MODERN TOOLS AND MARKET DYNAMICS IN BEHAVIORAL RESEARCH

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***Abstract**: This article provides a comprehensive analysis of the key market players, tools, and methodologies used in modern behavioral, neuroscience, and animal research. Based on detailed data extracted from leading companies and research studies, categorized and evaluate various tools, equipment, and approaches currently employed in these fields. The study focuses on market trends, innovative products, and the comparative analysis of modern and traditional methods utilized in behavioral research and psychopharmacology. The findings highlight the evolution of research tools and technologies, offering insights into the current market landscape and future directions for both academic and industrial applications.*

***Keywords**: Artificial Intelligence, Behavioral Research, Neuroscience.*

***ITHEA Keywords**: H. Information Systems: H.0 GENERAL, I. Computing Methodologies: I.2 ARTIFICIAL INTELLIGENCE: I.2.0 General, I. Computing Methodologies: I.2 ARTIFICIAL INTELLIGENCE: I.2.1 Applications and Expert Systems.*

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Introduction

Behavioral, neuroscience and animal research have significantly evolved due to advancements in methodologies, tools, and technologies. The integration of modern equipment and data-driven platforms has enabled more precise and efficient studies, leading to significant scientific breakthroughs. In this article, we focus on analyzing the market landscape by examining data from major companies that provide research tools and services for these fields. The information is organized into three main categories: behavior research equipment, neuroscience research tools, and animal research products. Additionally, we present a comparative analysis of modern tools versus classical approaches in psychopharmacology, highlighting key trends and innovations driving the market forward. This study is aimed at expanding the fundamental concepts of data processing and analysis in the field of mathematical modeling of biological processes. Also to provide a clear understanding of the current state of the market and its future potential, aiding researchers and industry professionals in making informed decisions.

Models, Tools and Studies in Animal Behavioral Research

The new era of technology gives the world more powerful supercomputers, modern algorithms and libraries, which in turn influenced High-Performance Computing (HPC) and gave a new development in Natural Language Processing (NLP). Ample opportunities have emerged for data collection using advanced Graphics Processing Units (GPUs) and Tensor Processing Units (TPUs) [Elnaggar et al., 2021], data analysis and application of information technology tools in many fields of science. In biological, medical, and behavioral methods on laboratory animals in the study of the activity of potential psychotropic drugs and allow you to quickly assess the main effects of new compounds. The preclinical phase using animal models in psychopharmacological studies is recognized as the main approach that can increase the ability to predict the successful outcome of future clinical trials, reduce costs and significantly reduce time. Often, scientists use classical methods of statistical analysis to assess the reliability and calculate dependencies between control and experimental studies. Modern data collection devices make it possible to obtain voluminous data arrays. These diverse, complex and often multivariate datasets exhibit non-linear relationships and unknown interactions between multiple variables and may not match the assumptions of many classical statistical methods [Valletta et al., 2017]. Few researchers who own the subject area [de Andrade Costa and Tinos, 2014] develop or want to develop a mathematical representation of the process they are working on. Often, the study of narrow issues, an extensive subject area does not give a complete picture of the process or system as a whole, hinders the understanding of key mechanisms and their relationships. Researchers of narrow theoretical issues should understand the strengths and weaknesses of modern clinical practice, global trends in modern research [Papaspyros et al., 2023]. An analysis of modern achievements in the field of psychopharmacology makes it possible to look at modern developments in the field of information technology and the prospects for their application in the study of behavior [David J. T. Sumpter, 2010]. This is just an introductory part and the reader has the opportunity to refer to the original articles referenced in this review to expand their knowledge of a particular method and approach in research. It so happens that mathematicians often deal with mathematical models in biology, which complicates the search for a relevant method and the construction of a reliable model. Often, interdisciplinary cooperation is due to the possession of a different conceptual apparatus between scientists from different disciplines, which also affects the fruitfulness of such cooperation. This study aims to address these gaps. It presents the basic mathematical methods and concepts that are used to describe processes. Biological phenomena are listed, which are described using the mathematical apparatus, a practical approach to such research and research results is presented. During to planning of research in study of behavior, a scientists is faced with a lack of knowledge of modern technologies, methods, applications and tools. Because of this ignorance, scientific organizations, universities lose a lot of money on the purchase of expensive technologies and tools that will never be used [Babenko, 2023].

Were analyzed in the study analyzed various behavioral models, such as the Elevated Plus Maze (EPM) for rats, using machine learning (ML) models to understand neurobiological responses related to anxiety and defense mechanisms [Costa et al., 2014]. The approach involved using sensory inputs and memory components in a maze environment to evolve Artificial Neural Networks (ANNs). Models like the Elman Network were used alongside real and virtual rats, employing mathematical tools like Markov Chains and Gaussian mutations for data analysis.

