the desired signal is achieved. Ventral root spike detection follows
492 identical parameters to afferent spike detection but requires additional inputs to define distinct
493 fictive swim bouts. Bursts within a motor command are defined by VR activity with a minimum
494 of two spikes within 0.1 ms of each other and lasted a minimum of 5 ms. All swim bouts are then
495 delineated by a minimum of three bursts with inter-burst intervals of <200 ms (**Figure 2B**).

496
497 Afferent activity is difficult to interpret when looking at a recording in its entirety. Pre-processing
498 scripts will overlay sections of afferent activity centered on a well-defined period of interest, in
499 this case, the onset of a swim bout (n = 33, **Figure 2C**) to assist in visualizing trends in signal
500 dynamics. Instantaneous afferent activity is calculated using a moving average filter and a 100
501 ms sampling window. Mean spontaneous activity shows dramatic changes in response to the
502 onset of motor activity (**Figure 2C**). To better dissect and analyze afferent activity, periods before
503 and after the swim are set to match the time interval of the corresponding swim bout. In the pre-
504 processing script and representative analyzed results these periods are termed “pre-swim” and
505 “post-swim”. Pre-swim, swim, and post-swim spike rates were calculated by taking the number
506 of spikes within the respective period over its duration. The precision of estimates for each
507 individual is partly a function of the number of swims, so we analyzed variable relationships using
508 weighted regressions, with individual weights equal to the square root of the number of swims.

509
510 Differences in afferent spike rates across the various periods of interest (pre-swim, swim, and
511 post-swim) were tested by a two-way analysis of variance (ANOVA). Tukey’s post-hoc test
512 detected significant differences in spike rates between swimming spike rates and spike rates of
513 both pre-swim (8.94 ± 0.2 Hz, relative decrease 57%) and post-swim (5.34 ± 0.2 Hz, relative
514 decrease 40%) periods. The spike rate did not immediately return to the baseline given we also
515 found that post-swim spike rate was lower than the pre-swim spike rate (Tukey post-hoc tests
516 across groups, $p < 0.001$; **Figure 3A**). Linear models were used to detect relationships between
517 relative spike rate and fictive swim parameters. Relative spike rate was calculated by taking the
518 swim spike rate over the pre-swim spike rate. Fictive swim parameters included swim duration,
519 swim frequency (i.e., number of bursts within a swim bout over the duration of the swim bout),
520 and duty cycle (i.e., sum of the swim burst durations over the swim bout total duration). In our
521 hands, the mean and variance of relative spike rate was correlated, so it was necessary for the
522 data to be log transformed for analysis. Afferent spike rate was negatively correlated with swim
523 duration meaning that the lateral line experiences had greater inhibition during swims of longer
524 duration ($r^2 = 0.186$, $F_{2,26} = 2.971$, $p = 0.045$; **Figure 3B**). There was no correlation detected

525 between relative spike rate and neither swim frequency nor duty cycle ($r^2 = 0.099$, $F_{2,26} = 1.431$,
526 $p = 0.231$, and $r^2 = 0.047$, $F_{2,26} = 0.645$, $p = 0.932$, respectively; **Figure 3C,D**). All analyses of variable
527 relationships were weighted by the number of swims per individual and all the variables were
528 then averaged by each individual ($n = 29$).

529

530 **FIGURE LEGENDS:**

531

532 **Figure 1: Simultaneous electrophysiological recording of posterior lateral line afferent neuron**
533 **and ventral motor root activity.** (A). Example of a loose-patch afferent (i) and ventral motor root
534 (ii) recording electrodes. Scale bars represent 50 μm . (B) Larval zebrafish are paralyzed and
535 pinned in four locations (cross symbols) to a Sylgard dish for recording stability. Bold crosses
536 represent insertion points for pins. (C) The electrophysiology rig is mounted on a vibration-
537 isolation table and consists of an upright fixed stage microscope on a motorized controller
538 capable of 40x magnification. Dual current clamp and voltage clamp head stages are mounted on
539 micromanipulators. (D) The myomeres of the body musculature are separated by myosepta that
540 serve as recording landmarks for motor neuron arborizations. The ventral motor root electrode
541 approaches the ventral body (left) and is centered and lowered on top of a myoseptum
542 (arrowhead). Scale bar represents 50 μm . (E) Screen capture of electrophysiological recording in
543 real-time allowing visualization of the spontaneous afferent activity (channel 1) and bursting
544 ventral root activity indicative of fictive swim bout (channel 2). The Record and Play buttons are
545 denoted with red arrows. (F) The posterior lateral line afferent ganglion (dashed line) lies just
546 under the skin and can be identified by a tight cluster of afferent soma. The ganglion can be
547 located by following the lateral line nerve past the cleithrum bone (arrowhead) to where it
548 connects to the ganglion. Scale bar represents 30 μm .

