SNIFF TEST

Dogs are the best bomb-detection technology we have. Can scientists do better?

BY JOSH DEAN

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It's Christmas season at the Quintard Mall,

in Anniston, Alabama, and were it not a weekday morning, the tiled halls would be thronged with shoppers, and I'd probably feel much weirder walking past Victoria's Secret with TNT in my pants. The explosive is harmless in its current form—powdered and sealed inside a pair of four-ounce nylon pouches that are tucked into the back pockets of my jeans—but it's volatile enough to do its job, which is to attract the interest of a homeland defender in training by the name of Suge.

Suge is an adolescent black Labrador retriever in an orange do-not-pet vest. He is currently a pupil at Auburn University's Canine Detection Research Institute and comes to the mall once a week to practice for his future job: protecting America from terrorists by sniffing the air with extreme prejudice.

Olfaction is a canine's primary sense. It is to him what vision is to a human, the primary input for data. For more than a year, the trainers at Auburn have honed that sense in Suge to detect something very explicit and menacing: molecules that indicate the presence of an explosive, such as the one I'm carrying.

The TNT powder has no discernible scent to me, but to Suge it has a very distinct chemical signature. He can detect that signature almost instantly, even in an environment crowded with thousands of other scents. Auburn has been turning out the world's most highly tuned detection dogs for nearly 15 years, but Suge is part of the school's newest and most elite program. He is a Vapor Wake dog, trained to operate in crowded public spaces, continuously assessing the invisible vapor trails human bodies leave in their wake.

Unlike traditional bomb-sniffing dogs, which are brought to a specific target—say, a car trunk or a suspicious package—the Vapor Wake dog is meant to foil a particularly nasty kind of bomb, one carried into a high traffic area by a human, perhaps even a suicidal one. In busy locations, searching individuals is logistically impossible, and fixating on specific suspects would be a waste of time. Instead, a Vapor Wake dog targets the ambient air.

As I approach the mall's central courtyard, where its two wings of chain stores intersect, Suge is pacing back and forth at the end of a lead, nose in the air. At first I walk toward him and then swing wide to feign interest in a table covered with crystal curios. When Suge isn't looking, I walk past him at a distance of about 10 feet, making sure to hug the entrance of Bath & Body Works, conveniently the most odoriferous store in the entire mall. Within seconds, I hear the clattering of the dog's toenails on the hard tile floor behind me.

As Suge struggles at the end of his lead (once he's better trained, he'll alert his trainer to threats in a less obvious manner), I reach into my jacket and pull out a well-chewed ball on a rope—his reward for a job well done—and toss it over my shoulder. Christmas shoppers giggle at the sight of a black Lab chasing a ball around a mall courtyard, oblivious that I had I been an actual terrorist, he would have just saved their lives.

That Suge can detect a small amount of TNT at a distance of 10 feet, in a crowded mall, in front of a shop filled with scented soaps, lotions, and perfumes is an extraordinary demonstration of the canine's olfactory ability. But what if, as a terrorist, I'd spotted Suge from a distance and changed my path to avoid him? And what if I'd chosen to visit one of the thousands of malls, train stations, and subway platforms that don't have Vapor Wake dogs on patrol?

STR/AFP/GETTY IMAGES

PERFECT SCENT
Bomb-sniffing dogs have become common in airports and trains stations, like this one in Beijing, because they can detect miniscule concentrations of explosives even in dense crowds.

Dogs may be the most refined scent-detection devices humans have, a technology in development for 10,000 years or more, but they're hardly perfect. Graduates of Auburn's program can cost upwards of $30,000. They require hundred of hours of training starting at birth. There are only so many trainers and a limited supply of purebred dogs with the right qualities for detection work. Auburn trains no more than a couple hundred a year, meaning there will always be many fewer scent dogs than there are malls or military units. And dogs are sentient creatures. Like us, they get sleepy; they get scared; they die. Sometimes they make mistakes.

As the tragic bombing at the Boston Marathon made all too clear, law enforcement and military personnel need dogs—and their noses. But it also made clear that they need something in addition to canines, something reliable, mass-producable, and easily positioned in a multitude of locations. In other words, they need an artificial nose.

