Behav Res (2012) 44:909–918
DOI 10.3758/s13428-012-0198-9

# The Vienna comparative cognition technology (VCCT): An innovative operant conditioning system for various species and experimental procedures

**Michael Morten Steurer · Ulrike Aust · Ludwig Huber**

**Abstract** This article describes a laboratory system for running learning experiments in operant chambers with various species. It is based on a modern version of a classical learning chamber for operant conditioning, the so-called "Skinner box". Rather than constituting a stand-alone unit, as is usually the case, it is an integrated part of a comprehensive technical solution, thereby eliminating a number of practical problems that are frequently encountered in research on animal learning and behavior. The Vienna comparative cognition technology combines modern computer, stimulus presentation, and reinforcement technology with flexibility and user-friendliness, which allows for efficient, widely automatized across-species experimentation, and thus makes the system appropriate for use in a broad range of learning tasks.

**Keywords** Comparative cognition · Operant conditioning chamber · Learning experiments · Laboratory system

**Electronic supplementary material** The online version of this article (doi:10.3758/s13428-012-0198-9) contains supplementary material, which is available to authorized users.

M. M. Steurer (✉) · U. Aust · L. Huber
Department of Cognitive Biology, University of Vienna,
Vienna, Austria
e-mail: michael.steurer@univie.ac.at

M. M. Steurer
Aerosol Physics and Environmental Physics, Faculty of Physics,
University of Vienna,
Vienna, Austria

L. Huber
Messerli Research Institute, University of Veterinary Medicine
Vienna, Medical University Vienna and University of Vienna,
Vienna, Austria

The operant conditioning chamber, or "Skinner box", is a standard apparatus used in the experimental analysis of animal behavior. Basically, it is a closed box that, apart from the subject to be tested, contains the following parts. First, an *operandum* is required—that is, a device that automatically detects the occurrence of a behavioral response. This may, for example, be a lever (typically used for primates and rats) or a response key (typically used for birds). Second, a Skinner box includes a means of delivering a *primary reinforcer* to serve as the unconditioned stimulus, usually a food or water dispenser, as well as a *conditioned reinforcer*, such as a light or a tone.

Initially devised to study the basics of operant and classical conditioning, the Skinner box has, by now, become a tool to explore a broad range of issues, including animals' perceptual abilities, visual categorization, and memory. To this end, a subject is typically presented with two or more stimuli that have to be discriminated and/or sorted into different classes according to an underlying (perceptual, functional, or logical) rule. This may be accomplished by training the subject to respond differentially to individual stimuli by using only one operandum. For example, a pigeon may be required to peck a key in response to one class of stimuli and not to peck in response to stimuli of a different class ("go/no-go" procedures; e.g., Aust & Huber, 2006; Vaughan & Greene, 1984), or it may be trained to choose stimuli of a particular category from an array of two or more simultaneously presented stimuli of different categories ("multiple-alternatives forced choice" procedures; e.g., the "multistimulus, multiple-matching learning paradigm" introduced by Huber, Apfalter, Steurer, & Prossinger, 2005; see also, e.g., Aust, Range, Steurer, & Huber, 2008). Alternatively, an animal may be required to use two or more operanda in response to different stimuli. For example, a pigeon may be trained to associate each of two (or more) stimulus classes with one of two (or more) response keys (e.g., Lazareva, Freiburger, & Wasserman, 2004).

Over the past four decades, researchers in the field of animal learning and cognition have modified, extended, and improved the design of the traditional Skinner box in many ways to adjust it to the growing technical demands associated with the broadened range of increasingly complex research topics and questions to be investigated. Modern Skinner boxes often have two or more operanda and feeders and allow for the presentation of a wide variety of stimuli, including lights, sounds, pictorial images, and videos. Accordingly, traditional operanda and devices for stimulus generation and presentation have increasingly been replaced with touchscreens (e.g., Cook, 1992; Cook, Geller, Zhang, & Gowda, 2004; Fagot & Paleressompoulle, 2009; Gibson, Wasserman, Frei, & Miller, 2004). Particularly interesting is a setup recently introduced by Fagot and Bonté (2010) that included 10 automated learning devices that were provided ad lib to a troop of semi-free-ranging baboons. For the most part, however, Skinner boxes are still devised as stand-alone units for carrying out particular types of learning tasks with a particular animal species, which severely limits their power as a tool for comparative research on a broad range of topics. Here, we describe a technology that we have developed over the last 10 years that regards Skinner boxes as flexible, multifunctional, integrated parts of a comprehensive modern laboratory concerned with the investigation of a wide range of perceptual and cognitive issues. The Vienna comparative cognition technology (VCCT) raises an established method to a modern technical level that allows for efficient, widely automatized, across-species experimentation (e.g., Aust et al., 2008).

**Fig. 1** Outdoor aviary compartments (top panel) and experimental indoor chambers (bottom panel)

## Overview

Initially, our laboratory equipment was developed for meeting the challenges of experimentation with pigeons. A secondary goal was to make it applicable to a wider variety of species, in order to allow for comparative research, with only minor modifications being necessary to account for interspecies differences with regard to morphological, physiological, and behavioral characteristics. Accordingly, the remainder of this article will mainly be oriented toward our pigeon laboratory, and a brief overview of the adjustments we have made for use with other species will be given in a separate section.