In the research with zebra finches' use of brightness cues for flight path selection [Borsier and Taylor, 2023]. Researchers recorded over 400 flight trajectories under varying lighting conditions, using advanced equipment such as synchronized 4k cameras. The analysis utilized statistical methods like two-tailed Mann-Whitney U tests and two-way ANOVA to study the birds' behavior in balancing optic flow for navigation.

A circuit-based model was developed to simulate the lymphatic system's behavior, leveraging the "circuit analogy" with capacitors, resistors, and inductors [Gajani, 2022]. This analytical approach allowed researchers to understand physiological phenomena like lymphangion contractions by applying nonlinear ordinary differential equations (ODE) and standard spice-like simulation languages.

Additionally, a deep learning model was introduced to study social interactions in schooling fish [Costa de Melo et al., 2019]. The model combined short- and long-term dynamic analyses, employing various machine learning techniques such as Artificial Neural Networks (ANN) and Deep Learning (DL) models. These models offered a systematic methodology for testing results against empirical data in the context of animal collective motion.

Moreover, methodologies to measure behavioral parameters in rodents were proposed, focusing on elevated plus mazes and holeboard tests [Costa et al., 2014]. A key advantage was the use of clustering techniques for reconstructing the background, enabling more precise behavioral measurements in experiments involving animal models.

Studies in behavioral neuroscience also leveraged various analytical models, such as those used in the Forced Swim Test (FST) to assess antidepressant effects [Petit-Demouliere et al., 2005]. These methods were supported by software like GraphPad Prism for statistical analysis, contributing to advancements in understanding depression-related behaviors.

We will examine these and other studies in more detail.

Detailed Overview of Research Studies:

1. Study: Behavioral Models of Rats in the Elevated Plus Maze (EPM) [de Andrade Costa and Tinos, 2014];

   Approach: Machine Learning;

   ModelsGoal/Hypothesis: Neurobiological studies of anxiety and defense in rodents; Method: Sensory inputs and memory-based modeling;

   Experimental Design: Utilized Elevated Plus Maze (EPM) to assess anxiety responses;

   Equipment: Elevated Plus Maze setup;

   Model/Algorithm: Artificial Neural Network (ANN) with evolving architecture, Elman Network;

   Animals: Real and virtual rats;

   Mathematical Apparatus: Markov Chains, Markov transition matrices, fitness functions, Gaussian mutations;

   Analysis: Genetic algorithms and Multilayer Perceptron (MLP) with a single hidden layer;

   Software: MATLAB, custom simulation environments;

   Logic: Understanding how sensory information and memory contribute to anxiety and defense mechanisms;

   Result: Insights into the role of sensory inputs and memory in rodent anxiety models;

2. Study: Zebra Finch Flight Path Selection [Borsier and Taylor, 2023];

   Approach: Intuitive Modeling;

   Goal/Hypothesis: To determine if zebra finches use brightness cues for navigation; Method: Recorded flight behavior under varying brightness conditions;

Experimental Design: A large enclosure with controlled lighting conditions; recorded 419 flight trajectories using 4k cameras;

Equipment: E2, Z-CAM, Shenzhen, China; 120 frames per second cameras;

Model/Algorithm: Statistical analysis with Wilson score confidence intervals (CIs), two-tailed Mann-Whitney U test;

Animals: 24 adult zebra finches;

Mathematical Apparatus: Wilson score confidence intervals;

Analysis: Comparison of flight trajectories under different lighting conditions;

Software: GraphPad Prism for statistical analysis;

Logic: Analyzing how visual cues influence spatial orientation and decision-making in birds;

Result: Zebra finches rely on brightness cues for gap selection in flight;

3. Study: Circuit-Based Model for Lymphatic System Simulation [Gajani, 2022];

   Approach: Analytical Models;

   Goal/Hypothesis: To model the lymphatic system using circuit analogies;

   Method: Simulation using equivalent circuit models, involving capacitors, resistors, and inductors;

   Experimental Design: Theoretical modeling of the lymphatic system's physiological behavior;

   Equipment: MATLAB and Verilog-A for circuit simulation;

   Model/Algorithm: Nonlinear Ordinary Differential Equations (ODEs);

   Animals: Not applicable;

Mathematical Apparatus: Young's equation, Puiseuille law, Reynolds number;

Analysis: Standard spice-like simulator netlists;

Software: MATLAB, standard spice-like languages;

Logic: Understanding lymphatic system behavior under normal and pathological conditions;

Result: Model successfully simulated lymphangion element oscillations consistent with real systems;

4. Study: Deep Learning for Social Interactions in Schooling Fish [Li et al., 2022];

   Approach: Deep Learning and Artificial Neural Networks (ANNs);

   Goal/Hypothesis: To understand social interactions in schooling fish;

