AI-Powered Tech Enables Continuous Lab Animal Monitoring

Scientists are using AI-powered, 24/7 home-cage monitoring to accelerate discovery, enhance reproducibility, and improve animal well-being.

Alejandra Manjarrez, PhD

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Recent advances in AI-powered continuous home-cage monitoring are helping scientists enhance research quality and data analysis while also improving lab animals' well-being.

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In the late 2000s and early 2010s, neurogeneticist Vivek Kumar, then a postdoctoral researcher at the University of Texas Southwestern Medical Center, screened thousands of randomly mutagenized mice. He was searching for subtle behavioral shifts in open-field activity and responses to psychostimulants—his first foray into studying animal behavior after a background in molecular biology.

Kumar recalled the rudimentary nature of these early behavioral analyses, where a simple computer program tracked mice as they explored the testing chamber for short periods of time—sometimes for as little as a few minutes—reducing their behavior to the movements of a single dot on a screen. He quickly recognized the limitations of this approach: "The dimensionality and the complexity of what the animal does versus what we're seeing on the computer, what we're capturing and we're studying, is just like night and day," he said. He pointed to grooming as an example, a behavior that entails a complex set of motions including paw licking, face washing, and body licking. "If we abstract the mouse to a center of mass, we cannot tell these movements apart," he noted.

"I started thinking about this problem a lot, and I realized we need to do better in terms of animal behavior quantification," said Kumar. As he continued studying the mouse brain to understand mental illnesses like addiction and depression, he also focused on developing tools to facilitate and improve rodent behavior research. Motivated by the need for more precise behavioral analyses, he has been developing complex home-cage environments equipped with continuous camera monitoring and machine learning algorithms to capture and analyze nearly every aspect of animal behavior in the lab.

Kumar is part of a growing group of scientists in neuroscience and biomedicine embracing 24/7 monitoring of lab animals. While this constant surveillance produces vast amounts of data, the integration of machine learning has turned this

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Around the same time Kumar was first grappling with the behavioral analysis of thousands of mice, interest in studying naturalistic animal behavior was experiencing a resurgence, fueled by advances in computational science. This movement gave rise to the field of computational ethology, which leveraged technologies such as machine learning and computer vision—a field focused on processing and analyzing digital images—to address long-standing methodological gaps in behavioral research, explained Talmo Pereira, a computational neuroscientist at the Salk Institute for Biological Studies.[1]

"In classic ethology, what comes to mind is something like a very dedicated graduate student sitting in a bush with a notepad and taking down notes of the sequences of behaviors that an animal might be exhibiting in its natural context," said Pereira. "Now, with the advent of these computational tools what we've been able to do is to have the same degree of fidelity in the way that we quantify complex behaviors." Instead of relying solely on time-consuming human observations—often constrained by subjective interpretation—these new tools open the door to novel experimental settings, such as monitored cages where the animals' actions can be analyzed with artificial intelligence (AI)-powered algorithms.

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Pereira has contributed to automating behavioral studies, particularly through motion capture using computer vision and deep learning. As part of his PhD at the Princeton Neuroscience Institute, he developed hardware and software to quantify the behavior of fruit flies during fighting and courtship. One of his key contributions is the Social LEAP Estimates Animal Poses (SLEAP) algorithm, which tracks the postures of subjects in a video—whether they're a molecule, a rodent, or a colossal mammal.[2]

SLEAP labels the body parts of one or more animals within a video and tracks their movements over time. Trained on multiple species, including flies, bees, mice, and gerbils, it also allows researchers to customize training for other animal models. As an open-source tool with a user-friendly interface, researchers have used SLEAP to explore a wide range of questions, from how social isolation affects bumblebees and how mice respond collectively to temperature changes, to the impact of ecotourism on whale sharks.[3-5]

From Dots to a Deluge: AI Boosts Data Collection

mouse behavior in their environment. Working alongside his colleagues at the Jackson Laboratory, he has developed several technologies to advance behavioral research, including the DAX system.[6]

DAX is a high-tech, self-contained unit equipped with an integrated cage, lighting, top and side cameras, and computational controls. Designed as a digital caging technology, it connects to a cloud-based Digital In Vivo System (DIV Sys). A top-mounted camera continuously monitors mice as they snooze, play, groom, and explore. A neural network processes the video frames by drawing boundaries around each mouse, separating them from the background, identifying key points on their bodies, and using data to tell individual mice apart. "This serves as our foundational metrics that are then used to annotate behavior," said Kumar.