Our pigeon laboratory consists of an outdoor complex (about 52 $m^2$) for housing the birds, which directly adjoins to an indoor complex (about 32 $m^2$) for experimentation. The outdoor complex is entirely enclosed and roofed. The pigeons (about 120) are group-housed in nine aviary compartments made of wire mesh. Five of these compartments are attached to the indoor area (see Fig. 1, top panel), with each of them separated from (or connected to) the indoors by a window through which the pigeons can enter and leave the experimental setups in the laboratory by means of a passageway system. This special housing technique was introduced by Huber (1994). It allows for pigeons to volunteer for experimental sessions (which ensures high motivation levels) and, at the same time, to benefit from almost natural housing conditions. All aviary compartments are equipped with perches and with boxes for resting and breeding, and group housing allows for a rich social life.

The indoor complex contains five operant chambers (modified “Skinner boxes”), each of which is assigned to one outdoor aviary compartment (Fig. 1, bottom panel). Each Skinner box is mounted onto a rack that holds it in position, but nevertheless allows for pivoting it. The feeder is an integrated part of the rack and is installed directly below the Skinner box. Furthermore, the rack houses a computer that controls the experimental sessions (Fig. 2, left panel).

Part of the laboratory constitutes the “control area” that houses a PC workstation with two 24-in. TFT displays for controlling the computers of the Skinner boxes and monitoring

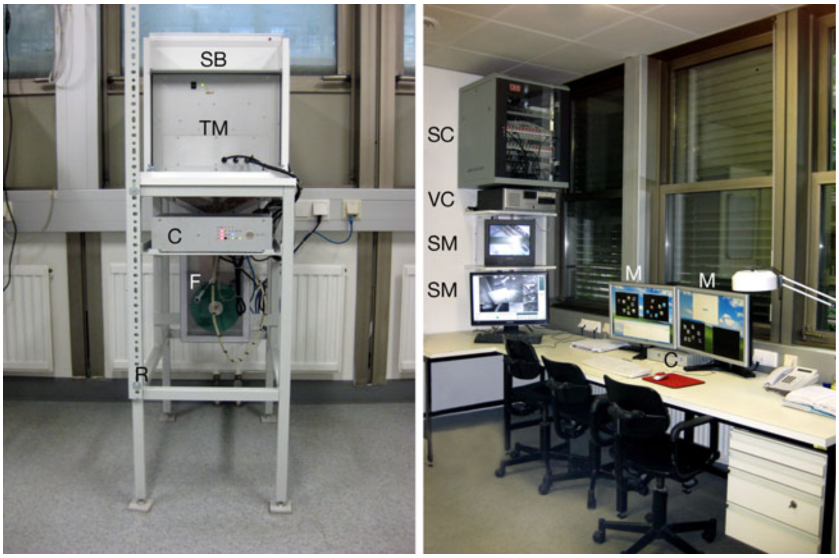

**Fig. 2** Skinner box with control unit and feeder (left panel) and control area (right panel). *Experimental chamber apparatus:* SB, Skinner box; TM, touch monitor (presentation device); C, computer for session control; F, feeder; R, rack. *Control area apparatus:* SC, switch cabinet containing BNC patch panels; VC, computer for video surveillance; SM, monitors for video surveillance; M, monitors for session control. C, computer for session control (connected to Skinner boxes via VNC client)

the experimental sessions, as well as video surveillance equipment for observing the pigeons' activities in both the aviaries and the Skinner boxes (Fig. 2, right panel; see the Video Surveillance System section for details). The laboratory is generously equipped with power points, LAN sockets, and cabling for video surveillance.

## Skinner boxes

Our experimental chambers are closed boxes of 39 cm × 40 cm × 53 cm (width × height × depth [interior measures]) with a movable 15-in. infrared (IR) touch monitor for stimulus presentation constituting the front wall (Fig. 3, left panel). The monitor is attached to the Skinner box by means of two aluminum elbows. The rear wall is a sliding door that can be vertically raised (and lowered) manually to let pigeons enter and leave. The top panel can be opened by means of a hinged lid, which facilitates handling of the subjects and cleaning. The boxes are made of coated wood panels, a material that allows for easy cleaning and that also provides some acoustic shielding. To support experiments on observational learning (which make the presence of two subjects in the box necessary), the interior of the chamber can be divided into rear and front parts by inserting a transparent (either Plexiglas or glass) plate into rails fixed to the side walls.

As the position of the monitor is flexible, the interior size (i.e., the depth) of the box can be varied to some extent. Also, it is possible to insert an intelligence panel with a pecking key at the default position of the monitor (while the latter is shifted to be fixed in a position behind the pecking key). When this is inserted, the subjects see the stimuli presented on the monitor through the transparent pecking key (Fig. 3, right panel). The monitor can be fixed with screws in both locations (touchscreen and pecking key presentation modes) so that a stable, predefined monitor position is ensured within and over sessions.

