Chapter 4
Programme reviews

Part 2
Preliminary results on the use of *Cricetomys* rats as indicators of buried explosives in field conditions

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Summary

APOPO, a Belgian research organisation, developed the idea of using rodents for mine detection. After exploring potentially suitable species, the African pouched rat, *Cricetomys gambianus,* was selected for this purpose. After an initial research phase in Belgium, the project moved to Tanzania in May 2000. *Cricetomys* rats were trained both in experimental lab settings and on an experimental minefield to recognise explosive odours. Results of a series of tests in the field with nine rats are presented here.

Rats conditioned on TNT were trained to walk lanes in experimental boxes (10 metres x 10 metres) each containing a variable number of mines (0 to 4). The rat processed the whole box by covering 40 lanes twice. An observer took notes on the behaviour of the rat while working. These notes were analysed afterwards to assess the performance of the rats. Concentric circles were drawn on the field maps around the mine with a radius of 0.8, 1.6 and 2.4 metres and all positive indications were mapped within these circles. Specific indications (biting or scratching the soil) within a radius of the circle of the mine was considered to be a hit for which the rat was rewarded by the trainer, while indications beyond the chosen circle were treated as false indications. From this data the success score of the rat was calculated.

On dry days mean success score of the rats ranged from 80 to 89 per cent depending on the evaluation circle chosen. On wet days the success score was considerably lower. There was considerable variation in performance between the free running rats. This variation was used to select the rats most suited to be free running rats. Beside the individual variation in success score between rats, success score was influenced by several external factors. Both increasing humidity and temperature had a negative effect on success score. Success score was also dependent on the number of mines present in a box, being lower when more mines were present. Certain aspects of how to improve the method used are analysed and discussed.

This paper attempts to define the capabilities of *Cricetomys* rats in searching for mines. Although testing of the free running rat is still in an experimental phase, this method might have great potential for the location of mines in suspect areas.

Introduction

The APOPO organisation was founded in response to the global landmine problem and because many mine detection techniques are comparatively slow and expensive. APOPO's overall objectives are to develop a low-priced methodology for efficient detection of landmines and UXO, to facilitate a reduction in the number of mine victims and to create mine-free land in post-war countries.

The idea of using rodents for mine detection was the outcome of an exploration and analysis of the mine detection problem. The Belgian Directorate for International Cooperation (DGIS) gave its first financial support to develop the concept in November 1997. APOPO vzw was registered under Belgian law as a non-commercial company and started its first experiments early in 1998.

A feasibility study was first implemented in a temporary lab in Belgium. To determine the most efficient way of training and using rats, APOPO tried several methods and methodologies in parallel approaches. One group of laboratory rats was trained to indicate the smell of explosive samples by pressing levers from within a caged set-up; another group of rats was taught to trace and indicate TNT samples hidden in a sandbox.

Meanwhile, APOPO started breeding and socialising African giant pouched rats, *Cricetomys gambianus*, imported from Tanzania, and developing concepts for the use of these animals in the demining theatre.

The promising results of both the training experiments and the breeding programme supported the planned transfer of APOPO's operational base to Africa. This would allow training and testing of the *Cricetomys* rats in near to natural conditions.

During the first half of 2000, APOPO established its premises and training area at the Sokoine University of Agriculture (SUA), in Morogoro, Tanzania. The choice of this location was a result of APOPO's collaboration with the Department of Biology of the University of Antwerp (RUCA), which had a long cooperation with SUA in the field of rodent research. With the logistic support of the Tanzanian People's Defence Forces (TPDF), APOPO has established extensive training and test minefields. Meanwhile, the project still has its Belgian support office at the University of Antwerp.

While APOPO's main objective is the widespread application of its technology, a scientific approach should guarantee the quality of the product and trigger further improvements. APOPO has therefore gained considerable knowledge and experience in rat training methodology and vapour detection, and has designed and developed a variety of technical devices and olfactometers. Much of this experience and technological development probably has applications for the dog training community. GICHD evaluated the APOPO project positively in May 2001. In May 2002, APOPO was in full preparation for its transition to operational work. The demining community has given a generally positive response to the rat detection technology and some major demining organisations have expressed interest in making new cooperation agreements.

The objective of this chapter is to present the first results on the deployment of *Cricetomys* rats as mine detectors in field situations.

Why rats?

How rats came into the picture

The idea of using rats for the detection of landmines came from the search for a cheap and efficient landmine detector which would be able to detect both metal and plastic landmines. Metal detectors had enough sensitivity to detect the metallic parts of plastic mines, but were giving far too many false positives. A lot of emphasis and resources were going into the development of ground penetrating radar systems with sophisticated image processing, either handheld or airborne — or even carried into the field by remote-controlled robots.

In reality, the only alternative technology to manual demining that has entered general use since the recent dramatic increase in humanitarian demining activity is mine detection dogs. Moreover, the concept of explosive vapour detection (EVD) was promising, allowing the vapour plume of a landmine to be detected at some distance from the mine — hence the high potential of the REST concept for area reduction (Chapter 2, Part 2).

There have been many studies on the olfactory capability of rats. The laboratory rat is one of the most widely studied animals, so the existence of research on its olfactory capabilities is not surprising. There have been specific attempts to use rats (Nolan *et al.*, 1978) and other rodents (Biederman, 1990) for the detection of explosives and narcotics. The authors claimed very high sensitivity to explosive vapours, high reliability and very long endurance (up to eight working hours per day) — and full training in an automated set-up could be achieved in a matter of weeks.

These characteristics suggest that rodents are good candidates to be mine detectors. Taking into account some of the disadvantages of dogs — such as the high initial cost price, a long and intensive training period and vulnerability to tropical disease — a cheap and easily maintained rat could be a better alternative for the job of mine detection.

Which rat?

Rodents are the biggest order of mammals, with almost 2,000 species. The choice of which species best fits the requirements was determined by identifying the desired characteristics of a mine detection animal. Essential desired characteristics are very good olfactory capacity, resistance to tropical diseases, long lifespan, easy to breed and handle, and easy to train and condition. Preferably, it would have to be a wild species, as it was argued that their olfactory capacity would be at peak performance compared with laboratory animals.

