Canine Performance Sciences
Advancing the Mobile Sensor Technology
To innovate canine detection technology by exploring basic and applied research frontiers in olfaction, behavior, cognition, neuroscience, genomics, and physical performance.
History

- Originated 2000-2001
- Gift of breeding stock from Australian Customs Service Breeding Program
  - Auburn Canine Detection Training Center / U.S. Customs / FAA Canine Program
- Continuous, but inconsistent, operation through 2013
  - As of 2016, Auburn has bred total of 121 liters
- 2013 AU breeding operations moved to Canine Performance Sciences program of the College of Veterinary Medicine
  - Led by Dr. Jim Floyd & guided by Dr. Eldin Leighton breeding program was revamped
  - Application of scientific selective breeding practices
  - Advanced veterinary reproductive medicine
  - Targeted phenotype: Vapor Wake® capable detector dog

Development of the Auburn Dog™

Current Mission

- Serve as a context for R&D to enhance detector dog capabilities
- Advance knowledge for optimizing detector dog production
- Inform & lead efforts to improve & increase domestic K9 resources
Examining the *Auburn Dog™ Phenotype*

**Background**

- Detector dog applications becoming more specialized
  - Military SSD etc., cargo inspection, passenger screening, PBIED, VW
- Increasing sophistication of detector dog practitioners
- Detector dog recognized as most capable tool for most detection tasks
- Higher demand for more capable candidate detector dogs

➢ **Numbers of available dogs exhibiting suitable characteristics to perform contemporary detection tasks has declined**
Production aim = physically & behaviorally capable of *Vapor Wake*®
- Independent but with high trainability
- Air scenting
- High vigilance/low distractibility in searching for & alerting to targets
- Deference for searching vs. social interaction with people
- Environmental soundness in extreme work environments – large event venues, mass transit, urban clutter

Specific defining characteristics important to *Vapor Wake*® performance that define the *Auburn Dog™*

Breeding + early development + initial training = outcome
8 Auburn Dogs™ with NYPD Counterterrorism Unit Graduates of VWK9 Vapor Wake® Class
Vapor Wake® K9 Explosives Detection
Examine if differences in expression of traditional detector dog characteristics by Vapor Wake® (VW) capable and non-capable dogs within Auburn population
The detector dog is a relatively modern use of dogs for which there has been relatively NO selective pressure compared to guide dogs, herding, or hunting/retrieving breeds.

Only small-scale and often short-lived selective detector dog breeding programs to date.

Modern detector dog applications need support of specialized selective breeding, early conditioning, & initial training.

Need systems to engineer, continuous quality improvement, more reliable, and specialized dog resources.
Examining the *Auburn Dog™ Phenotype*

- Subjects = 146 born & raised between SEP 2013 & SEP 2016
  - 28 litters from 17 dams & 18 sires; no sire/dam repeats
  - 119 Lab & 27 Lab X German Wirehaired Pointer (11 50%; 16 ≤ 25% GWP)
  - 11 dogs medically disqualified not included in 146 subjects analyzed

Traditional characteristics assessed:

