Brain, Behavior and Evolution

Abstracts

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The 29th Annual Meeting of the J.B. Johnston Club and the 21st Annual Karger Workshop

The 2009 meeting of the J.B. Johnston Club and Karger Workshop will be held immediately before the annual meeting of the Society for Neuroscience on Thursday, October 15 (the Karger Workshop), and Friday, October 16 (the regular JBJC meeting), 2009. Both the Karger Workshop and the regular JBJC meeting will take place at the Congress Plaza Hotel in Chicago, Ill., USA.

This year's Karger Workshop, made possible by the continuing support of Karger Press, was organized by Doug Wiley and is entitled 'Vision with an Eye to Ecology.' The Workshop features seven invited talks by speakers who will present new insights into the evolution of visual systems in vertebrates and invertebrates. On the following day, the program for annual JBJC meeting will consist of twelve talks submitted by JBJC members selected by the JBJC Program Committee (Andrew Iwaniuk, Sabrina Burmeister, and Ken Catania) plus a presentation by this year's invited Karger Speaker, Dr. Eric Warrent. Additional information and the final schedule of talks will be mailed to JBJC members before the meeting, and will be posted on the JBJC web site (www.jbjclub.org).

2009 Karger Workshop: Vision with an Eye to Ecology

Organized by: Doug Wiley (University of Alberta, Alberta, Canada)

Speakers giving presentations at the 2009 Karger Workshop are listed below. The final schedule of talks will be sent to the membership prior to the meeting and will be available at the registration desk during the meeting.

The Ecology of Vision in Darkness: Vision and Visual Behavior in Nocturnal Insects
Eric Warrant, Lund University (Sweden)

Polarization Vision and Visually Guided Behavior in Fishes
Craig W. Hawryshyn, Queen's University (Canada)

An Eye for (Chromatic) Detail: Assembling the Pieces of an Evolutionary Puzzle
Shaun Collin, University of Queensland (Australia)

Nocturnality and the Evolution of Mammalian Visual Ecology
Chris Heesy, Midwestern University (USA)

Evolution of Visual Telencephalic Regions and Their Role in Courtship and Navigation in Birds
Toru Shimizu, University of South Florida (USA)

A Taxonomy of Visual Motion Detection and Their Underlying Neural Mechanisms
Barrie Frost, Queen's University (Canada)

2009 J.B. Johnston Club Meeting Abstracts

Abstracts for talks scheduled for the 2009 annual meeting of the J. B. Johnston Club are listed in alphabetical order by presenting author. The final schedule of talks will be sent to the membership prior to the meeting and will be available at the registration desk during the meeting. This year's Karger Invited Speaker will be Dr. Eric Warrant. The title of Dr. Warrant's talk will be 'Seeing in the dark: Inferring ecology from visual adaptations in the world's dimmest habitats.'

Jam or Be Jammed: Behavioral Responses to Interfering Stimuli in Pulse Discharging Weakly-Electric Gymnotiformes

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The jamming avoidance response of wave-discharging gymnotiforms is a canonical neuroethological model. It consists of a smooth shift in discharge frequency in response to another fish discharging at a similar frequency. This results in a larger fre-