The combination of an abundance of mined countries in Africa and APOPO's special focus on Africa meant that it was logical to choose a species that was native and widespread in Africa. Such a species should have the highest chances of having good resistance to tropical diseases.

It would also have to be a docile animal, easily tamed and domesticated — and preferably not too small in size, in order to be able to locate it within the vegetation. The choice was made to use the African giant pouched rat, *Cricetomys gambianus*. Apart from showing the desired characteristics mentioned above, this is one of the few rats with a lifespan of about eight years, therefore optimising the return on the training investment. It has the habit of collecting food which it stores at various places underground and therefore uses its smelling capacity to find its food — behaviour quite similar to the mine detection task. Furthermore, this species was already bred as a pet in the U.S., indicating its potential for domestication.

Cricetomys gambianus

We will take a closer look at the characteristics of the *Cricetomys gambianus* from APOPO's experience.

Olfactory capacity

The smelling capacity of *Cricetomys* is very highly developed. Observing the animal, one can notice its nose being constantly very active and moving.

To quantify the rat's sensitivity to explosive odours is very difficult, as the extreme dilution of explosive samples needed in mine detection training renders the content uncertain and very subject to evaporation or contamination. Nevertheless, studies are being initiated that will give an indication of the animal's sensitivity for TNT.

So far, it appears that the sensitivity of the giant rats is satisfactory for both REST and direct location of landmines.

Trainability

Since the 1950s, rats have been commonly used for learning experiments and behavioural studies, often in an operant conditioning environment (the so-called Skinner boxes).

APOPO principally uses a combination of click training and food rewarding. Probably the main difference to most dog training is that the rats are not taught obedience. As such, the total training period can be relatively short. In APOPO's experience so far the field rats can be trained in six to ten months, and REST rats in four to six months. Training starts at the age of five weeks, when juveniles are weaned from the mother.

The rats are "smart" enough to learn the desired tasks relatively quickly, while being "uncomplicated" enough for learning to be mechanical and standardised. Food provides a strong and controllable source of motivation and the only effective motivating drive for performance.

Earlier experiments, which claimed up to eight hours of continuous attention in an automated setting (Weinstein *et al*., 1992), used electric brain stimulation (EBS) or the termination of electroshocks as a motivation. APOPO aims to use individually trained rats for many years for a humanitarian purpose, and uses food rewards strictly. This limits the animals' concentration span to 20-40 minutes, depending on the rewards, the kind of task and the temperature. Recent experiments suggest that rats will work for such a period at least twice a day.

The rats love to execute repetitive tasks, a characteristic that is an advantage for either field search, or for a REST design.

Size

African giant pouched rats weigh between 0.7 and 1.5 kilograms. The average body length is 30-40 centimetres, excluding the tail of 40 centimetres. A disadvantage of this small size is that the rat cannot be observed in long dense grasses. On the other hand, its small size also offers several advantages.

The housing requirements of the rats are considerably less than are required for dogs. APOPO is housing the animals by two in cages of about 80 cm x 50 cm x 50 cm — allowing 100 cages or 200 rats in a room of 6 m x 13 m. Temporary housing during transport can be considerably smaller, and some dozens of animals could be transported in a terrain vehicle.

In the field, their small size has the main advantage that the rats' nose is always close to the ground, even if the head is raised. The highest vapour concentration and the lowest wind speed are found close to the ground. Their size also gives the animals a good pace for scanning the field. In some situations, their small size will enable rats to reach where a dog cannot reach.

Their low weight makes it highly unlikely they would set off a mine by scratching or pointing — which increases overall security.

Maintenance

Being endemic to the whole of Sub-Saharan Africa, the African pouched rats are quite resistant to tropical disease. So far, no serious illness has been recorded among the APOPO rats. There have been some individual losses, which can be avoided with the necessary precautions. In a separate study, APOPO is preparing an inventory of all diseases that are occurring in these rats found in the wild. In comparison with dogs, veterinary care requirements are less for the rats.

Food intake is also less than for dogs. The trained rats live mainly on their reward diet, which they earn at the job, consisting mainly of banana and peanuts. Apart from this, they can be fed with grains, maize, carrots, fruits, fish, insects and many other kinds of food. Thus food supply should rarely be a problem.

Rats do not need a daily walk out. APOPO provides a free open run where the rats can play or habituate to the outside environment. Other rats get a free walk in the animal house during clean up of their cages, as they do not attempt to escape.

Handler issues

In APOPO's experience, all trainers who have been employed to train the animals (mostly Tanzanians) have picked up the training job quickly. There have been no cases of fear among the trainers, nor cases of mistreating or rough handling of the rats, which could initiate fear in them. In general, we observe quite gentle handling and respectful interaction with the animals.

An important advantage of the rats is their independence from a personal handler. Generally, most rats remain with the same trainer, but show no difference in performance when taken over by somebody else in the absence of the trainer. A rat could thus be trained by several people, or more importantly, be trained by one person and be tested or handled in the field by another. One handler team — consisting of two people — could thus easily operate ten rats consecutively. This also implies that the training of the handlers and the training of the animals can be separated.

Cost-related aspects

An exact cost calculation of the rodent mine detection technology will only be possible after relevant operational field experience over a period of time. A direct comparison with dogs could then be made if a detailed cost analysis for a mine dog detection programme is available.

Though any kind of new technology needs further research and development, the DGIS has already invested in the principal developments and research infrastructure. Both for REST and direct detection, the technology is available to the demining community at no cost.

In our opinion, the biggest cost saving in demining will be made by developing the REST system — which is now limited to roads — for area reduction. Research results from investigating this concept will soon be available.

Field application of the rat technology

Since the implementation of the project in Tanzania, several experimental set-ups have been investigated, with some proving to be more successful than others. Also, the training method for the rats changed throughout this period, with the main objective being to shorten the training period and increase the performance of the rats. We provide here the first set of results on the use of *Cricetomys* rats for the detection of buried explosives in the field.

Materials and methods

A series of 10m x 10m boxes were established, each containing a variable number of mines. Rats conditioned on TNT were trained to walk lanes 6m in length in the box and search for buried mines. The animal worked on a leash, which was attached to a glider under a 6m-long bar with a set of spokes at each end of the bar. One turn of the spoked ends gave a search lane width of 0.5 m, which the rat searched twice before the apparatus was rolled for one spoke to establish the next search lane.