<table>
<thead>
<tr>
<th>Domain</th>
<th>Measure</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Retrieve</td>
<td>Dog will enthusiastically retrieve any reward every time with full sprints out and back</td>
</tr>
<tr>
<td></td>
<td>Hunt</td>
<td>Dog constantly uses nose to search and investigate targets using closed-mouth search, not looking for handler guidance. Dog does not become over-excited when target odor is present and does not get discouraged when odor is not easily found</td>
</tr>
<tr>
<td></td>
<td>Focus</td>
<td>Dog is able to focus on rewards/tasks. Dog notices environmental stimuli, but does not respond to distractions (i.e., urine, ambient noises)</td>
</tr>
<tr>
<td>Physical possession</td>
<td></td>
<td>Dog holds reward in mouth, returns to handler holding reward, and looks for engagement with handler</td>
</tr>
<tr>
<td>Independence</td>
<td>Dog is willing to work at a distance from handler and spends a minimum amount of time looking back for assistance</td>
<td></td>
</tr>
<tr>
<td>Work effort</td>
<td>Will give 100% effort on every search/task every time. Dog is eager to find target to interact with handler</td>
<td></td>
</tr>
<tr>
<td>Air scenting</td>
<td>Dog is constantly using nose to find air currents, while consistently and efficiently searching air. Dog is not looking at specific targets/objects</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>Surfaces</td>
<td>Dog will transition across any and all kinds of surfaces without any hesitation</td>
</tr>
<tr>
<td></td>
<td>People</td>
<td>Dog notices people, but does not try to interact. Dog may sniff people, but does not focus on people. Does not show fear, distraction, or excitement elicited by people</td>
</tr>
<tr>
<td></td>
<td>Vehicles/urban clutter</td>
<td>Dog adapts to clutter and works normally without disruption in searching behavior. The urban clutter should elicit the dog’s searching behavior</td>
</tr>
<tr>
<td></td>
<td>Visual startle</td>
<td>Dog notices new, unusual, or sudden stimuli but quickly resumes working. Dog may react by noticing stimuli, but holds ground and recovers quickly and then goes forward to investigate area</td>
</tr>
<tr>
<td></td>
<td>Acoustic startle</td>
<td>Dog will notice loud stimuli, but holds ground and recovers quickly and then goes forward to investigate area</td>
</tr>
<tr>
<td></td>
<td>Excitability</td>
<td>Dog is very active, exicted to work, but not erratic. Dog may run through odor, but can recover and return to scent cone without giving up on task</td>
</tr>
<tr>
<td>General</td>
<td>Trainability</td>
<td>Dog is easily trainable. Dog learns new tasks quickly and easily with few trials and little direction</td>
</tr>
</tbody>
</table>
Examining the *Auburn Dog™ Phenotype*

- Assessed at 3, 6, 10, & 11-12 months
- Tailored to be age appropriate
- Evaluation always across 2-days
- 1-3 evaluators (68% 2 evaluators): Average of evaluators’ scores
- At least 1 evaluator was not directly involved in raising, preparing, or training dogs
- Each characteristic assessed on a subjective 1-5 Likert scale
- Higher scores more desirable performance
- Scale anchored at score of “3” as minimum score of characteristic predictive of being VW capable
Examining the *Auburn Dog™ Phenotype*

- Evaluative characteristic scores compared to dog’s final disposition
- Final disposition determined placement in service
- Placement in service determined by independent 30-day training evaluation by customer for dog* ...primarily, but not exclusively VWK9
  - Dogs demonstrably incapable of successfully performing VW and or EDD not presented for sale
- Final disposition categories:
  - Vapor Wake Dog (VWD) 63%
  - Explosive Detector Dog (EDD) 17%
  - Wash Out 20% (62.5% environmental / 37.5 performance)
- Average scores for each group were compared for each items at each evaluation time point
- Time points & items within domains collapsed to provide a composite performance, environmental, and trainability score for each dog
Separate 1-way ANOVA Group X Performance/Environmental/Trainability

- VWDs significantly outperformed the other groups in each domain except Environmental where not different from EDD as confirmed by post-hoc t-test
Examining the *Auburn Dog™ Phenotype*

**Performance X Timepoints**
- VWDs scored significantly higher at each time point than washouts and at 10 months and final evaluation than EDDs

**Environment X Timepoints**
- VWDs & EDDs not different and both significantly higher than Washouts at 10 month and final evaluations

**Trainability X Timepoints**
- VWDs improved across time points; EDDs and Washouts decreased across time
- VWDs scored higher than EDDs at 10 months & final and Washouts at 6, 10 month & final evaluation
- No difference EDDs and Washouts
Examining the *Auburn Dog™* Phenotype

