Title: Design and Construction of a Low-Cost and Repairable Operant Chamber for Rat Gambling Task

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To appear in: **Basic and Clinical Neuroscience**

Received date: 2026/05/09

Revised date: 2026/07/01

Accepted date: 2026/07/13

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Please cite this article as:

Ghasemi, E., Heidari, N., Azizi, H., Semnanian, S. (In Press). Design and Construction of a Low-Cost and Repairable Operant Chamber for Rat Gambling Task. Basic and Clinical Neuroscience. Just Accepted publication Jul. 10, 2026. Doi: http://dx.doi.org/10.32598/bcn.2026.6125.4

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Abstract

Introduction: Decision-making in animal models is important in behavioral neuroscience. Animal versions of the Iowa Gambling Task (IGT) are useful for studying choice under uncertainty and the conflict between immediate reward and long-term outcome. Accurate implementation of such paradigms requires controlled behavioral systems. However, commercial systems are often expensive and depend on specialized parts. In addition, they usually offer limited repairability and flexibility. Therefore, this technical/methodological study aimed to design, construct, and functionally validate a low-cost, repairable, and locally constructible five-choice operant platform for the rat gambling task (rGT) as a representative decision-making paradigm, with potential adaptability to other five-choice-based behavioral tasks and compatibility with simultaneous electrophysiological recording.

Methods: Based on a five-choice design, a custom operant chamber was developed. The system included LED- and infrared-equipped nose-poke holes, a reward magazine, an automatic pellet dispenser, a control unit, and a user-friendly MATLAB-based control interface. A rotary tether system was also designed for simultaneous LFP recording in freely moving animals. Behavioral events were synchronized with electrophysiological data by sending event markers from the microcontroller to the recording system. System performance was evaluated in male Wistar rats during a 60-minute rGT session by examining task execution, reward delivery, behavioral response recording, and synchronization of behavioral events with electrophysiological signals.

Results: The designed system allowed stable and accurate execution of the rGT, automatic recording of behavioral responses, controlled reward delivery, and temporal synchronization of behavioral data with electrophysiological signals. Behaviorally, animals showed a gradual increase in the percentage of advantageous choices during the session, suggesting within-session improvement in task performance. At the same time, clear inter-individual differences in performance were observed, with some animals reaching high levels of advantageous choice whereas others remained near chance level or showed low levels of advantageous choice by the end of the session. In addition, representative recordings showed that behavioral event markers could be precisely aligned with LFP signals.

Conclusion: The present system can be used as a practical, low-cost, repairable, and expandable alternative to commercial systems for performing the rat gambling task. In addition, its modular and flexible design allows adaptation for other five-choice-based behavioral paradigms and for combined behavioral and electrophysiological studies.

Keywords: Decision-making, rat gambling task, operant chamber, five-choice, low-cost system, electrophysiology

Plain Language Summary

Making good decisions often involves choosing between a small immediate reward and a better long-term outcome. This process is studied in animals in order to better understand how the brain controls choice behavior. One common laboratory task used for this purpose is the rat gambling task, which is similar in concept to the Iowa Gambling Task used in humans. However, this type of experiment usually requires expensive commercial equipment that may be difficult to repair, modify, or replace.

In this study, a low-cost operant chamber was designed and built for performing the rat gambling task in rats. The system was based on a five-choice design and included response holes with lights and sensors, a food reward magazine, an automatic pellet delivery unit, a microcontroller-based control system, and a MATLAB-based control interface. A rotary tether system was also added so that brain signals could be recorded at the same time without greatly disturbing the animal's movement.

The results showed that the system worked reliably. Stable task performance, automatic detection of behavioral responses, controlled reward delivery, and synchronization between behavioral events and recorded brain signals were achieved. The behavioral results also showed that the majority of rats improved their choices during the session, while clear differences between animals were still present.

These findings suggest that the designed system can be used as a practical and repairable alternative to expensive commercial setups. Decision-making is a complex process, and studying behavior alone may not be enough to fully understand how choices are made. By allowing simultaneous recording of behavior and brain signals, the system may help decision-making to be studied from more than one perspective and may support more direct investigation of the link between neural activity and choice behavior. In addition, the platform is flexible and may also be adapted for other behavioral tasks based on a similar five-choice structure. This kind of system may help more laboratories perform behavioral and electrophysiological research with lower cost and greater independence.

Highlights:

A low-cost five-choice operant chamber was developed.

The system enabled stable rGT performance and automated reward delivery.

Behavioral events were synchronized with LFP recordings with precise temporal alignment.

The platform detected learning trends and individual differences in choice.

Introduction

Decision-making is an important topic in behavioral neuroscience and has been widely studied in relation to reward, risk, and cognitive control (Bechara, 2003; Kable & Glimcher, 2009). Animal models, especially rodent models, provide a useful framework for studying choice behavior and its underlying mechanisms under controlled experimental conditions (Juavinett et al., 2018; Zeeb et al., 2009). In many situations, optimal performance requires balancing immediate reward against long-term outcome. Therefore, tasks that model this conflict are useful tools for studying decision-making under controlled laboratory conditions (Padoa-Schioppa, 2011; Rangel et al., 2008; Sanfey et al., 2006).

Choice- and reward-based tasks, including animal versions of the Iowa Gambling Task (IGT), are important tools for assessing decision-making under uncertainty (Bechara et al., 1994; de Visser et al., 2011; Zeeb et al., 2009). These paradigms model the conflict between immediate reward and long-term outcome and require simultaneous evaluation of reward probability, reward magnitude, and the cost of each choice (Bechara et al., 1994; de Visser et al., 2011). In rodent versions of these tasks, animals choose among options associated with different patterns of reward and punishment, making it possible to assess behavioral preference under controlled experimental conditions (de Visser et al., 2011; Rivalan et al., 2009; Zeeb et al., 2009). Such paradigms may also reveal inter-individual differences in performance, which can be useful for evaluating both behavioral variability and the functional output of the task system (de Visser et al., 2011; Rivalan et al., 2009).

Accurate implementation of such tasks requires controlled behavioral systems that can manage stimulus presentation, response detection, and reward delivery with appropriate timing (Bari et al., 2008; Morais Gancz et al., 2022). In this context, operant chambers are standard tools that allow automated stimulus control, recording of behavioral responses through infrared sensors, and precise reward delivery (Bari et al., 2008). They are widely used in the design and implementation of complex behavioral paradigms (Bari et al., 2008; Morais Gancz et al., 2022). In many operant versions of the rat gambling task (rGT), the basic system includes an array of response holes equipped with stimulus lights and infrared sensors, a food tray or magazine on the opposite wall, and a pellet dispenser for reward delivery (Morais Gancz et al., 2022; Zeeb et al., 2009). This design makes it possible to record nose-poke responses accurately and to control the outcome of each choice automatically (Zeeb et al., 2009). In some models, even four-hole operant chambers adapted from five-choice systems have been used to implement the conflict between higher immediate reward and better long-term outcome with high precision (de Visser et al., 2011; Rivalan et al., 2009).