549

550 **Figure 2: Pre-processing figure outputs visualize accurate spike detection.** (A) Extracellular,
551 loose-patch recording of posterior lateral line afferent neurons. Discrete spikes (labeled with red
552 dots) are detected with a minimum inter-spike interval of 1 ms. Baseline noise and activity from
553 other units are filtered out by thresholding to only include spike amplitudes within 50% of the
554 maximum. (B) Ventral motor root recording (VR) of fictive swim bouts reveal voluntary motor
555 commands throughout the duration of the recording. VR spikes (red dots) are detected using a
556 similar threshold filter and then binned into a single swim bout (green) by detecting a burst of
557 activity within 200 ms of one another (see insert; scale bar represents 200 ms). Spikes detected
558 outside the defined swim bout do not occur within the inter-spike interval of stereotyped burst
559 activity and are therefore excluded. (C) Mean spontaneous afferent spike rate centered on the
560 onset of each swim bout (time = 0 s) illustrating spike rate before, during, and after swimming.
561 Error bars represent \pm SEM.

562

563 **Figure 3: Quantification of afferent activity before, during, and after fictive swimming.** (A)
564 Afferent spike rate is significantly reduced during swimming and this effect persists even
565 afterwards. Statistically similar groupings are denoted by a and b. (B) Longer swim duration is
566 correlated to decreased afferent spike rate. (C–D) Swim frequency and swim duty cycle show no
567 correlation to afferent spike rate. All values represent mean \pm SEM. Outlying individuals with low
568 statistical weight were omitted.

569

570 **DISCUSSION:**

571 The experimental protocol described provides the potential to monitor endogenous changes in
572 sensory input across motor behaviors in an intact, behaving vertebrate. Specifically, it details an
573 in vivo approach to performing simultaneous extracellular recordings of lateral line afferent
574 neurons and ventral motor roots in larval zebrafish. Spontaneous afferent activity has been
575 previously characterized in zebrafish without consideration of potential concurrent motor
576 activity^{1,2,39-41}. Without monitoring the presence of motor activity with ventral root recordings,
577 deciphering afferent activity will likely be underestimated due to the influence of efferent
578 inhibition during, and even after, spontaneous swimming.

579

580 In vivo electrophysiological recordings are inherently challenging. In our experience, maintaining
581 a healthy preparation is the single greatest factor to achieving successful, long-lasting recordings
582 for afferent neurons and ventral motor roots. To do this, it is important to not only identify and
583 monitor fast blood flow, but also recognize the texture of the skin and underlying musculature.
584 We recommend observing several paralyzed larvae under a microscope before further handling
585 to become familiar with the intrinsic blood flow and skin state of healthy larvae. A successful
586 ventral root recording through the skin requires a smooth, healthy skin surface in order for the
587 recording electrode to generate a tight seal. This approach circumvents traditional protocols^{37,42}
588 that are invasive and time-consuming, which call for dissecting away the epithelium to expose
589 the underlying musculature. An inconvenience of recording through the skin is the potential
590 variability in time before signals are realized. Optimizing the magnitude and duration of applied
591 negative pressure will decrease the time required to establish a signal and potentially improve
592 the signal-to-noise ratio. Recordings from a healthy, active preparation should yield spontaneous
593 afferent spike rates between 5–10 Hz with fictive swim bouts occurring every few seconds.

594

595 In addition to revealing motor activity state, ventral root recordings can serve as a proxy for
596 monitoring efferent activity that discharges parallel to motor commands to attenuate lateral line
597 activity³⁰⁻³² as well as activity in homologous hair cell systems (e.g., the auditory and vestibular
598 system^{35,43-45}). Efferent neurons reside deep in the hindbrain, making electrophysiological
599 recordings of them exceedingly challenging. Zebrafish are a model genetic system, and our
600 electrophysiology protocol can be complemented by transgenic lines to powerfully investigate
601 aspects of corollary discharge, hair cell sensitivity, excitotoxicity, and beyond.

602

603 **ACKNOWLEDGEMENTS:**

604 We gratefully acknowledge support from the National Institute of Health (DC010809), National
605 Science Foundation (IOS1257150), and the Whitney Laboratory for Marine Biosciences to J.C.L.