- Comparison of individual characteristic scores averaged across time points

### Table 2: Mean (standard error) scores for each group by measure, collapsed across time points.

<table>
<thead>
<tr>
<th>Measure</th>
<th>VWD</th>
<th>EDD</th>
<th>Washout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrieve</td>
<td>3.07 (0.05)</td>
<td>3.03 (0.11)</td>
<td>2.84 (0.107)</td>
</tr>
<tr>
<td>Hunt</td>
<td>3.31 (0.06)</td>
<td>2.93 (0.12)</td>
<td>2.87 (0.116)</td>
</tr>
<tr>
<td>Focus</td>
<td>3.23 (0.06)</td>
<td>2.84 (0.12)</td>
<td>2.63 (0.121)</td>
</tr>
<tr>
<td>Possession</td>
<td>3.03 (0.06)</td>
<td>2.62 (0.13)</td>
<td>2.67 (0.125)</td>
</tr>
<tr>
<td>Independence</td>
<td>3.26 (0.06)</td>
<td>2.95 (0.12)</td>
<td>2.79 (0.12)</td>
</tr>
<tr>
<td>Work effort</td>
<td>3.24 (0.06)</td>
<td>2.93 (0.115)</td>
<td>2.67 (0.118)</td>
</tr>
<tr>
<td>Air scenting</td>
<td>3.06 (0.07)</td>
<td>2.79 (0.140)</td>
<td>2.99 (0.136)</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surfaces</td>
<td>3.23 (0.05)</td>
<td>3.22 (0.09)</td>
<td>3.01 (0.08)</td>
</tr>
<tr>
<td>People</td>
<td>3.28 (0.06)</td>
<td>3.16 (0.11)</td>
<td>2.86 (0.10)</td>
</tr>
<tr>
<td>Vehicles</td>
<td>3.27 (0.05)</td>
<td>3.13 (0.11)</td>
<td>2.90 (0.09)</td>
</tr>
<tr>
<td>Visual startle</td>
<td>2.96 (0.10)</td>
<td>2.98 (0.21)</td>
<td>2.17 (0.18)</td>
</tr>
<tr>
<td>Acoustic startle</td>
<td>3.13 (0.09)</td>
<td>2.88 (0.19)</td>
<td>2.06 (0.16)</td>
</tr>
<tr>
<td>Excitability</td>
<td>2.98 (0.04)</td>
<td>2.92 (0.07)</td>
<td>2.93 (0.07)</td>
</tr>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trainability</td>
<td>3.26 (0.05)</td>
<td>2.82 (0.10)</td>
<td>2.69 (0.10)</td>
</tr>
</tbody>
</table>

**Note:**
- EDD denotes that score was significantly higher than the explosives detection dog (EDD) group at the 0.05 level.
- W denotes that score was significantly higher than the Washout group at the 0.05 level.
Conclusions

- Suggest that several traditional detector dog evaluative characteristics have validity in relation to final disposition

- Higher expression of Performance (search) & Trainability related characteristics appeared to be more important difference between EDDs and VWDs than environmental soundness
  - In particular: Hunt, Focus, Possession, Independence, & Effort
  - Not: Retrieve & Air Scenting; however, VWDs did exhibit higher Air Scenting at earlier age

- Compared to standard EDDs, the degree of expression of several characteristics appear to define a distinct VWD phenotype

- Traditional detector dog evaluative characteristics could provide useful basis for phenotypic description for cooperative distributed breeding initiatives
  - But, substantial variability in definition & measurement of such characteristics across working dog community would have to be overcome: Need consensus standardization

- Auburn Dog™ breeding research activity represents first documented design/production of a dog for a specialized detection application

- Knowledge can be applied to increase & accelerate success of initiative for domestic production...but, much more technology can be applied to problem...
Behavioral, olfactory and cognitive traits are heritable.