However, commercial systems currently used for these experiments, such as Med Associates systems, often rely on fixed hardware and software structures, which may limit task modification and access to detailed behavioral output data (Hrelja et al., 2025; Morais Gancz et al., 2022). In addition, acquisition and maintenance of such systems can be difficult for many laboratories, particularly in resource-limited settings.

These limitations become more serious in laboratories with limited access to financial resources and specialized equipment. Under such conditions, dependence on commercial systems may interrupt experimental research and make the development of low-cost, repairable, and locally buildable solutions necessary.

Rodent behavioral systems that are flexible, technically accessible, and compatible with neural signal recording can expand the range of preclinical studies in decision-making and related paradigms (de Visser et al., 2011; Pais-Vieira et al., 2007; van den Bos et al., 2006). For this reason, development of locally buildable laboratory systems may help expand preclinical decision-making research (de Visser et al., 2011; van den Bos et al., 2006; Zeeb et al., 2009).

Despite this need, only limited reports are available on the design of integrated, low-cost, and repairable systems that can support both behavioral task execution and compatibility with neural signal recording. Although some efforts have been made to develop open-source and customizable behavioral systems, these platforms have mainly focused on the behavioral part of the setup and have emphasized trial design flexibility, stimulus structure, and hardware control (Morais Gancz et al., 2022). Therefore, there is still a need for low-cost, repairable systems that can also be practically integrated with simultaneous electrophysiological recording.

In the present study, we aimed to develop a technical/methodological platform for implementing the rGT as a representative five-choice-based decision-making paradigm. The primary goal was not to test a mechanistic hypothesis about decision-making or neural activity, but to design, construct, and functionally validate a low-cost, repairable, and locally constructible operant platform that can support controlled task execution, automated behavioral response detection, reward delivery, and synchronization of behavioral events with simultaneous LFP recording.

The system was developed with emphasis on repairability, reduced dependence on imported equipment, and the use of accessible components. Although the platform was validated here using the rGT, its modular hardware design and MATLAB-based task logic allow adaptation to other behavioral paradigms based on a similar five-choice structure. In this framework, the behavioral and electrophysiological data presented in this study are intended as functional validation of the platform rather than as a full mechanistic analysis of decision-making or event-related neural dynamics.

Materials and Methods

Animals

Ten adults male Wistar rats weighing 200–250 g at the beginning of the study were used. Animals were pair-housed under standard environmental conditions (22 ± 2 °C, 50 ± 5% humidity) on a reverse 12:12 h light/dark cycle, with lights on at 7:00 PM. Three days before the start of training, animals were food-restricted and maintained at 85% of their free-feeding weight. During training and task performance, they received 10 g of standard chow per day in addition to the chocolate pellets earned in the task (approximately 5 g/day). Each reward pellet weighed approximately 45 mg (Hales et al., 2025). All procedures were carried out in accordance with ethical guidelines for the use of laboratory animals and were approved by the Ethics Committee of Tarbiat Modares University (ir.modares.aec.1403.050).

System Overview

The system designed in this study consisted of a custom behavioral chamber (operant chamber), a microcontroller-based electronic control unit, a user-friendly control interface written in MATLAB, with adjustable parameters for training and the main task, an automatic pellet delivery system, and a rotary/tether-based mechanical interface for simultaneous electrophysiological recording. The system was designed to allow accurate implementation of five-choice-based behavioral paradigms while also being compatible with electrophysiological recording systems. In this study, local field potential (LFP) signals were recorded during task performance. To reduce electromagnetic noise, the recording system was placed inside a lightweight Faraday cage. An overview of the behavioral chamber and its main components is shown in Figure 1.