IN 1997, DARPA CREATED A PROGRAM to develop just such a device, targeted specifically to landmines. No group is more aware than the Pentagon of the pervasive and existential threat that explosives represent to troops in the field. It was also becoming increasingly apparent that the need for bomb detection extended beyond the battlefield. In 1988, a group of terrorists brought down Pam Am Flight 103 over Lockerbie, Scotland, killing 270 people. In 1993, Ramzi Yousef and Eyad Ismoil drove a Ryder truck full of explosives into the underground garage beneath the World Trade Center in New York, nearly bringing down one tower. And in 1995, Timothy McVeigh detonated another Ryder truck full of explosives in front of the Alfred P. Murrah Federal Building in Oklahoma City, killing 168. The "Dog's Nose Program," as it was called, was deemed a national security priority.

Over the course of three years, scientists in the program made the first genuine headway in developing a device that could "sniff" explosives in ambient air rather than test for them directly. In particular, an MIT chemist named Timothy Swager honed in on the idea of using fluorescent polymers that, when bound to molecules given off by TNT, would turn off, signaling the presence of the chemical. The idea eventually developed into a handheld device called Fido, which is still widely used today in the hunt for IED's (many of which contain TNT). But that's where progress stalled.

Olfaction, in the most reductive sense, is chemical detection. In animals, molecules bind to receptors that trigger a signal that's sent to the brain for interpretation. In machines, scientists typically use mass spectrometry in lieu of receptors and neurons. Most scents, explosives included, are created from a specific combination of molecules. To reproduce a dog's nose, scientists need to detect minute quantities of those molecules and identify the threatening combinations. TNT was relatively easy. It has a high vapor pressure, meaning it releases abundant particles into the air. That's why Fido works. Most other common explosives, notably RDX (the primary component of C-4) and PETN (in plastic explosives), have very low vapor pressures—parts-per-trillion, at equilibrium, and once they're loose in the air perhaps even parts-per-quadrillion.

"That was just beyond the capabilities of any instrumentation until very recently," says David Atkinson, a senior research scientist at the Pacific Northwest National Laboratory, in Richland, Washington. A gregarious, slightly bearish man with a thick goatee, Atkinson is the co-founder and "perpetual co-chair" of the annual Workshop on Trace Explosives Detection. In 1988, he was a PhD candidate at Washington State University when Pam Am Flight 103 went down. "That was the turning point," he says. "I've spent the last 20 years helping to keep explosives off airplanes." He might at last have found his solution.

And in mid-January he was excited to show it off. Atkinson beckons me into a cluttered lab with a view of the Columbia River. At certain times of the year, he says he can see eagles swooping in to poach salmon as they spawn. "We're going to show you the device we think can get rid of dogs," he says jokingly. In a corner of the lab, he points to an ungainly, photocopier-size machine with a long copper snout; wires run haphazardly from various parts.

Last fall, Atkinson and two colleagues did something tremendous: They proved, for the first time, that a machine could perform direct vapor detection of two common explosives—RDX and PETN—under ambient conditions. In other words, the machine "sniffed" the vapor as a dog would, from the air, and identified the explosive molecules without first heating or concentrating the sample, as currently deployed chemical detection machines (for instance, the various trace detection machines at airport security checkpoints) must. In one shot, Atkinson opened a door to the direct detection of the world's most nefarious explosives.

As Atkinson explains the details

AS THE BOMBING AT THE BOSTON MARATHON MADE CLEAR, WE NEED DOGS—AND THEIR NOSES.

LAB NOSE David Atkinson at the Pacific Northwest National Laboratory has created a system that uses a mass spectrometer to detect the molecular weights of common explosives in air.

COURTESY PACIFIC NORTHWEST NATIONAL LABORATORY

of his machine, senior scientist Robert Ewing, a trim man in black jeans and a speckled gray shirt that exactly matched his salt-and-pepper hair, prepares a demonstration. Ewing grabs a glass slide soiled with RDX, an explosive that even in equilibrium has a vapor pressure of just five parts per trillion. This particular sample, he says, is more than a year old and just sits out on the counter exposed; the point being that it's weak. Ewing raises this sample to the snout-end of a copper pipe about an inch in diameter. That pipe delivers the air to an ionization source, which selectively pairs explosive compounds with charged particles, and then on to a commercial mass spectrometer about the size of a small copy machine. No piece of the machine is especially complicated; for the most part, Atkinson and Ewing built it with off-the-shelf parts.