- Ancestors can be traced back to 1970s.
- Breeding and research efforts since 2000.
- 1,414-individual pedigree.
- Minimized inbreeding (IC = 0.011).
- Blood DNA available for 202 dogs.
Adoption of Vapor Wake® Technology
BREEDING PROGRAM

Breed superior quality detection dogs to detect emerging threats and enhance national security.

The Auburn Dog™
Breeding Program

CPS Breeding Program: Six Phases

Breeding → Pregnancy and Whelping → 0 to 7 weeks - Early Development at CPS → 7 weeks to 6 months - Intermediate Development at CPS → 6 to 10 months - Intermediate Development at Prisons → 10 to 12 months - Final Evaluation/Placement
Breeder Medical Testing

Breeder Requirements:
- PennHip - DI at or below 0.30
- OFA - Good/Excellent Hips
- Elbows/Shoulders/Stifles-Normal
- No Transitional Vertebrae
- EIC - Clear
- CNM - Clear
- prcd-PRA – Clear
- Eye CERF - Normal
- Echo-Normal
- Brucellosis - Negative
Breeding Program Management Difficulties And Lessons Learned

- Define breeder requirements and evaluation measures
  - Understand balance between issues and maintain breeder selection requirements
  - Goal is to make genetic progress
    - Do not expect to be clear of all problems after 1 generation

- Have a development and training plan
  - Early puppy development is critical

- Focus on improving the most impactful issues (i.e., Medical, Performance, Environmental)

- Grow gradually-learn how to manage growing number of puppies

- Breeder and trainers must have communication and teamwork

- Generally, high quality dogs tend to produce high quality dogs, but not always
  - Know there is risk involved with breeding animals
  - you WILL make a mistake

- Cannot control estrus cycles with drugs

- Do not try to manage “flaws” on outside population breeding dogs
  - must meet all requirements or simply not selected
Breeding Program

- Scientific Performance Evaluations
- Comprehensive Medical Examinations
- Advanced Puppy Development and Training
- Work daily with AUCVM Specialty Veterinarians
- Advancing Detector Dog Research with SMEs

**Example of Success:**
- Applied selective pressure with PennHip DI scores alongside OFA scores to reduce the prevalence of CHD
  - No hip dysplasia since 2015
Improvement of Phenotype

- Improve & Enhance
- Sires & Dams
- Operations Feedback
- Puppy Training
- Adult Training

Used with permission: Bryan Meltz, NY Times
Behavioral, olfactory and cognitive traits are heritable.

- Ancestors can be traced back to 1970s.
- Breeding and research efforts since 2000.
- 1,414-individual pedigree.
- Minimized inbreeding (IC = 0.011).
- Blood DNA available for 202 dogs.
Improving behavioral selection

Applying behavioral/cognitive tests of human development to dogs and relating to working dog performance

- Behavioral characteristics are often subjective and difficult to quantify
- “Puppy tests” rarely predictive of future behavior
- Measuring cognitive abilities (“intelligence”) to objectively and precisely identify critical skills

**Problem-solving**
- Learning ability
- Navigation skills
- Reaction time

**Social skills**
- Communication
- Cooperation
- Engagement

**General function**
- Behavioral regulation
- Memory
Successful puppies exhibit specific cognitive skills:

- Moderate level of engagement with people (measured by problem-solving tasks requiring communication/cooperation)
  - Too much = handler-dependent
  - Too little = not trainable

- Fast problem-solvers (measured by reaction time, persistence, time to solve a task)
  - Probably index of motivation

- Moderate level of arousal
  - Too much = lose focus
  - Too little = no motivation
Improving behavioral selection

Ideal phenotype:
- A dog that is independent, yet engaged enough to be trainable
- Persistent and motivated when faced with difficult challenges
- Focused and attentive but composed, manageable, stay cool under pressure

Next steps:
- Refine evaluations to capture these traits
  - Identify factors critical to success
  - Refine behavioral measures for more objective and earlier predictors of success
- Apply to development and training
  - Enhanced early development aimed to build independence, resilience, and emotion regulation
  - Identify weaknesses early on in order to target training that enhances these qualities
  - Linking project: combine with fMRI and genomics
Weeks 1-2 (Days 1-14)

- Puppies functionally blind and deaf, experience everything by smell and touch. Eyes begin opening towards the end of this period.