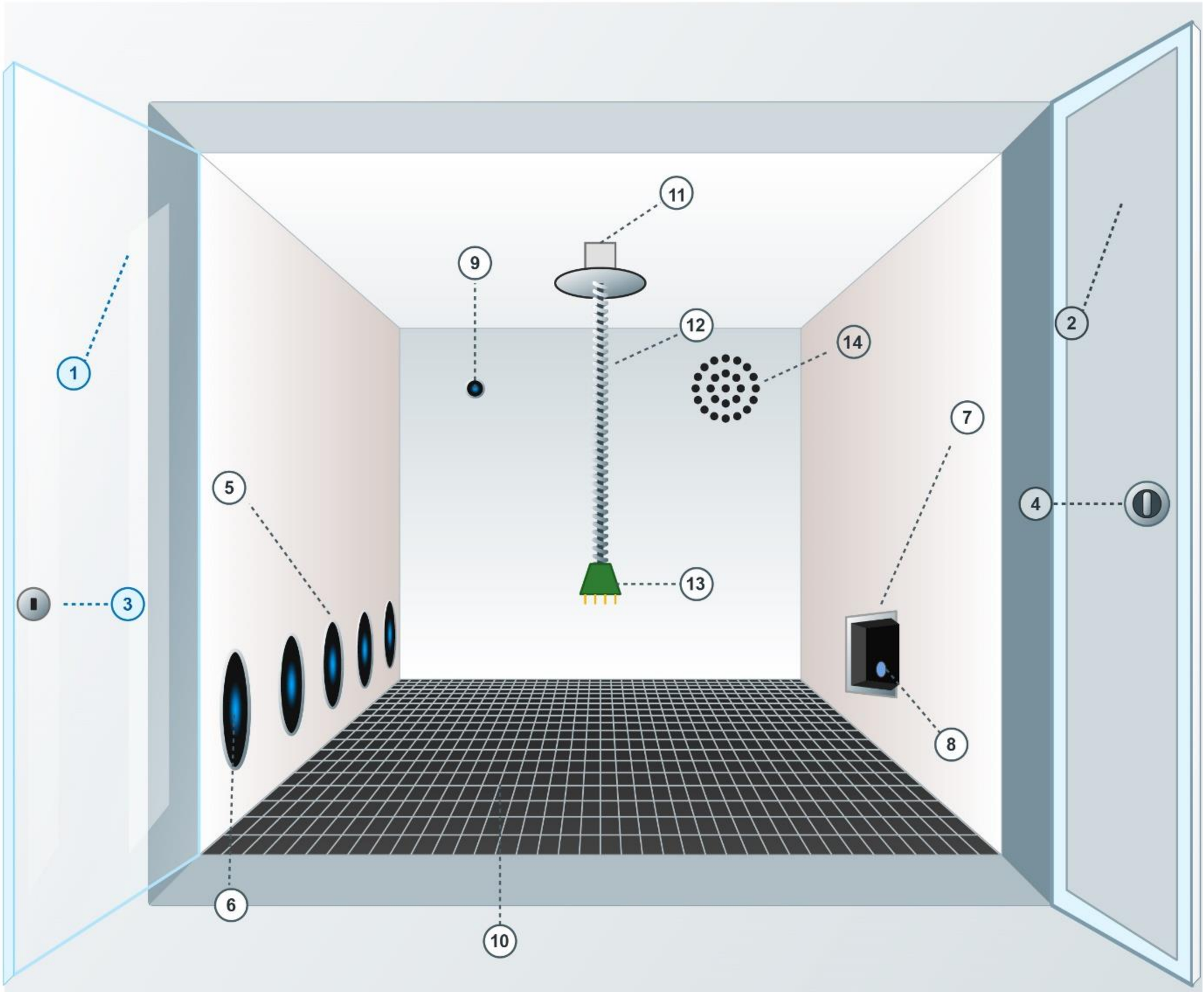

Figure 1. General structure of the five-choice operant chamber developed in this study. This figure shows a schematic view of the custom behavioral chamber used for five-choice-based paradigms. The main parts include the inner glass door (1), outer PVC door (2), locks for the inner and outer doors (3 and 4), nose-poke hole (5), hole LED (6), reward collection magazine (7), magazine LED (8), house light (9), grid floor (10), 12-circuit electrical slip ring/swivel (11), protective spring around the tether cable (12), connection port (13), and fan (14).

Behavioral Chamber Design

The behavioral chamber used in this study was custom-designed and built with dimensions of 30 × 30 × 30 cm. It was developed to support behavioral paradigms based on a five-choice structure. The chamber was built as a polyvinyl chloride (PVC) box with a wall thickness of 16 mm, which provided mechanical stability and allowed control of the internal environment. An inner glass door with a thickness of 4 mm was also incorporated to allow observation of the animal and controlled access to the chamber, as shown in Figure 1. Five nose-poke holes, each with a diameter of 2.5 cm and a center-to-center distance of 5 cm, were arranged horizontally on one wall of the chamber. The inner surfaces of the holes were lined with stainless steel. Each hole was equipped with an infrared (IR) sensor for response detection and a blue light-emitting diode (LED, 2 W) for visual stimulus presentation. The IR sensor was placed 1 cm behind the entrance of each hole.

On the opposite wall, a stainless-steel reward collection magazine measuring 2.5 × 2 cm was placed. Food rewards (pellets) were delivered to this magazine by an external pellet delivery system. The magazine had its own blue LED (2 W) to indicate reward delivery and an additional IR sensor placed 1 cm behind the magazine entrance to record the time of reward collection. The floor was made as a stainless-steel grid to facilitate cleaning and reduce accumulation of waste. In addition, to protect the connection cables and reduce damage caused by pulling or chewing by the animal, a protective system including a spring and an electrical swivel was installed above the chamber. This allowed the animal to move freely. A white LED (3 W) was used as the house light to provide general illumination during task operation. A fan was also built into the chamber body to improve ventilation and reduce heat accumulation. The chamber was also equipped with a door locking mechanism for safety and controlled access.

Electronic Control System

Behavioral control in this study was performed using an Arduino microcontroller board. The board was connected to a computer through a serial USB port, and all commands and data exchange between the MATLAB-based control interface and the hardware components were carried out through this connection. Communication between MATLAB and the microcontroller was established using the MATLAB Support Package for Arduino Hardware, which enabled stable interaction between the MATLAB-based control interface and the microcontroller.

The IR sensors in the nose-poke holes and reward magazine were directly connected to designated input pins of the microcontroller and were used to record behavioral responses. The LEDs of the holes, reward magazine, and house light were controlled through output pins. The task logic was implemented in MATLAB, and commands were sent to the microcontroller through this MATLAB–Arduino communication framework for stimulus presentation, response recording, and reward delivery.

For reward delivery, pulse and direction signals were sent from the microcontroller output pins to the motor driver. This triggered controlled rotation of the stepper motor in the pellet delivery system and delivered one reward pellet to the magazine. This structure also allowed accurate recording of behavioral event timing and synchronization with the electrophysiological recording system. To improve reproducibility and clarify the technical structure of the system, the main electronic, control, recording, and synchronization specifications are summarized in

Tables 1 and 2. The general connections between system components and signal pathways are shown in Figure 2.