A hole (with a diameter of 6 cm) in the bottom of the box, located directly in front of the pecking key position (i.e., the default position of the monitor) contains the outlet of the feeder, which is situated below the box. This design has several advantages. First, it ensures—at least for touchscreen-based solutions—high spatial coincidence between conditioned and unconditioned stimuli (i.e., a small distance between the stimuli presented on the monitor and the location at which food is offered). Second, pigeons' natural foraging conditions are simulated, which involve picking up grain from the ground. Finally, side biases are prevented, as the feeding location has the same distance from both side walls. Apart from providing

**Fig. 3** Inside view of a Skinner box with a touchscreen (left panel) and with a pecking key (right panel). The feeder hole is visible below the monitor (or the pecking key, respectively)

reinforcement, the (elevated) feeder outlet serves as a central support to hold the entire box in position, while still allowing for turning the box. A loudspeaker (4 W, 8 Ω) integrated into the top panel of the box allows for the presentation of acoustic stimuli as well as for secondary (acoustic) reinforcement.

In every box, a color camera is mounted in the rear so that the experimenter can monitor the pigeons' activities in the Skinner box. Each camera is equipped with an IR LED array to allow for observation under poor light conditions.

## Feeder

We developed a special type of feeder (called "grain lifter") in our workshop (Fig. 4). Basically, it consists of a crankshaft operated by an electric DC motor that lifts a steel piston up through a food reservoir and then through the feeder hole in the bottom of the Skinner box. The side walls of the food reservoir are made of Plexiglas so that its filling status can easily be checked. Food is refilled through side openings. While the piston moves through the reservoir, food is accumulated in a depression on top, from which it then becomes available to the subject. This top part is not made of steel but of polyamide, which makes it semitranslucent. A white LED (diameter of 5 mm) is inserted into the top part directly below the food depression, which provides illumination of the food during feeding. To allow for connecting the LED to the electronics, the piston is hollow. The top part may be unscrewed and replaced by another part with a different depression size; thereby, it is possible to vary the amount of reinforcement. Also the duration of the piston being lifted can easily be changed (i.e., is freely selectable) by making appropriate specifications in the experimental settings of the software. All mechanical parts are encased by a Plexiglas box to protect them from damage, dust, and dirt.

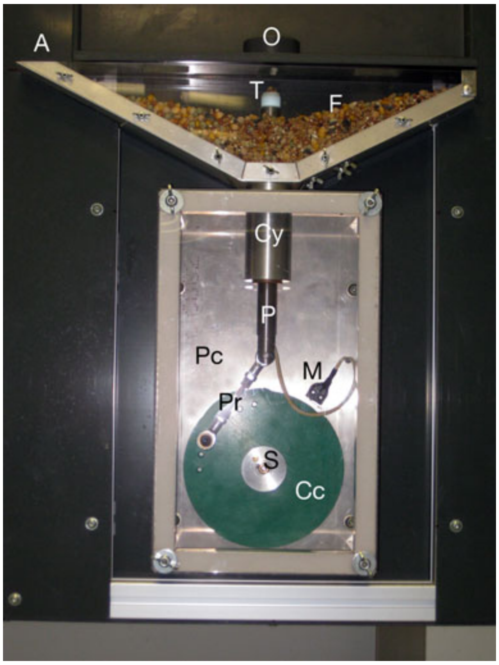

**Fig. 4** Grain lifter, realized as a crankshaft (consisting of a crank cheek, piston rod, and piston). The piston is shown in its waiting position, beyond the reach of the subject. A, aperture for refilling food; O, elevated feeder outlet at the bottom of the Skinner box; T, top of the piston, with feeder light and accumulated food; F, food reservoir; Cy, guide cylinder; P, piston; Pc, Plexiglas case; M, microswitch; Pr, piston rod; S, sliding clutch; Cc, crank cheek

The piston has two hold points, namely a "feeding position" and a "waiting position". The former signifies the uppermost position of the piston, in which the food well is accessible to the subject at the feeder outlet inside the box. The second hold point ("waiting position") is somewhat below this point, so that the piston cannot be reached by the subject any more. When feeding is terminated, the piston is moved from the feeding position down to the very bottom of the food reservoir and back up to the waiting position, where it stays until moved into the feeding position again at the beginning of the next feeding event. Control of the feeder is accomplished by a single-pole double-throw microswitch, which is attached to the crank cheek. It cooperates with the electronic control device according to the principle of a multiway-switching circuit that turns the motor on and off. For safety reasons, the crank cheek is connected to the engine shaft by means of a sliding clutch. This ensures that the motor can spin freely if, for some reason, the piston may get blocked (e.g., by stuck grain), thereby preventing damage to the device and injuries on the part of the experimenter or the animal subject.

