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DEPARTMENT OF BIOLOGY

INCREASED MALE SEXUAL DISPLAYS CORRELATE WITH VENTRAL POSTERIOR AMYGDALA VOLUME AND CELL VOLUME IN WILD-CAUGHT SIDE-BLOTCHED LIZARDS, *UTA STANSBURIANA*

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ABSTRACT

Variation in sexual display rate can induce variation in the ventral posterior amygdala (VPA), an area of the brain involved in reproductive behaviors. Specifically, increased sexual displays in the breeding season is correlated with increased VPA attributes. Previous research has demonstrated that higher rates of sexual displays are associated with a larger VPA volume and neuron soma size. However, it remains unclear if individuals residing in different populations reflect results found within the laboratory, as there are likely many more selective pressures in the field with which to contend. Thus, in the current study, we examined variation in VPA attributes of wild-caught side-blotched lizards (*Uta stansburiana)* from two different states, Oregon and Nevada. In the Nevada population, males have lower display rates than that found in the Oregon population, likely due to increased predation pressures in the Nevada population. Mirroring this, we found that the Nevada population exhibited decreased VPA volume and VPA cell volume suggesting that decreased display rates in the face of predation is associated with downregulated VPA attributes in the field.

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Chapter 1

Literature Review

Reproduction is important for the survival of all species, as it enables the transmission of genetic material to the next generation. Effective and successful sexual reproduction is often facilitated by the distinct discrimination of conspecifics and reproductive status based on physical, chemosensory, behavioral, and social cues and displays (Ball and Balthazar 2004; Schoralkova et al. 2018). Sexual displays, in particular, are often required for access to courtship opportunities (O'Bryant and Wade 2002; Sullivan and Kwiatkowski 2007). For example, adult male and female lizards of some species communicate via head-bobbing displays or with a throat fan extension called a dewlap extension; both of these displays increase conspicuousness to conspecifics and signal mate quality (Zani et al. 2013). Male lizards use head-bobbing displays for territorial defense, aggression towards other males (coupled with dewlap extension), and sexual interactions (without dewlap extension) (Lovern, et. al. 2004; Eifler et al. 2008). These and other conspicuous sexual displays have been associated with higher reproductive success (e.g., Salvador et al. 2008) and thus remain a strong target of sexual selection.

Variation in sexual displays is also associated with other selective forces beyond a signal of quality. Predation pressure is one of the important selective forces that can also shape the morphological, physiological, and behavioral characteristics of prey (Vervust et al. 2007). In particular, all animal species, especially males, exhibit different reproductive display behaviors in high vs. low predation areas. This can include a change from visual to non-visual sexual

behavior or moderation of the display rate under different light intensities (Magnhagen 1991). For example, male guppies (*Poecilia reticulata*) in high predation areas lower their rate of courtship displays and have evolved to become less colorful (e.g., Endler 1980). Also, water striders (*Gerris remigis*) decrease the mating duration and the number of matings in the presence of predatory fish (Magnhagen 1991). Overall, because increased levels of male sexual displays correspond with an increased risk of attack by predators, downregulating sexual displays is advantageous to avoid predation (Endler 1987). Lizard populations also demonstrate variation in predation rates with corresponding behaviors to adjust to increased predation. Male lizards in populations with high predation tend to flee at greater distances and more readily automize tails compared to males lizards in populations that experience lower predation rates. In high predation areas, they also alter or reduce their visual signaling behaviors, head-bobbing, and dewlap extension (Magnhagen 1991; Eifler et al. 2008; Zani et al. 2013). Hence, the plasticity and intensity of sexual behaviors can be modulated by changes in predation pressure (Zani et al. 2013), balancing the demands of increased sexual behaviors due to sexual selection with the demands of decreased consciousness due to natural selection.