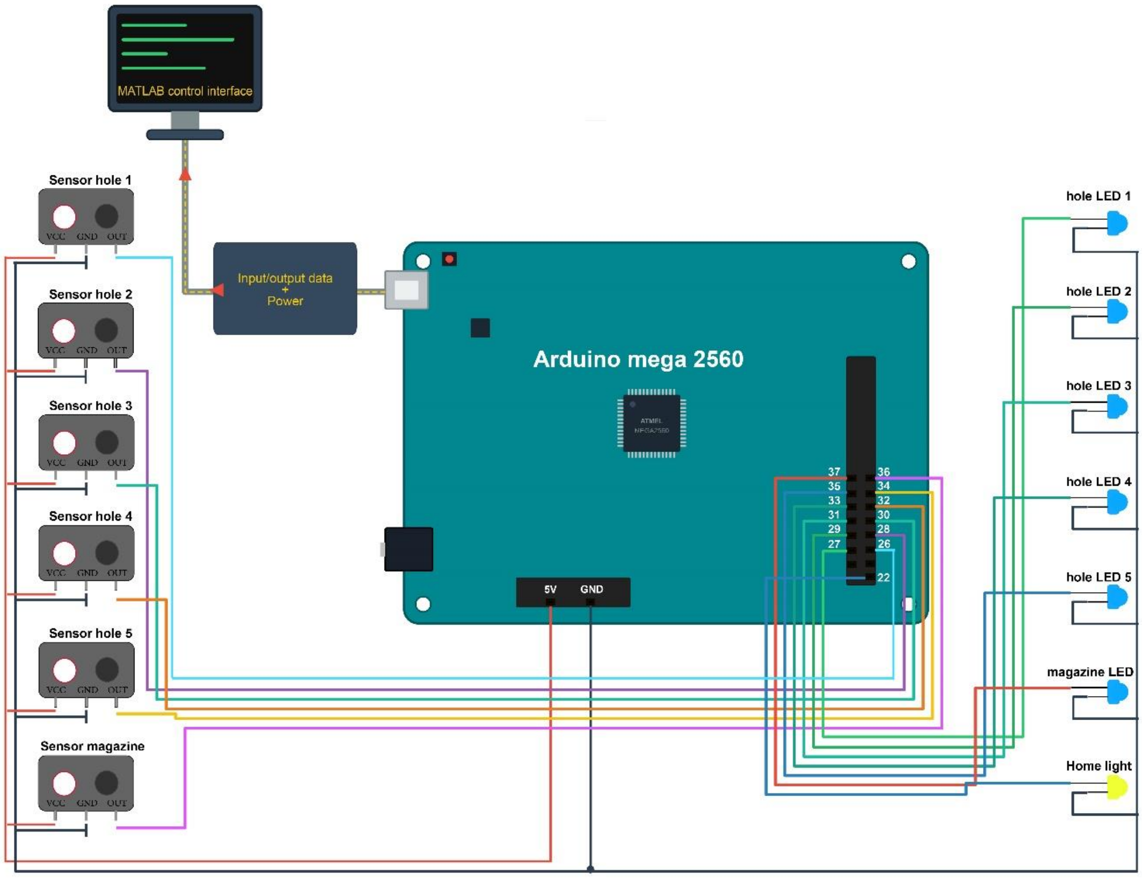

Figure 2. Schematic of the microcontroller-based electronic control system. This figure shows the electronic connections in the behavioral system. Infrared sensors from the nose-poke holes and reward magazine are connected to the input pins of the microcontroller. LEDs are controlled by output pins for visual stimulus presentation. The microcontroller communicates with the computer through a serial connection and receives task commands from a MATLAB-based control interface. A separate output is also used to activate the reward delivery system by sending the command for motor rotation and pellet delivery. Detailed pin assignments are provided in Table 2.

Table 1. Main technical specifications of the electronic control, reward delivery, and synchronization system**.**

System component	**Technical specification**	**Role in the system**
Control board	Arduino Mega 2560	Microcontroller for sensor input, LED control, reward delivery, and event-marker output
Task-control software	Custom MATLAB-based interface developed in MATLAB R2020a; Arduino communication through MATLAB Support Package for Arduino Hardware	Implements task logic and communicates with the microcontroller
IR sensors	LM393-based reflective infrared obstacle-avoidance sensor modules; 3.6-5 V DC; adjustable detection range approximately 1-10 cm	Detect nose-poke responses and magazine entries
Visual stimuli	Blue LEDs, 2 W, for nose-poke holes and magazine; white LED, 3 W, for house light	Provide hole cues, reward/magazine cue, and general chamber illumination
Reward motor	Stepper motor powered by a 12 V DC, 2 A adapter	Rotates the pellet-delivery disk
Motor driver	TB6600 stepper motor driver; supply range 9-42 V DC; operated with a 12 V DC adapter in this system	Controls motor pulse and direction for pellet delivery
Rotary interface	SRC012A-12, 12-circuit electrical slip ring	Allows cable rotation and reduces tether twisting during recording
Recording system	16-channel electrophysiological recording system with external event-marker input and LFP recording capability	Used for simultaneous LFP recording during validation
Event synchronization	Microcontroller-generated duration-coded square-wave event markers recorded together with the LFP data	Allows behavioral events to be aligned with LFP recordings

Table 2. Arduino pin assignments used in the behavioral control system.

Component	Arduino pin	Signal type / notes
Sensor hole 1	26	Digital input
LED hole 1	27	Digital output
Sensor hole 2	28	Digital input
LED hole 2	29	Digital output
Sensor hole 3	30	Digital input; central-hole response
LED hole 3	31	Digital output; unused in current rGT
Sensor hole 4	32	Digital input
LED hole 4	33	Digital output
Sensor hole 5	34	Digital input
LED hole 5	35	Digital output
Magazine sensor	36	Digital input
Magazine LED	37	Digital output
House light LED	22	Digital output
Motor PUL+	45	Motor pulse output
Motor DIR+	44	Motor direction output
VCC	Shared	Shared power line
GND	Shared	Common ground

Reward Delivery System

A custom pellet delivery system was designed to provide accurate and reliable food reward delivery (Figure 3). The system includes a cylindrical PVC pellet reservoir and a rotating plexiglass disk with a thickness of 3 mm. The rotating disk contains eight equally spaced holes, each with a diameter of 3 mm, for holding pellets. The disk is connected to a stepper motor through a mechanical coupling, and no custom shaft is used in the assembly. Motor movement is controlled by the stepper motor driver. Although this driver supports a 9–42 V DC supply range, it is operated with a 12 V DC adapter in the present system. This driver allows precise adjustment of rotation angle and therefore single-pellet delivery in each activation. When the control unit sends a command, the disk rotates by a defined amount and one pellet-containing hole is placed in the output path. The pellet is then guided through a silicone tube into the reward magazine. The mechanism is designed to minimize pellet jamming and to maintain stable performance during behavioral sessions. Its modular structure also makes repair and replacement of parts easier.