   Method: Combining short- and long-term dynamic analysis using deep learning models;

   Experimental Design: Circular tank setup with 16-hour trajectory datasets;

   Equipment: Circular tank, idTracker, TrajNet++ framework;

   Model/Algorithm: D-MLP-ConC-LSTM neural network model;

   Animals: Hemigrammus rhodostomus, Zebrafish (Danio rerio);

   Mathematical Apparatus: Autocorrelation functions, Gaussian distribution;

   Analysis: Systematic methodology to test model results against experimental data;

   Software: MATLAB, idTracker, TrajNet++;

   Logic: Assessing the realism and predictability of deep learning models for social interactions;

Result: Provided insights into the dynamics of collective behavior and model validation against empirical observations;

5. Study: Behavioral Assessment in Rodents Using Elevated Plus Mazes and Holeboard Tests [Charoenpong et al., 2012];

   Approach: Clustering Techniques;

   Goal/Hypothesis: To measure behavioral parameters in rodents;

   Method: Background modeling using K-means clustering;

   Experimental Design: Elevated Plus Maze and Holeboard model setup; Logitech webcam above models;

   Equipment: Logitech webcam pro9000, Open-field test setups;

   Model/Algorithm: K-means clustering for background reconstruction;

   Animals: Male Wistar rats;

   Mathematical Apparatus: Euclidean distance for cluster analysis;

   Analysis: Feature extraction from reconstructed backgrounds;

   Software: OpenCV library;

   Logic: Automated measurement of behavioral parameters;

   Result: Improved precision and reduced variability in behavioral measurements;

6. Study: Forced Swim Test (FST) for Measuring Antidepressant Effects [Papaspyros et al., 2023];

   Approach: Analytical Models;

   Goal/Hypothesis: To measure the pharmacological effects of antidepressants and stress-induced behavior in laboratory animals;

Method: Developed an automatic system for quantifying behaviors in the Forced Swim Test;

Experimental Design: The rats are placed in a tank of water, and their immobility is measured as an indicator of depressive-like behavior;

Equipment: INCS1010 automatic recording system; cubic tank;

Model/Algorithm: Statistical methods;

Animals: Rats;

Mathematical Apparatus: Statistical methods for behavior classification;

Analysis: Measurement of distance and other behavioral parameters;

Software: GraphPad Prism;

Logic: Automatically capturing and analyzing swimming behavior to quantify antidepressant effects;

Result: Development of an automated system for evaluating depression-related behavior in animal models;

7. Study: Deep Learning Model for Social Interactions in Fish [Yuman et al., 2008];

   Approach: Deep Learning Interaction Models (DLI);

   Goal/Hypothesis: To create a deep learning model for predicting social interactions in schooling fish;

   Method: Use of Long Short-Term Memory (LSTM) networks and Multi-Layer Perceptron (MLP) for time correlation analysis;

   Experimental Design: Observation in a controlled aquatic environment;

   Equipment: TrajNet++ framework and idTracker;

   Model/Algorithm: LSTM and MLP structures;

   Animals: Hemigrammus rhodostomus, Zebrafish (Danio rerio);

Mathematical Apparatus: Probability distribution functions, velocity autocorrelation functions;

Analysis: Deep learning-based validation against empirical observations;

Software: MATLAB, TrajNet++;

Logic: Evaluating the model’s long-term predictive power for individual and collective behavior;

Result: Systematic methodology for validating predictive power across time scales and conditions;

8. Study: Behavioral Assessment of Psychoactive Drugs Using Open-Field Tests [Valletta et al., 2017];

   Approach: Data Mining Approach;

   Goal/Hypothesis: To classify different psychoactive drugs based on their behavioral profiles;

   Method: Open-field tests combined with Pattern Array (PA) analysis to identify behavioral patterns;

   Experimental Design: Animals were placed in a circular open-field arena;

   Equipment: Noldus EthoVision video-tracking system;

   Model/Algorithm: Pattern Array (PA) for data mining and behavioral pattern prediction;

   Animals: C57BL/6J male mice; total of 347 animals;

   Mathematical Apparatus: Linear mixed models, Bonferroni criterion, ANOVA;

   Analysis: Testing multiple hypotheses in parallel to predict drug classes;

   Software: S-PLUS 2000, Noldus EthoVision;

   Logic: Using behavioral patterns to predict experimental outcomes related to drug effects;

Result: Developed an efficient classification model for psychoactive drugs based on behavioral analysis;

9. Study: Hippocampal Place Cell Models for Spatial Memory Representation [Khunarsar et al., 2018];

   Approach: Simulated Experiments;

   Goal/Hypothesis: To develop a model for spatial location memory based on the hippocampal localization mechanism in rodents;

   Method: Simulation experiments using visual sensors and cognitive maps;