606

607 **DISCLOSURES:**

608 The authors declare no competing financial interests.

609

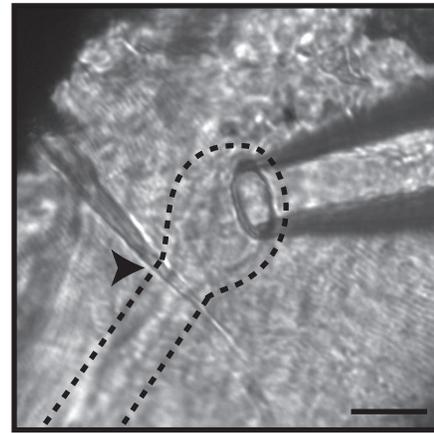
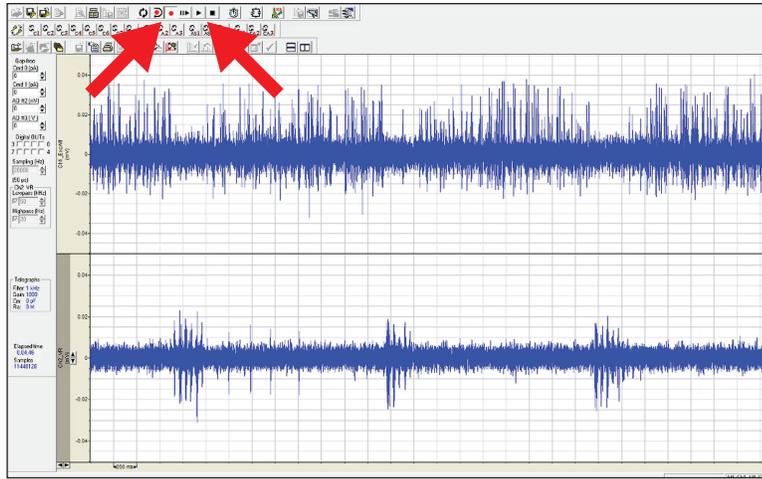
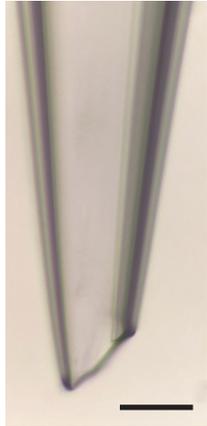
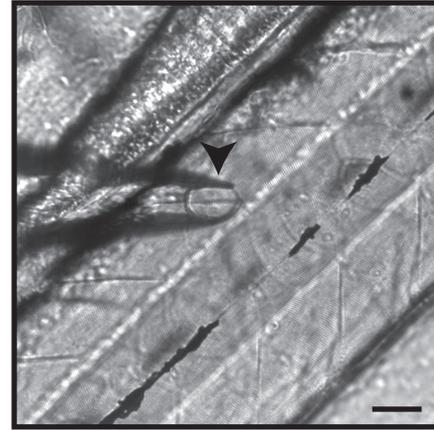
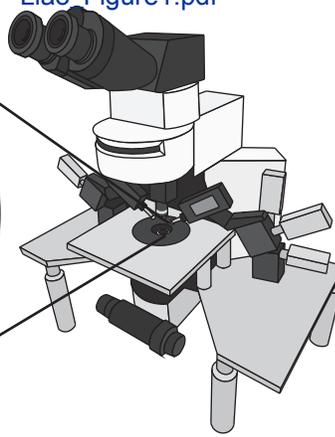
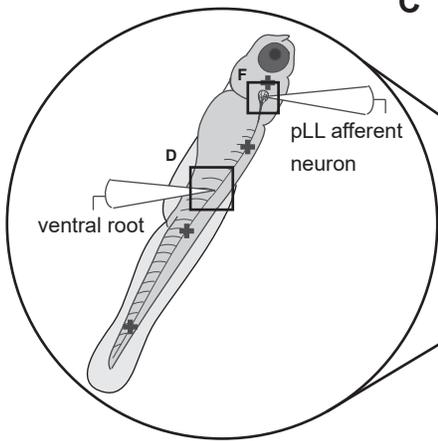
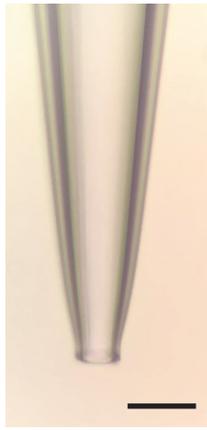
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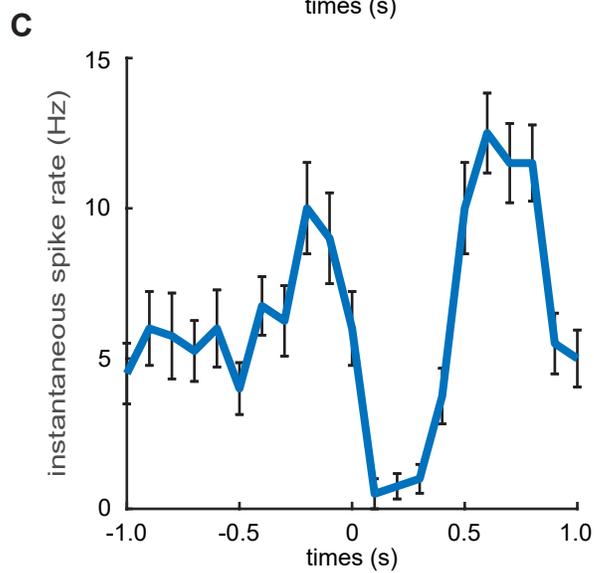
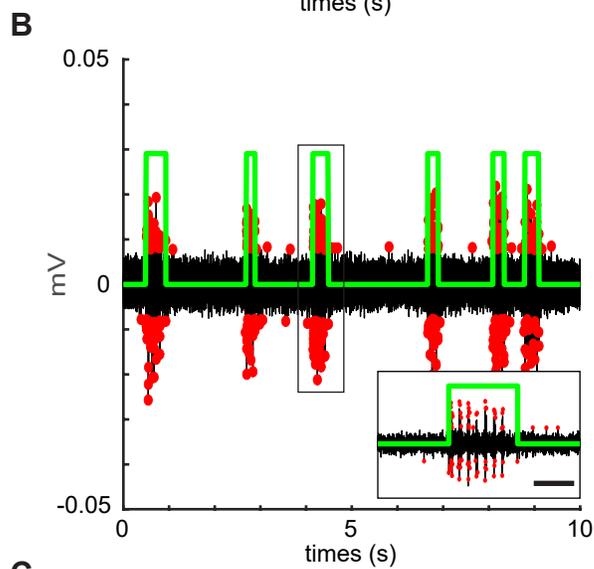
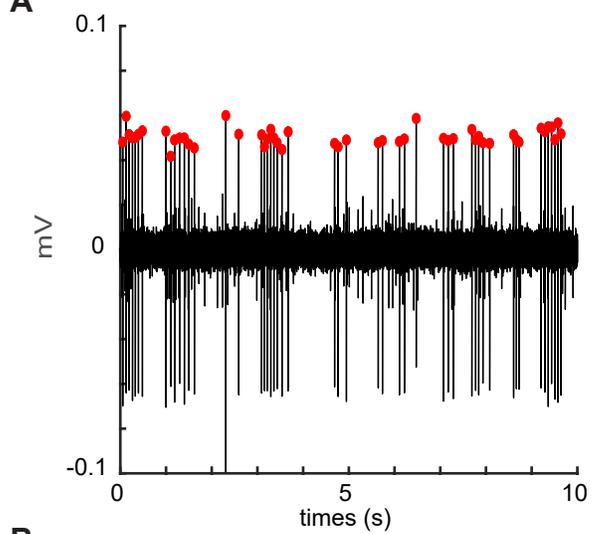
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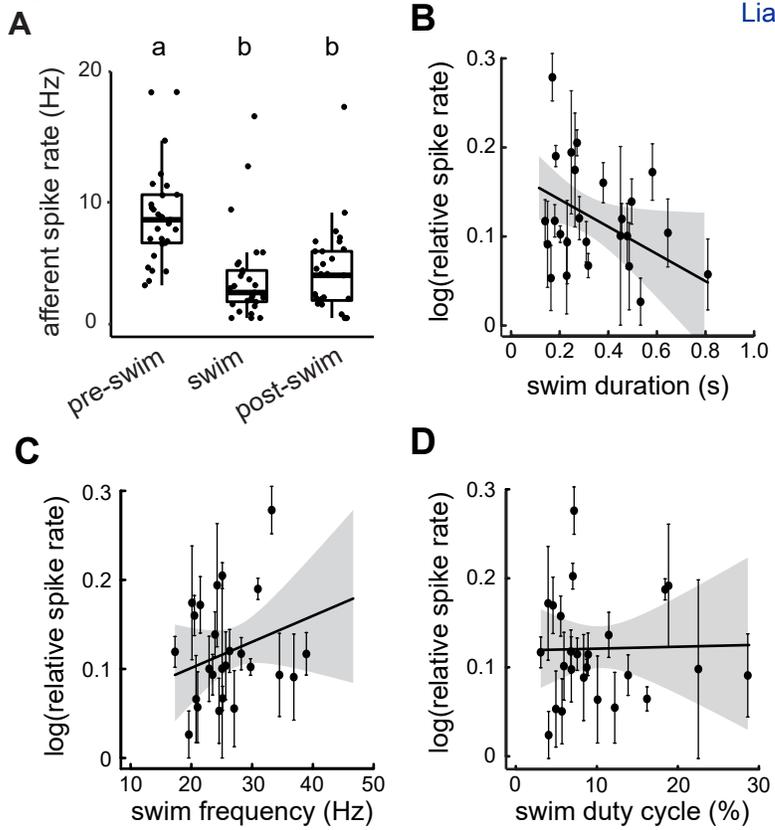
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Name	Company
100 mL beaker	PYREX
10x water immersion objective	Olympus
40x water immersion objective	Olympus
abfload.m	
AffVR_preprocess.m	
BNC coaxial cables	ThorLabs
borosilicate glass capillaries w/ filament	Warner Instruments
burst_detect	
computer	N/A
DC Power Supply	Tenma
electrophysiology digitizer	Axon Instruments, Molecular Devices
filament	Sutter Instrument Company
fine forceps	Fine Science Tools