The grain lifter yields the following advantages. First, it produces low noise levels, is low-maintenance, and works very reliably. So far, an estimated 400,000 trials have been carried out in each box without any major repairs of the feeders having been necessary. Occasional failures to lift grain (about once in 50,000 trials) may occur due to stuck grain that blocks the piston and, consequently, requires the loose sliding clutch as a failsafe. Such problems can, however, be easily fixed by the experimenter. Second, the grain lifter allows for the use of a wide variety of different forms and sizes of food (e.g., different types of grains or pellets). Third, in contrast to other feeder types (like food hoppers), the grain lifter administers reinforcement directly below the stimulus presentation area. Offering food below the stimuli was assumed to closely resemble the natural foraging conditions encountered by pigeons, which usually feed from the ground. Finally, it needs refilling less frequently than do the food hoppers typically used. This is due not only to the reservoir size, but, most importantly, to the fact that the grain lifter prevents the subjects from "stealing" and scattering food between feeding events, because the reward accessible in each trial is limited to the amount of grain accumulated on top of the piston. Also, the waiting position of the piston is too far away from the feeder outlet for the pigeons to reach. According to our experience, traditional food hoppers sometimes allow pigeons to pull up the food receptacles with their beaks between feeding intervals. This is not only undesirable in terms of proper experimentation, but also leads to considerable waste of food over time, because pigeons then tend to quickly remove as much grain as possible from the receptacle and spread it over the box floor for later consumption. With the grain lifter, such behavior is generally prevented, because the amount of food offered in a trial is limited to the small amount of grain provided, which is determined by the diameter of the piston employed and the depth of the well on top (with the piston we are presently using, about 10–12 pieces of mixed grain are delivered per trial, weighing less than 1 g altogether). Also, the grain lifter allows for effectively withholding reinforcement if the subject is not motivated to immediately collect the reward because—unlike in the case of pellet dispensers, for example—the food provided in a trial retracts with the rest of the piston after the feeding interval, thereby preventing food from accumulating in the box.

## Computers and electronics

Each Skinner box is connected to a control unit (CU) developed for application in laboratories carrying out learning experiments, mainly, but not exclusively, in the visual domain (Fig. 5). This device is based on a Schneider A4F® minicomputer (http://www.mappit.de). An anodized aluminum case (32 cm × 21 cm × 10 cm) contains a Mini-ITX main board (VIA EPIA[1] M10000, with 1-GHz CPU, 2 × USB, 1 × LAN 10/100 Mbit, sound, and VGA on board), 512 MB DDR RAM, a 40-GB 2.5-in. hard disc, and a digital visual interface (DVI) adapter. The corresponding DVI port, as well as two additional USB and two firewire ports, are integrated into the back panel of the aluminum case. Both graphic ports (VGA and DVI) can be used independently for different desktops (i.e., they show different pictures) or in twin mode (i.e., they show the same picture). The entire system is fanless and passively cooled, with the side panels being designed as heat sinks, to this end. It is largely dust-proof, which prevents entering dirt (e.g., pigeon dust) from damaging the interior parts.

The CU also contains the control electronics that allow for the flexible use of various peripheral devices. Up to two input devices (i.e., switches, such as levers or pecking keys), up to two feeders (including feeder lights), and a house light (or any other output device) can simultaneously be connected directly to the CU. Concerning illumination (i.e., the house light and feeder light), the system is devised for the use of LEDs (and thus a 5-V voltage is provided at the respective sockets). Relative to bulbs, LEDs bear the advantages of being brighter, more durable, and more robust, and they produce less heat loss and consume less current.

Different feeder types can be used, including solenoid food hoppers (e.g., by Med Associates Inc., St. Albans, VT), a grain lifter, or pellet dispensers. Therefore, the CU provides a number of different ports—namely, a double-pole port for connecting a motor or a hopper magnet, another double-pole port for connecting a feeder light, and a three-pole port for the microswitch that is required for the use of grain lifters or pellet dispensers. As two feeders can be connected simultaneously, two ports of each type are available.

The inputs (e.g., from the pecking key) are internally connected to electronic counters that register events such as, for instance, responses made by the subject. The advantage of integrating counter functions into the hardware is that this takes load off of the software (and the programmer). One pole of all input ports is the (common) ground, while the second pole is connected to the internal voltage source (5 V) via a 1-kΩ resistor. This makes the functional principle of the connected devices (e.g., pecking keys) quite simple: All they have to do is open and close the circuit. Furthermore, the use of low voltage (with maximum current limited to 5 mA) reduces the risk of electric shocks and equipment damage. All input signals are electronically debounced.

The individual input/output operations are handled by 1-Wire®[2]-based integrated circuits (ICs). All ICs are linked to one single 1-Wire bus, which is driven by a bus master connected to the serial interface (com2) of the main board. By means of a jack (RJ12) at the back panel, it is possible to connect further devices to the 1-Wire bus (and to the internal 5-V voltage source), and thereby to broaden the range of functions of the CU to adapt it to a wide variety of experiments. The 1-Wire standard is widespread, and thus it is easy to get compatible devices that provide many different functions. Also, it is relatively simple to write programs for controlling these ICs, and a wide range of software (including open source) and appropriate documentation are available—for instance, the 1-Wire public domain kit (http://www.ibutton.com/software/1wire/wirekit.html) and the 1-Wire File system (http://owfs.org/).