From this data, scientists can extract over 60 different variables, Kumar noted, including traits like body mass, posture, and biological age, and behaviors like grooming, freezing, and shaking. To expand the DAX system's applications, its algorithms have been trained on diverse mouse strains with variable sizes and coat colors.

Vivek Kumar and his team are advancing digital cage technology to better assess animal behavior.

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The Jackson Laboratory partnered with the animal housing manufacturer Allentown to commercialize an updated version of DAX/DIV Sys, launching the platform Envision. Looking ahead, Kumar shared, "What we plan to do in the future is essentially to allow other platforms, other methods, or other streams of data into Envision."

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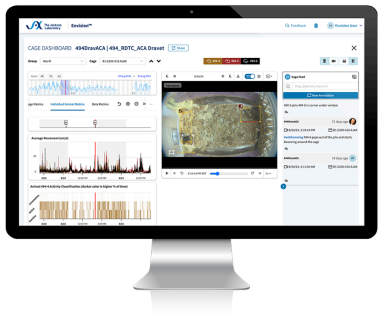
cortex, in mice. While her early work focused on their basic functions, her interest gradually shifted toward translational science, as these regions are among the first affected in Alzheimer's disease.

The shift influenced her experimental approach. In translational science, sample sizes increase significantly, Krupic noted, adding, "And that means that you have to automate [research], there is no other way you can do it."



Continuous monitoring of rodents, aided by AI tools, allows scientists to analyze several metrics, including body mass, posture, and biological age.

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As necessity is the mother of invention, Krupic teamed up with other scientists to develop smart-Kage, a fully automated home-cage monitoring system for mice. The system includes behavioral and cognitive tests, such as a T-maze and novel object recognition, to assess hippocampus function.[7] Similar to other monitoring systems, a top-mounted camera records behavior, which is then analyzed using deep learning algorithms, some adapted from existing algorithms that track the animal's skeleton and position.[8]

One of the biggest challenges, Krupic said, was designing a long-term, 24/7 habitat capable of delivering cognitive tests without human intervention. Fortunately, in 2018, around the time her team was working on these efforts, a surge in affordable hardware—such as Arduino microcontrollers and Raspberry Pi computers—made it possible to combine these tools with software algorithms.

system. Krupic said that research teams in the UK and abroad are already using smart-Kage to study circadian regulation and mouse models of conditions like Down Syndrome.

Smarter Research, Healthier Animals

Beyond providing more data, home-cage monitoring offers researchers several additional benefits. Traditional assessments often involve human interference that can skew results by restricting assessments to specific timepoints—for instance, testing nocturnal rodents during daylight hours. In contrast, long-term surveillance captures a more authentic picture of the animals' behavior. Furthermore, by reducing human intervention and bias, automated monitoring seems to improve reproducibility.[9,10]

These technologies may also improve lab animals' wellbeing. Conventional research methods require frequent handling and cage transfers, which can induce stress.[11] Home-cage monitoring reduces these disruptions, enabling data collection with minimal interference. This approach not only improves animal welfare but also helps scientists better understand their models and improve their care.

Continuous sensor monitoring further supports the animal health. For instance, if an animal's condition deteriorates, leading to reduced motor activity, an alert can notify researchers to investigate, explained Sara Fuochi, an animal welfare researcher at the Research Institute for Semiochemistry and Applied Ethology.

Finally, these advancements could also reduce the number of animals required for research. "[In] a longitudinal study, instead of having one hundred animals, you can perform the same analysis…more than one time on the same animal," said Fuochi.

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believe that people are trying to reduce prices as much as they can," she added. On the other hand, open-source alternatives are more affordable but demand specialized support for implementation. "And again, not every lab can have it," Kupric noted.

A major technological hurdle is accurately tracking multiple animals over long periods, said Pereira. While various algorithms, including SLEAP and Envision, can track several animals, maintaining flawless identity tracking remains difficult. Even a 0.1 percent error becomes critical when recording continuously, he explained. "A mistake in identity tracking means that you might mix up your experimental and your control [subjects], the mother and the pup, the resident and the intruder." Perfecting long-term identity tracking remains a key frontier in the field.

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To maximize these systems' potential, data sharing will be essential. Kumar envisions his platforms as collaborative hubs where users could share classifiers—algorithms trained to recognize specific traits or behaviors—and even video data. Fuochi also sees value in sharing recordings to facilitate data repurposing and reduce the number of animals used in research. However, she emphasized the need for clear policies on data ownership and intellectual property. "It requires definitely dedicated policies and agreements and consensus on propriety of data," she noted.

prioritize a few standardized systems or maintain diverse approaches to capture behavioral complexity while openly sharing data for comparison. Despite its relevance, she noted, "I'm not sure this kind of conversation is even taking place."