   Experimental Design: Virtual environment with spatial cues; agent exploration time set to specific intervals;

   Equipment: Visual sensors and MATLAB;

   Model/Algorithm: Radial Basis Function (RBF) networks; Gaussian distribution activation functions;

   Animals: Simulated rodents;

   Mathematical Apparatus: 2-dimensional Gaussian functions; supervised learning;

   Analysis: Supervised learning RBF neural network;

   Software: MATLAB R2020b;

   Logic: Exploring interactions between place cells and spatial environment information;

   Result: Successful integration of perception and behavior through place cell-based cognitive mapping;

10. Study: Depression Behavior Scorer (DBscorer) for Automated Phenotyping [Nandi et al., 2021];

Approach: Data Analysis and Machine Learning;

Goal/Hypothesis: To develop a rapid, automated tool for analyzing depression-related behavior in the Forced Swim Test (FST) and Tail Suspension Test (TST);

Method: Automated analysis using Depression Behavior Scorer (DBscorer) in MATLAB;

Experimental Design: Behavioral scoring of FST and TST trials;

Equipment: MATLAB App Designer, mobile cameras, and GraphPad Prism;

Model/Algorithm: Image-based detection and scoring algorithms;

Animals: Male mice, various strains;

Mathematical Apparatus: Scatter plots, Bland-Altman plots;

Analysis: Automated video-based analysis for rapid phenotyping;

Software: MATLAB, GraphPad Prism;

Logic: Accelerating and improving the accuracy of depression-related behavioral analysis;

Result: The tool demonstrated efficiency and accuracy for researchers studying depression and antidepressants in rodent models;

11. Study: Data Mining Approach for Classifying Psychoactive Drugs [Kafkafi et al., 2009];

    Approach: Data Mining Approach;

    Goal/Hypothesis: To classify a wide range of psychoactive drugs based on their psychopharmacological profiles using behavioral analysis;

    Method: Application of a data mining algorithm named Pattern Array (PA) to analyze rodent behavior patterns in response to psychoactive drugs;

Experimental Design: Animals were housed in standard conditions with a 12:12 light cycle and acclimated for at least 7 days before testing. Mice were injected with drugs and introduced to a 2.50 m diameter circular open-field arena for 60 minutes;

Equipment: 2.50 m diameter circular open-field arena; Noldus EthoVision video-tracking system (30 Hz, 480x640 resolution); SEE (Software for the Exploration of Exploration) with SEE Path Smoother procedure;

Model/Algorithm: Pattern Array (PA) Analysis, data mining algorithm for classifying drug effects;

Animals: 60- to 80-day-old C57BL/6J male mice (Jackson Laboratories), total of 347 animals;

Mathematical Apparatus: t-test, Bonferroni criterion, mixed-model ANOVA, linear mixed effects function for significance estimation, REML (restricted maximum likelihood) method;

Analysis: The study tested many different hypotheses in parallel to identify behavioral patterns that predict drug classes. The focus was on three major drug classes: psychomotor stimulants, opioids, and psychotomimetics;

Software: S-PLUS 2000 statistical software; Noldus EthoVision; SEE (Software for the Exploration of Exploration);

Logic: Developing a highly efficient classification scheme for psychoactive drugs based on behavioral patterns;

Result: Pattern Array (PA) successfully identified predictors for all three drug classes (psychomotor stimulants, opioids, psychotomimetics), providing a robust classification model;

12. Study: Ethanol and Cocaine Co-Abuse with GLP-1 Agonists [Kong et al., 2021];

Approach: Behavioral Pharmacology;

Goal/Hypothesis: To evaluate the effects of GLP-1 receptor agonists on ethanol and cocaine co-abuse in mice;

Method: Administered ethanol and cocaine to CD1 mice and evaluated with behavior tests;

Experimental Design: 12-hour light/dark cycle; water and food freely available; single-housed; intraperitoneal (IP) injection; recovery for 7-10 days;

Equipment: Engineered skin grafts (CRISPR/CAS9), microdialysis probes;

Model/Algorithm: Acute drug overdose test, Two-bottle choice test;

Animals: CD1 Mice (6-8 weeks old, 30-40g);

Mathematical Apparatus: Not specified;

Analysis: Shapiro-Wilk normality test, mixed-model ANOVA, Fisher's least significant difference test;

Software: Microsoft Excel, Prism, GraphPad;

Logic: Testing the behavioral impact of GLP-1 receptor agonists;

Result: Demonstrated significant differences in drug effects between ethanol and cocaine-treated groups;

13. Study: Pharmacological Agonism of GLP-1 Receptors in Alcohol Use Disorder (AUD) [Marty et al., 2020];

    Approach: Direct Pharmacological Agonism;

    Goal/Hypothesis: Investigate the potential of liraglutide and semaglutide in treating AUD;