A complete search of a box involved introduction of a rat into the corner of a box. The rat processed the whole box by covering 40 lanes twice. On average it took the rats about 28 minutes to complete a box (mean time of 70 boxes inspected).

Two people were present while the rat was working, one at each end of the apparatus. The trainer rewarded the rat when it indicated a buried mine. A reward involved the trainer clicking, after which the animal moved to the trainer to receive a reward before searching the remaining part of the lane. The second person, the observer, took notes on the behaviour of the rat while working.

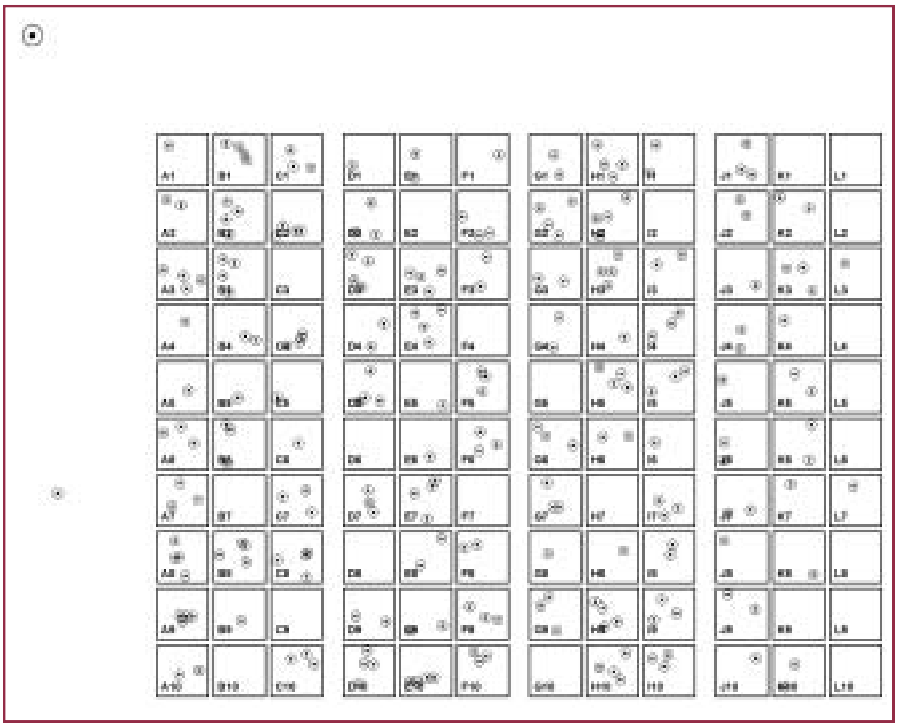
The following behaviours were recorded: a **hit** when there was a positive indication, a **miss** when the rat did not indicate the place where a mine was situated, and the frequently observed behaviours **grooming, eating, freezing, sniffing with the head in the air, returning in lane, pulling leash.** When indicating the location of a buried mine the rat showed a specific behaviour such as scratching or biting the soil or a combination of both. If a rat indicated on a spot more than 0.8 m from a buried land mine, this was noted as a **false positive.** For this indication the rat was not rewarded.

We analysed field trials for nine rats for data taken on nine days between 29 April and 10 May 2002. Testing was done between 7.30 a.m. and 10.30 a.m, depending on weather conditions. No tests were done when it was raining.

The experimental minefield

In the experimental minefield (Fig. 1) there were 120 boxes of 10m x 10m, containing 0 to 4 mines (type: PMN mines). Small lanes (0.5 m) separated boxes where both the trainer and observer could walk. The position of the mines was indicated with coloured poles placed at the borders of the box giving X and Y coordinates. Mines were buried in the boxes between July and October 2001. The depth of the mines was 5cm below ground surface. Vegetation in those boxes was kept short (<20 cm height) by slashing at regular intervals and slashed plants were removed outside the box.

Figure 1
Map of the experimental minefield with the location of mines in each box



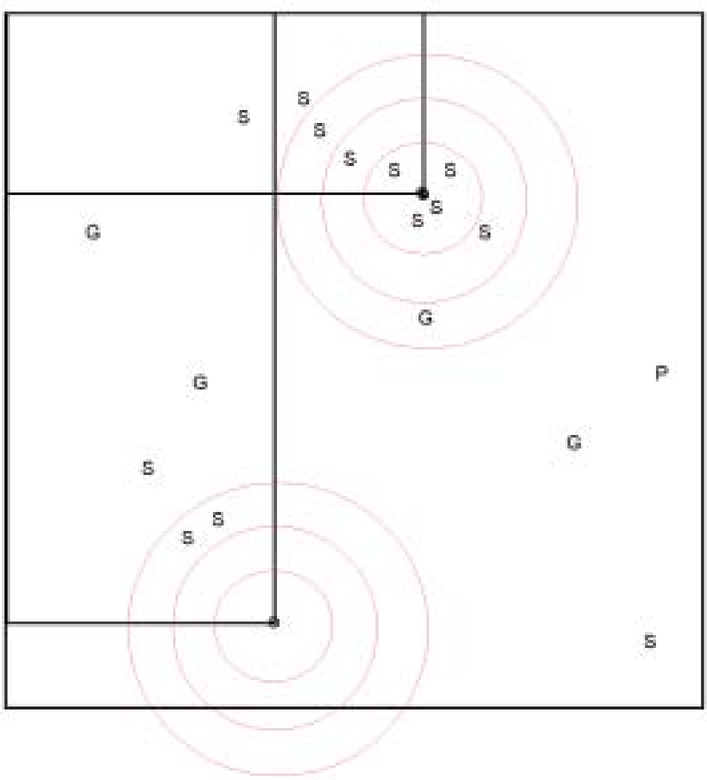
For this analysis data were collected from 30 boxes (columns G-H-I). Each box was searched by a rat about every three days. It was very unlikely that marking behaviour of one rat would influence the next rat because it was an open field with a lot of rat activity at night by wild *Cricetomys* rats. Fig. 1 gives the distribution of the mines in the experimental minefield. From this figure it can be seen that the concentration of mines per given area is variable within the minefield with a mean of 2.4 mines/ 100 m² (calculation excludes safe lanes).