fixed stage DIC microscope	Olympus
flexible, tapered pipette tip	Fisher Scientific
FluoroDish	World Precision Instruments Inc.
KimWipe	KimTech
Kwik-Gard	World Precision Instruments Inc.
MATLAB	MathWorks
microelectrode amplifier	Axon Instruments, Molecular Devices
microforge	Narishige
micromanipulator control unit	Siskiyou
micropipette puller	Sutter Instrument Company
microscope control unit	Siskiyou
motorized micromanipulator	Siskiyou
MultiClamp Commander	Molecular Devices
optical air table	Newport Corporation
pCLAMP	Molecular Devices
permanent ink marker	Sharpie
petri-dish	Falcon
pipette holder	Molecular Devices
pneumatic transducer	Fluke Biomedical Instruments
potassium hydroxide	Sigma-Aldrich
silicone tubing	Tygon
spike_detect	
stereomicroscope	Carl Zeiss
straight edge razor blade	Canopus
swimbout_detect	
syringe	Becton Dickinson Compoany
transfer pipette	Sigma-Aldrich
tricaine methanesulfonate	Syndel
tungsten wire	World Precision Instruments Inc.
vacuum filtration unit	Sigma-Aldrich
voltage-clamp current-clamp headstage	Molecular Devices
α -bungarotoxin	ThermoFisher