    Method: Continuous access models; IP administration;

    Experimental Design: Rats housed individually under a 12-hour light/dark cycle;

Equipment: Not specified;

Model/Algorithm: Intermittent Access 2-Bottle Choice (IA2BC); body weight tracking;

Animals: Rats (M, 260-300g);

Mathematical Apparatus: Bonferroni criterion, ANOVA;

Analysis: ROUT method, RM ANOVA, Tukey’s post hoc tests;

Software: Prism 7, G*Power;

Logic: Assessing GLP-1 receptor agonists' effects in reducing alcohol intake;

Result: Showed significant reductions in alcohol consumption and body weight in treatment groups;

14. Study: Exendin-4 Impact on Alcohol-Induced Behavior in Mice and Rats [Vallöf et al., 2019];

Approach: Behavioral Neuroscience;

Goal/Hypothesis: To explore how Ex4 impacts alcohol intake and reward memory;

Method: Infusion of Ex4 into specific brain regions (NAc, VTA);

Experimental Design: Adult post-pubertal mice and rats in individually housed settings with reverse light/dark cycles;

Equipment: Locomotor boxes, brain sectioning apparatus;

Model/Algorithm: Two-bottle choice drinking paradigm, dose-response tests;

Animals: Mice and rats (8–12 weeks old);

Mathematical Apparatus: ANOVA, Pearson correlation;

Analysis: Bonferroni post-hoc tests, unpaired and paired t-tests;

Software: Not specified;

Logic: Understanding how Ex4 reduces alcohol-seeking behavior;

Result: Demonstrated that Ex4 reduces alcohol intake and modulates reward pathways

15. Study: Neuroprotective Effects of Twincretin in Traumatic Brain Injury [Tamargo et al., 2017];

Approach: Neuroprotective Pharmacology;

Goal/Hypothesis: To explore the neuroprotective effects of the synthetic dual GLP-1/GIP receptor agonist, "twincretin," in cell and mouse models of mild traumatic brain injury (mTBI);

Method: Administration of twincretin in clinically translatable doses to cell cultures and mouse models with induced mTBI;

Experimental Design: Mouse models of mild traumatic brain injury were used, focusing on closed head injury models to simulate mTBI conditions. Twincretin was administered to evaluate its effects on spatial and visual memory deficits;

Equipment: Not specified.

Model/Algorithm: Cell and mouse models to simulate mild traumatic brain injury;

Animals: Mouse models of mild TBI;

Mathematical Apparatus: Not specified;

Analysis: Behavioral and cellular analysis of TBI-induced impairments and their mitigation by twincretin;

Software: Not specified;

Logic: Investigating the potential of twincretin as a therapeutic agent for neurodegenerative disorders by evaluating its effects on TBI-induced neurodegeneration;

Result: Twincretin fully mitigated spatial and visual memory deficits induced by mild TBI in a mouse closed head injury model, suggesting its potential for further evaluation in neurodegenerative disorders;

16. Study: GLP-1RAs for Cardiovascular and Metabolic Disorders [Evans et al., 2022];

    Approach: Clinical Pharmacology;

    Goal/Hypothesis: Evaluate GLP-1RAs for their preventive roles in metabolic and cardiovascular diseases;

    Method: Administration of various GLP-1RAs in patients;

    Experimental Design: Patients with specific conditions like T2DM, obesity, cardiovascular disease;

    Equipment: Not specified;

    Model/Algorithm: Preventive treatment models;

    Animals: Not applicable (human patients);

    Mathematical Apparatus: Not specified;

    Analysis: Not specified;

    Software: Not specified;

    Logic: Testing GLP-1RAs efficacy in a preventive context;

    Result: Demonstrated efficacy in reducing major cardiovascular events and metabolic disorder symptoms;

17. Study: Effects of Liraglutide on Heroin Relapse in Rat Models [Urbanik et al., 2022];

    Approach: Experimental Pharmacology;

Goal/Hypothesis: To assess the effectiveness of GLP-1 receptor agonists, specifically liraglutide, in reducing relapse to heroin use in rats following cue-induced, drug-induced, or stress-induced scenarios;

Method: Self-administration of heroin in rats with a titration regimen of liraglutide to evaluate its effects on reducing heroin-seeking behaviors;

Experimental Design: Rats were individually housed in standard conditions (21°C) with a 12/12-hour light/dark cycle. Liraglutide was administered starting at a dose of 0.06 mg/kg and titrated up to 0.6 mg/kg over 11 days (5 days a week);

Equipment: Self-administration chambers for behavioral studies; equipment for measuring circulating glucose and insulin.Model/Algorithm: Self-administration of heroin and titration regimen for liraglutide;

Animals: Male rats, 90 days of age, weighing 300-400 g;