Male reproductive behaviors in vertebrates are controlled by at least two limbic brain regions, the amygdala and the preoptic area (POA) (Ball and Balthazar 2004; Beck et al. 2008). While these brain regions appear to be conserved across the vertebrate lineage, most of the work looking at reproductive behavior and the brain has been performed in mammals. The amygdala is commonly known as the brain center for the basic forms of emotional learning, such as fear conditioning (Laberge et al. 2006). The medial amygdala (MeA) in rodents, along with the posteromedial cortical amygdala (PMCO), receive chemosensory inputs from the accessory olfactory bulb (Been and Petrulis 2011), the cerebral cortex, and hippocampus (Coolen and

Wood 1998), and projects to the bed nucleus of the stria terminalis (BNST), preoptic area (POA), and the motor and endocrine centers in the basal telencephalon, hypothalamus and midbrain (Canteras et al. 1995; Coolen and Wood 1998). These pathways regulate behavioral and physiological responses important for survival and reproduction (Pfaff et al. 1994; Been and Petrulis 2011). The MeA has been implicated in reproductive behaviors, including chemosensory investigation of females and sexual arousal (Cooke et al. 1999; Canteras et al. 1995; Wood and Coolen 1997; Coolen et al. 1997). The MeA also projects to various amygdala and hypothalamic areas that are closely related to the expression of sexual appetite (Beck et al. 2008; Ishii and Touhara, 2018). While the POA, which receives signals from the MeA, mainly controls copulatory behaviors, such as mounting and intromission (Wood 1997; Beck et al. 2008).

The medial amygdala and POA show morphological variation in both male and female species studied between the breeding and non-breeding seasons. For example, the nucleus in the POA and in the posterodorsal medial amygdala (MePD), as well as neuron soma size, are larger in males and females in the breeding season than in non-breeding seasons (Cooke et al. 1999, 2001). Because of the relationship between sexual displays and the amygdala and POA, sexual displays is an ideal behavior in which to study variation in behavioral function and changes in the morphological structure in the brain, including the neural circuitry, from receiving sensory cues to executing behavioral responses (Lovern et. al. 2004; Ishii & Touhara, 2018).

While previous studies have demonstrated that certain limbic regions show sex differences, seasonal variation, and responsiveness to environmental cues in mammals, the relationship between specific limbic regions and their morphology, and sexual behaviors in lizards remains relatively unclear. The ventral posterior amygdala (VPA), sometimes referred to as the ventromedial nucleus (AMY or VMN) (Greenberg et al. 1984; O'Bryant and Wade 2002),

has been shown to be important for male reproductive displays in lizards. The VPA in reptiles exhibits structural and functional homologies to the MeA in rodents (Bruce and Neary 1995; Lanuza et al. 1998). Homology is supported by lesion experiments on the VPA region in some lizard species; lesioned individuals reduce consummatory behaviors, including decreased dewlap extension and courtship rate (*Sceloporus occidentalis*: Tarr 1977: *Anolis carolinensis*: Greenberg et al. 1984), while leaving aggressive behaviors intact. Hence, the VPA, a subregion in the amygdala, appears to be specific for sexual behaviors in lizards.

The morphology of VPA attributes has also been shown to correlate with seasonal changes and differ between males and females, likely due to variation in sexual displays between the breeding and non-breeding season, and between males and females. For example, VPA volume and VPA neuron cell volume is larger in breeding male lizards than non-breeding males. Similarly, VPA attributes are also larger in males than females in both breeding and non-breeding seasons (O'Bryant & Wade 2002; Beck et al. 2008). Therefore, correlates of sexual displays, including variation in seasons or differences between the sexes, can also modulate differences in the VPA.

While previous research has demonstrated a link between reproductive behaviors and the VPA, understanding how population-level differences in sexual behaviors affects the brain is relatively unknown in lizards from the field. The present study was designed to investigate the effects of population-level differences in sexual displays on the morphology of the area of the forebrain responsible for reproductive behaviors in wild-caught side-blotched lizards, *Uta stansburiana.* This species is one of the most abundant in the western United States, with a range from Washington state down into Mexico (Parker and Pianka 1975). Interestingly, some of these populations differ in predation pressures, with some populations exhibiting more snakes, birds,

and predatory lizards, such as *Crotaphytus*, *Aspidoscelis*, and *Gambelia*, when compared with other populations (Zani et al. 2013). The increase in predation pressures in Nevada populations correlates with decreased time moving, fewer movements per minute, shorter distances moved, and fewer sexual displays per minute (Zani et al. 2013). As such, we predicted that the decrease in sexual displays due to increased predation pressures in a high-predation population in Nevada would correlate with decreased volume of the VPA and decreased volume of the neuron somas within the VPA.