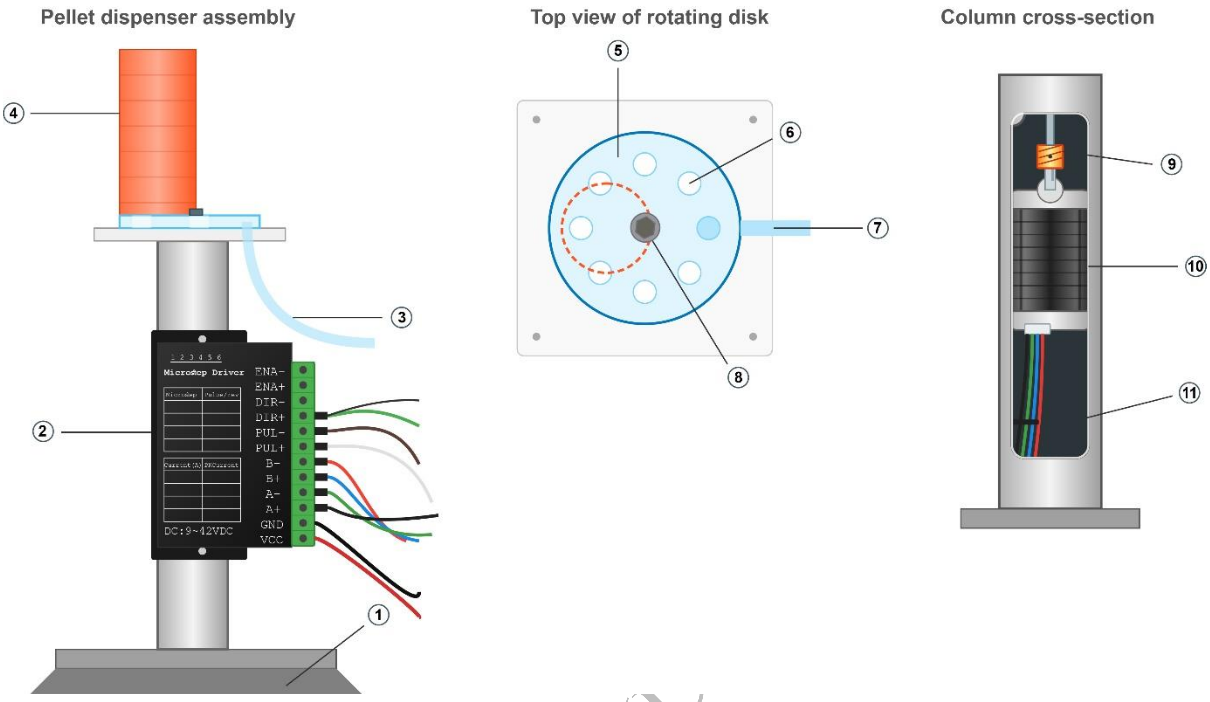

Figure 3. Schematic of the pellet delivery system. This figure shows the pellet delivery system, including the support base (1), TB6600 stepper motor driver (2), pellet transfer tubes to the reward magazine (3 and 7), cylindrical pellet reservoir (4), rotating disk (5), regularly arranged pellet holes (6), disk-to-base connection point (8), coupling between the motor shaft and the disk shaft (9), stepper motor (10), and motor wires and cables (11). This structure allows precise single-pellet delivery to the reward magazine.

Behavioral Task Design (rGT)

The rodent version of the Iowa Gambling Task (rGT) is used to evaluate decision-making behavior (Rivalan et al., 2009). During the habituation phase, animals first receive food pellets in their home cage to become familiar with the reward. Then, for magazine training, 60 sucrose pellets are delivered one by one into the reward magazine at random intervals ranging from 1 to 30 s.

In the initial training stage, animals are placed in free-choice sessions in which all holes are active and a response in any hole can be rewarded. Each session lasts 30 min or until the animal receives 100 pellets. After this, forced-choice sessions are conducted. In these sessions, only one hole is active at a time, and reward can be obtained only by responding in that hole. This stage is used to reduce the development of bias toward a specific hole. Then, two additional free-choice sessions are performed, in which reward magnitude is increased in the second half of the session. This is done to expose the animals to different reward values and to identify any side preference before the main task. This training order was used to gradually shape task-related behavior before exposure to the final rGT contingencies. Progression through training required stable task engagement, including reliable magazine entry, repeated nose-poke responding to illuminated holes, and completion of the scheduled session or reward limit.

In the present rGT configuration, four holes remain active, each with a specific reward-punishment schedule. The central hole is not assigned to an active reward–punishment option, but its sensor remains active throughout the task to record center-hole responses. The corresponding LED is retained in the hardware design for compatibility with other five-choice-based behavioral paradigms. Two holes are defined as advantageous options. These deliver a smaller reward (one pellet) but are associated with shorter time-out penalties of 6 or 12 s and probabilities of 0.5 and 0.25, respectively. The other two holes are disadvantageous options. These deliver a larger reward (two pellets) but are associated with much longer time-out penalties of 222 or 444 s with the same probabilities. The probability assigned to each hole remains fixed throughout the session. After each choice, the LED inside the selected hole remains illuminated to indicate which response has led to the subsequent outcome. During time-out periods, the general chamber lights are turned off and the system is functionally inactive. Nose-poke responses made during this period can still be detected, but have no programmed consequence. After the end of the time-out, the house light is turned on for a 1-s interval, signaling the upcoming start of the next trial.

In each session, the animal chooses between options that differ in immediate reward and long-term outcome. Each main session lasts 60 minute or until the animal receives 250 pellets. To control for side bias, the positions of advantageous and disadvantageous holes are assigned for each animal based on the side preference observed during the final free-choice sessions. This task structure allows evaluation of preference between options with higher immediate reward and options with better long-term return (Cocker et al., 2020; Daniel et al., 2017).

Rotary/Tether System for Simultaneous Recording

To allow simultaneous electrophysiological recording during behavioral testing while preserving free movement of the animal, a rotary/tether system was designed and implemented. In this system, the recording cable was connected to the recording device through the slip ring installed above the chamber. This swivel allowed free cable rotation and prevented cable twisting during animal movement. To protect the cable and reduce mechanical tension, a custom spring structure with an overall diameter of 3 mm was placed around the cable. This spring increased flexibility, reduced pulling force at the connection point, and prevented chewing by the animal. Because the cable and connector were suspended from the swivel, little mechanical load was applied to the animal during movement. The cable was connected to the animal through a lightweight connector. The female part of the connector was fixed on the animal's head, and the male part was connected to the recording cable. The design of this interface provided a stable connection while causing minimal disturbance to the animal's normal movement. The size and weight of the swivel, cable, spring, and connector were selected to avoid restricting normal behavior, including nose-poke responses. To habituate the animals to this system, the connector was connected to the animal's head during the 2 days before the main test and during training sessions, while the recording system remained off.

Electrophysiological Recording System

In the validation experiments, LFP signals were recorded using a 16-channel electrophysiological recording system (Resana Research Instruments, Tehran, Iran). The system included a PA10 preamplifier with a 10× preamplifier gain and up to 1000× main-system amplification. The acquisition system supported sampling rates up to 40 kHz. In the present study, three LFP channels were recorded during task performance. The animal was connected to the recording system through the rotary/tether system, which allowed free movement without cable twisting. To reduce electromagnetic noise, the recording system was placed inside a Faraday cage. The behavioral platform was not designed to depend on this specific recording system and can be connected to other electrophysiological acquisition systems that can receive external event markers.

To synchronize behavioral data with electrophysiological signals, behavioral events recorded by the operant system were sent directly to the recording system in real time. In this setup, microcontroller-generated event markers were sent to a separate recording channel of the recording system as duration-coded square-wave pulses. Different pulse durations were used to identify different behavioral and task events, including LED onset, nose-poke/choice response, magazine entry/reward collection, and ITI onset. These event markers were stored together with the LFP data and allowed offline temporal alignment between behavioral events and neural activity. A representative example of LFP alignment with behavioral event markers is shown in Figure 4A.