- Tactile stimulation:
  - Gently handle each puppy, touching head, back, belly, ears, tail, legs, and paws
  - Stroke puppies with different materials of various textures
    - Examples: rubber glove, cloth, wool, soft brush
Week 2

- Ears begin to open, appearance of startle response

- Tactile stimulation:
  - Continue to handle each puppy, touching head, back, belly, ears, tail, legs, and paws.
  - Place surfaces of different textures on the ground in puppy area.
    - Examples: grass mats, rubber mats, carpet squares, tile square
  - Place safe objects and toys of different materials in area.
    - Examples: empty milk jug, soft/plastic/squeaky toys.

- Visual stimulation:
  - Hang visually stimulating objects in and around puppy area (out of their reach).
    - Examples: hang flags, lanterns, tinsel
  - Exposure to colorful toys and objects of different shapes and sizes, mirrors, TVs.

- Possession building/engagement:
  - Individual play (tug toys)- always let puppy win
Early Puppy Development

Week 3-4:

➢ Tactile and Motor Development stimulation:
  • Continue above, gradually increasing difficulty/intensity.

➢ Visual and Auditory stimulation:
  • Continue above, gradually increasing difficulty/intensity.
  • Place animated toys in puppy area (toys that move, make sounds)

➢ Possession building/engagement:
  • Individual play (tug toys)- always let puppy win
Weeks 5-7:

- Advanced Visual, Auditory, and Motor Development
- Continue above, gradually increasing difficulty/intensity
  - Expose puppy to as many new people of different ages, sizes, and ethnicities
    - Ensure all introductions are safe and positive.
  - Encourage puppies to navigate small obstacles, walk through doorways and over surface transitions
  - Continue building possession and engagement with tug games, add short tosses and encourage retrieves
• **Canine Breeding:** Refining the production of the exclusive “Auburn Dog™” and exploring genetic and behavioral practices to enhance performance capabilities and innovate an efficient production model on a national scale

• **Behavioral:** AU interdisciplinary team conducting unique transformational discovery in functional imaging of canine brain activity and canine training practices

• **Genetic:** Established partnerships with world-renowned genetic institutes to discover the genetic code of superior detection dogs

• **CVM Leverage:** Leveraging the Auburn Dog™ and CVM SME for a federally funded National Detection Dog Breeding Program

• **Impact:** Addressing an international security gap in the production of Real-Time Mobile CBRNE Sensors
Auburn interdisciplinary team goal is to develop the ultimate detection dog.
**Genotype-Environment-Phenotype Map**

**Phenomics**
- Genome
  - Maternal
  - Paternal
- Cellular Level
- Tissue Level
- Physiology
- Organismal
  - Behavior
  - Fecundity

**Individual**
- Genotype
- Internal Phenotype
- External Phenotype
- External Environment
Genomics, epigenomics, metagenomics and maternal influences in canine breeding

Xu Wang
Why genetics and genomics?

Behavioral, olfactory and cognitive traits are heritable.

- Ancestors can be traced back to 1970s.
- Breeding and research efforts since 2000.
- 1,414-individual pedigree.
- Minimized inbreeding (IC = 0.011).
- Blood DNA available for 202 dogs.
Characterizing the missing heritabilities

Advantages of MAS in canine breeding compared to trait-based selection

- **Epigenetics** – covalent modifications of the DNA; erased and reset during gametogenesis through epigenetic reprogramming.

- **Gut microbiota** – the microbiome-brain-gut axis was discovered for a long time. The gut microbiota can produce neurotransmitters impacting the CNS and affecting human cognition and behavior, especially stress-related psychiatric diseases including depression, anxiety and autism.