Catalog Number	Comments
1000	resceptacle for etchant
UMPLFLN10xW	low magnification for positioning larvae and recording electrophysiology
LUMPLFLN40XW	higher magnification for position electrode tip and establishing connections
supplemental coding file	custom written MATLAB script for converting raw electrophysiology data to MATLAB format
supplemental coding file	custom written MATLAB script for preprocessing recording data
2249-C-12	connecting amplifier and digitizer channels; require 4 channels
G150F-3	inner diameter: 0.86, outer diameter: 1.50; capillary glass used for pulling electrodes
supplemental coding file	custom written MATLAB script for swimbout_detect
N/A	supplemental coding file
72-420	any computer should work
Axon DigiData 1440A	used for electrically etching dissection pins
FB255B	enables acquisition of patch-clamp data
Dumont #5 (0.05 x 0.02 mm) Item No. 11295-10	2.5 mm box filament used in micropipette puller
BX51WI	used to manipulate larvae and insert pins
02-707-169	microscope used to visualize and establish patch-clamp recordings
FD3510-100	flexible tips enable insertion into recording electrode to dispense agarose
34155	cover glass bottomed dish recording dish
710172	task wipe used for wicking away excess fluid from larvae
R2020b	self-mixing sylgard elastomer
MultiClamp 700B	command line software for preprocessing data
MF-830 microforge	patch clamp amplifier for dual channel recordings
MC1000-eR/T	to polish recording electrode
Flaming/Brown P-97	4-axis dial coordinator for controlling micromanipulator
MC1000e	for pulling capillary glass into recording electrodes
MX7600	positions the microscope around the fixed stage and prepares the stage
2.2.2	positions the headstage and attached recording electrode for recording
VH3036W-OPT	downloadable from Axon MultiClamp 700B Commander download page
10.7.0	downloadable from Axon pCLAMP 10 Electrophysiology Data Manager
order from amazon.com	breadboard isolation table to float microscope and minimize vibrations
35-3001	downloadable from Axon pCLAMP 10 Electrophysiology Data Manager
1-HL-U	for marking the leading edge side of the VR electrode to ensure proper orientation
DPM1B	used to immerse larvae in paralytic
221473-25G	hold recording electrode and connect to the headstage
14-169-1A	for controlling recording electrode internal pressure
supplemental coding file	etchant for etching dissection pins
Stemi 2000-C	tubing to connect pneumatic transducer to pipette holder
order from amazon.com	custom written MATLAB function necessary to run AffVR_preprocess
supplemental coding file	used to visualize pin tips and during preparation of larvae
309602	cuts the tungsten wire while making dissection pins
Z135003-500EA	custom written MATLAB function necessary to run AffVR_preprocess
12854	filled with extracellular solution to inject into recording electrode
715500	single use, non-sterile pipette for transferring larvae
SCGVU11RE	pharmaceutical anesthetic used to euthanize larvae with high concentration
CV-7B	0.002 inch, 50.8 μm diameter; used to make dissection pins
B1601	single use, sterile, vacuum filtration units used to sterilize extracellular solution
	supplied with MultiClamp 700B amplifier used as left and right channels
	for immobilizing the larvae prior to recording

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using patch-clamp
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used to form recording electrodes
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download page
reduces vibrations during recordings
see Acquisition & Analysis Software Download page
ensure proper orientation when inserting into pipette holder

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Editorial comments

1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.

We thank the editor for the opportunity to revisit the manuscript, and we did our best to make edits where appropriate.

2. Please revise the following lines to avoid previously published work: 32-34, 66-73, 440-461

We thank the editor for bringing the similarity of the included text to our previously published work. We have revised and restructured the lines in question to avoid previously published work.