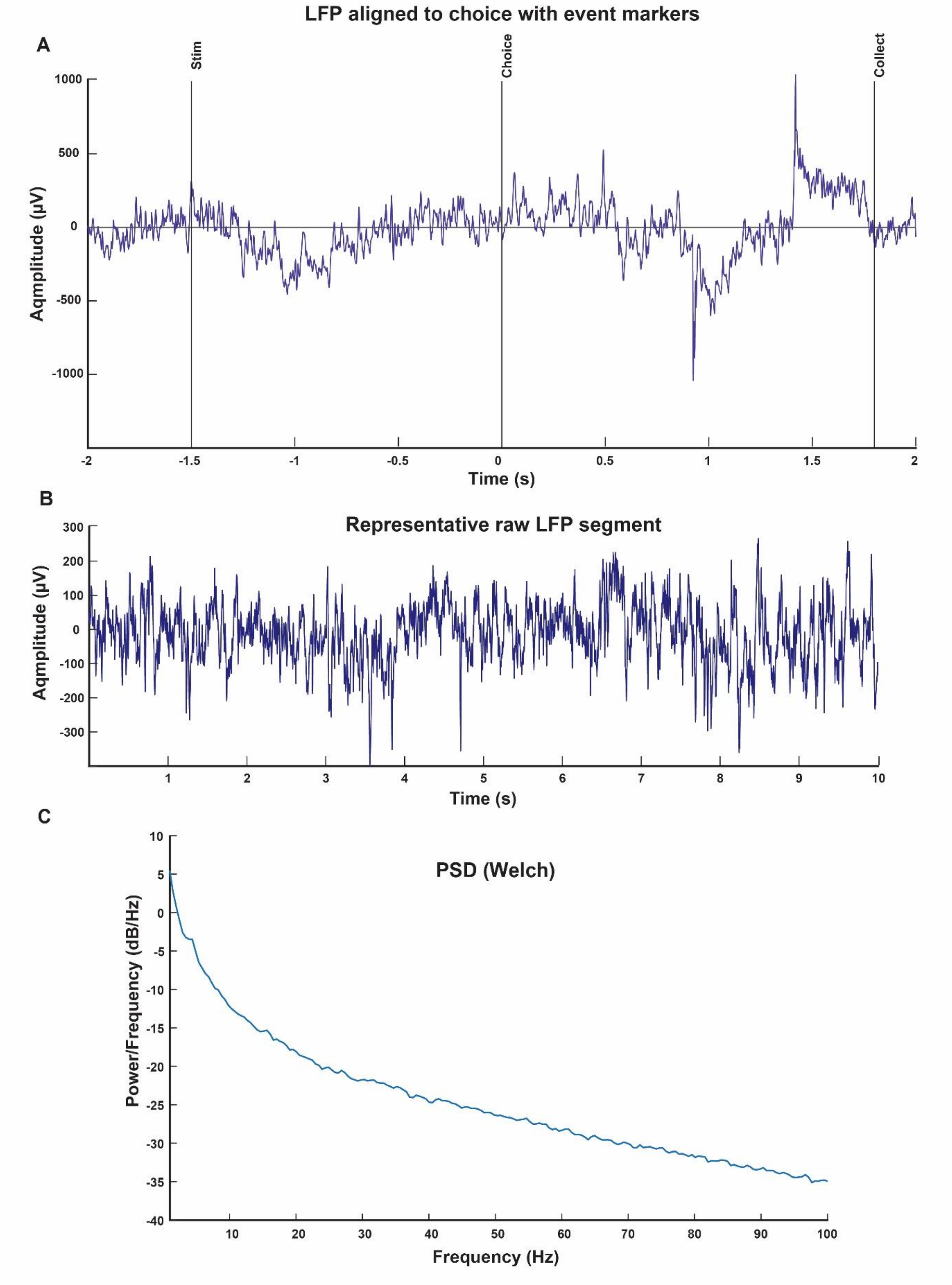

Figure 4. Electrophysiological recording and event-marker validation. (A) Representative LFP trace aligned with behavioral event markers recorded during task performance. Event markers were stored together with the LFP data as duration-coded square-wave pulses. (B) Representative artifact-free raw LFP segment from the decimated 1000-Hz LFP recording, showing continuous electrophysiological activity without obvious saturation.

(C) Power spectral density of the representative LFP recording calculated using Welch's method, showing a frequency-dependent power profile with stronger low-frequency power and decreasing power at higher frequencies.

Data and statistical analysis

Behavioral performance in the rGT was evaluated as the percentage of advantageous choices in 10-min bins across the 60-min session. Within-session changes in advantageous choice percentage were analyzed using a Friedman test across the six time bins. To directly evaluate the change from the beginning to the end of the session, a planned paired comparison between the first and final 10-min bins was performed using a Wilcoxon signed-rank test. Statistical significance was set at $p < 0.05$.

To quantify event-marker stability, the recorded duration-coded marker signal was extracted from six validation sessions. The recorded square-wave markers were thresholded, and the onset and offset of each marker were identified from the recorded signal. Marker duration was then calculated and compared with the programmed duration code for each event type. Classification accuracy, duration error, absolute duration error, and maximum absolute error were calculated across all extracted markers.

Functional reliability testing was performed to quantify the stability of the main behavioral-control components. Pellet-delivery reliability was assessed by sending 200 repeated reward-delivery commands to the feeder and visually inspecting whether each command resulted in a single pellet being delivered to the magazine. Missed deliveries, double deliveries, and pellet-jamming events were recorded. Sensor-detection reliability was assessed by repeated manual activation of the five nose-poke sensors and the magazine sensor while the MATLAB–Arduino system recorded the detected events. Detection success was calculated as the percentage of expected activations that were correctly logged by the system. These tests were performed under calibrated sensor conditions and using pellets with appropriate size and shape for the feeder.

For electrophysiological signal validation, decimated LFP data sampled at 1000 Hz were used. Representative artifact-free LFP segments were visually inspected to confirm that continuous neural signals could be recorded during task performance. Power spectral density was calculated using Welch's method as a signal-quality validation measure. The PSD was used to evaluate whether the recorded LFP showed an analyzable frequency-dependent power profile.

Results

Event-marker synchronization validation

Event-marker synchronization was quantitatively evaluated across six validation sessions. In total, 1602 duration-coded event markers were extracted from the recorded marker signal. All markers were successfully classified according to their programmed duration code, with no unclassified markers. Across all markers, the mean duration error was -0.0106 ± 0.0125 ms, the mean absolute duration error was 0.0107 ms, and the maximum absolute error was 0.025 ms. Given the 40 kHz sampling rate, this maximum error corresponds to one sample. These results indicate stable recording of duration-coded behavioral event markers and support reliable offline alignment between behavioral events and LFP activity.