References +

Keywords

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Detecting emerging and re-emerging viral pathogens is crucial for public health. While next-generation sequencing (NGS) approaches can permit the unbiased identification of known and novel viral infectious agents, high levels of contaminating human nucleic acids reduce the method's analytical sensitivity. A hybridization-based target enrichment strategy can overcome this limitation.

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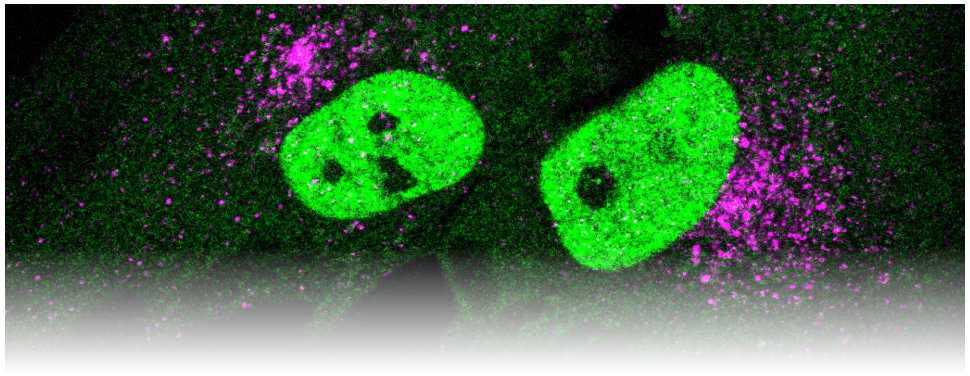
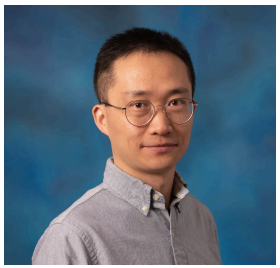


Cells constantly face stress from infection, diseases, and aging. To detect foreign DNA threats, they use the cGAS-STING pathway, a defense mechanism that is conserved across species. The STING protein is crucial for antiviral and inflammatory responses through type I interferon production, a function recently identified in vertebrates.[1] However, cells can also alleviate cellular stress and promote survival by removing harmful material. This led Jay Xiaojun Tan, a cellular biologist from the University of Pittsburgh, to explore whether the cGAS-STING pathway had other overlooked roles in stress management.



Jay Xiaojun Tan studies the cell biology of aging, focusing on the longevity promoting organelle—lysosomes.

JAY XIAOJUN TAN

"We thought [this pathway] should have protective functions or stress clearance functions, in addition to the very famous inflammation function." Tan's team explored whether the cGAS-STING pathway interacts with lysosomes, the cell's housekeeping organelle responsible for clearing cellular damage and promoting longevity. Their findings, published in *Molecular Cell,* revealed an ancient role for this pathway in lysosomal biogenesis and stress clearance, which predates type I interferons.[2]

When STING is triggered, TANK-binding kinase (TBK1) activates and leads to interferon production. However, Tan and his team wanted to identify other transcription factors regulated by STING. On screening human cells to identify proteins that shuttled from the cytosol to the nucleus during STING activation, they identified 17 candidates.

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of autophagy and innate immunity.[3]

Through cell-based assays, the researchers determined that STING activated TBK1 and TFEB independently, where the lipidation of autophagy proteins mediated TFEB activation. Using RNA sequencing, they identified upregulated genes during this process. They noted an increase in TFEB-target genes that promote lysosomal biogenesis and autophagy, supporting a cytoprotective rather than an inflammatory role.

Tan hopes these insights will support therapeutic development, as chronic activation of STING is seen in aging and neurodegenerative diseases like Alzheimer's disease, which involve impaired lysosome trafficking.

Nan Yan, a molecular biologist at the University of Texas Southwestern Medical Center, who was not involved in the study, remarked, "This paper shows the good and bad activity coming from different parts of the protein. So conceivably, you can selectively manipulate either one."

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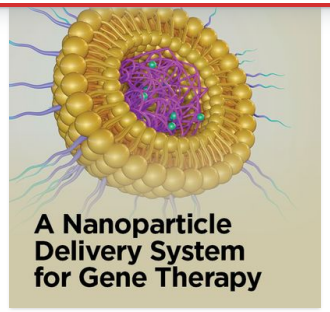

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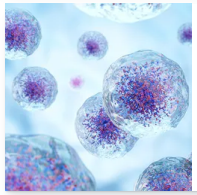

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