Research Article

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Technical assessment of mechanical and electronic traps to facilitate future improvements in trap efficacy and humaneness

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Abstract

BACKGROUND: Snap traps and electronic traps are the main devices for nonchemical management of rodent pests. Traps should be efficient and should not cause unnecessary suffering of animals. Harmonized, systematic test methods are required to make sure that mechanical forces or electrical parameters are optimal to achieve swift unconsciousness and death. This study aimed to describe technical trap properties that can be used to facilitate future improvements in trap efficacy and humaneness.

METHODS: We constructed a device to assess spring energy, triggering force, impulse and clamping force, and developed an arrangement to assess effective voltage, current, effective current and effective energy taking effect on rodent bodies in electronic traps – all without the use of animals. Descriptive data of trap characteristics were collated.

RESULTS: All factors showed variability among snap trap models and trigger types, and there was considerable overlap between mouse and rat traps. For most trap models, there was no difference among new snap traps and traps that had been trigged 20 times. Effective current and effective energy decreased with lower voltage input, but the traps indicated weak battery by LED lights, and one model switched off automatically when voltage was insufficient.

CONCLUSION: With the device and the electronic arrangement, the majority of snap trap models and electronic traps available on the market can be assessed in a standardized and repeatable way. Matching the data generated in this study with data on time for trapped target animals to reach irreversible unconsciousness, and experiences from pest control practitioners, should allow relating properties of traps to efficacy and animal welfare issues. This can support further development and optimization of traps for nonchemical rodent pest control.

Supporting information may be found in the online version of this article.

Keywords: electronic trap; nonchemical; rodent pest; rodent management; snap trap; trapping

1 INTRODUCTION

Some rodent species cause problems because they damage infrastructure, agriculture and forestry, eat or contaminate stored goods, and are hygiene/health pests.[1] This is particularly the case for commensal rodents such as house mice (*Mus musculus*), Norway rats (*Rattus norvegicus*) and black rats (*Rattus rattus*).[1]

Rodent management usually relies on the use of rodenticides.[1,2] Rodenticides are increasingly considered as problematic regarding animal welfare,[3] and in the case of anticoagulant rodenticides there are concerns about resistance and environmental effects[4] such as secondary exposure of nontarget species.[2] As a result, restrictions on use increase[5] and so does the need for suitable alternatives including traps. The latter have been promoted recently by the Biocidal Products Committee of the European Chemical Agency for house mouse management.[6] Rodents also are snap-trapped for various studies of rodent biology and ecology including population dynamics, demography, dispersal or the epidemiology of rodent-borne pathogens and parasites. Snap trapping allows swift removal of dead rodents, which is beneficial not only in such studies, but also in management compared to carcasses of rodenticide poisoned rodents decaying in locations that are difficult to access.

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Two fundamentally different traps are generally used for the management of house mice and rat species: mechanical traps (mainly snap traps = jaw traps = break-back traps) and electronic traps. The function of snap traps is based on a rotating or dropping bar that is particularly effective when the skull or cervical spine is hit.[7] Electronic traps deliver a fatal electronic current and could be more effective regarding efficacy and animal welfare[8] depending on positioning of the animal in the electronic trap and various electrical parameters including current and resistance.[9]

Optimal snap traps are designed in such a way that they catch effectively and do not cause unnecessary suffering of animals during capture.[10,11] This results in the calls for appropriate legislation, trap testing, and certifying procedures and trapping devices that conform to animal welfare requirements.[12] The development of guidance documents for testing rodent traps regarding efficacy and animal welfare have been suggested and realized.[13–15] These approaches are usually based on regulation relating to time to irreversible unconsciousness, for example the International Agreement on Humane Trapping Standards[16] and may require live rodents to be used in trials.

Snap traps do not generally require approval worldwide except in Sweden.[8,17] In other countries, there is no mandatory animal welfare assessment of traps for rodents, with the exception of some species covered by hunting legislation.[16,18]

Clamping force and impulse are two characteristics of snap traps generally recognized as suitable proxies for time to irreversible consciousness, the latter being an indicator regarding animal welfare of rodents captured with snap traps.[19,20] They can vary considerably among and between house mouse traps and rat traps.[17] Optimizing triggering force might be a tool to increase efficacy, welfare performance and species specificity.

It is unclear which thresholds of mechanical forces or of electrical parameters are optimal to achieve swift unconsciousness/death of the target rodent as this will vary among species. Apart from Baker *et al.*,[17] there is no published information about a device that measures relevant impulses and forces inherent to snap traps, and to assess electronic traps in a systematic and standardized manner. Prototypes for such test devices were developed for larger fur-bearing animals.[21,22]

Test systems for measuring technical key parameters of traps can and should be established and used to assess whether a trap model is suitable for killing target rodents in an animal welfare-friendly and effective way. Traps have been identified that cause immediate unconsciousness[10,17] – the most ethical option for rodent kill traps – and more may surface in current testing schemes.[13] Is an animal welfare-friendly result unlikely because impulses, forces or electric currents don't reach thresholds required for swift unconsciousness/death in the target rodent, such unsuitable models could be excluded from further test procedures (e.g. in animal experiments). However, presently, such thresholds are not known. This is a consequence of (i) the lack of a standardized device to collect relevant data on trap impulses, forces and currents systematically, and (ii) the lack of publicly available data that can be used to correlate data from (i) to efficacy and welfare performance of traps.

In this project, we developed a test device that can be used to determine the physical properties of a large variety of snap traps for house mice and rats and a protocol and set up for assessing the physical properties of rodent electronic traps. With the device, we conducted measurements of physical-technical parameters for rodent traps available on the market and compared them among trap models, between new and used traps and among trap trigger types. With a separate standardized set up, we assessed relevant parameters of electronic traps.

When findings are combined with existing data for example obtained in approval trials, the device could be used to assess the suitability of traps before traps are tested in future animal experimentation related to trap approval procedures. This will improve efficacy and animal welfare in future approval procedures, and when trapping rodents in commensal situations and beyond.

2 MATERIAL AND METHODS

2.1 Traps

From a pre-selection of 61 house mouse and 42 rat traps available in physical stores in Germany and online shops (amazon.com, ebay.com, alibaba.com), 20 mouse and 14 rat trap models were selected that differed sufficiently in design (Table 1). This model selection was the basis for the development of the measuring device. Traps were categorized by the trigger types: treadle (step-on release), lift trigger (release by lifting a trigger when entering the trap or to reach a bait) and push–pull trigger (release by pulling or pushing a bait plate or by pressing against a structure obstructing access to bait). Within the trigger types, models differed in material (plastic, metal, wood), impact mechanism (rotating bar, drop bar) and other mechanical characteristics (Table 1).

Two electronic mouse traps (Victor electronic mouse trap, Victor multi-kill electronic mouse trap) and one electronic rat trap (Victor electronic rat trap) were considered, all using metal surface contact plates as the triggering mechanism. The small number of electronic traps compared to snap traps included in this study reflects the smaller number of electronic traps commercially available and the considerable similarity of models. Single-catch electronic traps must be brought to operating condition after each triggering. Multiple-capture electronic traps have a collection container for trapped animals to empty the capture chamber for the next catch.