The supply voltage for the main board, as well as for the control electronics, is provided by an internal power adapter. A second internal power adapter provides the supply voltage for the connected feeders. Thus, the circuits of the motors (or solenoids) and the electronic circuits are galvanically isolated from each other. The supply voltage generated with

---

[1] VIA and EPIA are trademarks of VIA Technologies, Inc.

[2] 1-Wire is a registered trademark of Maxim Integrated Products, Inc., Sunnyvale, CA.

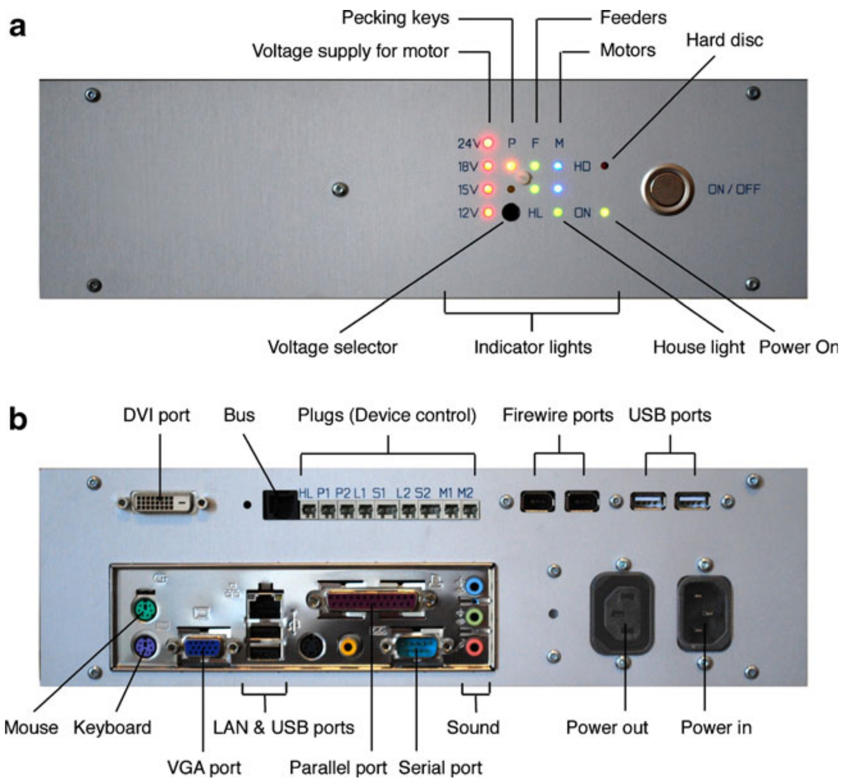

**Fig. 5** Control unit (CU). (A) Front panel. This includes the main switch of the CU, as well as a power indicator and a light that signals hard-disc activity. An array of indicator lights provides information on the function of the control electronics. Two yellow LEDs (P) indicate closed circuits for the connected input devices (i.e., switches, such as levers or pecking keys). Two green LEDs (F) provide information on two independent feeding systems. These lights are turned on during the feeding interval. The blue LEDs (M) indicate that voltage is applied to the feeders. The selector for the feeders' voltage is located below the "P" LEDs: Either 12, 15, 18, or 24 V can be chosen by turning the selector with a screwdriver. The selected voltage is indicated by the red LED column (i.e., 24 V in the example shown in the figure). (B) Back panel. The back panel includes the main power plug, a power outlet for connecting a monitor, the sockets of the main board, an additional DVI output, two firewire ports, and two additional USB ports. Furthermore, the back panel contains the sockets for device control: namely, a house light (HL), two input devices (P1 and P2), and two independent feeder systems (feeder lights L1 and L2, microswitches S1 and S2, and feeder/motor M1 and M2)

the second adapter can be varied (12, 15, 18, or 24 V) and thus can be adapted to the chosen feeder.[3] The control circuits for the feeders can operate in two different modes: They either react to the state of the microswitch (multiway-switching mode, required by the grain lifter) or to changes in the state of the microswitch (edge-triggered mode, required by pellet dispensers). The use of food hoppers is possible in the multiway-switching mode without a microswitch. See the supplemental materials for an overview of the different operation modes.

The CU is appropriate for use with any mains voltages between 110 and 220 V and any mains frequencies between 50 and 60 Hz. All ports are located on the back panel, including a power connector for the presentation monitor. By switching off the CU, all modules (PC, control electronics, monitor, and feeder) are turned off, as well.

## Presentation device

The stimuli are presented on a special IR touch monitor, which was developed according to the requirements of animal learning experiments. Like the control computer, the monitor possesses a dust-proof, fanless (passively cooled) anodized aluminum case that contains all of the required components (see below). The case measures 39 cm × 30 cm × 8 cm (width × height × depth), and all side panels are entirely plane (i.e., they have no roundings), which ensures that the monitor fits gaplessly into the Skinner box (i.e., it constitutes the front wall). Four threads are embedded into the bottom panel of the box, which serve to affix the monitor to the Skinner box.

The aluminum case contains a 15-in. XGA color TFT-LCD Modul (Model G150XG01 by AU Optronics Corp., Taiwan; http://www.auo.com). The display area is 304 mm × 228 mm (381-mm diagonal) with a resolution of 1,024 × 768 pixels. (Each pixel thus has a size of 0.297 mm × 0.297 mm.) The monitor is equipped with VGA and DVI ports, and a port converter is integrated into the aluminum case.