3. Figure 3B: Please use SI abbreviations for time: s instead of sec.

Edit is now incorporated

4. Please present references numerically in order: Line 63, 71

Edit is now incorporated

5. Line 69: Please present references as numbered superscripted instead of listing the author and year in the text.

Edit is now incorporated

6. Please include the ethics statement before your numbered protocol steps, indicating that the protocol follows the animal care guidelines of your institution.

We have moved the ethics statement about animal care guidelines to precede the protocol.

7. Line 110: Please specify the units for the dimensions of the capillary (inner and outer diameter).

Edit is now incorporated

8. Line 191: Do you mean "Immerse the larvae in extracellular solution containing 10 μ L of 0.1% α -bungarotoxin.." ? What is the α - bungarotoxin diluted with?

We thank the editor for bringing this ambiguity to our attention. We have included a "Solution Preparation" section to the protocol that should add clarity. The alpha-bungarotoxin is diluted with extracellular solution to 0.1% and the larvae is then immersed in a 10 μ L aliquot for paralysis.

9. Please specify the euthanasia method used for the larvae.

We have included a euthanasia section to the protocol approved by the University of Florida Institutional Animal Care and Use Committee that details the methods used to euthanize the larvae.

10. Please highlight up to 3 pages of the Protocol (including headings and spacing) that identifies the essential steps of the protocol for the video, i.e., the steps that should be visualized to tell the most cohesive story of the Protocol. Remember that non-highlighted Protocol steps will remain in the manuscript, and therefore will still be available to the reader.

We have highlighted steps in the protocol that we feel outlines the essential steps of the protocol and will generate a visually interesting video with a comprehensive narrative.

11. Please ensure that the highlighted steps form a cohesive narrative with a logical flow from one highlighted step to the next. Please highlight complete sentences (not parts of sentences). Please ensure that the highlighted part of the step includes at least one action that is written in imperative tense.

While highlighting the essential steps we made sure to follow the helpful instructions outlined by the editor.

Reviewers' comments:

Reviewer #1:

Major Concerns:

The part of the protocol that describes the actual recording of signals and settings for amplifiers and software is very specific and applies only to the set up the authors used. I would recommend keeping this section either more general or state in the beginning of the section which equipment and software was used. I am giving some examples below.

We thank the reviewer for raising this important concern. Per the reviewer's examples stated in the below "Minor Concerns", we have stated more clearly at the beginning of each appropriate section the piece of equipment and software used for each step. We believe with these revisions the relevant sections should be easier to follow and much more applicable to readers with comparable equipment.

Minor Concerns:

Line 60: In my view, "clusters of hair cells" is not equivalent to "neuromast", since a neuromast consists of hair cells, support cells and mantle cells. I would recommend changing this to "hair cells contained in neuromasts"

The reviewer makes a strong point, and we agree that "hair cell contained in neuromasts" is a more apt phrase to avoid conflating support cells and mantle cells with the sensory hair cells.

Line 79-80: This reads as if the authors consider the recording from the motor neurons also as „loose patch ". I understand "loose patch recording" as a recording from cell bodies (as in the case of the afferent neurons in the ganglion). I recommend referring to the recording from motor neurons as extracellular recording from the ventral motor root.

We thank the reviewer for their clarifying suggestion, and we have revised the language of the sentence to make a clear distinction between the “loose patch” technique used in the afferent recording and the extracellular recording technique used for the ventral motor root recording.

“The protocol will describe how to establish a stable loose patch recording of afferent neurons and extracellular ventral root (VR) recordings of motor neurons.”

Line 103: When describing the chemical etching, I would recommend pointing out those positive and negative wires should not be touching each other during this procedure, since sparks may occur which could be a fire hazard.

We have included a “CAUTION” note to bring attention to the potential fire hazard and describing how to avoid such hazards.

“CAUTION: Negative and positive wires should not contact one another during this procedure as you may run the risk of producing sparks which could pose a potential fire hazard.”

Line 111: Although, stated in the material list, I would recommend mentioning here what type of micropipette puller the authors use/recommend (vertical/horizontal, what kind of filament). Does any other aspect besides the opening diameter matter for the afferent neuron-recording pipette (e.g. taper of tip ...)?

We have included descriptions of the pipette puller and filament. In our hands, we have not found that aspects of the afferent neuron recording pipette other than tip diameter have affected recording success or quality, but we included a little more description of the tip that are consistent with the image provided in Figure 1 Ai for additional clarity.

“Pull borosilicate glass capillary tube (inner diameter: 0.86 mm, outer diameter: 1.50 mm) using a horizontal micropipette puller with box filament into electrodes with 30 μ m diameter tip with slight taper (Figure 1 Ai)”

Line 127 ff.: Although mentioned in the material list, I would recommend pointing out here what type of recording set up (amplifier, digitizer and software) the authors used. The instructions in section 1.4 are very specific to the system and software the authors used. I also would recommend stating which general system requirements are necessary for this type of recording (e.g. two analog input channels, sampling rate, filtering ...) Not every system may fulfill these requirements.