2.2 Triggering force

The triggering force reflects the weight needed to release the trap mechanism. Preliminary tests showed mean triggering forces of 0.35 N for rat traps and 0.03 N for mouse traps. To measure the triggering force, the sensor had to be sufficiently flat to allow the probe tip to reach the release mechanism of all traps. It was prevented from being hit by an additional strap to catch the bar [Fig. 1(a)]. Commercially available force sensors could not meet these technical and geometric requirements. Therefore, a hand-held probe sensor (Supporting Information, Fig. S1) with a nominal load of 0.5 N was designed, built and used [Fig. 1(a)]. This sensor used the principle of a double bending beam with four active strain gauges in a Wheatstone full bridge circuit. In this arrangement, the change in resistance was only sensitive to changes in lateral force and was independent of the length of the probe tip mounted on the front spacer to trigger the traps. The spacers and the probe tip were made of plastic to make the front end of the probe as light as possible for accurate measurements. Calibration was performed by placing the weight of a precision balance on the measuring tip. Data acquisition of the triggering force was run at 20000 samples s^{-1}. For automated evaluation of the measurements, it was necessary to accurately determine the triggering force from the force signal measured by the handheld sensor superimposed by the mass forces resulting from its movements. Therefore, a microphone was added to the measurement set-up directly next to the trap, which, when the trap was triggered, provided a sufficiently high voltage

Table 1. General description of snap traps for mice and rats considered in the study

Trap	Cover	Trigger	Spring design	Impact mechanism
GORILLA TRAPS mouse trap	Open	Treadle	Double torsion spring	Rotating bar
Kness Snap-E mousetrap	Open	Treadle	Double torsion spring	Rotating bar
LUNA Mousetrap	Open	Treadle	Single torsion spring	Rotating bar
FOX Mousetrap	Open	Treadle	Single torsion spring	Rotating bar
Victor Easy Set Mouse Trap	Open	Treadle	Single torsion spring	Rotating bar
Mouse Trap SuperCat	Open	Treadle	Helical spring	Rotating bar
'No See, No Touch' mousetrap	Tunnel	Treadle	Single torsion spring	Rotating bar
Tomcat Mouse Snap Trap	Open	Treadle	Tension spring	Rotating bar
TRAPPER Mini-Rex	Open	Treadle	Double torsion spring	Rotating bar
Celaflor Mousetrap Ultra Power	Open	Treadle	Double torsion spring	Rotating bar
Cumarax tunnel mouse trap	Tunnel	Treadle	Tension spring	Rotating bar
Pre-Baited Snap Trap	Open	Treadle	Tension spring	Rotating bar
Anticimex Smart Snap	Open	Treadle	Double torsion spring	Rotating bar
GORILLA TRAPS mouse trap 2.0	Open	Treadle	Double torsion spring	Rotating bar
Mouse Trap PRO SuperCat	Open	Lift	Helical spring	Rotating bar
WINDHAGER Mouse trap SNAP	Open	Lift	Tension spring	Rotating bar
LUCHS Mousetrap	Open	Push–pull	Single torsion spring	Rotating bar
Victor Quick-Set Mouse Trap	Open	Push–pull	Double torsion spring	Rotating bar
TRAPPER Hidden Kill	Tunnel	Push–pull	Tension spring	Drop bar
Victor Kill-Vault Mouse Trap	Tunnel	Push–pull	Clasp spring	Drop bar
GORILLA TRAPS rat trap	Open	Treadle	Double torsion spring	Rotating bar
Kness Big Snap-E Rat Trap	Open	Treadle	Double torsion spring	Rotating bar
LUNA Rat Trap	Open	Treadle	Single torsion spring	Rotating bar
FOX Rat Trap	Open	Treadle	Single torsion spring	Rotating bar
Victor Easy Set Rat Trap	Open	Treadle	Double torsion spring	Rotating bar
Rat Trap SuperCat	Open	Treadle	Helical spring	Rotating bar
TRAPPER T-Rex	Open	Treadle	Double torsion spring	Rotating bar
Little Nipper Rat Trap	Open	Treadle	Single torsion spring	Rotating bar
Sure-Set Rat Trap	Open	Treadle	Double torsion spring	Rotating bar
Rat Trap PRO SuperCat	Open	Lift	Helical spring	Rotating bar
WINA Rat Killer	Open	Push–pull	Double torsion spring	Rotating bar
LUCHS Rat Killer	Open	Push–pull	Double torsion spring	Rotating bar
Victor Metal Pedal Rat Trap	Open	Push–pull	Double torsion spring	Rotating bar
Easy Setting Metal Rat Trap	Open	Push–pull	Double torsion spring	Rotating bar

signal for evaluation at a digital input of the measurement system [Fig. 1(a)]. This signal marked the trigger point for data recording. The force to trigger the trap was determined from the maximum force in a small interval immediately before this point in time.

2.3 Impulse of the bar (impulse)

The impulse $\Delta\overrightarrow{p}$, is a measure of how powerfully the trap bar hits a target animal and is an objective physical quantity suitable for describing the effect of the trap when it strikes a target animal, but it cannot be measured directly. The trap bar moves rotationally in most traps. Instead of examining its angular momentum, only the currently tangential component of the movement is considered as translation. For this translational motion, the impulse $\Delta\overrightarrow{p}$ is defined as the impulse from the initial state at time t_0 to the momentum at time t_1.

$$\Delta\vec{p} = m\vec{v}(t_1) - m\vec{v}(t_0)$$

The effect of a force $\overrightarrow{F}(t)$ acting in the interval from t_0 to t_1 causes the impulse.

$$\Delta\vec{p} = \int \vec{F}(t)\mathrm{d}t$$

Thus, the impulse $\Delta\overrightarrow{p}$ between the moment of impact of the trap bar on the rodent and the final resting state can be determined by numerical integration of a high-resolution measured force curve $F(t)$ in the interval between t_0 and t_1.

The experimental device was fitted with a safety catch for the trap bar. This gripper became effective 20 mm before impact on the base plate for mouse traps and 40 mm for rat traps [Fig. 1(b)]. The reaction force of the safety catch that was required to brake the trap bar was measured with a load cell with nominal load of 200 N at a sampling rate of 10^5 samples s^{-1}. A damper in the load cell support reduced the peak load and prolonged the impact process without influencing the determined impulse.

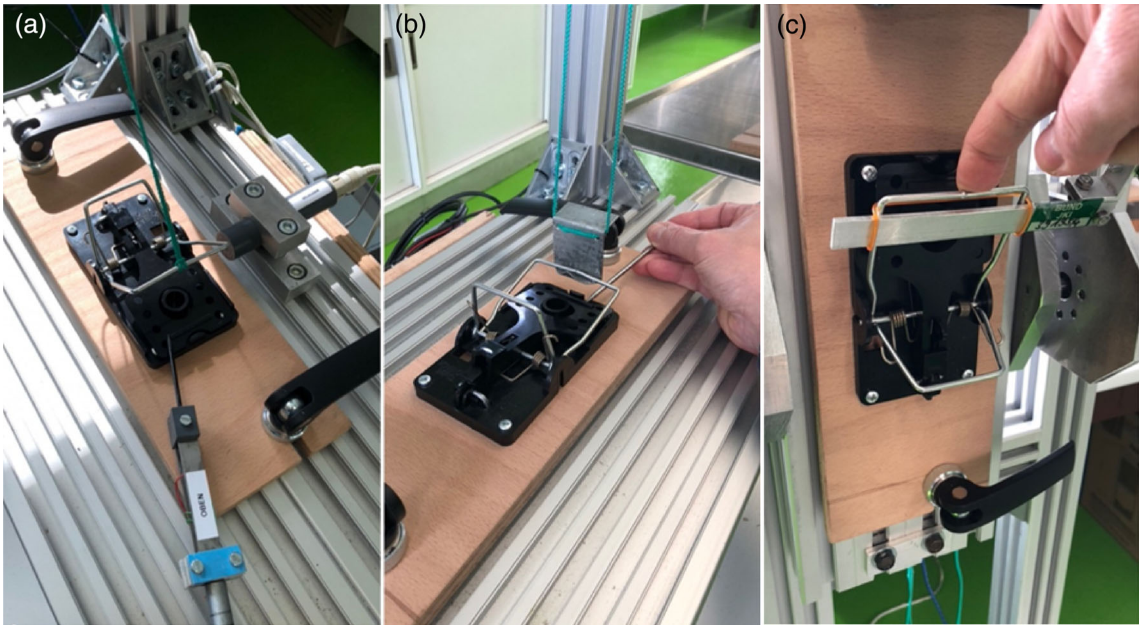

Figure 1. Traps fixed to a wooden plate used to position traps in the apparatus at several sensor positions to measure (a) triggering force (b), impulse and clamping force, and (c) spring energy.

2.4 Clamping force

The clamping force that restrains the rodent after the trap closes was determined using the same testing procedure and method as for the impulse test [Fig. 1(b)]. The static force acting on the trap bar after the impact was read from the impulse data. This value corresponded to the clamping force when the distance between the bracket and base plate was 20 mm for mouse traps and 40 mm for rat traps.