Ewing allows the machine to "sniff" the RDX sample and then points to a computer monitor where a line graph that looks like an EKG shows what was being smelled. Within seconds, the graph spikes. Ewing repeats the experiment with PETN and then a third time with C-4, a plastic explosive consisting mostly of RDX. Each time, the machine senses the explosive.

A commercial version of Atkinson's machine could have enormous implications for public safety, but to get the technology from the lab to the field will require overcoming a few hurdles. As it stands, the machine recognizes only a handful of explosives (at least nine as of April), though both Ewing and Atkinson are confident that they can work out the chemistry to detect others if they get the funding. Also, Atkinson will need to shrink it to a practical size. The current smallest version of a high performance mass spectrometer is about the size of a laser printer—too big for police or soldiers to use in the field. Scientists have not yet found a way to shrink the device's vacuum pump. DARPA, Atkinson says, has funded a project to dramatically reduce the size of vacuum pumps but it's unclear if the work can be applied to mass spectrometry.

THE MACHINE SNIFFED JUST AS A DOG WOULD AND IDENTIFIED THE EXPLOSIVE MOLECULES.

If Atkinson can reduce the footprint of his machine, even marginally, and refine his design, he imagines plenty of very useful applications. For instance, a version affixed to the millimeter wave booths now common at American airports (the ones that require passengers to stand with their hands in the air—also invented at PNNL, by the way) could use a tube to sniff air and deliver it to a mass spec. Soldiers could also mount one to a Humvee or an autonomous vehicle that could drive up and sniff suspicious piles of rubble in situations too perilous for a human or dog. If Atkinson could reach backpack size or smaller, he might even be able to get portable versions into the hands of those who need them most, the marines on patrol in Afghanistan, the Amtrak cops guarding America's rail stations, or the officers watching over a parade or road race.

Atkinson is not alone in his quest for a better nose. A project at MIT is studying the use of carbon nanotubes lined with peptides extracted from bee venom that bind to certain explosive molecules. And at the French-German Research Institute in France, researcher Denis Spitzer is experimenting with a chemical detector made from micro-electromechanical machines (MEMs) and modeled on the antennae of a male silkworm moth, which is senstitive enough to detect a single molecule of female pheromone in the air.

Atkinson may have been first to prove extremely sensitive chemical detection—and that research is all but guaranteed to strengthen terror defense—but he and other scientists still have a long way to go before they approach the sophistication of a dog nose. One challenge is to develop a sniffing mechanism. "With any electronic nose, you have to get the odorant into the detector," says Mark Fisher, a senior scientist at Flir, the Portand, Oregon-based company that holds the patent for Fido, the IED detector. Every sniff a dog takes, it processes about half a liter of air and a dog sniffs up to ten times per second. Fido processes fewer than 100 milliliters per minute and Atkinson's machine sniffs a maximum of 20 liters per minute.

Another much greater challenge, perhaps even insurmountable, is to master the mechanisms of smell itself.

OLFACTION IS THE OLDEST of the sensory systems and also the least understood. It is complicated and ancient, sometimes called the primal sense because it dates back to the origin of life itself. The single-celled organisms that first floated in the primordial soup would have had a chemical detection system in order to locate food and avoid danger. In humans, it's the only sense with its own dedicated processing station in the brain—the olfactory bulb—and also the only one that doesn't transmit its data directly to the higher brain. Instead, the electrical impulses triggered when odorant molecules bind with olfactory receptors route first through the limbic system, home of emotion and memory. This is why smell is so likely to trigger nostalgia or, in the case of those suffering from PTSD, paralyzing fear.

All mammals share the same basic system, though there is great variance in sensitivity between species. Those that use smell as the primary survival sense, in particular rodents and dogs, are orders of magnitude better than humans at identifying scents. Architecture has a lot to do with that. Dogs are lower to the ground, where molecules tend to land and linger. They also sniff much more frequently, and in a completely different way (by first exhaling to clear distracting scents from around a target and then inhaling), drawing more molecules to their much larger array of olfactory receptors. Good scent dogs have 10 times as many receptors as humans, and 35 percent of the canine brain is devoted to smell, compared with just 5 percent in humans.