Chapter 2

Materials and Methods

All animals were collected under appropriate state permits and all procedures were approved by the Institutional Animal Care and Use Committee at the Pennsylvania State University (#46874). We captured 22 male side-blotched lizards from a population in Oregon (n = 12) and a population in Nevada (n = 10); all animals were captured in June of 2016 during the peak of the breeding season. Soon after capture, individuals were anesthetized with a lethal overdose of tricaine methanesulfonate (intracoelomic injection of 500 mg/kg 1% sodium-bicarbonate buffered solution, followed by 1.0 ml unbuffered 50% solution). Heads were removed and post-fixed in 10% methanol-free formalin (from paraformaldehyde) for 2 w. After 2 w, the brains were removed and cryoprotected in 15% sucrose for 24 h, followed by 30% sucrose solution for an additional 24 h. Brains were then flash-frozen on dry ice and stored at -80°C until sectioning. Brains were sectioned on a cryostat (Leica CM 3050S, -20°C) in the coronal plane every 50 μm and every other section was mounted and nissl-stained with thionin to visualize the brain region boundaries and the VPA neuron somas. Slides were coded thus neural attributes were measured blind to population of origin. All methods followed LaDage et al. (2009, 2013, 2017).

Brain Analysis

We used standard, unbiased stereological techniques (StereoInvestigator, Microbrightfield, Inc., Williston, VT; Leica M400B microscope) optimized for this species (all coefficient of errors < 0.10, Gundersen et al. 1999) to estimate VPA volume and VPA neuron

soma volume. We also measured the volume of the remainder of the telencephalon (i.e., total telencephalon volume minus VPA volume) to assess if the effects of population of origin was specific to the VPA or representative of global changes within the brain (e.g., LaDage et al. 2009, 2013, 2017). The left and right hemispheres of the VPA (Fig. 1) and the remainder of the telencephalon were contoured in their entirety. Volume estimations were then generated with the Cavalieri procedure (Gundersen and Jensen 1987) using a 200-μm grid. We also estimated VPA neuron soma volume with the nucleator procedure using four rays (Fig. 2). There were no significant differences in volume between the left and right hemispheres of either the VPA or remainder of the telencephalon (paired t-tests: VPA, $t_{19} = -1.054$, $p = 0.305$; remainder of the telencephalon, $t_{36} = 1.054$, $p = 0.304$), nor were there differences in neuron soma volumes between the left and the right hemisphere (paired t-test: $t_{18} = -1.259$, $p = 0.224$). Consequently, volumes of the VPA from the left and right hemispheres were summed and neuron soma volumes from the left and the right hemispheres were averaged; subsequent analyses were performed on the pooled data. Due to histological artifacts, not all brain attributes could be analyzed in all subjects.