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quency difference between the pair and allows each individual to maintain distinct channels for electrolocation. In contrast, the mechanisms that pulse-discharging gymnotiforms use to maintain electrolocation in the presence of jamming signals are less well known. Pulse-discharging fishes produce brief discharges separated by quiet periods lasting as long as tens of milliseconds. These species have two possible strategies to avoid jamming. They might increase the frequency difference between pairs, reducing the number of near simultaneous discharges per unit time; or they might reduce the frequency difference and attempt to synchronize a particular phase relationship, thereby avoiding coincident pulses altogether. We surveyed seven genera of pulse gymnotiforms and measured their response to potentially jamming stimuli. *Hypopygus, Stegostenopos, Steatogenys, Gymnorhamphichthys*, and *Brachyhypopomus* only respond robustly to jamming pulses that occur close in time to their own discharge. In contrast, *Microsternarchus* and *Racenisia* respond to jamming pulses that occur throughout the duty-cycle, including between discharges. When presented with phase-locked jamming signals, the first group of fishes tends to accelerate their discharge rate and the second group tends to decelerate. All genera exhibit both frequency shifts and phase locking behaviors in response to free-running pulse trains at a similar starting frequency, however there is a great diversity in effective stimuli and response patterns. Species of *Microsternarchus* were most likely to exhibit a smooth frequency shift that increased the frequency difference between the subject and synthetic discharges. Other species commonly accelerated to both negative and positive frequency differences, sometimes increasing, sometimes decreasing, the difference in frequencies. When the frequency difference was decreased, phase-locking was often, but not always also observed. Phase-locking occurred for periods ranging from tens of milliseconds to 10 s (the length of the jam) and appeared to serve both jamming and jamming avoidance functions. In some cases the subject maintained alternate phase, discharging only between the discharges of the playback, but in other cases maintained near simultaneous discharges, either immediately preceding (jamming) or following the synthetic pulses (being jammed). Additionally, in some instances the subject fish repeatedly scanned the synthetic pulses, allowing phase sweeps across the synthetic discharge (both increasing and decreasing phase directions were observed). In other words, individuals either avoided jamming or ensured it. The diversity of responses and the apparent deliberate jamming behaviors suggest that coincident discharging in pulse fishes is part of a repertoire of social interactions that both avoid and inflict interference in electrolocation.

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Beyond Species Identity: Cricket Auditory Systems Process More than Just a Stereotyped Call

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Invertebrates allow for comparative evaluation of the neural basis of behavior at the level of single neurons. Auditory communication in crickets is a productive model system because the females' response to the males' calling song is quantifiable, the interneurons in the auditory circuit are accessible and identifiable, and manipulation of the neural and hormonal bases of the behavior is not difficult. Under the initial paradigm, calling songs and the resulting phonotactic responses were thought to be stereotyped and species identifying. A 'simplicity hypothesis' proposed that species recognition is based mainly on the rate of syllable repetition (syllable period). Some studies reported that recognition circuitry in the brain is sharply tuned to the species-specific calling song.

This paradigm has allowed for substantial progress in understanding neural circuitry involved in signal recognition, but it has encountered issues that it cannot address. Female selectivity for the syllable period of model calling songs is more variable than was expected. In several species, the females respond to a range of syllable periods that is much wider than the males' signals. The response of a single female also shows a considerable amount of plasticity within a few hours. These rapid changes in the behavior are more dynamic than the described responses of neuronal mechanisms imply. Additional signal recognition processing occurs in the prothoracic ganglion via the first order interneurons AN2/L3 and ON1, which work together to help produce the syllable period-selective response in females. This plasticity can be further modified in minutes by injecting juvenile hormone III into the prothoracic ganglion.

An examination of variability in the males' calling song, from field recordings of *Gryllus veletis* and *G. pennsylvanicus*, showed that the temporal and spectral features of the chirp are more variable than was previously reported. This variation appears both between and within individuals. Gamma regression analysis showed that changes in environmental conditions – temperature, day of the year, time of day, and humidity – can describe up to 70% of the variability in the features of the calling song. Probable sources for the remaining variability are inter-individual differences – like fitness and age – which we are investigating in *Acheta domesticus*. Also, most features of the calling song covary. As syllable duration, the basic element of the chirp, increases, the syllables' amplitude, inter-syllable interval, chirp duration, and inter-chirp interval all increase.

The covariation in the temporal features in the natural calling song contrasts with the static model calling songs used in most behavioral and electrophysiology experiments. The features of a model chirp are usually set at 'attractive' values, and syllable period is varied to determine its affect on the female's behavior. However, this artificial combination of features and the preponderance of attractive features in the chirp may be confounding the selectivity processes, causing the female to respond to a syllable periods that would normally not be attractive. Experiments done with *A. domesticus* that modified the amplitude of the first syllable in a model chirp resulted in significant changes in signal processing by interneurons in the prothoracic ganglion and the behavioral rejection of a previously attractive signal. This indicates that shorter, smaller syllables at the beginning of the chirp have the potential of making the natural calling song unattractive. Based on these findings, perhaps we need to re-evaluate the approach taken to understanding the variability in the production of this signal, the perception of the signal by the female, and the neural mechanisms underlying both behavioral processes.