- **Maternal influences** – as a critical organ for nutrient transport, gas exchange and immunity functions between the mother and the fetus, placental function can affect the fetal development and behavior.
Identify behavior and performance QTLs in the dog genome

QTLs (quantitative trait loci): genetic underpinnings of phenotypes
- Sequence, assemble and annotate 8 genomes of the AUCPS dogs.
- Low coverage sequencing on all dog samples.
- Genotype all dog samples through bioinformatic imputation.
- Map the QTLs using association mapping and genome-wide TDT.

Transmission/Disequilibrium Test (TDT) – a powerful approach to map QTLs

![Diagram of QTL transmission](chart)
Gut microbiome and behavior – the microbiome-gut brain axis

- Gut Microbiota
- Phenotype of interest
- Diet Environment Exercise
- Host genotypes
- QTL mapping

causation
Maternal influence on behavior – the zonary placenta

Identify signatures in placental transcriptome associated with traits of interest

- Placenta function is critical for fetal morphological and behavioral development.
- Placental immunity/inflammation status affects offspring behavior and the level of stress.
- Parent-of-origin effect has been observed in the CPS pedigree and understanding the maternal influence on fetal developmental and behavioral traits will be informative to improve the breeding strategy and canine health.

TZ: transparent zone
PZ: pigmented zone
AC: allantochorion
AM: amnion
UB: umbilical cord
Marker-assisted selection for more efficient breeding

Advantages of MAS in canine breeding compared to trait-based selection

- We will know the genetic predisposition of training success at an early age.
- Some traits are hard to measure or need long-term measurements. For example, a good breeder may not be the best performer.
- We can select for different performance and behavior traits based on our prior knowledge of different QTLs.
- We could purge the deleterious alleles during breeding (i.e., EIC).
- We can make sure we are not selecting for non-heritable traits.

Potential benefit from microbiome research

- Define what a healthy gut microbiome is for dogs.
- Identify beneficial microbes associated with performance and environmental soundness.
- Pilot fecal/microbiome transplantation experiments to improve the phenotypes of interest.
- Guide the probiotics application.
- Predict the training outcomes based on metagenomic profiles.
From genotype to phenotype

- Genomics: SNPs, indels, CNVs, fusion genes
- Epigenomics: Methylation, histone mods
- Transcriptomics: Gene expression, scRNA-seq
- Metabolomics & Proteomics: Metabolites, proteins
- Epigenomics: Methylation, histone mods
- Genomics: SNPs, indels, CNVs, fusion genes

- Phenomics: behavior, olfactory, cognitive phenotypes
- Physiology: fMRI data, physiological measurements
- Endophenotypes: mQTLs, pQTL metabolic pathways
- Metabolomics & Proteomics: eQTLs, expression networks
- Epigenomics: methQTLs, epigenomic changes
- Genomics: QTLs, causal genetic variants

Performance

Maternal Environment

Gut Microbiome
Challenges

• Increased global demand for best dogs
• Inadequate domestic supply of superior dogs
• Growing need for dogs with advanced capabilities
• Security gap in real-time detection of chem/bio

Proposed Solution

• Science-driven initiative to increase domestic supply of highest quality detector dogs
• R&D for innovation in detector dog technology
Creating Domestic Supply of Highest Quality Detector Dogs

Years 6-10....

Distributed Breeding Consortium
600+ expandable to demand for detector Dogs

Year 5
Gross 300 dogs
Net 210 working dogs
National Breeding Genetic Stockpile

Year 4
Gross 200 dogs
Net 140 working dogs
Selection & genomic tools applicable

Year 3
Gross 135 dogs
Net 90 working dogs
Selection & genomics tools applicable

Year 2
Gross 90 dogs
Net 45 working dogs

Year 1
Gross 60 dogs
Net 30 working dogs
Stop Talking I Need A Break