Analysis of the data

As we are unable to directly measure the concentration of explosives at different distances from the buried mine, it is difficult to tell if a positive indication by a rat is either a "good" hit or a false positive. One can expect a negative relationship between the distance from the place of indication to the mine, and the probability that the indication is a false positive. Therefore we drew concentric circles on the field maps around the mine with radii of 0.8 m, 1.6 m and 2.4 m and mapped all positive indications within these circles (Fig. 2).

Figure 2

Map of box G4 with two mines surrounded with evaluation circles and the different behavioural patterns of the rat Apoc (S=scratching which is an indication; G=grooming; P=pulling string). The upper mine is scored correctly close to the actual position. For the lower mine there are indications at a distance of 2m from the mine, these indications are not considered as hits by the trainer and consequently the rat gets no reward. However, the interpretation afterwards shows there is a good possibility that it is a positive indication. The S in the lower right corner is clearly a false positive when one only considers its position within this box. When looking at Figure 1 one can see that this indication is close to a mine in the left upper corner of box H5.



Each indication within a radius of 0.8 m of the mine was considered to be a hit, for which the rat was rewarded by the trainer. Indications between 0.8 m and 1.6 m and

1.6 m and 2.4 m from the mine were considered doubtful, and were therefore noted but not rewarded. All indications beyond 2.4m were treated as false indications. The reason for adopting the 0.8m radius as a cut-off distance for hits was made for practical reasons. If a rat made an indication in a lane next to the lane where a mine was buried this was still considered as a hit but in a lane further away it was considered as doubtful or a false positive. For all indications in adjacent lanes (38), the average distance from the exact position of the mine to the indication was 0.78 cm. We therefore accepted a radius of 0.8 m as the cut-off point.

When looking at the example in Fig. 2, it is clear that interpretation of field data is not straightforward. The upper mine is indicated nine times with four indications within the 0.8 m circle (for which the rat was rewarded). There were also three indications in the outer circles and two outside the 2.4 m circle, which were noted in the field as false positives. When reviewing the field notes afterwards, we considered the most appropriate explanation to be that all nine indications were caused by the presence of that one mine because of the directional relationship between the mine and the indications. Further supporting the conclusion was that there had been heavy rains in the days before and run-off of water was in the direction towards the more distant indications. When analysing the data, the four indications within the 0.8 m circle were taken together as one hit while all indications outside this inner circle were treated as individual false positives. In some analyses indicated below, we also used the 1.6 m and the 2.4 m radius for acceptance of all indications as a hit. In the example given in Fig. 2, this would mean that for a 2.4m radius there would be seven indications inside (giving one hit) and two false positives outside.

In the case of the lower mine in Fig. 2, the two indications in the outer circle would have been counted as two false positives for either the 0.8 m or 1.6 m evaluation circles, but as one hit for the 2.4 m circle.

This approach becomes difficult when two or more mines are situated close together and their evaluation circles overlap. However, as most rats indicate several times in the vicinity of a mine giving a clear grouping of indications, it is possible in most cases to make a decision on the probable positions of the two mines. From an operational perspective, interpretation of such data can be difficult and one may take factors such as topography of the area into account when making a decision.

The performance of a rat inspecting a box was expressed as the number of hits divided by the number of mines present in that box, hereafter called the **success score**.

Results

Rats working in the field are subject to many factors that influence their behaviour. First, there are factors that influence the concentration of explosives in the air and topsoil (temperature, humidity and structure of the soil, presence and density of vegetation, density of mines). Second, local conditions may profoundly alter the behaviour of the rats while searching (humidity, sunshine and temperature, density and height of vegetation). Third, some variation might be expected depending on the interpretation of the behaviour of the rats as observed by the trainer. Fourth, there are differences in the performance between rats.

Overall performance

The nine rats evaluated 81 boxes (9 / rat). It rained during three nights (28-29 / 5, 30 / 4-1 / 5 and 5-6 / 5) giving wet conditions on the following days. A rat stopped evaluating a box before it was completely finished on 11 occasions, and these results were not incorporated into the analysis (Table 1). On dry days, rats stopped working because it became too hot, whereas during wet days animals stopped because vegetation and soil were too wet.

When there was rain the previous night, success score was lower than when there was no rain (Table 1, Fig. 3). Success score improved when indications were accepted from a larger area around the mine, especially when conditions were wet.

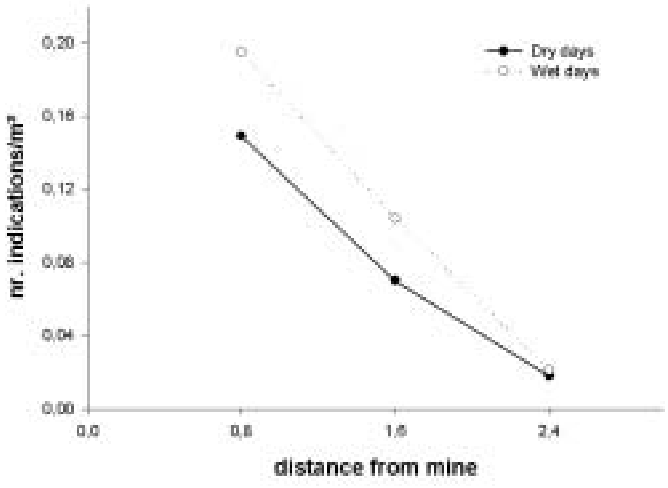
Table 1
Summary of the performance of *Cricetomys* rats under different weather conditions and at various distances from the location of the mine

	Dry days	Wet days
Number of boxes tested	53	28
Number not completed	6	5
Number of mines	125	65
Hits (within 0.8 m radius)	100	41
% success score <0.8 m	*80.0*	*63.1*
Hits (within 1.6 m radius)	103	50
% success score <1.6 m	*83.7*	*74.6*
Hits (within 2.4 m radius)	110	52
% success score <2.4 m	*88.7*	*80.0*

In order to determine whether the rats were giving most indications close to mines, we plotted the density of indications made by all rats in the area between the circles with a 0.8 m and 1.6 m radius (6.02 m^2), the area between the circles with a 1.6m and 2.4 m radius (10.05 m^2), and all indications outside the 2.4 m radius (81.91 m^2). These values were expressed as per square metre for the three given areas. If indications were randomly distributed throughout the box rather than concentrated close to mines, then one would expect the graph to be a flat line. However, a sharp drop in density of indications by the rats in relation to distance from the mine can be seen in Fig. 3, indicating that most indications were close to mines.