2.5 Potential energy of the spring (spring energy)

The spring energy is the potential energy stored in the trap mechanism. In most traps, the trap bar rotates around an axis and is tensioned by a torsion spring. To specify the potential energy E_{pot} of the tensioned spring, the mechanical work W done by the moment $M(\varphi)$ applied to tension the spring along the angle φ of the rotating trap bar needed to be determined. Assuming frictionless motion, this work W corresponds to the change of elastic potential ΔE_{pot} of the spring:

$$\Delta E_{pot} = W = \int_{\varphi 0}^{\varphi 1} M(\varphi) d\varphi$$

The angle φ_0 describes the position of the trap bar in the released state and φ_1 in the tensioned state of the trap. The maximum difference $(\varphi_1 - \varphi_0)$ was $\approx 180°$, but in some traps only $\approx 90°$. The traps were mounted with their uniform base plate on a rocker whose rotation around the axis was prevented by a torque sensor with a nominal load of 20 Nm. A MEMS-based tilt sensor with a measuring range of 360° and resolution of 0.2° was clamped to the trap bracket for angle measurement [Fig. 1(c)]. In this arrangement, the reaction torque and the angle could be measured synchronously when the spring was manually tensioned. The work W performed between the initial angle φ_0 and the final position φ_1 could be calculated by numerically integrating the measured relationship of torque and angle.

The experimental set-up for investigating snap traps was mounted in a stable profile system frame (Fig. 2), which housed all sensors and cabling for signal conditioning. Individual traps were affixed with screws to sensor positions on standardized base plates crafted from laminated wood. This may not optimally reflect the variety of surfaces where traps are placed for practical use but provided the opportunity for standardized measurements. The base plates could be easily and consistently secured to the frame using clamping levers according to the desired test configuration (Fig. 1). Tunnel traps, where the mechanism was concealed within a casing, have been opened to expose and investigate the mechanism.

A PicoScope® 5000D-Series oscilloscope, together with PicoScope 6 software (Pico Technology, Cambridgeshire, UK), was used to acquire and store raw data. Within this project, we developed PicoPulse, a database software that enables management of all tested traps, tests, measurements, analyses and parameters. The acquired data were evaluated and visualized semi-automatically with user control. The software also offers interfaces to MS Excel (Microsoft, Redmond, WA, USA) for data export and further analysis as needed.

2.6 Electronic traps

Quasi-static measurements were conducted at the beginning and end of retriggering traps using a TRMS multimeter (VoltCraft VC 251, 600 V, 45-400 Hz, 10 MΩ; Conrad Electronic SE, Hirschau, Germany). In a quasi-static process, variable values (in this context voltage and current) change so slowly that there are hardly any or 'virtually/quasi' no changes if measurements are done in quick succession. Therefore, it was sufficient to obtain quasi-static measurements at the beginning end of the process. For these measurements, it was necessary to open the trigger compartment of the electronic traps before deactivating protective devices and, if necessary, to create usable contact points for power supply, measuring devices and dummy bodies. The power supply for electronic traps was provided by a laboratory power supply unit

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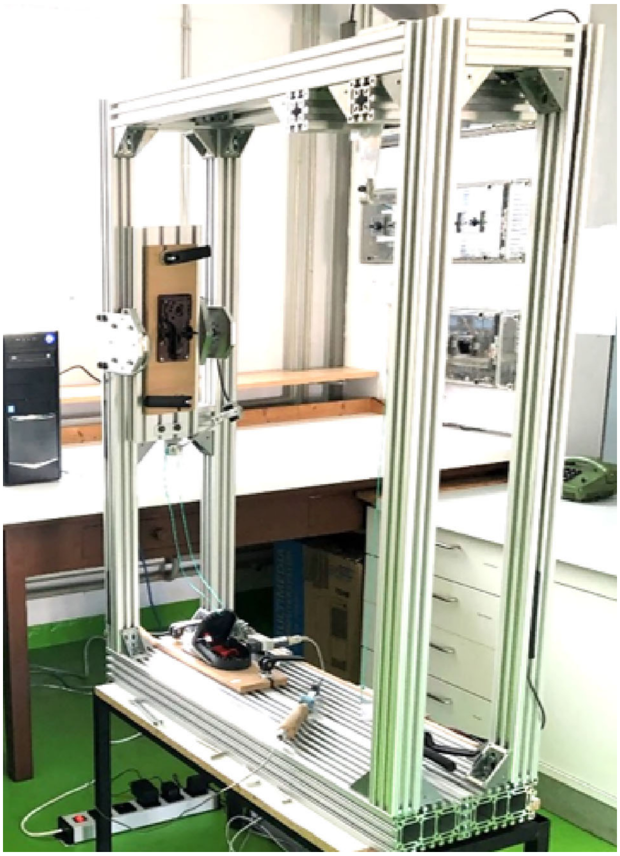

Figure 2. Profile system frame with sensors for spring energy (left), triggering force (centre), impulse and clamping force (right), and traps fixed to the apparatus.

(PeakTech 6225A, 0-30 V, 0-5 A; PeakTech, Ahrensburg, Germany) simulating new as well as aged batteries. The maximum output current was fixed to 2.5 A.

2.7 Effective voltage and current

The voltage (V) is a measure of the potential difference of electric charges between two points in an electrical circuit (difference of negative and positive electrical charges). The current measures the 'amount' of electrical charges flowing through an electrical circuit trying to balance the difference between negative and positive charges. Voltage and current are not proportional to each other. It is possible to have a high voltage with a low current or *vice versa*. The ratio between the two units is the electrical resistance.

To measure voltage, a passive high-voltage probe (VoltCraft H40, 28-40 kV, 60 Hz, 1000 MΩ, Ratio 1000:1; Conrad Electronic SE) was connected between the contact surfaces of the electronic traps and connected to the TRMS multimeter (measuring range 20 V~). The trap was triggered by statically bridging the trap contact surfaces with different electrical resistances (MFR1145 metal surface resistor, 1–1.5 kΩ; Weltron Elektronik GmbH, Feuchtwangen, Germany) simulating a triggering rodent.

Each electronic trap was assessed with an input voltage of 6.3 V (corresponding to new battery), 6 V, 5.5 V, 5 V and 4.5 V (corresponding to aged batteries). Depending on the input voltage, the trap was triggered either by short contacting (<1 s) of the trap contact surfaces via a resistor (1 kΩ) or via permanent contacting with a resistor of 1 kΩ or 1.5 kΩ. For each combination of input voltage and electrical resistance trigger, three current and high voltage measurements were conducted and the mean values for these measurements were calculated. It also was noted whether the battery warning indicator (low voltage supply) of the electronic trap kicked in. Between the measurement runs, there were pauses of ≥2 min when the traps were without current. Between charging and triggering the trap, there were breaks of 20 s.

During each measurement, the output voltage and the output current from the laboratory power supply unit to the electronic trap as well as the high voltage emitted by the electronic trap were recorded from the power supply unit and multimeter readings. The values were read during charging as well as in the first and last 5 s of a trigger interval, if necessary also after half a trigger interval. The duration of charging the electronic trap and the duration of the triggering intervals were determined to the second using a digital stopwatch (TFA Dostmann, art.-no. 38.2029; TFA Dostmann GmbH & Co. KG, Wertheim-Reicholzheim, Germany).

2.8 Effective current and effective energy

Effective energy is the energy acting in the body of an animal caused by the relation of the alternating high voltage parameters (from the electronic trap) and the electrical resistance of the animal's body. The voltage emitted via the contact surfaces of the electronic traps, and the effective current acting on the rodents are decisive for the effect of an electric current on house mice and rats. Both parameters depend on the effective electrical body resistance of the animal, which the animal causes between the trap contact surfaces. The effective current cannot be measured directly but was determined by dividing high voltage by electrical resistance of the animal's body (Ohm's Law):

$$\textit{effective current}\ (I_e) = \frac{\textit{high voltage}\ (U_H)}{\textit{body resistor}\ (R_b)}$$

The energy acting on the animal, was calculated as:

$$\textit{Energy}\ (J) = \textit{high voltage}\ (U_H) \times \textit{effective current}\ (I_e) \times \textit{period duration}\ (T)$$

where the period duration was calculated as:

$$\textit{period duration}\ (T) = \frac{1}{\textit{clock frequency}\ (f_H)}$$

Because the TRMS multimeter gives the effective voltage as a root-mean-square of the sinusoidal AC curve, the peak voltage (voltage at the peak value of the sinusoid curve) was calculated by the effective voltage multiplied by the factor 1.414. All measurements were conducted at room temperature (18–20 °C) and relative humidity of 40–55%.