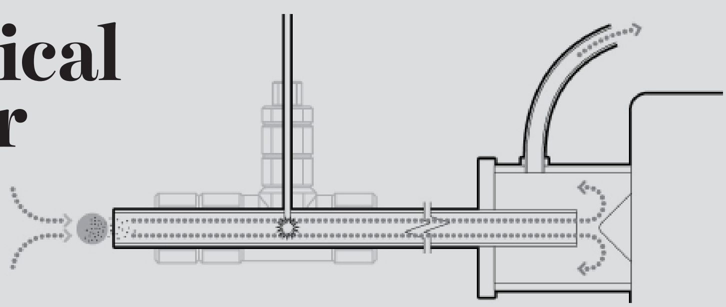
Unlike hearing and vision, both of which have been fairly well understood since the 19th century, scientists first explained smell only 50 years ago. "In terms of the physiological mechanisms of how the system works, that really started only a few decades ago," says Richard Doty, director of the Taste and Smell Center at the University of Pennsylvania. "And the more people learn, the more complicated it gets."

BOMB PATROL The trainers at Auburn supply vapor wake dogs to the police, armed forces, and in the case above, the Amtrak Police in Washington DC's Union Station.

Whereas Atkinson's vapor detector identifies a few specific chemicals using mass spectrometry, animal systems can identify thousands of scents that are, for whatever reason, important to their survival. When molecules find their way into a nose, they bind with olfactory receptors that dangle like upside-down flowers from a sheet of brain tissue known as the olfactory epithelium. Once a set of molecules links to particular receptors, an electrical signal is sent through axons into the olfactory bulb and then through the limbic system and into the cortex, where the brain assimilates that information and says, "Yum, delicious

The Mechanical Bomb Sniffer

Last fall, a team at the Pacific Northwest National Laboratory announced that it had "sniffed" certain explosives in ambient air for the first time. Most common explosives—RDX, PETN, blasting gels—exist in very low ambient concentrations, often in the parts-per-quadrillion range. Existing detectors are not that sensitive, meaning security forces need to test suspects directly, as in airports. A version of Atkinson's machine could simply sniff targets, speeding the process. "It could change the way we do screening for explosive threats," he says. *— Josh Dean*



1 Scientists spike a glass slide with residue from a few known explosives. A vacuum pump within the detector sucks air through a one-inch wide opening at a rate of between one and five liters per minute.

2 The vapor passes through a copper tube toward an ionization source. Nitrate ions, which have a high charge affinity, collide with the highly polar explosive molecules, so they tend to stick together, forming an adduct—or cluster molecule.

3 To ensure that every one of the explosive molecules in the airstream is ionized, Atkinson's team used a long, copper reaction tube to extend the reaction period to appoximately two seconds.

4 Electric fields on the front of the commercial mass spectrometer guide the charged ions through a 600-micron-wide passage into the mass spectrometer itself.

5 The mass spectrometer analyzes the sample and determines the molecular weight. Currently, Atkinson's team can detect at least nine explosives, including PETN, RDX, C4, Semtex, smokeless powder, and some blasting gels.

COURTESY AUBURN CANINE DETECTION INSTITUTE; ILLUSTRATION BY TREVOR JOHNSTON

WHILE DOGS ARE FLUENT IN THE MYSTERIOUS LANGUAGE OF SMELL, SCIENTISTS ARE ONLY NOW LEARNING THE ABCS.

coffee is nearby."

As is the case with explosives, most smells are compounds of chemicals (only a very few are pure; for instance, vanilla is only vanillin), meaning that the system must pick up all those molecules together and recognize the particular combination as gasoline, say, and not diesel or kerosene. Doty explains the system as a kind of code, and, he says, "The code for a particular odor is some combination of the proteins that get activated." To create a machine that parses odors as well as dogs, science has to unlock the chemical codes and then program artificial receptors to alert for multiple odors as well as combinations.

In some ways, Atkinson's machine is the first step in this process. He's unlocked the codes for a few critical explosives and has built a device sensitive enough to detect them, simply by sniffing the air. But he has not had the benefit of many thousands of years of bioengineering. Canine olfaction, Doty says, is sophisticated in ways that humans can barely imagine. For instance, humans don't dream in smells, he says, but dogs might. "They may have the ability to conceptualize smells," he says. For example, instead visualizing an idea in their mind's eye, they might smell it.