The Bizarre Visual System of Diving Beetle Larvae: From Asymmetric Spherical Eyes to Tubular Eyes and Scanning Behavior

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Sunburst diving beetle larvae are highly efficient visually-guided predators. Their visual system consists of a cluster of six single lens eyes (stemmata) and one eye patch on each side of the head capsule. The organization of all these eyes is unusual, but the two largest stemmata on each side differ most strongly from 'typical' eyes. Specifically they are tubular in shape, and have up to three morphologically distinct retinas. In eye one these are: (1) a narrow band of rhabdoms along the medial side of the eye tube, (2) a flattened cone-shaped region towards the bottom of the tube which is formed by many layers of receptor cells, and (3) two horizontal rows of long rhabdoms that form a linear retina (proximal) retina. A second large eye is organized similarly but lacks the medial band. The physical organization of these two tubular eyes results in a particularly narrow vertical visual field that only extends a few degrees. Horizontal visual fields are between 30 and 50°.

There are several examples of animal eyes with linear retinas, or with linear arrangements of specific receptor types. In these animals, the eyes, or parts of the eyes typically are movable and perform scanning movements to increase the visual field. Sunbust diving beetle larvae on the other hand are incapable of moving their eyes or any part of their eyes. A detailed frame-by frame video analysis reveals that instead they perform a series of bodily dorso-ventral pivots prior to prey capture, thereby behaviorally extending the vertical visual field up to 50°.

An outstanding question is: how may these bizarre eyes have evolved? One clue to this comes from a phylogenetic comparison of several diving beetle species, including the genera *Rhantus, Cybister and Dytiscus*. Interestingly among the investigated species only the most derived ones have tubular eyes. The gaze angle of these tubular eyes varies considerably, and the remaining eyes tend to be similar to the eyes of ancestral species, all of which tend to have relatively smaller but somewhat asymmetrical eyes. In *Thermonectus marmoratus* these smaller eyes are characterized by a layered organization of the retina as well.

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Altricial and Precocial Birds Evolved Distinct Developmental Strategies to Enlarge Their Telencephalon

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To determine how evolution altered brain development to endow distantly related groups of birds with enlarged telencephalons, we examined embryonic brain development in two highly telencephalized altricial species (zebra finches and parakeets), two highly telencephalized precocial species (ducks and geese), and some precocial species with proportionately small telencephalons (turkeys, chickens, and bobwhite quail). We estimated brain region volumes and neurogenesis timing in all of these species. After controlling for species differences in incubation time, we found that zebra finches and parakeets delay and prolong telencephalic neurogenesis relative to other species. In contrast, ducks and geese possess an enlarged telencephalon (compared with other species) by the time telencephalic neurogenesis begins. These findings suggest that ducks and geese enlarged their telencephalon by altering developmental parameters prior to neurogenesis onset. Collectively, our findings show that precocial and altricial species expanded their telencephalon by means of different developmental strategies. We hypothesize that precocial species rarely, if ever, enlarge their telencephalon by extending telencephalic neurogenesis into the post-hatching period, presumably because their hatchlings must fend for themselves soon after hatching.

Geographically Isolated Populations of *Paramormyrops kingsleyae* Undergo Rapid, Paedomorphic Electric Signal Evolution

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In this presentation, we describe patterns of geographic variation in electric signaling within the mormyrid electric fish species, *Paramormyrops kingsleyae*, along with correlated variation in electric organ anatomy. *P. kingsleyae* belongs to the recently discovered species flock of *Paramormyrops* (= *Brienomyrus*) which is endemic to central West-Africa, including Gabon. Our analysis includes study of electric organs and electric organ discharges (EODs) from 316 voucher specimens collected from 12 localities in Gabon from 1998 to 2001.

The 2-ms EOD consists of two main peaks, a head-positive phase, P1, followed by a head negative phase, P2. It is usually preceded by a very weak head negative phase, P0. We measured time, slope, and voltage values from 9 defined landmarks on each EOD and determined peak spectral frequencies from each waveform. Data were subjected to principal components analysis. The variation in EODs is explained by two factors: the first related to EOD duration and other time measures; the second related to the magnitude of the weak head-negative pre-potential, P0. There is clinal variation in EOD duration. EODs are shorter in eastern Gabon and longer in western Gabon. Peak P0 is slightly larger in northern Gabon and smaller in the southern Gabon.