---

[3] Indeed, we have even run a 28-V solenoid food hopper at 24 V without any problems.

A 15-in. IR "CarrollTouch" touchframe (Model D87587-001, 15 in., without filter) by Elo (Menlo Park, CA; http://www.elotouch.com) is used for detecting responses (see the supplemental materials for details). These touchframes are available either with an integrated transparent acrylic filter, with an integrated glass filter, or without a filter. Because the filters are normally fixed directly below the IR arrays (or the IR light barriers), there is almost no parallax between the touch point detected by the IR touchframe and the point targeted by a subject on the LCD display. We have, however, found that this design is not ideal for pigeons. First, they frequently "peck through" between neighboring IR beams, which means that pecks are not registered. Second, the acrylic filters get scratched by the pigeons' beaks after some time, which results in severe deterioration in the quality of the stimuli viewed through the filters. Therefore, we have employed IR frames without filters. Instead, a safety-glass plate is mounted behind the IR array, which protects the LCD display from damage and dirt. The distance between the glass plate and the frame is 7 mm. A rectangular plastic frame serves as a spacer between the IR frame and the glass plate, creating a properly closed unit with the IR frame. Because of the distance between the IR beams and the glass plate, the pigeon's beak interrupts the beams with its (broad) base and not with its (thin) apex, which makes pecks that go unregistered quite unlikely.

A consequence of this "two-layer arrangement" is, however, a slight parallax between the targeted image point and the detected point of touch, which occurs with oblique viewing angles. Furthermore, the subject has to retract its beak entirely from the IR-beam matrix before another peck can be detected ("click-on-touch" mode). While this has turned out to be no problem for pigeons, with other species—for instance, keas—we have encountered difficulties with this setup. Both effects—parallax error and the long retraction distance of the beak—can be alleviated by mounting the touchframe (i.e., the IR frame plus the spacer) inversely. Then, the IR grid is located (without a gap) directly in front of the safety glass plate (and the spacer has no function except bridging the gap between the aluminum case and the frame). This flexibility allows for using the presentation device in experiments with a wide variety of species.

Furthermore, the aluminum case contains a CarrollTouch 4000U USB Controller, which serves as an interface for the IR touchframe, as well as a switching power supply for all of the incorporated devices. On the back panel of the monitor is a central on/off switch for the LCD display, the IR touchframe, the touchframe controller, and the LVDS-port converter.

The IR technology we have used has at least three main advantages over some other types of touchscreens. First, no additional layers, apart from the safety glass plate, are required for the LCD display. Any additional layers would deteriorate the stimulus quality and would, moreover, get increasingly damaged by pecking. Second, the detection of responses does not require any strain on the part of the subject (i.e., by touching the monitor), as is the case with other touchscreens. Actually, pigeons and other birds may find vigorous pecking onto the monitor painful, particularly in procedures that require high response rates, such as go/no-go tasks, and this may result in motivation decrements. Third, beaks (and other objects) can easily trigger a response, which is not always ensured with other types of touchscreens. Capacitive touchscreens, for example, require a conductive connection of the releaser to the ground, but this is not provided by beaks, which are almost nonconductive.

## Network

All Skinner box units are connected to a local-area network complying with current standards (100 Mbit). Because all stimuli and files necessary for running the experiments, as well as the logged data, are centrally stored on a fileshare (located on a server), it is possible to train every animal in every box. This may be advantageous if a subject has to be moved to another aviary compartment or in the case of a malfunction of one of the boxes, and it facilitates time and data management. Furthermore, the application of VNC®[4] (Virtual Network Computing) allows for controlling the experimental sessions from one single workstation, and thus makes individual control monitors and keyboards for each experimental chamber unnecessary.

## Video surveillance system

The surveillance cameras in the Skinner boxes and the aviaries can be connected to a surveillance monitor and to a computer (plus monitor) equipped with video digitization hardware, which are established in the control area. Several cameras can be connected simultaneously to both video output devices (the surveillance monitor and the computer). This allows for flexibly observing and recording in parallel the activities of several birds inside the boxes, as well as in the aviaries.

A switch cabinet containing BNC patch panels is installed overhead in the control area (see Fig. 2, right). The cameras of the individual boxes and aviaries, as well as the input ports of the video computer and of the surveillance monitor, are connected to the patch panels. This enables the experimenter to flexibly patch the cameras to the output devices. Furthermore, the switch cabinet houses the central DC power supply for the cameras, which (including their illumination systems) can be

---

[4] VNC is a registered trademark of RealVNC Ltd. in the U.S. and in other countries.

switched on and off individually. The outlets of the system cables (i.e., combined coaxial cables plus shielded power supply cables) are located in immediate proximity to the Skinner boxes, which allows for easily unplugging and exchanging individual cameras and/or boxes.