2.9 Statistical analyses

Five traps per snap trap model and two electronic traps per model were evaluated. The traps were unused upon receipt from the supplier in the first run. In the second run, each trap was triggered 20 times using a 'dummy' made of rolled-up paper towels fixed with insulating tape. The dummy had a diameter of 20 mm (house mouse) or 40 mm (rat). Three measurements were taken for each parameter and mean values calculated for new traps and triggered 20 times for each trap model.

For each variable, we used two individual sets of statistical models to assess the effect of snap trap model, condition (new/20 times triggered) and trigger type (treadle/lift/push–pull) on the parameters triggering force, impulse, clamping force and spring energy. This was done separately for mouse traps and rat traps. In the first model, the effect of trap model and condition was tested with an ANOVA (standard least squares) (factors: condition, trap model and interaction) for the four parameters. Significant interaction effects are reported for new and used models of the same trap model. Effects of trigger type were tested separately with an ANOVA (standard least squares). A Tukey's significant difference (HSD) *post hoc* test was run when the ANOVA indicated differences.

According to the results of Tukey's HSD tests, trap models were ranked regarding impulse, clamping force and spring energy in decreasing values (lowest rank number for highest parameter value). Triggering force was not considered because it is not directly associated to hitting and holding the rodent. The rank numbers for these three parameters were added per trap model, which resulted in a rank sum used to compare relative overall performance of traps models. Spring energy could not be measured for two mouse traps (Hidden kill mouse trap, Victor Kill Vault mouse trap) because they have a drop bar mechanism. These two traps were not considered in the ranking.

For electronic trap models data were pooled and we used a fully factorial ANOVA model to assess the effects of input current and resistance on the parameters effective voltage, current, effective current and effective energy. A Tukey's HSD *post hoc* test was run when the ANOVA indicated differences.

Analyses were run with JMP v17.0.0 (JMP Statistical Discovery LLC). Means and standard error are reported throughout.

3 RESULTS

3.1 House mouse snap traps

The mean triggering force of house mouse snap traps was 0.14 ± 0.03 N [Fig. 3(a)]. It ranged from 0.04 N to 0.66 N, with 95% ($n = 19$) of traps in the range of 0.04–0.19 N and differed among trap models ($p < 0.001$) (Table 2). The highest triggering force was measured for TRAPPER Hidden Kill (Table 2). The triggering force of traps in the factory-new condition (0.15 ± 0.04 N) were similar to those after 20-fold release (0.13 ± 0.02 N) ($p = 0.09$). There was an interaction of trap model and condition showing that the triggering force of used TRAPPER Hidden Kill traps was different to new models (new 0.8 N; used 0.5 N) ($p < 0.001$). The mean triggering force of house mouse traps with push–pull

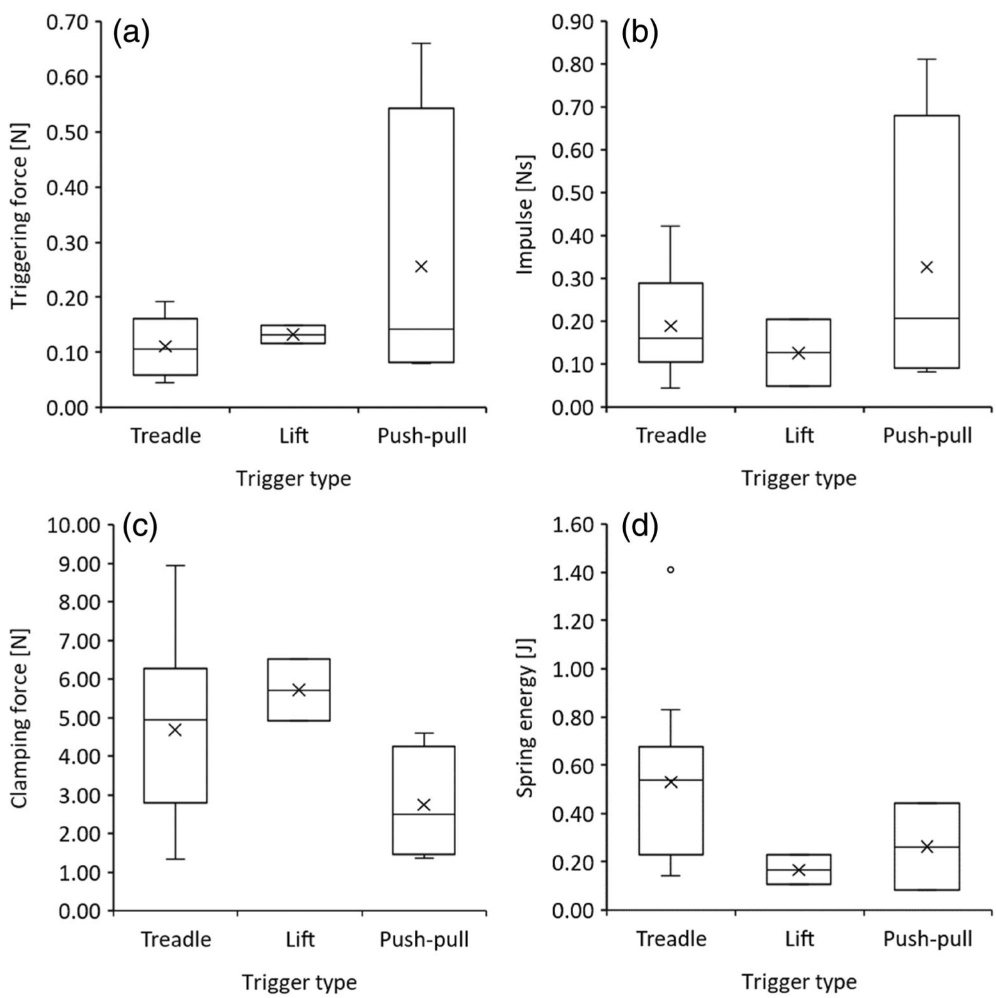

Figure 3. Technical characterization of mouse traps by trigger type regarding (a) triggering force, (b) impulse, (c) clamping force and d) spring energy. Box, 25/75% quartile; X, mean; horizontal line, —median; whiskers, minimum/maximum (<1.5-fold interquartile distance); dots, outlier (>1.5-fold interquartile distance).

Table 2. Mean values ± standard error (SE) of triggering force, impulse, clamping force and spring energy for rat traps and mouse traps