Electrophysiological signal validation

Representative LFP recordings showed continuous electrophysiological activity during task performance. As shown in Figure 4B, a visually selected artifact-free segment of the decimated 1000-Hz LFP recording showed stable LFP fluctuations without obvious saturation. Power spectral density analysis was then used as a signal-quality validation measure. As shown in Figure 4C, the PSD displayed a frequency-dependent power profile, with greater power at low frequencies and decreasing power at higher frequencies. These results support the feasibility of recording analyzable LFP signals during operation of the behavioral platform.

Functional reliability of core system components

Functional reliability was evaluated for the core components of the platform, including reward delivery, sensor detection, and event-marker classification. Under calibrated test conditions, 200 repeated feeder commands resulted in single-pellet delivery without missed deliveries, double deliveries, or pellet-jamming events. Manual activation of the five nose-poke sensors and the magazine sensor was also detected correctly in all tests. In addition, all 1602 duration-coded event markers extracted from the recorded marker signal were classified according to their programmed duration codes, with no unclassified markers. These findings support reliable operation of the reward-delivery, response-detection, and event-synchronization components of the platform under the tested conditions (Table 3).

Table 3. Functional reliability metrics of the operant platform.

System function	Validation procedure	Number of tests	Successful events	Failure events	Success rate
Pellet delivery	Repeated pellet-delivery commands were sent to the feeder and delivery was visually inspected.	200	200	0 missed deliveries, 0 double deliveries, 0 jamming events when pellets had appropriate size and shape	100%
Nose-poke sensor detection	Each nose-poke sensor was manually activated under calibrated sensor conditions while the MATLAB-Arduino system recorded the detected events.	500	500	0 missed detections	100%
Magazine sensor detection	The magazine sensor was manually activated under calibrated sensor conditions while the MATLAB-Arduino system recorded the detected events.	100	100	0 missed detections	100%
Event-marker classification	The recorded duration-coded marker signal was extracted and classified offline.	1602	1602	0 unclassified markers	100%

Note. Nose-poke sensor detection reflects five nose-poke sensors tested 100 times each. Magazine sensor detection reflects 100 manual activations. Reliability values are reported under calibrated sensor conditions and using pellets with appropriate size and shape for the feeder.

Behavioral validation of rGT performance

Animal performance in the rGT was evaluated as the percentage of advantageous choices during a 60-min session in 10-min time bins. Across animals, advantageous choice percentage increased from 49.1 ± 1.18% in the first 10-min bin to 74.2 ± 10.61% in the final 10-min bin. As shown in Figure 5, individual animals showed variable trajectories across the session, while the group-level pattern indicated an overall increase in advantageous choice. A Friedman test showed a significant effect of time bin on advantageous choice percentage, $\chi^2(5) = 14.10$, $p = 0.015$, Kendall's $W = 0.28$. A planned comparison between the first and final 10-min bins also showed a significant increase in advantageous choices, Wilcoxon signed-rank test, $p = 0.0195$. These results indicate that the behavioral output generated by the system captured both within-session improvement in advantageous choice and inter-individual variability in task performance.

Among the 10 animals shown in Figure 5, 7 reached more than 70% advantageous choices by the end of the session, 1 remained near chance level, and 2 remained below 30%. These data indicate that the system was able to record not only overall behavioral trends across the session, but also clear inter-individual differences in task performance. Similar inter-individual variability in single-session rGT performance has also been reported in previous studies. Rivalan et al. described good decision makers as animals showing more than 70% advantageous choices, poor decision makers as those showing less than 30% advantageous choices, and an intermediate group with no clear preference. In addition, Hultman et al. showed that although most rats gradually move toward advantageous options, the strength of this shift and the final performance pattern differ across animals (Hultman et al., 2022; Rivalan et al., 2009). More recent studies have also continued to use the rGT to identify stable individual differences in decision-making patterns (Hynes et al., 2025).

These findings indicate that the designed system supported stable task implementation, automated behavioral recording, and detection of both session-dependent behavioral change and inter-individual variability. This supports the functional validity of the platform for rGT performance and related behavioral paradigms.

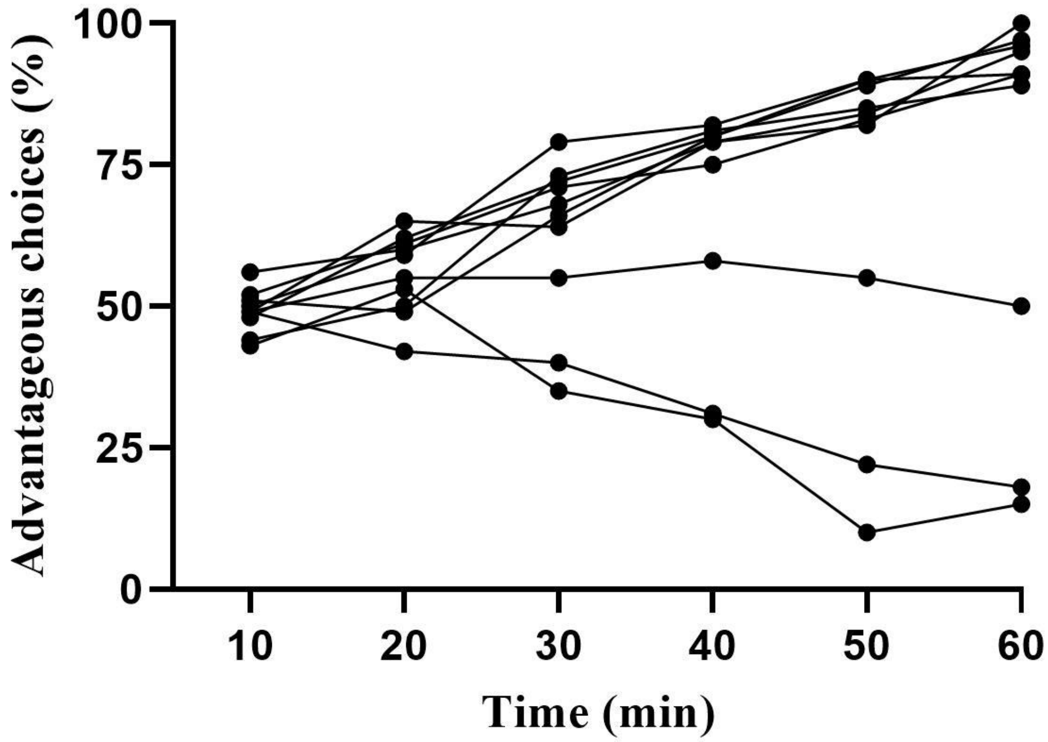

Figure 5. Changes in the percentage of advantageous choices during a 60-min rGT session. Each line represents the performance of one animal across 10-min time bins. Across animals, advantageous choice percentage changed significantly across time bins, Friedman test, $\chi^2(5) = 14.10$, $p = 0.015$, Kendall's $W = 0.28$. A planned comparison between the first and final 10-min bins also showed a significant increase in advantageous choices, Wilcoxon signed-rank test, $p = 0.0195$. Among the 10 animals shown, 7 reached more than 70% advantageous choices by the end of the session, 1 remained close to chance level, and 2 remained below 30%. Overall, the figure illustrates both a general tendency toward increasing advantageous choice during the session and clear inter-individual differences in task performance.