We identify two anatomical correlates of EOD diversity based on a sub-sample from each of the 12 localities. First, the presence of phase P0 in the EOD correlates with the presence of penetrating-stalked electrocytes in the electric organ while absence of peak P0 correlates with the absence of penetrating-stalked electrocytes. Second, among those specimens with penetrating-stalked electrocytes, the average number of penetrations per electrocyte correlates with the magnitude of P0.

While most *P. kingsleyae* have three-phase EODs, and anteriorly innervated, penetrating stalked electrocytes, we discovered two independent, geographically- separated populations, isolated from others by watershed boundaries, where all individuals have two-phase EODs, lacking the initial peak, P0. Their electric organs lack penetrating-stalked electrocytes. At one site, adjacent to one of these watershed boundaries populated by fish with two-phase EODs, we found both signaling phenotypes in sympatry and three out of six specimens sampled there had intermediate morphology electric organs: electrocytes in the anterior part of the electric organ had penetrating stalks while those in the posterior organ had non-penetrating or penetrating-stalked electrocytes in alternating bands.

The pattern of geographic variation described here for a single species, taken with multiple instances paedamorphic losses of penetrating stalked electrocytes within five *Paramormyrops* species, and seven genera of Mormyrinae, suggest that this key anatomical feature may be under a simple mechanism of control and may be easily manipulated by selection or drift throughout the evolutionary history of Mormryids.

Dual Function of Aromatase in the Blenniid Fish *Salaria pavo:* Regulation of Testicular Investment and Control of Sexual Behavior

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Aromatase is the key enzyme in the conversion of androgens into estrogens and by regulating the local availability of these hormones in tissues controls many physiological processes. In the peacock blenny *Salaria pavo* smaller and younger males reproduce by mimicking females in their appearance and courtship behavior in order to approach the nests of larger males and parasitically fertilize eggs. Small males switch into nesting males and during the transitional phase the testes regress and transitional males do not reproduce. Aromatase activity in the testes of transitional males is higher than in the testes of female-like or nesting males and correlates negatively with the gonadosomatic index, a measure of testicular investment, across males. Also, nesting males regress their testes outside the breeding season and aromatase activity increases during this period. This suggests that aromatase controls both ontogenetic and seasonal variation in testicular investment, with higher levels of aromatase activity inducing testicular regression. In the brain, aromatase mRNA expression was higher in nesting males from a population with low levels of male sexual and aggressive displays when compared with nesting males from a population with higher levels of these behaviors. In general, estrogen administration to fish has been shown to reduce the expression of both aggressive and sexual displays in males, while the reverse pattern has been described for androgens. The lower availability of androgens and/or the higher synthesis of estrogens as a consequence of higher brain aromatase levels may thus explain the lower frequency of sexual and aggressive displays in nesting males from one of the populations. Therefore, aromatase seems to regulate different aspects of male reproductive biology in *S. pavo*, including testicular development and the frequency of sexual behaviors.

Neural Coding of Conspecific Signals in Female Túngara Frogs *(Physalaemus pustulosus)*