	Triggering force (N)		Impulse (Ns)			Clamping force (N)			Spring energy (J)			
RAT TRAPS	Mean ± SE	Diff.	Mean ± SE	Diff.	Rank	Mean ± SE	Diff.	Rank	Mean ± SE	Diff.	Rank	Rank sum
WINA Rat Killer	0.56 ± 0.0216	BC	0.83 ± 0.0017	A	1	21.32 ± 1.29	B	2	9.36 ± 0.285	A	1	**4**
LUCHS Rat Killer	0.69 ± 0.0123	B	0.71 ± 0.0073	ABC	3	14.27 ± 0.34	D	4	7.65 ± 0.013	B	2	**9**
TRAPPER T-Rex	0.29 ± 0.0001	CDE	0.69 ± 0.0016	ABC	3	18.77 ± 0.04	C	3	2.38 ± 0.002	G	7	**13**
Easy Setting Metal Rat Trap	1.04 ± 0.1152	A	0.73 ± 0.0013	AB	2	8.49 ± 0.08	GH	8	5.18 ± 0.024	D	4	**14**
Rat Trap PRO SuperCat	0.50 ± 0.0007	BCD	0.57 ± 0.0300	CDEF	6	24.97 ± 1.26	A	1	2.6 ± 0.014	G	7	**14**
GORILLA TRAPS Rat Trap	0.36 ± 0.0045	CDE	0.60 ± 0.0004	BCDE	5	11.15 ± 0.14	E	5	2.5 ± 0.015	G	7	**17**
Victor Metal Pedal Rat Trap	0.25 ± 0.0003	DE	0.57 ± 0.0006	CDEF	6	7.94 ± 0.36	H	9	6.23 ± 0.004	C	3	**18**
Sure-Set Rat Trap	0.18 ± 0.0002	E	0.66 ± 0.0120	BCD	4	11.27 ± 0.14	E	5	0.71 ± 0.002	I	9	**18**
Kness Big Snap-E Rat Trap	0.39 ± 0.0039	BCDE	0.42 ± 0.0006	FG	9	13.65 ± 0.07	D	4	2.15 ± 0.002	G	7	**20**
LUNA Rat Trap	0.16 ± 0.0005	E	0.37 ± 0.0008	G	10	10.47 ± 0.18	EF	6	4.47 ± 0.002	E	5	**21**
Victor Easy Set Rat Trap	0.14 ± 0.0007	E	0.48 ± 0.0004	EFG	8	6.27 ± 0.19	I	10	5.12 ± 0.014	D	4	**22**
FOX Rat Trap	0.23 ± 0.0009	DE	0.38 ± 0.0006	G	10	9.49 ± 0.24	FG	7	4.27 ± 0.023	E	5	**22**
Little Nipper Rat Trap	0.25 ± 0.0013	DE	0.51 ± 0.0004	DEFG	7	5.18 ± 0.04	I	10	3.72 ± 0.005	F	6	**23**
Rat Trap SuperCat	0.13 ± 0.0001	E	0.20 ± 0.0003	H	11	13.26 ± 0.01	D	4	1.28 ± 0.001	H	8	**23**
					GORILLA TRAPS mouse 2.0							
GORILLA TRAPS mouse	0.18 ± 0.019	BCD	0.42 ± 0.015	B	2	8.95 ± 0.28	A	1	1.41 ± 0.088	A	1	**4**
Anticimex Smart Snap	0.09 ± 0.008	BCDE	0.33 ± 0.018	BC	3	6.28 ± 0.09	BC	3	0.64 ± 0.021	C	3	**9**
GORILLA TRAPS mouse	0.19 ± 0.020	BC	0.32 ± 0.012	C	4	6.02 ± 0.17	C	4	0.56 ± 0.007	D	4	**12**
Kness Snap-E mousetrap	0.13 ± 0.013	BCDE	0.18 ± 0.007	EFGH	9	6.75 ± 0.1	B	2	0.67 ± 0.01	C	2	**13**
TRAPPER Mini-Rex	0.12 ± 0.014	BCDE	0.28 ± 0.011	CDE	6	6.74 ± 0.11	B	2	0.3 ± 0.008	G	7	**15**
'No See, No Touch' mousetrap	0.19 ± 0.013	BCD	0.23 ± 0.024	CDEF	7	5.45 ± 0.2	D	5	0.26 ± 0.017	GH	7	**19**
Mouse trap PRO SuperCat	0.15 ± 0.025	BCDE	0.20 ± 0.029	DEFG	8	6.52 ± 0.11	B	2	0.23 ± 0.012	HI	9	**19**
Celaflor Mousetrap Ultra Power	0.08 ± 0.009	BCDE	0.16 ± 0.003	FGHI	10	4.94 ± 0.08	DE	6	0.52 ± 0.015	DE	5	**21**
Victor Easy Set Mouse Trap	0.06 ± 0.003	DE	0.11 ± 0.006	HIJ	13	3.03 ± 0.03	GH	10	0.83 ± 0.021	B	2	**25**
LUNA Mouse Trap	0.04 ± 0.007	E	0.12 ± 0.009	GHIJ	12	2.38 ± 0.06	I	13	0.69 ± 0.018	C	2	**27**
FOX Mouse Trap	0.06 ± 0.005	CDE	0.16 ± 0.015	FGHI	10	2.71 ± 0.08	HI	12	0.47 ± 0.01	EF	6	**28**
Tomcat Mouse Snap Trap	0.15 ± 0.011	BCDE	0.13 ± 0.026	FGHIJ	11	3.7 ± 0.09	F	8	0.15 ± 0.011	JK	11	**30**
Mouse Trap SuperCat	0.06 ± 0.005	DE	0.10 ± 0.011	HIJ	13	4.97 ± 0.1	DE	6	0.14 ± 0.005	JK	12	**31**
Victor Quick-Set Mouse Trap	0.08 ± 0.008	BCDE	0.12 ± 0.005	GHIJ	12	4.59 ± 0.05	E	7	0.08 ± 0.005	K	14	**33**
LUCHS Mouse Trap	0.19 ± 0.010	B	0.08 ± 0.004	IJ	14	1.75 ± 0.07	J	14	0.44 ± 0.017	F	6	**34**
Tomcat Mouse Snap Trap	0.12 ± 0.006	BCDE	0.05 ± 0.005	J	15	4.91 ± 0.03	E	7	0.11 ± 0.005	JK	13	**35**
Pre-Baited Snap Trap	0.12 ± 0.007	BCDE	0.05 ± 0.003	J	15	2.82 ± 0.06	GHI	11	0.17 ± 0.014	IJ	10	**36**
Cumarax tunnel mouse trap	0.06 ± 0.010	DE	0.05 ± 0.003	J	15	1.35 ± 0.02	J	14	0.25 ± 0.009	GH	8	**37**
TRAPPER Hidden Kill	0.66 ± 0.107	A	0.81 ± 0.062	A	1	3.25 ± 0.14	FG	9				
Victor Kill-Vault Mouse Trap	0.09 ± 0.008	BCDE	0.29 ± 0.024	CD	5	1.36 ± 0.23	J	14				

Statistically significant differences among trap models for rat traps and mouse traps are indicated by letters in column Diff. (trap models within rat traps and mouse traps connected by the same letter are similar). Ranking of traps is based on differences among traps and was added for impulse, clamping force and spring energy to result in a rank sum where the smallest value is related to the highest parameter values. For the trap models Victor Kill-Vault Mouse Trap and TRAPPER Hidden Kill, no spring energy could be measured because of their drop bar mechanism and it was not considered for rank sums.

trigger was more than double that of treadle trigger ($p < 0.001$) and lift trigger traps ($p = 0.006$) (Fig. 3(a)).

The mean impulse of house mouse traps was 0.17 ± 0.04 Ns [Fig. 3(b)] (Table 2). The values of the individual trap models ranged from 0.05 to 0.81 Ns, with 95% of the trap models achieving values between 0.05 and 0.42 Ns and differed among trap models (Table 2) ($p < 0.001$). The tunnel trap TRAPPER Hidden Kill had the highest impulse (0.81 Ns). The impulse of traps in the factory-new condition and after 20-fold triggering tended to differ ($p = 0.052$). The mean impulse of house mouse traps with push–pull trigger was more than 50% higher than for treadle trigger traps ($p < 0.001$) and almost triple compared to lift trigger traps ($p < 0.001$) [Fig. 3(b)].

The mean clamping force of mouse traps was 4.4 ± 0.45 N (range 1.35–8.95 N) [Fig. 3(c)] and differed among trap models ($p < 0.001$) (Table 2). Clamping force was highest in GORILLA TRAPS mouse trap 2.0 (8.95 ± 0.28 N). There was no overall effect of condition on clamping force ($p = 0.09$) but an interaction of condition and trap model ($p < 0.001$). The latter indicated significant differences in clamping force between new traps and trap models triggered 20 times in GORILLA TRAPS mouse trap (new 5.6 N; used 6.5 N), GORILLA TRAPs mouse trap 2.0 (new 8.2 N; used 9.6 N), Kness Snap-E mousetrap (new 7.0 N; used 6.5 N), 'No See, No Touch' mousetrap (new 5.6 N; used 5.0 N), Tomcat Mouse Snap Trap (new 3.9 N; used 3.5 N) and Victor Kill-Vault Mouse Trap (new 1.9 N; used 0.8 N). Trigger type mattered for clamping force ($p < 0.001$). It was considerably lower in push–pull traps (2.7 ± 0.64 N) than in treadle trigger traps (4.7 ± 1.2 N) ($p < 0.001$) and lift trigger traps (5.7 ± 0.9 N) ($p < 0.001$) [Fig. 3(c)].