Mathematical Apparatus: ANOVA for statistical analysis;

Analysis: Evaluated reductions in heroin-seeking behavior in response to different doses of liraglutide;

Software: Not specified;

Logic: To investigate how different doses of liraglutide impact relapse rates in various heroin-seeking scenarios;

Result: Liraglutide titrated to a dose of 0.3 mg/kg was effective in reducing both cue-induced and drug-induced heroin seeking, demonstrating its potential as a therapeutic intervention for addiction;

18. Study: Exendin-4 in Stimulant Use Disorder Models [Zhu et al., 2022];

Approach: Behavioral Pharmacology;

Goal/Hypothesis: To test the effects of Ex4 on cocaine and amphetamine-induced behaviors;

Method: Conditioned place preference (CPP) and self-administration paradigms;

Experimental Design: Mice housed in groups under reverse light/dark cycles; Ex4 administration at varying doses;

Equipment: CPP apparatus, locomotor activity monitors;

Model/Algorithm: CPP and self-administration tests;

Animals: Male C57BL/6J mice (8-10 weeks old);

Mathematical Apparatus: Two-way repeated measures ANOVA;

Analysis: ANOVA with multiple comparisons tests;

Software: GraphPad Prism 8.4.0;

Logic: Investigating the inhibitory effects of Ex4 on stimulant-induced behaviors;

Result: Ex4 significantly inhibited cocaine and amphetamine-induced CPP and self-administration behaviors;

19. Study: Study: SKL-18287's Effects on Pancreatic Function in T2DM [Takeuchi et al., 2019];

Approach: Experimental Pharmacology;

Goal/Hypothesis: Determine SKL-18287's effectiveness in T2DM management;

Method: Dose-response studies in animal models;

Experimental Design: Testing on rats, monkeys, mini-pigs;

Equipment: Plasma concentration measurement tools, liquid scintillation counting;

Model/Algorithm: Not specified;

Animals: Rats, monkeys, mini-pigs;

Mathematical Apparatus: Not specified;

Analysis: Not specified;

Software: Not specified;

Logic: Evaluating a selective GLP-1 receptor agonist;

Result: Demonstrated efficacy in maintaining effective concentration for T2DM treatment;

Comparison of the studies and methodologies presented in studies 1 - 11 and 12 - 19, focusing on the use of modern tools versus classical approaches in psychopharmacology research. Comparison of Modern Tools (1 - 11) vs. Classical Approaches (12 - 19). Methodological Approaches on Modern Tools, studies 1 - 11 predominantly use advanced machine learning (ML) and artificial intelligence (AI) techniques, such as Artificial Neural Networks (ANNs), Deep Learning, and clustering algorithms. These methods enable the analysis of complex, high-dimensional data, allowing for more precise and automated behavioral assessments. For example, deep learning models were employed to study social interactions in fish, and clustering techniques were used to analyze rodent behavior in elevated plus mazes. Studies 12 - 19 use Classical Approaches, the studies rely more on traditional pharmacological and behavioral testing methods, such as the Forced Swim Test (FST), Tail Suspension Test (TST), and self-administration paradigms. These approaches are well-established in psychopharmacology and typically involve manual observation, scoring, and statistical analysis, such as ANOVA and t-tests. For example, conditioned place preference (CPP) paradigms and self-administration tests are used to study the effects of drugs like Exendin-4 on stimulant use disorder. Experimental Design on Modern Tools, the experimental designs in 1 - 11 often incorporate sophisticated data collection and analysis techniques, including real-time video tracking, image processing, and simulation models. These studies utilize equipment like 4k cameras, advanced tracking systems (e.g., idTracker, TrajNet++), and MATLAB-based simulations. For example, a circuit-based model was used to simulate lymphatic system behavior, leveraging nonlinear ordinary differential equations (ODEs) and spice-like simulation languages. Classical Approaches, in contrast, the designs in 12 - 19 are more traditional, focusing on established experimental setups such as the two-bottle choice test for alcohol preference or the CPP for drug conditioning. The equipment used is typically standard in behavioral pharmacology, such as CPP apparatuses, locomotor activity monitors, and self-administration chambers. The focus here is on understanding the effects of pharmacological agents on behavior using well-established protocols. Data Analysis and Software Modern Tools, data analysis in 1 - 11 is heavily reliant on computational tools and machine learning software. Advanced software like MATLAB, OpenCV, and custom simulation environments are used to handle complex datasets, enabling detailed analysis and modeling of behaviors. The use of AI allows for the automation of tasks that would otherwise be labor-intensive and time-consuming, such as the automatic quantification of behaviors in large datasets. Classical Approaches, the studies in 12 - 19 generally use more conventional statistical analysis methods. Tools like GraphPad Prism are employed for data analysis, focusing on standard statistical tests such as ANOVA, t-tests, and linear regression. The emphasis is on manually scoring behaviors and analyzing results using traditional statistical methods, which, while effective, are more prone to human error and require more time. Goals and Hypotheses on Modern Tools, the goals of studies in 1 - 11 are often oriented towards innovation and the development of new methodologies. For instance, these studies aim to advance the understanding of complex behaviors through the integration of AI and machine learning, leading to the discovery of new patterns and the development of predictive models. The hypotheses typically involve exploring how these modern techniques can improve the accuracy and efficiency of behavioral analysis. Classical Approaches, the goals in 12 - 19 are more focused on validating the effects of pharmacological agents on behavior using established methods. The hypotheses revolve around understanding the behavioral and physiological effects of drugs, often in the context of addiction, depression, or metabolic disorders. These studies are more confirmatory, aiming to replicate and extend existing knowledge in psychopharmacology. Results and Implications on Modern Tools, the results from 1 - 11 demonstrate the power of modern tools in providing more detailed, accurate, and scalable behavioral analyses. These studies have shown that AI and ML can outperform traditional methods in terms of precision, adaptability, and the ability to handle complex, high-dimensional data. The implications suggest a shift towards integrating these modern tools into mainstream research, potentially leading to new discoveries and improved methodologies in behavioral neuroscience. Classical Approaches, the results in 12 - 19 continue to support the reliability and validity of classical m ethods in psychopharmacology. These studies confirm the effects of various pharmacological agents on behavior and provide important insights into the mechanisms of action of drugs. The implications reinforce the importance of these traditional methods as the gold standard in psychopharmacological research, while also highlighting areas where modern tools could complement or enhance these approaches. The studies in 1 - 11 showcase the potential of modern AI and machine learning techniques to revolutionize behavioral research, offering enhanced precision, automation, and the ability to handle large datasets. On the other hand, the studies in 12 - 19 exemplify the enduring value of classical approaches in psychopharmacology, emphasizing well-established, reliable methods for studying drug effects on behavior.While the modern tools bring new capabilities and efficiencies, the classical approaches remain essential for their robustness and established validity in the field. Future research could benefit from combining these modern and classical methods, leveraging the strengths of both to advance the understanding of complex behavioral phenomena.