## Software

The CU can be operated with any available operating system compatible with an Intel®[5] x86 architecture. Currently, we use Microsoft® Windows XP.[6]

The software package we have employed, CognitionLab (Version 1.9) presently supports go/no-go experiments with a pecking key or a touchscreen input device, conditioned discriminations (like matching to sample), sequence-learning procedures (which require the subject to choose a number of stimuli in a particular order), and multiple-alternative forced choice procedures (which allow for simultaneous presentation of freely selectable numbers of positive and negative stimuli; see Huber et al., 2005, for details). Furthermore, CognitionLab has many possibilities for easy adjustments and modifications (e.g., the use of correction procedures) and provides the user with great flexibility regarding the experimental settings (such as time intervals, numbers of stimuli presented in a trial, stimulus positions, etc.). Finally, the program offers a number of simple procedures for pretraining the subjects (including autoshaping and peck-training procedures).

The program is operated in batch mode—that is, trial definitions are successively loaded from a text file and processed. Data are logged into a single text file, which can easily be analyzed (both manually and in an automatized fashion). Before a session is started, the entire file to be processed is analyzed and checked for possible syntax errors, wrong file names (e.g., nonexisting files), damaged bitmap files, and so forth. All of the data required for executing a trial (such as the stimuli to be presented) are loaded during the preceding intertrial interval (ITI). Also, all necessary computations (e.g., pseudorandom stimulus placements) are carried out during the ITI. All log entries are buffered in the process memory and are transferred to the log file only after the trial is terminated. This ensures that the program remains responsive during a trial, without any delays due to slow input/output operations or computations. Therefore, all files (the stimuli, text files to be processed, and log files) can be stored on network shares without any loss in speed, which provides a considerable advantage for handling a large laboratory with several Skinner boxes that are operated in parallel.

## Adjustments for different species

So far, we have used the reported technology for experimentation with pigeons, keas, corvids (ravens, crows and jackdaws), dogs, wolves, marmosets, small reptiles (currently tortoises), and humans (see, e.g., Aust & Huber, 2009, 2010; Aust et al., 2008; Bayer, 2008; O'Hara, 2011; Range, Aust, Steurer, & Huber, 2008). For testing with humans, the software is run on a standard workstation with a computer mouse usually serving as the input device. Figure 6 shows modifications of the apparatus for use with different species.

Dogs and wolves, which do not work in closed chambers, are trained in modified versions of our Skinner boxes (Bayer, 2008; Range et al., 2008). The IR touch monitor is placed at head level, which can be achieved in two ways: Either the monitor is mounted in a way that allows for adjusting it vertically, or (in the case of very small dogs) the subjects are provided with a pedestal. Left and right of the monitor are white side panels made of synthetic material to shield the subjects' view and also to prevent the experimenter from seeing the monitor. The latter precaution is necessary to avoid behavioral cueing. Beneath the monitor is the outlet of the feeder, which is a pellet dispenser built in our workshop. It uses the same motor type as the grain lifter, but here, a rotating disc (30-cm diameter) made of polyoxymethylen copolymer is directly mounted onto the motor shaft. Circularly on the rim of the disc are arranged 36 small holes (16-mm diameter) in which food pellets can be placed. Food is prevented from immediately falling through by a second, stationary disc that is mounted between the rotatable disc and the motor. This disc has just one peripheral hole, and whenever one of the holes of the rotating disc is above the single hole of the stationary disc, the food pellet falls through a tube, which transports it to the food outlet beneath the monitor. Thirty-six equidistant notches are cut into the rim of the rotatable disc, each corresponding to one of the holes. These notches are sensed by a single-pole double-throw microswitch. For controlling the pellet dispenser, the CU is operated in edge-triggered mode (see the supplemental materials) and responds to the registration of a notch by switching off the motor.

The same types of modified Skinner boxes and feeders used for the dogs are also used for experimentation with keas and corvids. In addition, a perch is mounted in front of the monitor, and food coming out of the feeder outlet is collected in a receptacle. For all species, the same presentation and input

---

[5] Intel® is a trademark of Intel Corporation in the U.S. and/or other countries.

[6] Microsoft® and Windows® are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

**Fig. 6** Different species working with variations of our Skinner box (pigeon, kea, jackdaw, tortoise, dog, and human)

devices, control computers, and software are used. For keas, the touchframes are mounted inversely to shorten the retraction ways for the beaks (see the Presentation Device section).

## Sources of supply and costs

The costs are about €1,500 for one CU and about €1,300 for one IR touch monitor (VAT excluded). The material costs are about €300 for a feeder and about €100 for a Skinner box (pigeons). Our feeders, Skinner boxes, and racks were entirely devised and built by the workshop of the Department of Cognitive Biology (University of Vienna), and are thus not freely available commercially. For further information on sources of supply, please contact the first author.

## Conclusion

The laboratory system described in this report was devised with the goal of providing solutions to a number of research needs that have been met only in part or in an unsatisfactory way by the standard equipment normally used in experiments on animal learning and cognition. The main advances of the VCCT can be summarized as follows.