The mean spring energy of house mouse traps was 0.46 ± 0.08 J. The values of the individual models ranged from 0.08 to 1.41 J (Table 2) [Fig. 3(d)] and differed among trap models ($p < 0.001$). The highest spring energy was recorded for GORILLA TRAPs mouse trap 2.0 (1.41 ± 0.09 J) (Table 2). There was an impact of the condition of traps on clamping force ($p < 0.001$) as a result of a decrease of ≈10% in spring energy after triggering the traps 20 times across all pairs of trap models. The interaction of condition and trap model ($p < 0.001$) was significant for GORILLA TRAP mouse trap 2.0 (new 1.7 J; used 1.2 J) ($p < 0.001$) and Victor Easy Set Mouse Trap (new 0.9 J; used 0.8 J) ($p = 0.027$). Spring energy differed among trigger types ($p < 0.001$) [Fig. 3(d)]. It was higher for treadle trigger traps (0.51 ± 0.03 J) than for lift trigger traps (0.17 ± 0.04 J) ($p < 0.001$) and push–pull trigger traps (0.26 ± 0.13 J) ($p = 0.004$) [Fig. 3(d)].

3.2 Rat snap traps

The mean triggering force of the rat trap models was 0.37 ± 0.05 N (range 0.13–1.40 N) [Fig. 4(a)] and differed among trap models (Table 2) ($p < 0.001$). Triggering force was highest in Easy Setting Metal Rat Trap (1.4 N) (Table 2). There was no significant difference in triggering force between new and used trap models ($p = 0.64$) and no interaction between trap model and condition ($p = 0.896$). The mean triggering force of rat traps with treadle trigger was only about half that of push–pull trigger ($p < 0.001$) and lift trigger traps ($p = 0.005$) [Fig. 3(a)].

The impulse of rat traps was on average 0.55 ± 0.04 Ns [Fig. 4(b)]. The individual values of the trap models ranged from 0.20 to 0.83 Ns and differed among models ($p < 0.001$) (Table 2). The impulse was highest for WINA Rat Killer (0.83 ± 0.002 Ns). There was no overall effect of condition on impulse ($p = 0.73$), but for Rat Trap PRO SuperCat there was an interaction between trap model and condition (new 0.4 Ns; used 0.7 Ns) ($p = 0.023$). The mean impulse for push–pull triggers was almost double that of treadle triggers ($p < 0.001$) but similar for push–pull/lift triggers and lift/treadle triggers ($p > 0.05$) [Fig. 4(b)].

The mean clamping force of rat traps was 12.61 ± 1.23 N (Table 2). The values of the individual models ranged from 5.18 to 24.97 N and differed among trap types ($p < 0.001$) (Table 2) [Fig. 4(c)]. Rat Trap PRO SuperCat had the largest clamping force. The clamping forces of new traps and 20-times triggered traps were similar ($p = 0.189$), but there was a statistically significant interaction of condition and trap model. This was not a result of differences between new and used traps of the same trap model, but, rather, related to differences between new and used traps of the different trap models. The rat trap with lift trigger (Rat Trap PRO SuperCat) achieved the highest clamping force of all rat traps of 24.97 ± 0.06 N (Table 2) and was higher than for push–pull triggers (13 ± 2.70 N) ($p < 0.001$) and treadle triggers (11.05 ± 1.27 N) ($p < 0.015$) [Fig. 4(c)].

The mean spring energy of rat traps was 4.12 ± 0.53 J and ranged among individual trap models from 0.71 to 9.36 J ($p < 0.001$) (Table 2). Spring energy was highest for WINA Rat Killer (9.36 ± 0.2 J) (Table 2). There was no overall effect of condition on spring energy ($p = 0.089$) and no interaction between condition and trap model ($p = 0.649$). The spring energy of push–pull models was more than twice as high as the spring energy of lift triggers ($p < 0.001$) and treadle triggers ($p < 0.001$) [Fig. 4(d)].

For mouse traps and rat traps there was a considerable difference in rank sums (based on the ranking of impulse, clamping force and spring energy) ranging from 4 to 37 for mouse traps and from 4 to 23 for rat traps. The overall score for mouse traps was highest for GORILLA TRAPS mouse trap 2.0 and lowest for Cumarax tunnel mouse trap. The overall score for rat traps was highest for WINA Rat Killer and lowest for Little Nipper Rat Trap and Rat Trap SuperCat.

3.3 Electronic traps

After trap-triggering, the traps of the single-catch model for house mice emitted high voltage continuously for 20 s. The multiple-catch model for house mice triggered twice for 17 s, interrupted by a 5 s pause. For the single-catch model for rats, it was 180 s.

Although the single-catch electronic trap model for rats triggered equally well at all input voltages, the single-catch model for house mice was difficult to trigger at input voltages of 5 V and 4.5 V. In some cases, several triggering attempts were necessary. The low battery indicator (flashing red LED) was triggered in both trap models at an input voltage of 5 V or lower. For the multiple-catch model for house mice, one trap failed to trigger at an input voltage of ≤5 V, and the other failed to trigger at an input voltage of 4.5 V. The battery-warning indicator was activated at 5.01 V for the first trap and 4.99 V for the second trap. In both cases, trap triggering stopped.

3.4 Effective voltage and current

For all electronic trap models effective voltage increased with increasing input voltage ($p < 0.001$) and decreased with increasing resistance ($p < 0.001$) [Fig. 5(a)]. The most striking difference was a >10-fold effective voltage for open circuit compared to dummy resistances of 1 kΩ and 1.5 kΩ. The interaction of input voltage and resistance also was statistically significant ($p < 0.001$), generally showing an overlap of effective voltage for open circuit and a separation of dummy resistances of 1 kΩ and 1.5 kΩ.

While charging, effective voltage increased with increasing input voltage from 2829 ± 117 V to 3546 ± 116 V reflecting peak voltages of 4000 ± 117 V and 5014 ± 116 V [Fig. 5(a)]. At open

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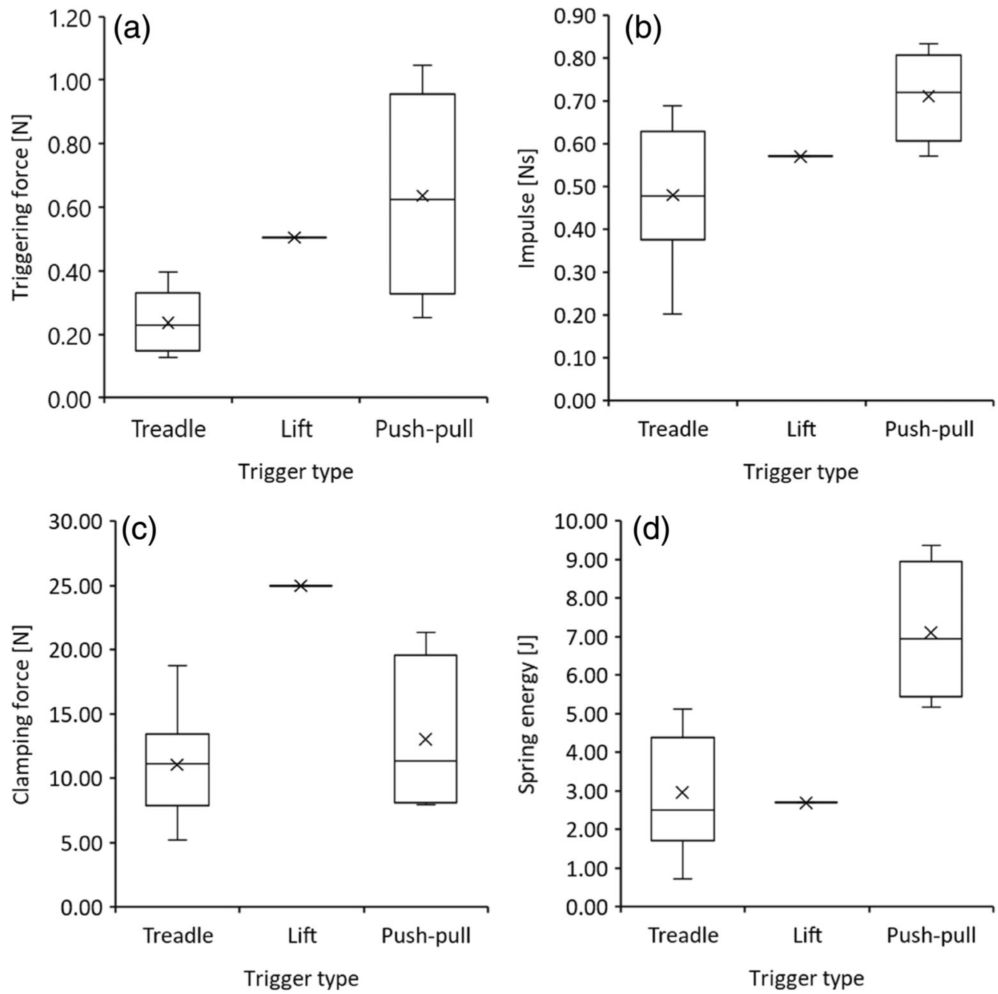