Discussion

The present study should be interpreted as a technical/methodological study with functional validation. The main aim is not to provide a full behavioral or neurophysiological account of decision-making, but to introduce and evaluate a low-cost, repairable, and expandable five-choice operant platform for the rGT with simultaneous electrophysiological recording capability. In this context, the behavioral and electrophysiological results are used to demonstrate stable task execution, automated behavioral response detection, controlled reward delivery, simultaneous LFP recording, and behavioral-event synchronization.

Compared with commercial operant systems, the main advantage of the present platform is its low-cost, repairable, and locally constructible design, while preserving the core functions required for rGT implementation, including controlled stimulus presentation, automated nose-poke detection, reward delivery, and event synchronization with electrophysiological recordings. Unlike fully closed commercial systems, the Arduino–MATLAB structure allows task parameters and event-marker codes to be modified according to experimental needs. At the same time, the present system should be viewed as a flexible technical platform rather than a complete replacement for all commercial systems, because further validation would be required for other behavioral paradigms, long-term multi-laboratory use, and other electrophysiological recording configurations.

Accordingly, the current findings support the functional validity of the platform rather than a mechanistic conclusion about the neural basis of decision-making. Deeper analyses of event-locked LFP dynamics, differences between advantageous and disadvantageous choices, or neural predictors of individual decision-making patterns are beyond the primary scope of this technical validation study and should be addressed in future experiments.

An additional strength of the present system is that its modular hardware and MATLAB-based control structure allow task parameters, stimulus sequence, reward contingencies, and output/event-marker codes to be modified according to experimental needs. This flexibility is consistent with previous reports showing that open-source and customizable five-choice systems can facilitate the development of non-standard behavioral paradigms by allowing easier modification of task sequence, stimulus type, and output format (Morais Gancz et al., 2022). Therefore, although the system was validated here using the rGT, it is not limited to this task and may be adapted to other behavioral paradigms based on a similar five-choice structure.

From a behavioral point of view, the results showed that in many animals, the percentage of advantageous choices increased across the session. This pattern suggests gradual learning of task rules and movement toward more optimal choice behavior. At the same time, marked inter-individual differences were observed. Some animals reached high levels of advantageous choice by the end of the session, whereas others remained near chance level or showed lower final performance. This finding is consistent with previous reports on the rGT. Previous studies have likewise shown that although most animals gradually shift toward advantageous options, the strength of this shift and the final performance pattern can differ across individuals (Hultman et al., 2022; Rivalan et al., 2009).

In addition, rodent IGT-like tasks have been reported to include subgroups of animals that continue to prefer disadvantageous options (de Visser et al., 2011; Rivalan et al., 2009). In the present study, the importance of this variability lies not only in the behavioral pattern itself, but also in the ability of the designed system to detect meaningful differences in behavioral output across animals. From this perspective, the presence of inter-individual differences should not be considered a weakness of the platform. Rather, it supports the functional suitability of the system for recording task performance and distinguishing different behavioral patterns.

One of the distinctive features of the present system was the possibility of simultaneous LFP recording and direct synchronization of behavioral events with neural signals. In this setup, behavioral events such as nose-poke responses and magazine entries were transmitted to the recording system and stored as event markers, enabling precise temporal alignment between behavior and neural activity. This feature increases the practical value of the platform for studies requiring simultaneous behavioral and electrophysiological recording. In addition, the rotary/tether design allowed the animals to move naturally during the task, including nose-poke behavior, without obvious movement restriction.

Despite these advantages, the present study also had some limitations. First, the main focus of this work was the design, construction, and functional validation of the system, rather than a systematic evaluation of electrophysiological signal quality. Therefore, although simultaneous LFP recording was successfully achieved, no quantitative comparison was made between the signal quality of this system and that of commercial systems or specialized headstage-based setups. Second, the electrophysiological recording system itself was not the main innovation of this study. The main novelty was the integration of a low-cost operant chamber with simultaneous recording capability and behavioral-neural synchronization. Third, although simultaneous LFP recording and accurate synchronization with behavioral events were successfully achieved, full analysis of event-related neurophysiological dynamics was beyond the scope of the present study and can be addressed in future work.

Overall, the findings of this study show that the designed system can serve as a practical, low-cost, repairable, and expandable alternative to commercial systems. The platform is suitable not only for the rGT, but also for other five-choice-based behavioral paradigms, and it can provide a useful basis for future studies in behavioral neuroscience and electrophysiology.

In future studies, systematic evaluation of signal quality obtained with this system and comparison with commercial setups can provide a clearer picture of its strengths and limitations in terms of recording stability, noise level, and temporal precision of synchronization. In addition, because of the modular and customizable nature of the platform, it can be extended to other behavioral paradigms based on a five-choice structure. Finally, this system can be used in future work to directly examine event-locked LFP changes related to advantageous and disadvantageous choices and to help clarify the neural mechanisms underlying decision-making during ongoing behavior.

Author Contributions

Elmira Ghasemi: Methodology, Investigation, Visualization, Writing – original draft**; Nima Heidari:** Methodology, Investigation, Visualization, Writing – review and editing; **Hossein Azizi:** Methodology, Visualization, Writing – review and editing; **Saeed Semnanian:** Conceptualization, Supervision, Project administration, Funding acquisition, Writing – review and editing.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Acknowledgments

The authors gratefully acknowledge the Iran National Science Foundation (INSF), the Cognitive Sciences and Technologies Council of Iran, and the School of Cognitive Sciences, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran, for their support. The authors also thank Faezeh Shafiei for her valuable assistance with coding and Mahdieh Ramezan Dehnavi for her assistance with visualization.

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