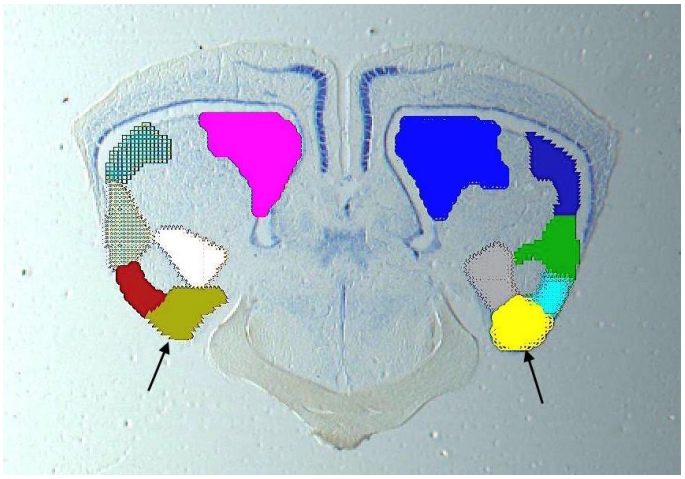

Figure 1. VPAs in right and left hemisphere are indicated by arrows

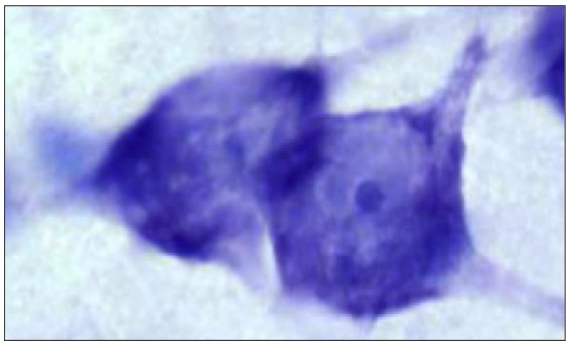

Figure 2. Two neuron somas

Statistical Methods

Homogeneity of variances was assessed with Levene's test and all data conformed to the assumption (all $p > 0.05$). We used a general linear model to assess the effects of population of origin on the volume of the VPA, using the remainder of the telencephalon volume as a covariate. Doing so assured that these results were specific to changes in the VPA, rather than global changes in the brain. We also used a general linear model to assess the effects of population of origin on the VPA neuron soma volumes, using VPA volume as a covariate. Finally, we performed the two analyses without the covariates to ascertain any statistical

differences when not controlling for those covariates. All analyses were conducted with SPSS (version 25.0, IBM Corp., Armonk, NY) with $\alpha = 0.05$.

Chapter 3

Results

When controlling for the remainder of the telencephalon (telencephalon covariate: $F_{1,23}$ = 0.652, p = 0.429), we found that population of origin had a significant effect on the volume of the VPA ($F_{1,23}$ = 9.018, p = 0.007), with individuals from Oregon possessing larger VPAs (Fig. 3). When controlling for volume of the VPA (VPA volume covariate: $F_{1,22}$ = 3.665, p = 0.071), we found that population of origin also had a significant effect on the volume of the neuron somas in the VPA ($F_{1,22}$ = 7.668, p = 0.012), with individuals from Oregon possessing larger VPA neuron somas (Fig. 4). Elimination of the covariates from all the above analyses yielded similar statistical results and therefore did not alter the interpretation of the results.

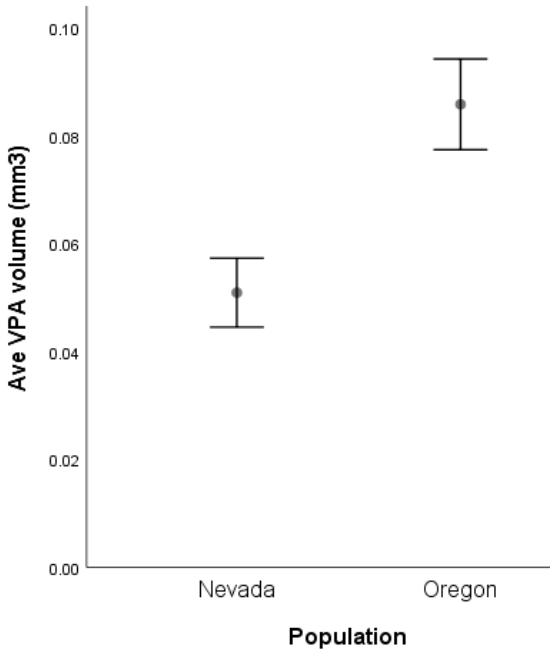

Figure 3. Average VPA volume (mm^3) increased in Oregon vs. Nevada.