Figure 4. Technical characterization of rat traps by trigger type regarding (a) triggering force, (b) impulse, (c) clamping force and (d) spring energy. Box, 25/75% quartile; X, mean; horizontal line, median; whiskers, minimum/maximum (<1.5-fold interquartile distance); dots, outlier (>1.5-fold interquartile distance).

circuit resistance, effective voltage was 2234 ± 117 V to 3488 ± 78 V with peak voltages of 3159 ± 96 V and 4932 ± 78 V. Triggering traps with a dummy resistance of 1 kΩ, effective voltage was 155 ± 1 V to 264 ± 8 V [Fig. 5(a)] with peak voltage of 219 ± 1 V to 373 ± 8 V. The effective voltage increased by 28% to 183 ± 14 V to 344 ± 7 V when the dummy resistance was elevated to 1.5 kΩ and related peak voltage was 259 ± 14 V to 486 ± 7 V.

Current generally increased with increasing input voltage ($p < 0.001$) and was highest for 6.3 V input voltage ($p < 0.05$) and lowest for 4.5 V input voltage ($p < 0.05$) [Fig. 5(b)]. It was >40% higher for the dummy resistances than for charging and open circuit resistance ($p < 0.05$) [Fig. 5(b)]. The interaction of input voltage and resistance was not statistically significant ($p = 0.32$).

The current was 205 ± 39 mA to 295 ± 57 mA when charging and 231 ± 4 mA to 291 ± 57 mA when triggering [Fig. 5(b)]. The multiple capture house mouse trap used about half of the current for charging (134 ± 7 mA) and in triggering/open circuit (150 ± 5 mA) compared to the single capture house mouse and rat traps (312 ± 13 mA; 334 ± 18 mA). A dummy resistance of 1 kΩ caused a current of 296 ± 29 mA to 480 ± 53 mA. In this scenario, the current for the multiple capture house mouse trap (326 ± 12 mA) was about a third less than that of single capture house mouse and rat traps (511 ± 13 mA). A dummy resistance of 1.5 kΩ lead to a current of 285 ± 27 mA to 467 ± 27 mA [Fig. 5(b)].

3.5 Effective current and effective energy

Effective current increased with increasing input voltage ($p < 0.001$) and for 6.3 V input voltage was about three times the value for 4.5 V input voltage ($p < 0.05$) [Fig. 5(b)]. It was about 10% higher for a dummy resistance of 1.5 kΩ than for a dummy resistance of 1 kΩ ($p < 0.001$). The interaction of input voltage and resistance was not statistically significant ($p = 0.33$). The effective current was 155 ± 9 mA to 264 ± 8 mA at 1 kΩ resistance, and 121 ± 9 mA to 229 ± 5 mA at 1.5 kΩ resistance [Fig. 5(c)].

Effective energy increased with increasing input voltage ($p < 0.001$) and was highest for 6.3 V input voltage ($p < 0.05$) and lowest for 4.5 V input voltage ($p < 0.05$) [Fig. 5(c)]. It was about 10% lower for a dummy resistance of 1 kΩ than for a dummy resistance of 1.5 kΩ ($p < 0.001$) [Fig. 5(b)]. The interaction of input voltage and resistance was not statistically significant ($p = 0.33$). Effective energy was 0.007 ± 0.001 J to 0.021

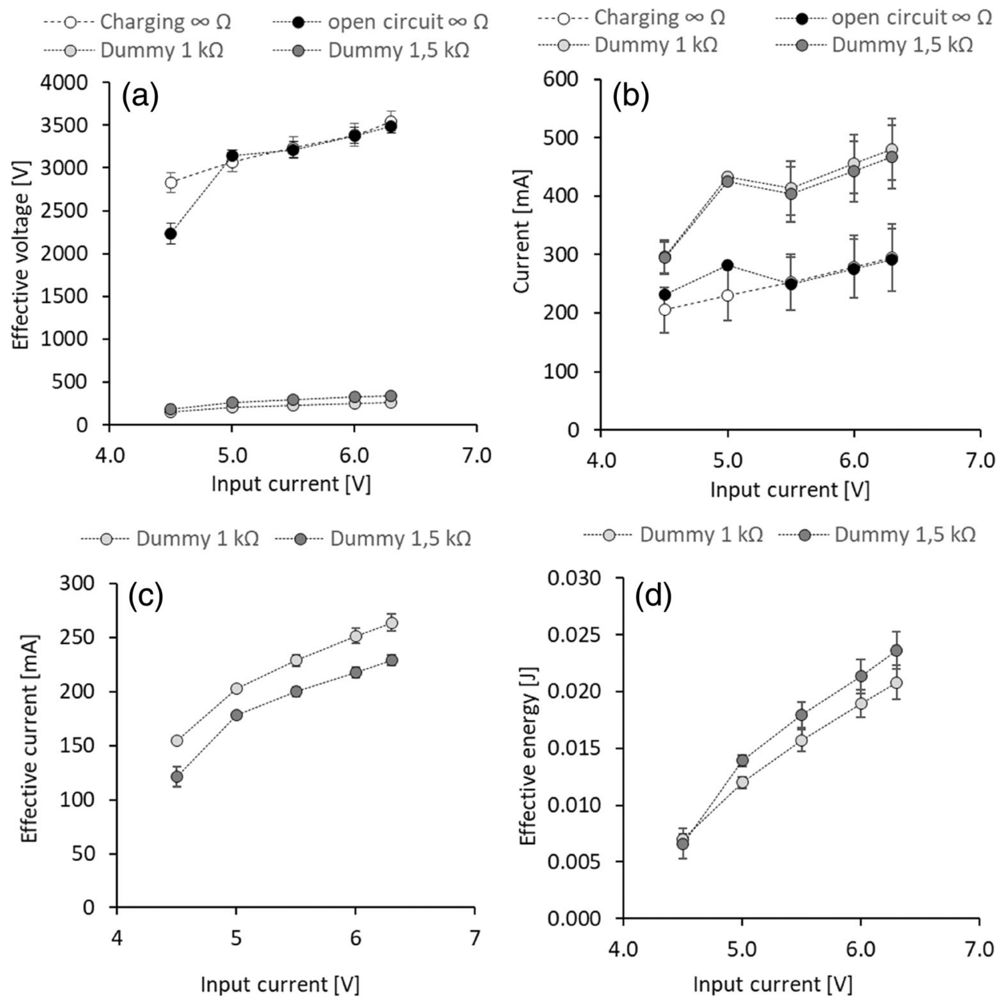

Figure 5. Technical characterization of rat electronic traps based on (a) effective voltage, (b) current, (c) effective current and (d) effective energy. Values are means ± standard error.

± 0.002 J at 1 kΩ resistance, and 0.007 ± 0.001 J to 0.024 ± 0.002 J at 1.5 kΩ [Fig. 5(d)].

4 DISCUSSION

This study provides detailed information about the technical properties of a large number of snap traps and electronic traps that are widely used for house mice and commensal rat species in and around private and commercial buildings, home gardens and in livestock holding. A newly developed device was used to measure several trap characteristics in a standardized and repeatable manner. The design of the measuring device and associated sensors were suitable to accommodate the considerable variation between rat and mouse traps for all necessary measurements.