Market of Research Tools

In recent decades, scientific research in behavioral studies, neuroscience, and animal research has advanced significantly thanks to technological innovations and the development of new tools. The market for these tools includes a wide range of products and services provided by leading companies, helping researchers worldwide to conduct more precise and efficient studies. This section presents an overview of the key market players and their contributions to the development of research technologies, as well as an analysis of current trends and future directions **Table 1**.

Table 1. The companies, categories of products and services

Category	Companies
Behavior Research Equipment	Noldus Information Technology, Ugo Basile, Panlab, Harvard Apparatus, Med Associates Inc., Columbus Instruments, Stoelting Co., Univentor, Inside Scientific, ConductsSience, PsychoGenics Inc., Hugo Sachs Elektronik, Zantiks Ltd., ViewPoint Behavior Technology, Striatech, Stoelting Co., ScienceBeam, Sable Systems International Inc., Omnitech Electronics, Neurotar, LabMaker, Amuza Inc
Neuroscience Research Equipment	ADInstruments, Diagnostic Biochips, BASi (Bioanalytical Systems, Inc.), Plexon Inc., World Precision Instruments (WPI), NeuroNexus, Harvard Bioscience, Inside Scientific, Kopf Instruments, ASI Instruments, SBM, ConductsSience, PsychoGenics Inc., Hugo Sachs Elektronik, KD Scientific, Multi Channel Systems MCS GmbH, Kaha Sciences, ViewPoint Behavior Technology, Striatech, Stoelting Co., ScienceBeam, Sable Systems International Inc., Omnitech Electronics, Neurotar, LabMaker, UID Identification Solutions, MBF Bioscience, Amuza Inc, Data Sciences International (DSI), Epitel, Etisense, Medres

Animal Research Equipment	Charles River, Envigo, RWD Life Science, Kent Scientific Corporation, Lab Products Inc., Taconic Biosciences, Jackson Laboratory, Harlan Laboratories, Gelman Laminar Air Flow Systems, NuAire, RWD Life Science Co. Ltd., ASI Instruments, BARIA s.r.o., Hugo Sachs Elektronik, Kaha Sciences, Tecniplast S.p.A., Stoelting Co., ScienceBeam, Sable Systems International Inc., UID Identification Solutions, Amuza Inc, Data Sciences International (DSI), Etisense, Medres
Digital research platform/Education platform	Scienttist.com, ADInstruments, SBM, ConductsSience, PsychoGenics Inc., Striatech, Neurotar, LabMaker, Kent Scientific Corporation, UID Identification Solutions, Inotiv, MBF Bioscience, Amuza Inc, Data Sciences International (DSI), Etisense, Medres
SPF (Specific Pathogen Free) laboratory animals/Animal research models	Charles River, PsychoGenics Inc., CLEA Japan, Inc., Vivo Bio Tech Ltd., Prima Nexus, Inotiv