Animals can also convey metadata with scent. When a dog smells a telephone pole, he's reading a bulletin board of information: which dogs have passed by, which ones are in heat. Dogs can also sense pheromones in other species. The old adage is that they can smell fear, but scientists have proved they can smell other things, like cancer or diabetes. Gary Beauchamp, who heads the Monell Chemical Senses Center in Philadelphia, says that a "mouse sniffing another mouse can obtain much more information about that mouse than you or I could by looking at someone." If breaking chemical codes is simple spelling, deciphering this sort of metadata is grammar and syntax. And while dogs are fluent in this mysterious language, scientists are only now learning the ABCs.

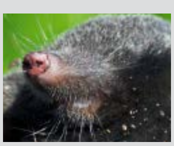
THERE ARE FEW PEOPLE who better appreciate the complexities of smell than Paul Waggoner, a behavioral scientist and the associate director of Auburn's Canine Research Detection Institute. He has been hacking the dog's nose for more than 20 years.

"By the time you leave, you won't look at a dog the same way again," he says, walking me down a hall where military intelligence trainees were once taught to administer polygraphs and then out a door and past some pens where new puppies spend their days. The CRDI occupies part of a former Army base in the Appalachian foothills and breeds and trains between 100 and 200 dogs—mostly Labrador retrievers, but also Belgian Malinois, German shepherds, and German shorthair pointers—a year for Amtrak, the Department of Homeland Security, and police departments across the U.S. Training begins in the first weeks of life, and Waggoner points out that the floor of the puppy corrals is made from a shiny tile meant to mimic the slick surfaces they will encounter at malls, airports, and sporting arenas. Once weaned, the puppies go to prisons in Florida and Georgia, where they get socialized among prisoners in a loud, busy, and unpredictable environment. And then they come home to Waggoner.

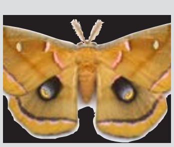
What Waggoner has done over tens of thousands of hours of careful study is begin to quantify a dog's olfactory abilities. For instance, how small a sample dogs can detect (parts-per-trillion, at least); how many different types of scents they can detect (within a certain subset, explosives for instance, there seems to

Five Feats of Smell

FIND SCHOOLS OF FISH: The albatross can smell fish from the air. Researchers have found that an albatross will alter its course toward prey located well out of visual range. The birds can monitor a miles-wide swath of ocean as they fly in a single direction.



SMELL IN STEREO: Scientists recently discovered that the Eastern American mole smells in stereo. Because they're blind and have little use for hearing, moles use stereoscopic smell to determine their location and the location of their prey.



LOCATE A DISTANT MATE : Moths don't have noses. Instead, they have antennae covered in scent receptors. While they don't detect every scent well, male silkworm moths can smell a single molecule of female sex hormone from a few miles away.

DETECT SPECIFIC PROTEINS: Sharks breathe with their gills, so their noses serve only to smell. They are particularly well tuned for hunting. Sharks can sense a prey's amino acids at concentrations as low as one part per billion.

TARGET A SINGLE SCENT: Dogs have a keen ability to discriminate among smells. An Auburn search and rescue dog can track a single human trail, laid more than 24 hours before, across a campus crisscrossed by tens of thousands of students. —*Susan Matthews*

TOP DOWN: STEVE ALLEN/ GETTY IMAGES; JUSTUS DE CUVELAND/ GETTY IMAGES; DON FARRALL/ GETTY IMAGES; JEFF ROTMAN/ GETTY IMAGES

BOTH THE DOG PEOPLE AND THE SCIENTISTS WORKING TO EMULATE THE CANINE NOSE HAVE A COMMON GOAL: TO STOP BOMBS FROM BLOWING UP.

be no limit, and a new odor can be learned in hours); whether training a dog on multiple odors degrades its overall detection accuracy (typically, no); and how certain factors like temperature and fatigue affect performance.