The progressive drop in indications at increasing distances from the mine implies that contamination of the soil around a mine is not limited to a small area — explaining why the rats gave some indications at a distance from the mine. The pattern of spread of odour away from the mine will depend very much on local topographical characteristics, soil texture and local water flow. Although few indications were given outside the 2.4 m radius, it is clear that decisions about the relationship between mines and indications requires consideration of a larger area than just the inner 0.8m circle. The contamination at larger distances is more pronounced when it is wet. In this data set, the number of indications beyond a distance of 2.4 m was very low and there was no difference between wet and dry days. On average a rat had 1.6 such false indications per box. These indications will be considered as false positives in all subsequent analyses.

Figure 3
Relation between the number of positive indications and distance from the mine



Individual variation

There was considerable variation in performance between the free running rats. This variation can be used to select those rats most suited to be free running rats, and identify rats needing re-training or rejection using a defined criterion.

As performance of the rats in the field is potentially influenced by several known factors (weather, time of the day, number of mines present in a box) and probably also still unknown factors, we have to take these into account when assessing the quality of the rats. Table 2 summarises some aspects of the performance of the nine rats in the field when they searched a lane one or two times.

Success score varied considerably between individuals, ranging from as low as 67 per cent (Dina) up to 100 per cent (Julie) when conditions were dry using an evaluation radius of 2.4 m (two-lane evaluation). Also the number of boxes scored without errors, meaning that all mines present in the box were found and no false positive indications were given, varied in the same way from 0 per cent (Johan) up to 100 per cent (Bean and Julie).

The source of the individual variation was explored using a one-way breakdown analysis of variance of the grouping variables age and sex on the measured dependent variables of: i) success score, ii) search time, and iii) number of false positive indications. This analysis allows evaluation of the differences between dependent variables (success score, search time, false positives) in relation to defined independent (grouping) variables (age and sex). If the variance within each dependent variable is larger than the variance between grouping variables, then one can conclude that there is no effect of age or sex on the measured variables. On the other hand, if the between-group

Table 2
Summary of performance of the individual rats as evaluated at 0.8 and 2.4m from the mine for wet and dry testing days (m-index = mean number of mines present in the boxes that a particular rat investigated; time = mean time in minutes the rats started working on the field, 7.00 a.m. is taken as zero point)

Rat	Boxes correct				Success score			
	Wet		Dry		Wet		Dry	
	0.8 m	2.4 m	0.8 m	2.4 m	0.8 m	2.4 m	0.8 m	2.4 m
Rataplan	*(**Box-wet n** = 3, m-index = 2.3, time = 160;*				***Box-dry** n = 5, m-index = 2.8, time = 142)*			
2-lanes	0%	67%	40%	60%	29%	71%	79%	86%
1-lane	0%	33%	40%	60%	29%	43%	64%	79%
Bean	*(**Box-wet** n = 3, m-index = 2.7, time = 53;*				***Box-dry** n = 5, m-index = 2.2, time = 99)*			
2-lanes	0%	67%	100%	100%	50%	88%	100%	100%
1-lane	0%	33%	80%	80%	38%	75%	91%	91%
Apoc	*(**Box-wet** n = 3, m-index = 3.3, time = 113;*				***Box-dry** n = 7, m-index = 2.3, time = 100)*			
2-lanes	0%	33%	86%	86%	60%	80%	94%	94%
1-lane	0%	33%	86%	86%	50%	70%	88%	88%
Bianca	*(**Box-wet** n = 2, m-index = 3.5, time = 60;*				***Box-dry n** = 5, m-index = 2.6, time =108)*			
2-lanes	0%	0%	20%	40%	43%	57%	62%	69%
1-lane	0%	0%	20%	40%	29%	57%	54%	69%
Dina	*(**Box-wet** n = 1, m-index = 3, time = 55;*				***Box-dry** n = 5, m-index = 3.0, time = 76)*			
2-lanes	(100%)	(100%)	20%	40%	100%	100%	60%	67%
1-lane	(0%)	(0%)	20%	40%	67%	67%	47%	67%
Switch	*(**Box-wet** n = 3, m-index = 2.3, time = 100;*				***Box-dry** n = 5, m-index = 2.2, time = 56)*			
2-lanes	67%	67%	60%	80%	86%	86%	82%	91%
1-lane	67%	67%	60%	80%	86%	86%	82%	91%
Johan	*(**Box-wet** n = 3, m-index = 2.7, time = 110;*				***Box-dry** n = 4, m-index = 3.5, time = 88)*			
2-lanes	33%	33%	0%	0%	75%	75%	71%	71%
1-lane	33%	33%	0%	0%	75%	75%	64%	71%
Mathias	*(**Box-wet** n = 2, m-index = 3.5, time = 100;*				***Box-dry** n = 6, m-index = 3.0, time = 79)*			
2-lanes	0%	0%	50%	50%	57%	71%	78%	83%
1-lanes	0%	0%	33%	33%	57%	57%	67%	78%
Julie	*(**Box-wet** n = 3, m-index = 2.7, time = 78;*				***Box-dry** n = 5, m-index = 2.3, time = 76)*			
2-lanes	67%	100%	100%	100%	88%	100%	100%	100%
1-lanes	33%	67%	60%	100%	75%	88%	100%	100%
Results of all rats pooled								
2-lanes	6/23	12/23	26/47	30/47	41/65	52/65	100/125	105/125
	26%	52%	55%	64%	63%	80%	80%	84%
1-lanes	4/23	7/23	22/47	27/47	36/65	45/64	90/125	101/125
	17%	30%	47%	57%	55%	69%	72%	81%

variance is larger than the within-group variance, then it can be concluded that there is a strong effect of age or sex on the dependent variables. There was no effect of sex on the three listed parameters. For age, there was a non-significant trend for success score to become better as animals aged, which is probably because older rats have been trained for a longer time. There was no effect of age on search time or false positives.