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Female túngara frogs *(Physalaemus pustulosus)* use acoustic signals produced by males to actively choose particular mates. Females exhibit behavioral preferences for the signals of their own species (species recognition) and they often prefer certain conspecifics to others (mate discrimination). One approach to understanding the mechanisms of female choice behavior is to study the ways in which male signals are processed in the brain. Using this approach, a recent study found that, in túngara frogs, a neural response-bias toward conspecific calls over heterospecific calls emerges early in the auditory pathway. We followed up this study by asking the question, what acoustic features of the conspecific call elicit such a bias? We then asked whether there is a similar neural response bias for preferred conspecific calls over less-preferred calls. In túngara frogs, the 'whine' advertisement call is both necessary and sufficient for species recognition. Previous behavioral experiments show that sequential presentation of 800 and 500 Hz tones (800 + 500) are recognized by females and are as attractive as a whine; yet, females do not recognize these tones presented in the reverse order (500 + 800). We exposed females to one of four stimuli: silence, natural whine, 800 + 500 Hz tones, and 500 + 800 Hz tones. We measured the expression of the neural activity-dependent gene, *egr-1*, in the auditory system and found that whines and whine-like tones (800 + 500) elicited greater neural activation in the auditory midbrain than 500 + 800 Hz tones. In contrast, we found that the superior olivary nucleus appears to respond only to whines and not to other sounds. These data demonstrate that the neural responses in the auditory midbrain correspond to behavioral responses of females to the same acoustic stimuli and they suggest a hierarchical processing of conspecific calls. Next, we investigated the neural response to preferred and less-preferred conspecific calls. Túngara males can increase the complexity of their whine by adding 1–6 broad-spectrum call components known as 'chucks.' Chucks are not necessary for species recognition, but females strongly prefer whines with chucks to the simpler whine. We exposed female túngara frogs to one of five acoustic stimuli: no sound, a noise control stimulus, whine, whine + 1chuck, whine + 3chucks. Our data show that the neural response to all conspecific calls, regardless of complexity, is similar, suggesting that the auditory system does not have a neural bias for female-preferred calls. Thus, different neural mechanisms may underlie species recognition and conspecific mate preferences.

Convergence in Ultrasonic Communication in Frogs

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Among the vertebrates, only microchiropteran bats, cetaceans and some rodents are known to produce and detect ultrasounds (US) for the purpose of communication and/or echolocation, suggesting that this capacity may be restricted to mammals. We now provide the first evidence of US communication in an amphibian – the concave-eared torrent frog, *Amolops tormotus* (Ranidae) from Huangshan Hot Springs, China. Males of *A. tormotus* produce diverse bird-like melodic calls with pronounced frequency modulations that often contain spectral energy in the US range. Acoustic playback experiments conducted in the animal's natural habitat confirmed that the audible as well as the US components of an *A. tormotus* call could effectively evoke males' vocal responses. Electrophysiological recordings from the auditory midbrain confirmed the US hearing capacity of these frogs and that of a sympatric species facing similar environmental constraints. This extraordinary upward extension into the ultrasonic range of both the harmonic content of the advertisement calls and the frog's hearing sensitivity is likely to have coevolved in response to the intense, predominately low-frequency ambient noise from local streams. Because amphibians are a distinct evolutionary lineage from microchiropterans and cetaceans, US perception in these animals represents a novel example of independent evolution. A second, distantly related species, *Huia cavitympanum*, inhabits vegetation along swiftly running streams in Sarawak, Malaysian Borneo. Males of this species produce high-pitched calls with prominent ultrasonic components. In fact, some calls are completely in the ultrasonic range. High levels of ambient stream noise are characteristic of the habitats of both *A. tormotus* and *H. cavitympanum* and provide, we believe, the selective pressure to produce ultrasonic call components in these species.

Qualitative Differences in Call Recognition among Sibling Species

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In many species of acoustically communicating insects and anurans, females use the temporal pattern to recognize the conspecific calls and discriminate them from the calls of sympatric heterospecifics. Among sibling species, calls often differ in one temporal parameter (e.g. the pulse rate), with females of each species preferring the conspecific value of this parameter.

Behavioral experiments reveal that the call recognition mechanisms which generate the preferences for the temporal call recognition often differ qualitatively among closely related species. For example of three species of Tettigonia katydids, one evaluates pulse rate, the second pulse duty cycle, and the third absolute duration of pulses and interval. This phenomenon has been described by numerous authors in many anuran and insect groups.

We comparatively studied call recognition mechanisms in the Tettigoniid (katydid) genus *Neoconocephalus* within a phylogenetic background. In this group calls vary at two scales. First, in several species the ancestral pulse pattern was changed (e.g. from single do double pulses), and second, in other species a verse structure has been added to the ancestrally continuous calls. We determined call recognition mechanisms at both scales in behavioral experiments using a psychophysical approach.