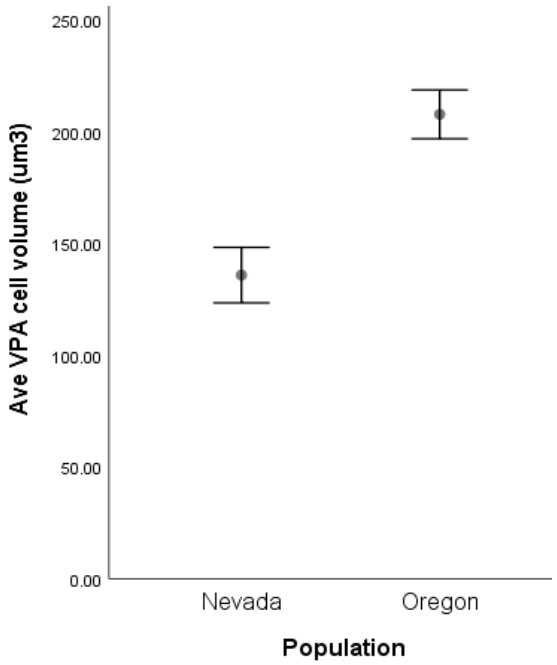

Figure 4. Average neuron soma cell volumes (μm^3) were larger in Oregon vs. Nevada.

Chapter 4

Discussion

The current study reports variations in VPA volume and volume of VPA neuron somas in side-blotched lizards from two different populations in Nevada and Oregon. Individuals from a population in Nevada with suppressed sexual displays had smaller VPAs (Fig. 3) with smaller VPA neuron somas (Fig. 4). Inclusion of a covariate in the statistical model did not change the interpretation of the results, indicating that these changes were localized and not a result of overall brain changes. Results are consistent with our prediction that the brain area that is responsible for sexual displays is downregulated in a population with a suppression of sexual displays. These results support previous studies indicating that VPA neuron soma cell size correlates positively with the rate of dewlap extension in male lizards (Neal and Wade 2007). In male rats and rams, MeA volume and neuron soma sizes are larger in males exhibiting increased sexual behaviors (Alexander et al. 2001). Therefore, the results of this study support previous studies showing a positive relationship between sexual displays and the brain region responsible for sexual displays.

The relationship between sexual displays and changes in brain morphology is most likely regulated by the natural fluctuations in circulating steroid hormones that occur across the breeding and nonbreeding seasons (Wade and Crews 1991; Wade et al 1993; Thompson and Adkins-Regan 1994; Cooke et al. 1999; Riters et al 2000). As is common across vertebrates, sex hormones are important for both sexes in regulating reproductive displays and the adult activation of sexual behaviors in lizards (O'Bryant and Wade 2002). Testosterone is higher in the breeding season than in the non-breeding season (Lovern and Wade 2001; Beck et al. 2008) and

is the major steroid hormone that stimulates sexual behavior in adult male lizards (Pearson et al. 1976; Lovern et al. 2004). Circulating testosterone levels are lower in adult females compared to male lizards, and sexual display rates in females, such as head-bobbing and dewlap extensions, tend to be lower than in males (Lovern et al. 2001; O'Bryant and Wade 2002). Finally, testosterone may be reduced to dihydrotestosterone through reduction and converted to estradiol by aromatase, an enzyme that is concentrated in amygdala (Roselli et al. 1984). These metabolites may also be important in regulating sexual behaviors (Wade et al. 1993).

Steroid hormones have been shown to have marked and direct effects on the neural architecture and sexual behaviors. The castration of male rodents reduces the MeA volume and causes a decrease in sexual display rates (Cooke et al. 1999; Beck et al. 2008). When males were castrated and supplemented with implants of testosterone, MeA volume returned to the level of controls and reproductive behaviors were restored (Wood and Newman 1995; Cooke et al. 1999; Maras and Petrulis 2006; Beck et al. 2008). Likewise, testosterone treatment in castrated adult male lizards activates sexual displays and increases VPA neuron soma cell size (*A. carolinensis*: O'Bryant and Wade 2002; Neal and Wade 2007; *Urosaurus ornatus*: Crews and Morgentaler 1979; Kabelik et al. 2008). Finally, MeA and POA volumes and cell volumes in male rodents are larger than that in females (Cooke et al. 1999), demonstrating the relationship among testosterone, display behaviour, and the MeA/VPA.