Time animals are working

Soil humidity had an important effect on performance and this relationship could also be true for temperature. *Cricetomys* rats are very temperature sensitive and all testing was done between 7.30 a.m. and 10.30 a.m, after which it became generally too hot for rats to function properly. At 7.30 a.m. temperatures were around 20°C and rose to between 27 and 32°C towards 10.30 a.m., depending on the amount of cloud.

In Fig. 4 we plot the relation between the time through the morning and success score, the number of all indications given by the rats within the 0.8-2.4 m sector (calculated in the same way as for Figure 3), and the number of indications given outside the 0.8-2.4 m sector. Relationships were analysed using regression analysis, which investigates the pattern of change for a factor across a series of measurements (in this case through time).

When conditions are dry, success score decreases significantly through the morning ($r=0.9791$; $p=0.0036$). There is no such clear relationship when rain falls during the night before testing so that the ground is wet during testing. On dry days there is always some dew in the early morning, which disappears quickly making evaporation less and the concentration of explosives above ground level decreases.

Indications in the 0.8-2.4 m zone support the result above. During dry days there is a sharp drop in the number of indications early in the morning, after which indications stabilise. During wet days the decrease is more gradual and the number of indications is higher compared with dry days.

The patterns for the number of indications outside the 2.4 m circle were different for wet and dry days, and also differed from the patterns in the other two graphs, suggesting no relationship with environmental conditions.

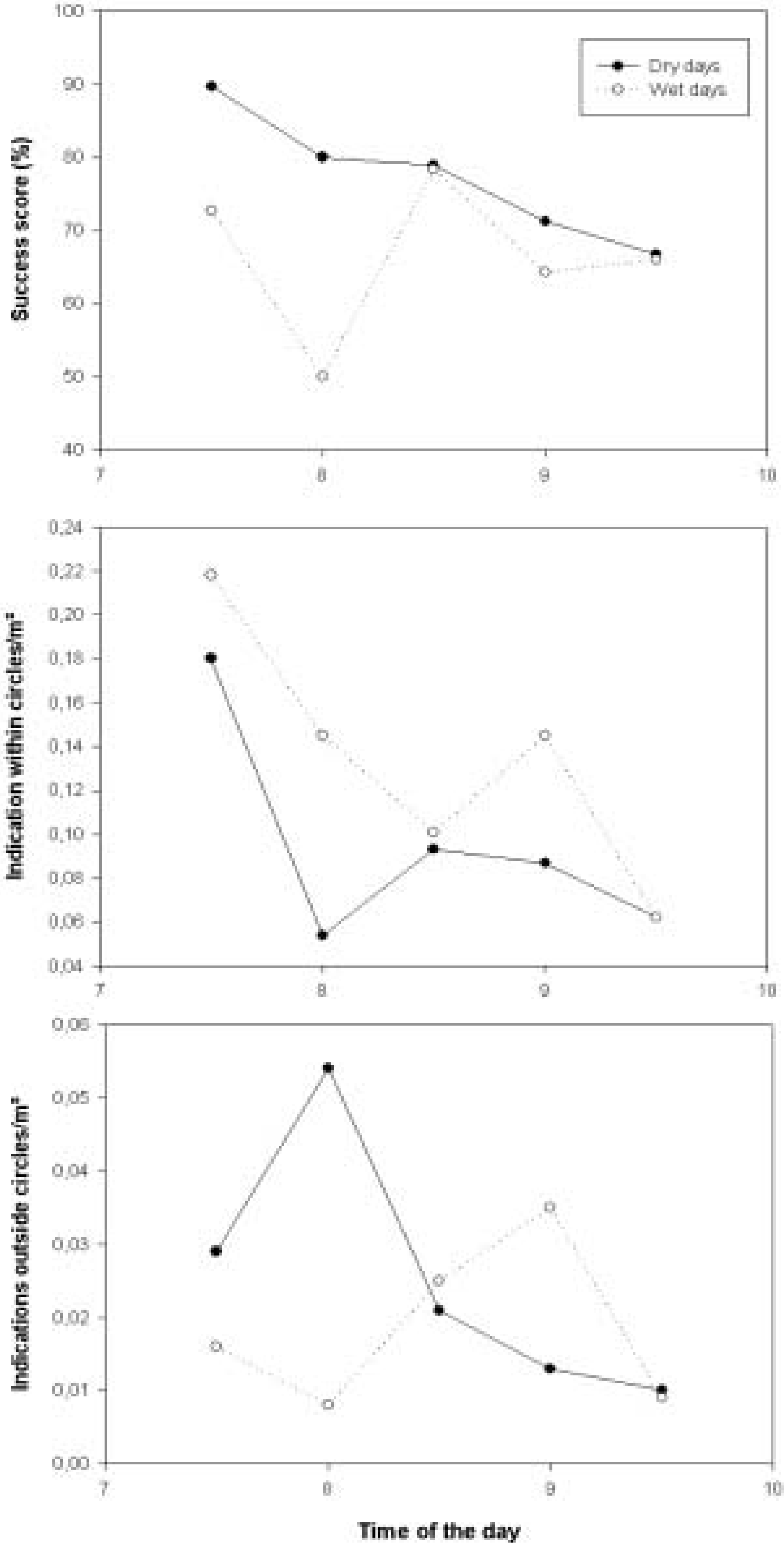
Effect of evaluation radius, times a lane was evaluated, and number of mines on the success score

Data from the boxes allow us to analyse how success score varies with evaluation radius, and the number of times a lane is searched (one or two). A summary of the analysis is given in Table 3.