1. *Simplification and flexibility* The use of a control computer as described here brings about considerable simplifications concerning technical and electronic challenges, as well as a high level of flexibility. The control devices can, by themselves, be used with different types of feeders without any need to make changes in the hardware, and they even allow for the use of two feeders at the same time. Likewise, two input devices and another output device can be operated simultaneously. The 1-Wire ICs are simple to operate (electronic installation and software programming), and the 1-Wire bus allows for easily extending the system's range of functions with self-made electronics. The Skinner boxes can optionally be used with either pecking keys or touchscreens, and switching between the two can be accomplished in a fast and simple manner.
2. *Advanced technology* Its dust-proof design makes the equipment quite suitable for use in animal labs. Innovative developments, like the grain lifter, provide a number of methodological improvements (such as a minimum distance between stimuli and the reward, as well as prevention of "food stealing"). The employed presentation units exhibit outstanding optical characteristics (regarding brightness, contrast, viewing angle, etc.), and their design makes them ideal for use with Skinner boxes. The video surveillance system allows for observing the subjects during experimental sessions as well as for recording their behavior for later analysis.
3. *Applicability* The employed IR technology was initially adapted for experimentation with pigeons, but as it is (with only minor modifications) also appropriate for use with other species, it has a huge potential for comparative cognition research.
4. *Low maintenance requirements* All in all, the technology we employ requires relatively little servicing, which is an absolute necessity in a large laboratory with a variety of experiments being run simultaneously in several boxes. This aspect of the system is also advantageous for different teams working in parallel on similar tasks with different species.

**Author note** Our pigeon laboratory (aviaries and technical equipment) was established with the financial support of projects funded by the Austrian Science Foundation (P10975, P14175, P17157, T139, V3-

B03, P19574). The electronics and software described in this report have been developed by the first author independently of any funding. Thanks are due Peter Hoffmann, for discussion and technical advice, and Wolfgang Berger, Walter Witek, and Walter Pogats from the workshop of the Department of Cognitive Biology, for constructing the Skinner boxes and feeders.

## References

Aust, U., & Huber, L. (2006). Picture–object recognition in pigeons: Evidence of representational insight in a visual categorization task using a complementary information procedure. *Journal of Experimental Psychology: Animal Behavior Processes, 32,* 190–195. doi:10.1037/0097-7403.32.2.190

Aust, U., & Huber, L. (2009). Representational insight in pigeons: comparing subjects with and without real-life experience. *Animal Cognition, 13,* 207–218.

Aust, U., & Huber, L. (2010). The role of skin-related information in pigeons' categorization and recognition of humans in pictures. *Vision Research, 50,* 1941–1948.

Aust, U., Range, F., Steurer, M., & Huber, L. (2008). Inferential reasoning by exclusion in pigeons, dogs, and humans. *Animal Cognition, 11,* 587–597.

Bayer, K. (2008). *Objektdiskrimination bei Hunden (Canis familiaris)*. Unpublished diploma thesis, University of Vienna.

Cook, R. G. (1992). Acquisition and transfer of visual texture discriminations by pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 18,* 341–353. doi:10.1037/0097-7403.18.4.341

Cook, R. G., Geller, A. I., Zhang, G.-R., & Gowda, R. (2004). Touchscreen-enhanced visual learning in rats. *Behavior Research Methods, Instruments, & Computers, 36,* 101–106. doi:10.3758/BF03195555

Fagot, J., & Bonté, E. (2010). Automated testing of cognitive performance in monkeys: Use of a battery of computerized test systems by a troop of semi-free-ranging baboons (*Papio papio*). *Behavior Research Methods, 42,* 507–516. doi:10.3758/BRM.42.2.507

Fagot, J., & Paleressompoulle, D. (2009). Automatic testing of cognitive performance in baboons maintained in social groups. *Behavior Research Methods, 41,* 396–404. doi:10.3758/BRM.41.2.396

Gibson, B. M., Wasserman, E. A., Frei, L., & Miller, K. (2004). Recent advances in operant conditioning technology: A versatile and affordable computerized touchscreen system. *Behavior Research Methods, Instruments, & Computers, 36,* 355–362. doi:10.3758/BF03195582

Huber, L. (1994). Amelioration of laboratory conditions for pigeons. *Animal Welfare, 3,* 321–324.

Huber, L., Apfalter, W., Steurer, M., & Prossinger, H. (2005). A new learning paradigm elicits fast visual discrimination in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 31,* 237–246. doi:10.1037/0097-7403.31.2.237

Lazareva, O. F., Freiburger, K. L., & Wasserman, E. A. (2004). Pigeons concurrently categorize photographs at both basic and superordinate levels. *Psychonomic Bulletin & Review, 11,* 1111–1117. doi:10.3758/BF03196745

O'Hara, M. (2011). *Reversal learning in the kea (Nestor notabilis): Comparing the touchscreen to a reality approach*. Unpublished diploma thesis, University of Vienna.

Range, F., Aust, U., Steurer, M., & Huber, L. (2008). Visual categorization of natural stimuli by domestic dogs (*Canis familiaris*). *Animal Cognition, 11,* 339–347.

Vaughan, W., & Greene, S. L. (1984). Pigeon visual memory capacity. *Journal of Experimental Psychology: Animal Behavior Processes, 10,* 256–271. doi:10.1037/0097-7403.10.2.256