While there is a robust relationship between testosterone, sexual behaviors, and the area of the brain responsible for sexual behaviors, it remains unclear if testosterone acts directly on neurons or via some other mechanism. Neurons in the MeA in mammals and neurons in the VPA in lizards have a high expression of androgen and estrogen receptors (Cooke et al 1999; Beck et al. 2008), with testosterone and/or dihydrotestosterone binding directly to the androgen receptors

while metabolites bind to estrogen receptors. Consequently, sex steroid hormones appear to have a direct influence on neurons. In support of this, testosterone and estrogen have been shown to induce the proliferation of dendritic branches, increase soma density and axodendritic synapses, and increase the expression of neuropeptides such as substance P, cholescystokinin, and vasopressin in the MeA (Toran-Allerand 1980; DeVries et al. 1985; Frankfurt et al. 1990; Frankfurt and McEwen 1991; Segarra and McEwen 1991; Lorenzo et al. 1992; Malsbury and Mckay 1994). Overall, it appears that sex steroids can have a direct influence on the neural substrate and sexual behaviors but it is unclear how this relationship operates and is modulated.

While testosterone modulates sexual displays and likely has a direct effect on the brain, in our particular study there are likely a multitude of different factors that vary between the Nevada and Oregon populations that could modulate VPA attributes. Previous research has linked an increase in predation rate with a reduction in sexual displays, as more conspicuous sexual displays make an individual more likely to be noticed by a predator (e.g., Endler 1987). Mechanistically, this has been attributed to activation of the hypothalamic-pituitary-adrenal (HPA) axis, resulting in the release of glucocorticoids, specifically cortisol and corticosterone. In wild population of vertebrates, predatory stress causes an acute increase of glucocorticoids, the mechanistic basis for increased antipredatory behaviors (Thaker et al. 2010). Glucocorticoids are important for regulating behavioral responses to repeated interactions with predators or other aversive stimuli. An elevated corticosterone level stimulates rapid behavioral changes including changes in foraging, aggression, locomotion, and aversive learning (Sapolsky et al. 2000; Thaker et al. 2010). In particular, glucocorticoid release has been shown to suppress sexual behaviors and increase escape behaviors (e.g., Wingfield et al. 1998). Interestingly, in side-blotched lizards, males supplemented with corticosterone and males supplemented with testosterone and

corticosterone both suppressed aggressive behaviors, indicating that corticosterone may be the primary influencer on sexually-selected behaviors (Denardo and Licht 1993). Because of the relationship among variation in predation rates in our populations, sexual behaviors, and the brain, increased predatory stress leading to increased glucocorticoid release may also affect the brain directly and may be a more important driver of variation in the VPA.

Glucocorticoid receptors are widely distributed throughout the brain, particularly in the VPA (Moga et al. 2000); this is similar to what has been demonstrated in the hippocampus (Woolley et al. 1990). In contrast to sex hormones, excessive glucocorticoids induce neuronal damage, decrease dendritic branching, and suppress neurogenesis in the hippocampus (Woolley et al. 1990; Gould et al. 1997; Sousa et al. 1998) while mild glucocorticoid release has been shown to increase excitability of neurons in the amygdala (e.g., Duvarci and Paré 2007) and may have different, even opposite, effects in different areas of the amygdala (e.g., Dunn 1987; Sapolsky 2003). Anderson et al. (1985) demonstrated that when male rats are exposed to prenatal stress, such as extreme temperature variation, nutritional deprivation, or predation, they exhibit lower rates of reproductive behaviors and a smaller POV cell volume than non-stressed males. Overall, the contribution of stress hormones to the neural phenotype is complex, even in the well-studied hippocampus. Therefore, stress-stimulated release of glucocorticoids could directly affect VPA attributes in the Nevada population where high predation pressure is found.

While variation in predation rates may have direct effects on glucocorticoid release and suppression of sexual behaviors, other indirect factors may modulate sexual behaviors and VPA volume as well. Social cues, in particular chemosensory cues, from conspecifics influence reproductive displays and the morphology of brain regions that are responsible for sexual behaviors. Social isolation can impair androgen production, reduce sexual behaviors, decrease

neurogenesis, and decrease associated brain volume and neuron cell volume. Resko et al. (1996) showed that isolated rams have a lower concentration of serum testosterone and decreased testosterone biosynthesis and aromatase activity in the POA than socially-exposed rams. Similarly, isolated male Long Evans rats display significantly fewer non-contact erections than males raised in groups, smaller seminal vesicle weights, and smaller MeA volumes (Cooke et al. 2000). In female prairie voles, housing females with males led to a 3-fold increase in newly generated cells in the amygdala compared to isolated females (Fowler et al. 2002).