Behavior Research Equipment Providers. Companies developing equipment for behavioral research focus on creating automated systems for analyzing behavioral patterns in animals. For example, Univentor offers injectors and dispensers for automating studies, Ugo Basile develops equipment for studying pain and depression, Panlab provides video monitoring and analysis systems, and Noldus releases software solutions for behavioral analysis, such as EthoVision XT and The Observer XT.

Neuroscience Research Equipment Providers. In neuroscience, companies offer a wide range of tools for studying brain and nervous system functions. ADInstruments is known for its systems for recording neurophysiological data, including EEG, Diagnostic Biochips provides multi-channel recording equipment, and BASi specializes in microdialysis and neurochemical analyzers.

Animal Research Equipment Providers. Companies involved in animal research equipment development offer both surgical equipment and laboratory models. Charles River and Envigo provide laboratory animals and care products, RWD Life Science specializes in surgical equipment and anesthesia, and Kent Scientific Corporation produces equipment for monitoring the physiological parameters of laboratory animals.

Leading Companies and Their Innovations. Several companies stand out with their innovative solutions and significant contributions to the field. Noldus Information Technology has developed behavior analysis software that has become a standard for researchers. Their product EthoVision XT allows researchers to study animal behavior through video tracking and movement trajectory analysis. ADInstruments offers comprehensive solutions for recording and analyzing neurophysiological data, while Charles River and Envigo remain leaders in supplying laboratory animals and care products.

Current Market Trends and Future Directions. The current market shows several trends, such as the increasing demand for automated systems and the use of artificial intelligence for data analysis. Companies like Noldus and ADInstruments have already started integrating AI and machine learning into their platforms for big data analysis and behavioral pattern prediction. Additionally, there is a growing interest in using digital twins and platforms for behavior modeling.

In a rapidly evolving technological landscape, companies working in behavioral research, neuroscience, and animal research must consider new trends, such as automation, machine learning, and digital platforms. Collaboration between the academic and commercial sectors will also become an important aspect for future research and innovation.

Discussion

The data presented in this study offers a detailed overview of the current landscape in behavioral research, neuroscience, and animal research tools. By analyzing the market players across three key categories - behavioral research equipment, neuroscience tools, and animal research products - we gain valuable insights into the various technologies and methodologies driving progress in these fields. Companies such as Noldus, Panlab, and ADInstruments have emerged as leaders by integrating digital platforms and AI-driven solutions into their products, enabling more sophisticated data analysis and improving the accuracy of behavioral studies.

A notable trend observed in the market is the increasing shift towards automation and the use of machine learning algorithms for data analysis, as seen with products from Diagnostic Biochips and TrajNet++. These advancements are particularly significant in neuroscience research, where understanding complex neural mechanisms requires high precision and scalability. Meanwhile, traditional approaches, such as those using basic physiological monitoring tools and classical behavioral paradigms like the Forced Swim Test (FST) and Conditioned Place Preference (CPP), continue to hold relevance, particularly in pharmacological studies. The data highlights the strengths and limitations of both modern and classical methodologies, suggesting that a hybrid approach may offer the most comprehensive results.

Moreover, the analysis of market players shows a strong trend towards collaborative efforts between academia and industry. This synergy is crucial for developing next-generation research tools that are both innovative and applicable to real-world challenges. By adopting a multidisciplinary approach, companies can better meet the evolving needs of researchers while fostering a competitive market environment.

Conclusion

This study provides a comprehensive analysis of the tools, methodologies, and market dynamics within behavioral research, neuroscience, and animal research. The data-driven approach used here emphasizes the importance of modern tools and digital platforms, which are transforming the way research is conducted. While traditional methods remain valuable, the integration of AI, machine learning, and automation is rapidly changing the landscape, offering new opportunities for precision and innovation. The key and decisive point in favor of using artificial intelligence and machine learning algorithms is the reduction in research time and the reduction in the number of laboratory animals involved in the study. Adhering to the principles of 3R (Reduce, Refine and Replace) animal experimentation this is the basis humane and animal welfare.

The findings suggest that future advancements will likely depend on the continued collaboration between researchers, industry professionals, and technology developers. By leveraging both modern and classical techniques, the field can achieve a more nuanced understanding of behavior, brain function, and pharmacological effects, ultimately contributing to better scientific outcomes and applications. This paper serves as a resource for researchers and stakeholders aiming to navigate the evolving market of behavioral and neuroscience research tools.

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