Table 3
Influence of the number of mines present in a box on success score, the radius where indications are scored as hits and the number of times the same lane is evaluated, for nine rats searching 70 boxes

Condition		Wet			Dry	
Evaluation radius	0.8m	1.6m	2.4m	0.8m	1.6m	2.4m
One mine/box		(n=3)			(n=8)	
% success score						
- lane twice	33	33	100	100	100	100
- lane once	33	33	100	100	100	100
Two mines/box		(n=5)			(n=14)	
% success score						
- lane twice	60	90	90	82	89	93
- lane once	60	90	90	71	86	89
Three mines/box		(n=9)			(n=11)	
% success score						
- lane twice	67	74	78	76	79	79
- lane once	56	59	63	67	76	76
Four mines/box		(n=6)			(n=14)	
% success score						
- lane twice	63	79	79	77	79	80
- lane once	58	71	71	70	77	79

Figure 4
Relation between the time through the morning and success score (number of indications within the 0.8-2.4 m circles, and number of indications outside the 2.04 m circle)



To investigate which of the three factors (number of mines, number of times the lane was searched, and evaluation radius) influenced the success score we used a multivariate linear Anova after log-transforming the raw data. The analysis identifies variables with significant amounts of variation. Log-transformation is used to satisfy background assumptions of the analysis, and does not change the patterns in the data. Data for dry and wet days were analysed separately. The results from this analysis are straightforward as can be seen in Table 4.

Table 4
Result of the multivariate linear Anova investigating the effect of the number of mines, number of times a lane was searched and the evaluation radius used on success score; design: (radius-mines-lanes)

	Factor	df	F-value	p-value
Wet days	1-mines	3	17.96760	**0.000**
	2-lanes	1	0.29921	0.585
	3-radius	2	20.09292	**0.000**
	Interaction 1x2	3	0.10495	0.957
	Interaction 1x3	6	7.46691	**0.000**
	Interaction 2x3	2	0.00631	0.994
	Interaction 1x2x3	6	0.01665	1.000
Dry days	1-mines	3	4.95503	**0.002**
	2-lanes	1	1.69083	0.195
	3-radius	2	3.39827	**0.035**
	Interaction 1x2	3	0.71733	0.542
	Interaction 1x3	6	1.92891	0.077
	Interaction 2x3	2	0.83243	0.436
	Interaction 1x2x3	6	0.35312	0.908

For both wet and dry days the number of mines present in a box and the evaluation radius used were both very significant, with more mines / box resulting in a lower success score, and a larger evaluation radius resulting in a higher success score (see Table 1). The significant interaction for mines x radius (significant for wet days and nearly significant for dry days), indicates that the two factors have opposite effects: the negative effect on the success rate of having more mines in a box will be largely compensated by the positive effect of using a larger evaluation radius. The fact that this is more obvious for wet days than for dry days is understandable as we have seen that probably contamination / evaporation of the surroundings of a mine is more widespread during wet days and therefore this interaction should be stronger.

Evaluating a lane once or twice by the same rat had no significant effect on the success score. Although there is a relatively large difference when the evaluation area is small (<0.8 m), the difference disappears nearly completely when a larger evaluation area is used.

For practical reasons (locating the mine) it is important to keep the evaluation radius as small as possible. In this study we used three circles (radius 0.8 m, 1.6 m and 2.4 m) around the centre of the site where the mine was buried. The largest circle (2.4 m) gave the best results, but using that radius means that a large area around the indication is treated as suspect (18 m²). Therefore one should try to find the best compromise between radius and increase in success score. In the case of the dry field data the success score increased as described below (only results from boxes with more than one mine were used because those with only one mine had a success rate of 100 per cent).

The biggest increase in success score is attained when the radius is increased to 1.6 m and when the lane is searched once only. Increasing the radius further has very little effect on the success score. With a radius of 1.6 m an area of 8 m^2 has to be cleared instead of 18 m^2 in the case of a 2.4m radius (Table 5).

Table 5
Influence of increasing the size of the evaluation radius on the success score (SS)

	% increase in SS; 0.8 to 1.6 m	% increase in SS; 1.6 to 2.4 m
2 lanes evaluation	5.0	1.9
1 lane evaluation	13.6	2.0

These results indicate that when using a larger evaluation area around the mine there is almost no difference between the success score of a rat searching each lane once or twice. Therefore the time for evaluating a box can be reduced by a factor of two when all lanes are evaluated only once, if the larger clearance areas are used. It can also be expected that when using this method the success score could increase, as concentration of the rats will remain higher if they work for a shorter time period, especially at higher temperatures. A second possibility for reducing total working time is to increase the width of lanes from 0.5-1 m. This possibility has to be tested in future field experiments.

The fact that there is a strong negative relation between success score and the number of mines present in a box will only pose a problem in very dense minefields. As with dogs, rats are likely to be removed from such situations and other demining techniques used.

Selection criteria for free running rats

The number of mines per box and time during the morning of working had an important impact on the success score of individual rats. When selecting animals for maximum performance these factors should therefore be taken into account. In order to find out which of the two factors (number of mines per box or working time) had the biggest impact on success score, we used a multiple regression analysis. The dependent variable was success score, and mean number of mines per box and time of the day when the animals were working were the independent variables. We used the data of the one lane evaluation.

The most important factor was the number of mines per box ($r=0.7887$, $df=2,6$; $F=4.937$; $p=0.0540$; partial correlation for success score versus mines per box $t(6)=-3.0044$ with $p=0.0239$ and partial correlation for time versus success score $t(6)=-0.6129$ with $p=0.5624$). Residual analysis indicated two animals that did not fit the general equation, namely Bianca and Dina. Excluding them from the data-set produced a nearly perfect fit ($r=0.90058$, $df=2,4$; $F=8.585$; $p=0.0357$; partial correlation success score versus mines per box $t(4)=-4.11204$ with $p=0.0147$ and partial correlation of time versus success score $t(4)=-0.27318$ with $p=0.7982$).

From this analysis one can conclude that if the number of mines in the boxes were the same, then seven of the nine rats would have a comparable success score. The exceptions were Bianca and Dina, whose success score was considerably lower and they should therefore not be used as free running rats with the present level of performance (Table 6). At this time, it is too early to define an acceptance criterion for accrediting a free-running rat for operational purposes, as all rats are still in a training stage. The results are plotted in Fig. 5.