As previously mentioned in response to the reviewer’s “Major Concerns” we appreciate the reviewer’s recommendations to be more transparent about what type of recording equipment we used in each step they were used. We have also included general system requirements.

.
Line 173 ff.: I would recommend making a section for "fish preparation" and for "preparing solutions".

We thank the reviewer for this very useful recommendation. Making sections specifically for preparing solutions and preparing the larvae has alleviated areas of ambiguity addressed by other reviewers.

Line 184: Which diameter do the authors recommend for the petri dish?

We recommend a 35 mm petri dish and have included the dimensions in a parenthetical. This diameter is consistent with the petri dish listed in the "Materials List".

Line 219: Is it correct that no anesthesia (Tricain) was used during the preparation, specifically pinning?

It is true that no anesthesia (i.e. MS-222/Tricaine) was used during the preparation. Guidelines from the National Institute of Health state that larval zebrafish prior to 8 days post fertilization are exempt from many vertebrate protocols (https://oacu.oir.nih.gov/sites/default/files/uploads/arac-guidelines/b17_zebrafish.pdf). Possibly more relevant to our preparation is that MS-222 blocks the basal K^+ currents and voltage sensitive Na^+ channels of larval zebrafish hair cells and neurons, respectively. Therefore, it has been stated MS-222 cannot be used when studying zebrafish lateral line physiology *in vivo* (Olt et al. 2016). We hope the reviewer finds this explanation satisfactory and we want to reassure them that our protocol is in accordance with the University of Florida Institutional Animal Care and Use Committee.

Line 226 ff.: Could the authors comment on whether special caution has to be taken in avoiding pinning through the lateral line nerve? Do the authors have any recommendations regarding avoiding pinning or pinching the lateral line nerve?

The notochord in which the pins are inserted lies dorsal to the lateral line nerve so pinning avoids disrupting the relevant circuitry by design. However, it is worthwhile for the reader to be aware of part of the reasoning behind pinning through the notochord so we have commented on this in a "NOTE".

"The notochord is dorsal to the posterior lateral line nerve, so with proper pinning, no damage is expected to lateral line sensory neurons."

Line 295: Do the authors recommend any criteria in assessing larval health?

We agree it is important to remind the reader of the criteria for assessing larval health so we reiterate here that sustained fast blood flow is our recommended metric for monitoring larval health.

Line 361: The source/ author of abfload.m from Mathworks File exchange should be cited (abfload, version 1.4.0.0 (7.42 KB) by Harald Hentschke, abfload imports data in the Axon abf format). Unless, it is this a different "abfload.m" used here?

We thank the author for bringing this omission of credit to our attention. The author of `abfload.m` is indeed Harald Hentschke and we have made sure to include the citation in our references.

Line 377 ff.: Could the authors comment on whether the m files mentioned in the following section were custom written by the authors? Will these files be available for download along with this protocol?

We are the authors of the custom written matlab scripts and have commented to make that clear in the protocol. The files were included with the original manuscript submission and will be made available for download along with the protocol.

“Download Matlab script `AffVR_preprocess.m` and associated functions, custom written by the authors.”

Line 387: What input parameter does the thresholding require? Does it allow, for example, entering multiples of the noise standard deviation? How do the authors treat spikes originating from several neurons versus spikes from the same neuron? (For example in figure 2A it looks like there are spikes from two neurons, one with larger amplitude and one with smaller amplitude, it seems the authors only count the larger spikes?).

We thank the reviewer for bringing this ambiguity to our attention. Thresholding for spike detection is a crucial step in processing the data so it is important we clearly define the input parameters and their function. The custom written script does not directly allow for inputting multiples of the noise standard deviation. We used upper and lower-bounds of the spike amplitude to isolate individual afferent units. In the appropriate “NOTE” section we have more clearly described the parameters as well as included an example relevant to the trace in Figure 2A.

*“Baseline noise and activity from other units are filtered out by thresholding to only include spike amplitudes within a percent (e.g. ‘`spk_detect_lb`’) of the maximum (e.g. ‘`spk_detect_ub`’). Thresholding also ensures accurate binning of motor activity spikes into bursts and collective fictive swim bouts. Generally, start with a threshold lower bound of 0.5, and gradually decrease until accurate detection is achieved. For example, setting ‘`spk_detect_lb`’ as 0.5 and ‘`spk_detect_ub`’ as 1.0 will detect all spikes equal to or greater than 50% of the spike amplitude maximum and exclude noise or additional neurons of lower spike amplitudes (**Figure 2 A**). Alternatively, one could also lower the ‘`spk_detect_ub`’ from 1.0 to exclude neurons of higher spike amplitudes in order to isolate the neurons of lower spike amplitudes.”*

Reviewer #2:

Major Concerns:

none

Minor Concerns:

Abstract: it would be useful to link hair cell/sensory inputs to afferents earlier. Also link hair cells to

neuromast to lateral line more clearly as these structures/concepts have not been introduced yet.