Likely the interaction of conspecific chemosensory cues and hormonal signals is necessary to produce sexual behaviors as the signals are relayed through the same pathway (Wood and Newman 1995; Coolen et al. 1997; Wood 1997; Wood and Coolen 1997). The chemosensory cues from the accessory olfactory bulb stimulate signal transmission between the MeA, posterior bed nucleus of stria terminalis (BNST), and medial POA (Coolen and Wood 1998; Been and Petrulis 2011), where these three limbic regions are concentrated with steroid-responsive neurons. Steroid hormones promote dendritic branching and the formation of synapses, effects which tend to promote connectivity. But in the absence of steroids, connections between neurons attenuate and the transmission of odor cues is impaired (Wood and Newman 1995). For these reasons, individuals in Oregon, with lower predation pressure, may have more social interactions with opposite-sex conspecifics, triggering a higher level of testosterone, a stronger sexual arousal, and increased brain attributes associated with sexual behaviors.

Finally, variation in the neural morphology can also be attributed to changes in seasonality/photoperiod, which can affect hormonal regulation and the brain (Bentley et al. 1999). Photoperiod and temperature play an important role in lizard spermatogenesis and the production and action of androgens (Pearson et al. 1976), which may, in turn, affect brain

regions. For example, VPA volume and VPA cell volume in male lizards are larger in the breeding season than non-breeding season (O'Bryant and Wade 2002). It is also consistent in rodents; the MeA neuron soma size in Siberian hamsters decreases in the non-breeding season (Cooke et al. 2001). In addition, gonadectomized juncos (Dloniak and Deviche 2001) and European starlings (Bentley et al. 1999) show increased volume of song control nucleus high vocal center (HVC) when exposed to longer days. Furthermore, testosterone treatments enhance this photoperiodic effect in longer days, but the effect of testosterone is lessened during shorter days (Licht 1967; Smith et al. 1997), likely due to shorter day-lengths that increase the duration of night melatonin secretion, which reduce androgens synthesis in the testes (Bentley et al. 1999). Thus, the changes in brain region related to sexual display could be the result of the interaction between hormonal and environmental factors.

Chapter 5

Conclusion and Future Research

The present study helps inform our understanding of the ecological-relevance of sexual behaviors and the brain. The results suggest that the decreased sexual display rates in the face of predation correlate with downregulation of VPA attributes in field-caught lizards. The changes in brain region volume parallel those from a number of other species, and suggest that side-blotched lizards, like many mammals and birds, exhibit increased sexual behaviors with a larger volume in brain areas associated with sexual behaviors. The precise changes underlying the morphological changes are not clear and require further investigation, but our results suggest the increase in soma size could be partially responsible for VPA volume changes. Although beyond the scope of this study, we could estimate the number of neuron soma cells in the VPA to strengthen our understanding of the relationship between increased sexual displays and increased VPA volume. Currently, it remains unclear that whether the increased VPA volume correlates with increased neuron numbers or increased production of new neurons. Interestingly, Beck et al. (2008) found that total VPA neuron numbers were greater in non-breeding lizards so it may be cells are being lost but the ones that remain are larger. Alternatively, the difference in the number of neuron soma cells could be simply the cyclical pattern of cell birth and/or death.