Figure 5
Relation between mean success score of an individual rat and the mean number of mines present in the box, Bianca and Dina are not included in the regression

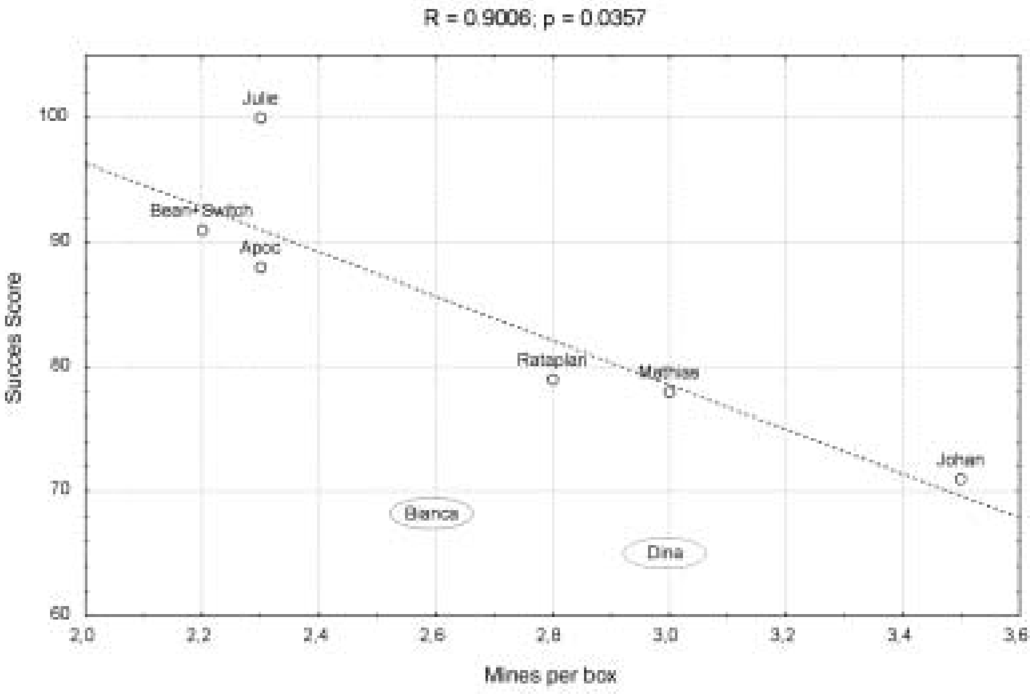


Table 6
The effects on overall performance of omitting both Bianca and Dina from the success scores.

Rat	Boxes correct				Success score			
	Wet		Dry		Wet		Dry	
	0.8 m	2.4 m	0.8 m	2.4 m	0.8m	2.4 m	0.8 m	2.4 m
Results of all rats pooled								
2-lanes	6/23	12/23	26/47	30/47	41/65	52/65	100/125	105/125
	26%	*52%*	*55%*	*64%*	*63%*	*80%*	*80%*	*84%*
1-lanes	4/23	7/23	22/47	27/47	36/65	45/646	90/125	101/125
	17%	*30%*	*47%*	*57%*	*55%*	*9%*	*72%*	*81%*
Results of all rats pooled without Bianca and Dina								
2-lanes	5/20	11/20	24/37	27/37	35/55	45/55	83/97	87/97
	25%	*55%*	*65%*	*73%*	*64%*	*82%*	*86%*	*90%*
1-lanes	4/20	7/20	20/37	24/37	32/55	39/55	80/97	87/97
	20%	*35%*	*54%*	*65%*	*58%*	*71%*	*82%*	*90%*

How many rats have to inspect a given box to get effective detection?

Sixteen boxes were searched by four or more rats and each lane of the box was evaluated twice by each rat. To calculate how many rats should inspect a box to be sure that all mines were identified, we analysed all possible combinations of rats that evaluated boxes with 1, 2, 3 and 4 mines for both the one- and two-lane evaluation. The combination with the highest number of rats needed to get 100 per cent detection was taken as the minimum number of rats required. Results presented here are for the 2.4 m evaluation radius and figures give the minimum number of rats needed to get 100 per cent detection (Table 7).

Table 7
Number of rats needed to get 100% detection for boxes containing different numbers of mines and for a one-lane or two-lane evaluation

Mines/box	Nr. boxes	One-lane evaluation	Two-lane evaluation
1	4	2	1
2	4	3	2
3	4	4	3
4	4	4	4

As was expected from the previous results, the more mines present in a box the more rats are needed to evaluate a box to get 100 per cent detection. If we expect that never more than two mines will be present on a 100 m² area, then three rats should be enough to evaluate such an area. If high density bands of mines are encountered, the rats should be withdrawn and some other search / clearance technique used.

Conclusions

The approach used in this paper was to attempt to define the capabilities of *Cricetomys* rats in an experimental way by using the rats themselves to search for mines. Although testing of the free running rat is still in an experimental phase, this method might have great potential for the location of mines in suspected areas. In these analyses, we have identified a range of factors that affect the quality of performance of rats. Conversion of these factors to rules will further improve the reliability of rats in a mine detection role. In order of importance these are:

- Never let them work during or just after rain or when the soil is too wet;
- Start working early in the morning when temperatures are likely to rise fast or when it is an open blue sky.

From the results of this study it is clear that several adaptations could be made to further increase the efficiency of rats in a mine detection role. Evaluating a lane once rather than twice would improve search rate. Increasing the distance between lanes will further increase productivity, and is potentially justified as contamination from a mine is probably more widespread than 0.5 m. More information is needed on the distribution of explosive odours in the soil and factors that influence this distribution, so that optimal working conditions can be determined.

The use of rats as bio-sensors can have a direct application to the process of area reduction.

References

Biederman, G.B. (1990)
The detection of explosives by an automated small-animal system, National Research Council, National Aeronautical Establishment, Ottawa.

Nolan R.V., S. Weinstein and C. Weinstein (1978)
Neurophysiological, operant, and classical conditioning methods in rats in the detection of explosives, presented at 3rd Annual Meeting of Role of Behavioral Science in Physical Security.

Weinstein C., S. Weinstein and R. Drozdenko (1992)
"The challenge of biodetection for screening persons carrying explosives", in S.M. Khan (ed.) *Proceedings, First International Symposium on Explosive Detection Technology*, pp. 759-769.

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