Snap traps for particular target species (mice/rats) of different trigger types (treadle/lift/push–pull) seemed to overlap in triggering force, impulse, clamping force and spring energy. This confirms previous findings for impulse and clamping force.[17] Insufficient impulse, clamping force and spring energy will impair effective trapping and raise welfare concerns. The performance of electronic trap is largely dependent on the effective energy delivered to the target organism. The input current and the resistance of the target organism determine effective energy.

The mean triggering force of traps for house mice (0.15 N) was as expected lower than for rat traps (0.37). This may limit the triggering of rat traps by house mice and other small mammals of similar body weight. There was considerable overlap in triggering force between house mouse traps and rat traps (house mouse traps 0.04–0.66 N; rat traps 0.13–1.04 N). It is not clear how the triggering forces relate to the efficacy of snap traps in catching the target rodent and to the risk of catching nontarget species, but a trigger force that is too high will exclude some target rodents and a triggering force that is too low (of rat traps) will lead to catching smaller nontarget species. However, mice in rat traps are unlikely to be hit in the neck and may suffer hits to other body parts which raises animal welfare concerns.

Many small mammal species overlap in body weight and size.[23] Therefore, it seems unlikely that triggering force can be adjusted exactly to a particular target species.[24] As with rodenticides, using protective covers and monitoring before trap use with wildlife cameras may help. In mouse traps, triggering force was particularly high for models with push–pull release (0.26 N), whereas in rat traps, it was higher in traps with lift or push–pull trigger than in traps with a treadle. More detailed analyses of trap designs are required to reveal the effects of differences in construction (distance of trigger to be moved for triggering, angles, connection to striking bar) alone or in combination on triggering force of various trap and trigger designs.

The mean impulse of mouse trap models was 0.21 Ns, but one tunnel trap with drop-bar mechanism (TRAPPER Hidden Kill) deviated with an impulse of 0.81 Ns, possibly because of its unique combination of spring design and impact mechanism. Rat traps with treadle triggers had the lowest impulse (0.44 Ns), whereas the trap models with push–pull trigger had the highest (0.71 Ns). This can be explained by the 180° angle of the striking bar of most push–pull trigger rat traps that may lead to more energy stored and hence a higher impulse when triggered.[17] The more than two-fold higher impulse in rat *versus* mouse traps suggests a higher impact in rat traps that is likely to be necessary for swiftly killing the larger rat species. Whether this two-fold higher impulse is sufficient to quickly kill rats remains unknown.[17]

Rat traps had an approximately three-fold greater mean clamping force (12.6 N) than mouse traps. With 25 N, a rat trap model with a lift trigger achieved the highest clamping force, whereas the model with the lowest value achieved 5.2 N clamping force. This is a remarkable difference that does not seem to be simply related to the general design of trap, trigger type and striking bar. The higher clamping force of rat taps might be appropriate to hold and kill rats more efficiently.

The spring energy of the traps for house mice varied significantly from 0.08 to 1.41 J. One model with a treadle trigger had the maximum value whereas all lift triggers had low spring energy. The spring energy of rat traps varied considerably (0.71–9.36 J). Although treadle and lift triggers differed little, push–pull traps had consistently higher spring energy suggesting a correlation of trigger type and spring energy for house mouse and rat traps.

There were few cases where mechanical parameters were affected by triggering traps 20 times. In most cases, differences were small (≤15%) indicating no/little loss of mechanical properties after occasional use. However, differences were considerable for Victor Kill-Vault Mouse Trap (triggering force new +59%) and TRAPPER Hidden Kill (clamping force new +130%) and for Rat Trap PRO SuperCat (clamping force new −37%). A decrease in forces seems plausible and might be a consequence of wear of material. The increase of clamping force of Rat Trap PRO SuperCat seems odd and may have been caused by the particularly strong coil of this trap, which might change position slightly after triggering. It should be noted that the lower value of the new Rat Trap PRO SuperCat was higher than the values of several other new rat traps.

There are hardly any publications on electronic traps for catching commensal rodents based on systematically collected data. Based on data from human risk assessment a current of 30–50 mA causes ventricular fibrillation,[25] which is achieved with the tested traps.

The higher the alternating high voltage emitted by the electronic trap and the lower the animal's body resistance are, the higher the electric current that "flows" through the body of the animal. The higher and long acting the current is, the more likely it is to cause quick irreversible unconsciousness and death.[9] Other parameters such as the shape of the alternating high voltage (e.g. sine wave, square wave) and frequency influence the effect of the current in the animal's body, too. However, they play a rather minor role in the context of the alternating high voltage emitted by the trap and the electrical resistance of the animal's body.[9]

Two models have been tested recently and passed the animal welfare criteria[8] according to the NoCheRo-Guidance.[8,13] Regardless of the technical characteristics of electronic traps, as with snap traps, positioning,[19] baiting where appropriate,[26] optimal trap spacing,[27] avoidance of sites frequently used by nontarget species and trap covers[28] are likely to optimize trapping success and animal welfare. New models appearing on the market should be tested in future studies to expand the database for this relatively new type of traps.

It should be noted that not only characteristics inherent to trap design influence efficacy, but also attractiveness of bait,[29] background food availability,[30] behaviour of target species[31] and location of traps have an effect.[32-34] Independent of trap characteristics, the positioning of snap traps and electronic traps and measures to guide rodents to enter the trap to receive a swift lethal blow[7] can optimize animal welfare. The combination of treadle triggers with trap boxes or trap tunnels has been suggested to direct the position of head and neck of target rodents optimally for an efficient kill.[13,19,35] There also is the option to design traps that are only triggered when the animal is correctly positioned for the strike[19] such as trap triggers that require the rodents to position the head optimally in relation to the trap bar. Risks for nontarget species can be reduced using taxon-specific lures,[26] optimal spacing,[27] trap covers[28] and avoiding locations that are frequently used by nontarget species such as birds. Snap traps are potentially much less a concern regarding occupational health and safety than rodenticides, but operator safety should be taken into account when impulse momentum and clamping force of snap traps are particularly high.

Operating the device developed in this study is labour-intensive, requires expert knowledge, and some of the components are custom-made and some are costly. However, the device provides the opportunity to minimize the use of animals in trap testing and some measurement procedures might be automated in future versions.

The ranking of rat traps and mouse traps was based on the values of impulse, clamping force and spring energy. This was done solely to demonstrate differences among trap models but cannot be used to assess quality of traps regarding trapping efficacy or animal welfare as long as it is not known how these three parameters matter in practical use. Deriving such information from technical parameters alone is difficult because strike location is highly relevant for the action of trap parameters on the target species.[17,22,36] From the data collected here, no conclusions can be drawn regarding efficacy and animal welfare issues in the practical use of electronic traps and snap traps. Both aspects are relevant for trap quality. This would require linking information on trap characteristics (electronic and mechanical parameters) individually or in combination to results of empirical data. Such data are available from trap tests according to the German Infection Protection Act and possibly from other national trap assessment schemes[8,37] and from practical experience. Four house mouse traps and one rat trap considered here have passed testing according to NoCheRo Guidance[13] for voluntary listing of traps according to the German Protection against Infection Act (https://www.umweltbundesamt.de/dokument/liste-ss-18-infektionsschutzgesetz). Given the large variety of trap models and trigger types, more such tests resulting in publicly available data are needed to identify threshold values for trap characteristics that allow exclusion of unsuitable traps before animals are used. In combination with the results from this study, trap testing could be optimized to identify traps that represent the most welfare-friendly option for killing commensal rodents[10] while maintaining effective pest rodent management.

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CONFLICT OF INTEREST STATEMENT

There is no conflict of interest.

AUTHOR CONTRIBUTIONS

BW, JJ conceived the research. BW, AB, PH, SW, JJ designed the research. BE, HE, PB, VG, OS, HW conducted experiments. BW and JJ analyzed data. BW and JJ wrote the 1st manuscript draft, AB, BW, JJ, PH and SW wrote the final version of the manuscript. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

Original data are available from the authors.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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