We thank the reviewer for this useful suggestion. We agree the manuscript would greatly benefit from more clearly introducing the components of the lateral line system earlier. We have revised the abstract to include a clear link between hair cells, neuromasts, and lateral line. We also made a clear link between sensory input, hair cell, and afferents. We believe the abstract now better prepares the reader for concepts introduced later.

“For example, when fish swim flow generated from body undulations is detected by the mechanoreceptive neuromasts, comprised of hair cells, that compose the lateral line system. The hair cells then transmit information about the fluid motion from the sensor to the brain via the sensory afferent neurons.”

line 52, stimulating hair cell leads to their deflection -> leads to the deflection of mechanosensory structures.

We thank the reviewer for presenting a more clear and accurate description of hair cell stimulation and have revised the sentence to incorporate their suggestion.

“Stimulating hair cells lead to their deflection, which modifies mechanosensory structures, thus triggering an increase in action potentials (spikes) in afferent neurons”

Line 92, make it more clear that the self-mixing silicone elastomer is Sylgard (if it is) and add to the Table of Materials.

We have added a parenthetical to make it more clear that the self-mixing silicon elastomer is in fact Sylgard and have ensured it was included in the ‘Materials List’.

Lines 110 and 133, refer to the glass the same way to ensure the reader knows they are pulling the same glass to make electrodes.

Also make it more clear what these 2 electrodes are for recording- especially 1.3.1.

We thank the reviewer for this useful suggestion to include consistent language to ensure the reader understands. We have also rewritten steps 1.3.1 and 1.3.2 to be more clear about what electrodes are fabricated in each step.

*1.1.1 Pull borosilicate glass capillary tube (inner diameter: 0.86 mm, outer diameter: 1.50 mm) using a horizontal micropipette puller with box filament into electrodes with 30 μm diameter tip with slight taper (**Figure 1 Ai**) that will be used to record from the posterior lateral line afferent neurons.*

1.1.2 Pull an additional borosilicate glass capillary tube into a pair of electrodes with smaller tip diameters (1-5 μm). Holding one electrode in each hand, gently run the tips across one another to break them to a $\sim 30^\circ$ angle. Using a microforge, polish the beveled tip until smooth. Final tip

diameter should be between 30-50 μm and will be used as the ventral root (VR) recording electrode (Figure 1 Aii).

Line 129, make it clear early here what recording you are assigning rt & left headstage and Channel 1 and Channel 2 to.

We have gone through and clearly labeled, here and elsewhere, what recordings are assigned to the respective headstages and channels to be more clear about the configuration of the electrophysiology setup.

Line 181, is this the recipe for Hanks solution or 10% Hanks solution?

We thank the reviewer for bringing this ambiguity to our attention. The recipe was indeed for Hanks solution, but 10% Hanks solution was used in the protocol. We have included a "Solution Preparation" section to provide clarity and have added "10%" where appropriate.

Line 241 add upright to the description?

Edit is now incorporated

Reviewer #3:

Major Concerns:

My only major comment is to define fictive swimming and explain its value in the protocol.

We thank the reviewer for this useful suggestion and have incorporated more information to define fictive swimming. We then highlight how measuring motor commands from an immobilized preparation still informs us of the behavioral state of the animal while also measuring parameters to extrapolate kinematic data.

"NOTE: Fictive swim bouts are the activity patterns of the VR motor neurons that continue to transmit despite the preparation is paralyzed. Therefore, fictive swims are an accessible means of determining the behavioral state of the animal and measuring locomotor parameters while simultaneously performing afferent neuron recordings that require an immobilized preparation."

Minor Concerns:

1.4.3 change click to clicking

Edit is now incorporated

Line 210- comma before "which"

Edit is now incorporated

Line 219 - sometimes you make stereomicroscope one word and other times you make it 2 words. Please be consistent.

Edit is now incorporated

Line 237 - comma before "which"

Edit is now incorporated

Line 255 - add space between mm and Hg, here and throughout.

Edit is now incorporated



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Supplemental Coding Files
abfload.m





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AffVR_preprocess.m



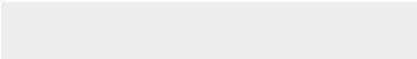
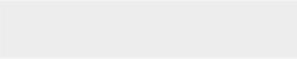


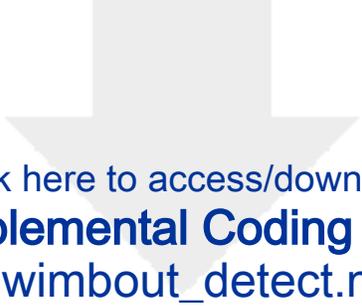
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