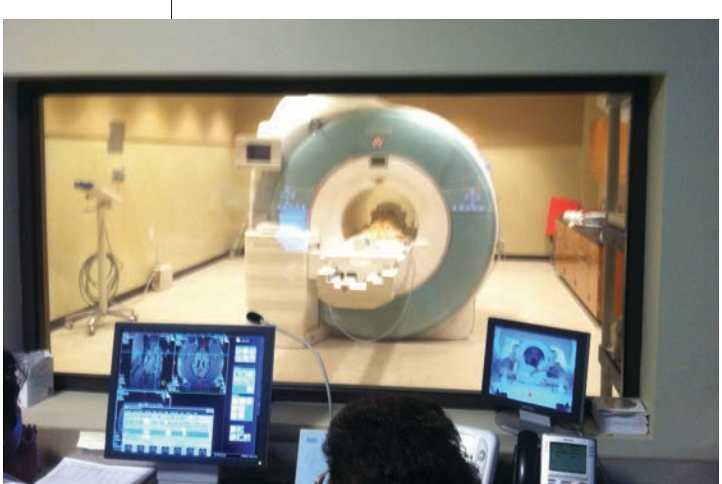
The idea that the dog is a static technology just waiting to be obviated really bothers Waggoner, because he feels like he's innovating every bit as much as Atkinson and the other lab scientists. "We're still learning how to select, breed, and get a better dog to start with—then how to better train it and, perhaps most importantly, how to train the people who operate those dogs."

Waggoner even taught his dogs to climb into an MRI machine and endure the noise and tedium of a scan. If he can identify exactly which neurons are firing in the presence of specific chemicals and develop a system to convey that information to trainers, he says it could go a long way toward eliminating false alarms. And if he could get even more specific –if, say, RDX fires different cells than PETN—that information might inform more targeted responses from bomb squads.

After a full day of watching trainers demonstrate the multitudinous abilities of CRDI's dogs, Waggoner leads me back to his sparsely furnished office and clicks a video file on his computer. It was from a lecture he'd given at an explosives conference, and it featured Major, a yellow Lab wearing what looked like a shrunken version of the Google Street View car array on its back. Waggoner calls this experiment Autonomous Canine Navigation.

Working with preloaded maps, a computer delivered specific directions to the dog. By transmitting beeps that indicated left, right, and back, it helped Major navigate an abandoned "town" used for urban warfare training. From a laptop, Waggoner could monitor the dog's position using both cameras and a GPS dot, while tracking its sniff rate. When the dog signaled the presence of explosives, the laptop flashed an alert, and a pin was dropped on the map.

ANIMAL MIND Paul Waggoner at Auburn University treats dogs as technology. He studies their neurological responses to olfactory triggers with an MRI machine.



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It's not hard to imagine this being very useful in urban battlefield situations or in the case of a large area and a fast-ticking clock—say, an anonymous threat of a bomb inside an office building set to detonate in 30 minutes. Take away the human and the leash, and a dog can sweep entire floors at a near sprint. "To be as versatile as a dog, to have all capabilities in one device, might not be possible," Waggoner says.

It's important to recognize that both sides—the dog people and the scientists working to emulate the canine nose—have a common goal: to stop bombs from blowing up. And the most effective result of this technology race, Waggoner thinks, is a complementary relationship between dog and machine. It's impractical, for instance, to expect even a team of Vapor Wake dogs to protect Grand Central Terminal, but railroad police could perhaps one day install a version of Atkinson's sniffer at that station's different entrances. If one alerts, they could call in the dogs.

There's a reason Flir Systems, the maker of Fido, has a dog research group, and it's not just for comparative study, says the man who runs it, Kip Schultz. "I think where the industry is headed, if it has forethought, is a combination," he told me. "There are some things a dog does very well. And some things a machine does very well. You can use one's strengths against the other's weakness and come out with a far better solution."

Despite working for a company that is focused mostly on sensor innovation, Schultz agrees with Waggoner that we should be simultaneously pushing the dog as a technology. "No one makes the research investment to try to get an Apple approach to the dog," he says. "What could he do for us 10 or 15 years from now that we haven't thought of yet?"

On the other hand, dogs aren't always the right choice; they're probably a bad solution for screening airline cargo, for instance. It's a critical task, but it's tedious work sniffing thousands of bags per day as they roll by on a conveyor belt. There, a sniffer mounted over the belt makes far more sense. It never gets bored.

"The perception that sensors will put dogs out of business—I'm telling you that's not going to happen," Schultz told me, at the end of a long conference call. Mark Fisher, who was also on the line, laughed. "Dogs aren't going to put sensors out of business either." PS

Josh Dean lives in Brooklyn, New York and is the author of SHOW DOG: THE CHARMED LIFE AND TRYING TIMES OF A NEAR-PERFECT PUREBRED