A single mechanism for recognizing the ancestral pulse pattern occurs in multiple species: females evaluate the duration of silent intervals between the pulses. To date we have identified four derived mechanisms to recognize the derived pulse patterns. Females of two species recognize the double pulse rate of the male call, while a third species requires the presence of two pulse rates in the pulse pattern. The fourth species evaluates both absolute pulse and interval duration. These four mechanisms evolved independently from each other.

At the scale of the verse pattern we have found three different recognition mechanisms. In addition to the ancestral mechanism, which recognizes continuous calls, there are two mechanisms responding only to calls with verse structure. One of them responds to a specific verse pattern and generates a stabilizing preference for verse rate, while the other mechanism generates a directional preference for faster verse rates.

We used a modeling approach to develop hypotheses about the underlying neural changes leading to this plethora of call recognition mechanisms in *Neoconocephalus*. Based on behavioral and neuroanatomical data, we developed a biophysical model of hypothetical filter neurons in the katydid brain. This model indicated that intrinsic properties of neurons may generate even complex temporal selectivities and that individual neurons may explain the selectivity observed in behavioral experiments. This suggests that small changes in the expression of ion channels may lead to qualitative changes of the temporal filter properties. Thus, the neural differences among the different call recognition mechanisms may be largely in the intrinsic properties of neurons rather than in the network topology or synaptic connectivity.

The multitude of call recognition mechanisms among different species makes *Neoconocephalus* a promising system to study the generation of temporal selectivity, and may serve as a model for the more complex hearing systems of vertebrates.

Environmental, Perceptual and Behavioral Aspects Accounting for the Remarkable Diversity of the Mammalian Vomeronasal System

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Mammals have developed an exquisite sensibility to scents related to a diverse set of ecological contexts. In particular, social and sexual interactions are largely mediated by the vomeronasal system (VNS), which senses semiochemicals from the environment and modulates the neuroendocrine and behavioral outcomes of the organism by means of its amygdaline and hypothalamic interconnections.

In most mammals, the VNS is dichotomous. Two functional and anatomically distinct populations of sensory neurons, expressing either V1R or V2R receptors, and coupled to either Gi2 or Go protein, send segregated projections that end in glomeruli located at either the rostral (rAOB) or caudal (cAOB) half of the accessory olfactory bulb (AOB), respectively. In muroid rodents, these pathways have been associated to different operationalities: small, volatile ligands activate Gi2-expressing neurons, while non-volatiles and peptides activate Go-positive neurons. Also, the Gi2-expressing rAOB is predominantly activated when animals sniff opposite-sex conspecifics, whereas the Go-cAOB seems to be involved in same-sex (i.e., male-male) or aggressive interactions. Additionally, we have found that the rostral and caudal AOB subdomains show opposite patterns of glomerular asymmetries in two species of hystricognath rodents that differ in their habitat (semi-arid scrubland vs. flooded rainforest), in their visual habits (strictly diurnal vs. crepuscular/nocturnal) and in their scent-marking strategies (dust-bathing vs. oily deposits).

The dichotomical segregation of Gi2- and Go-pathways, described in opossums, rodents and rabbits, was initially thought to represent a common feature in mammals with a functional VNS. However, several species such as marmosets, dogs, horses, goats and musk shrews present the Gi2-pathway only, throughout AOB glomeruli. Nevertheless, the phylogenetic distribution and ecological conditions that may account for that trait are not clear yet. When we considered current molecular phylogenetic hypotheses for Eutheria, we noticed that species that lost the Go-pathway were grouped in two clades: Primates and Laurasiatheria, suggesting at least two independent events of deterioration. We also noted that both lineages show visually conspicuous sexual dimorphisms, so we hypothesized that the ability to detect other males at distance (without the need of engaging in body-contact sniffing) would have permitted the degeneration of the Go-pathway by disuse. To support this, we searched for sexually dimorphic species in other lineages, and found that the rock hyrax (Afrotheria: Hyracoidea) and the ground squirrel (Rodentia: Sciurognathi) – both species diurnal, social and markedly dimorphic– also show the Gi2-pathway only throughout glomeruli. Thus, our results suggest that the degeneration of the Go-pathway has occurred at least four times in Eutheria, and supports our hypothesis that its loss is most probably associated to the emergence of conspicuous sexual dimorphisms, and the ability of detecting other males at distance.