We are also interested in studying the relationship between POA and sexual behavior. The POA appears in diverse taxa of vertebrates, including rats (Gorski et al. 1978), garter snakes (Krohmer and Crews 1987), whiptail lizards (Rozendaal and Crews 1989), and leopard geckos (Edward et al. 2004). The POA forms connections with the MeA in mammals (Coolen and Wood

1998) and the VPA in reptiles (Lanuza et al. 1997) and stimulate masculine reproductive behaviors (Greenberg et al. 1984). Therefore, variation in POA attributes may also correlate with sexual displays rate in lizards. The POA volume and neuron soma size in breeding male lizards is larger when compared to non-breeding males (*A. carolinensis*: O' Bryant and Wade 2002; *Cnemidophorus inornatus*: Wade and Crews 1991). It could be due to POA expression of androgen and estrogen receptors, which may act similar to the VPA (birds, mammals: Ball and Balthazar 2004; lizards: Moga et al. 2000). The binding of steroid hormones on the androgen receptors in the POA could cause an increase in POA volume and POA cell volume as well. Therefore, the relationship between sexual display rates and the POA attributes need to be further investigated. We can expand our understanding of the relationship between behavior, specifically sexual behaviors, and the amygdala subregions, such as VPA and POA, as different amygdaloid regions may differentially correlate with steroid hormone release. In particular, we are interested in controlling the effect of steroid hormones on regulating the displays rate and the volume of brain regions associated with sexual behaviors.

Overall, the population-level differences in the VPA we found in the current study could be attributable to several environmental factors that may vary between Nevada and Oregon (temperature, rainfall, predation rates, etc.). Also, conspecific interactions can also modulate this relationship, particularly those between opposite-sex conspecifics. Finally, competing environmental factors may differentially select for brain attributes in different areas of the brain. Understanding how these factors modulate steroid hormone release, and how the environmental factors, social factors, and steroid hormone release interact to modulate the brain is a complex yet interesting undertaking.

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Academic Vita of Tracy Yu

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Education:

Bachelor of Science
Pennsylvania State University
Major: Biology Minor: Chemistry
Schreyer Honors College, Altoona Honors Program

Honors/ Award / Scholarship

Dean's List	Fall 2015- Spring 2018
Penn State Altoona Majors Scholarship	Every semester from Fall 2016 to Spring 2018
Undergraduate Research Fair – 3rd place	Spring 2018
Biology Major Award	Spring 2017
Secretary, Tribeta Biological Honor Society	Fall 2018
Member, Biology Club	Spring & Fall 2018

Research Experience

Department of Biology, Pennsylvania State University, Altoona, PA Jan 2018- Present
-Manage care of lizards, including feeding with crickets, cleaning and changing tanks
-Apply the Cavalieri principle to estimate the amygdala volume

Department of Chemistry, Pennsylvania State University, Altoona, PA Aug 2016 –Spring 2018
Fabrication of Micro- and Nanowires Using Impure Aluminum
-Examine the anodization behavior of aluminium alloy Al-1050 at a range of anodizing voltage and phosphoric acid concentrations
-Use simple DC electrodeposition to apply cobalt into the pores of aluminum oxide templates.
-Use scanning electron microscope to image the deposits of the temperate
-Results show that the pore diameter and channel depth correlated with anodizing voltage, but do not with acid concentration.

Relevant Skills

Language: Fluent in speaking and writing in Cantonese, Mandarin, and English

Knowledge of lab techniques:

UV/Vis Spectrophotometer	1H /13C/2-D NMR	Electrophoresis
Mass spectrometers	ELISA	Crystallization
Immunohistochemistry	Brain sectioning/staining	Electrochemistry
Cyclicphotometry	Chromatography	

Use of lab equipment:

Centrifuge	Distillation column	Reflux condensation
Solutions Preparation	Aseptic Technique	Titration
Cryostat	Light microscope	

Computer software: StereoInvestigator, Minitab, Python, Chemdraw, Microsoft (Excel, Word, Powerpoint)

Other Relevant Experience

Tutoring, Pennsylvania State University, Altoona, PA Aug 2016 – Present

- Tutored students in Inorganic Chemistry courses and Organic Chemistry Courses

Shadowing program, UPMC Altoona Hospital, PA Aug 2017

- Clinical rotation in Laboratory, Primary Care, Women's health, Emergency Room, Inpatient, Vascular Surgery.

Volunteer Work

Spooktacular Science Show, Penn State Altoona, PA Sept 2016 & 2017

- Organized the hands-on experiment for children in the community

Brain Awareness Week, Penn State Altoona, PA April 2018

- Organized activities to introduce our brain for children in the community