A Spitting Image: Visual Specializations of the Archerfish *(Toxotes chatareus)*

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Archerfishes are renowned for their ability to spit jets of water at aerial prey, knocking them down to the water's surface where they can be captured. This feeding behavior requires that they be able to correct for image distortions due to the different refractive index of air and water. When objects are viewed from below the water's surface, their image is shifted upwards relative to their actual position and they appear smaller and farther away than they actually are. To accurately spit at targets and evade predation while spending most of the time at the water's surface suggests a plethora of unique visual adaptations. We examined the visual system of the large-scale archerfish *(Toxotes chatareus)* using anatomical, behavioral and microspectrophotometric techniques. *T. chatareus* possesses a 'duplex' retina containing both rod and cone photoreceptors for dim and bright light vision, respectively. Topographic analysis of photoreceptor distribution across the retina reveals areas of high density in the ventral periphery that provide high spatial resolution for the detection of prey and predators in the aerial field of view. Combining spatial resolving power with the optics of the eye and the image distortion at the air-water interface permits a comparison of calculated visual acuity to behavioral measures of visual acuity. Behavioral visual acuity was measured using an optomotor response, and a modified Landolt C test in which fish spat at their choice of target 'o' or 'c' depending on which one they had been trained to. By gradually decreasing the size of the letters, so that the gap in the 'c' gradually became smaller, we obtain an estimate of visual acuity. Spectral sensitivity is another component of target detection and this was estimated by measurements of rod and cone photoreceptor absorbance. The range of absorbance values in the retina of *T. chatareus* indicates the presence of a vitamin A_1/A_2 based chromophore interchange system, as well as differential expression of opsins in different parts of the retina and coexpression of opsins within individual cones. The complexity of the combination of dynamic A_1/A_2 ratio and variable opsin expression across the retina has been observed recently in other teleosts and the function of both of these spectral tuning mechanisms remains enigmatic. However, our understanding of the specialized behavior of archerfish combined with measurements of the natural light environment and behavioral experiments are enabling us to provide insight into the fascinating and complex question of how archerfishes are able to find and accurately spit at prey above the water's surface.

Lateral Line Variation among Diverse Populations of Threespine Stickleback *(Gasterosteus aculeatus)*

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The lateral line is a mechanosensory system that is unique to fish and amphibians. Variation in the lateral line among fish lineages has been associated with differences in both habitat and behavior. In order to gain insight into the selective forces and genetic changes that underlie lateral line evolution, we characterized lateral line variation within a single species that consists of many diverse but inter-fertile populations. In the present study, we examined variation in neuromast number and patterning among sixteen populations of threespine stickleback *(Gaste-*

rosteus aculeatus) from a variety of habitats (marine, stream and lake) in the Pacific Northwest and Japan. We found that all sixteen populations have a reduced lateral line system, with a consistent pattern of twelve lines of superficial neuromasts and an absence of canal neuromasts. However, in one marine population, neuromasts on the dorsal and ventral aspects of the head (the supraorbital and mandibular lines) are located in grooves that resemble half-formed canals.

By dividing the populations into basic habitat categories (marine, stream and lake), we identified significant differences in neuromast number between habitat groups: both lake and stream populations have more total neuromasts than marine populations. In addition, we performed pairwise comparisons between stickleback populations that occupy alternative habitats within shared watersheds. In the Little Campbell River, stream-resident sticklebacks have more neuromasts in nine out of twelve lines when compared to migratory marine sticklebacks. We also examined two sets of sympatric lake populations. In each of these independent lakes, a limnetic population occupies the pelagic open water zone, and a benthic population occupies the deeper and more vegetated littoral zone. In both lakes, benthic sticklebacks had more neuromasts on the trunk than limnetic sticklebacks, suggesting that there may be parallel selective forces acting on the lateral line in these populations. Taken together, our data show that habitat differences are associated with patterns of lateral line variation among stickleback populations; in some cases, common selective regimes may be shaping this sensory system. We are currently using linkage analysis to identify the genomic regions that underlie differences in neuromast number between threespine stickleback populations.