# Teaching Giant African Pouched Rats to Find Landmines: Operant Conditioning With Real Consequences

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## ABSTRACT

Giant African pouched rats recently have been used as mine-detection animals in Mozambique. To provide an example of the wide range of problems to which operant conditioning procedures can be applied and to illustrate the common challenges often faced in applying those procedures, this manuscript briefly describes how the rats are trained and used operationally. To date, the rats have performed well and it appears they can play a valuable role in humanitarian demining.

Keywords: animal training, giant African pouched rats, humanitarian demining, landmines, operant conditioning, operant discrimination training

Behavior-analytic practitioners use a variety of procedures based on principles of operant conditioning to help their clients learn to behave in gainful ways. Similar procedures can, of course, be used to develop useful behavior in nonhuman animals. Some applications, such as training dogs to obey commands like sit, stay, and come are so well understood as to hardly merit comment, at least until one encounters a big, dirty, untrained dog. Others, however, generate considerable interest in some quarters. A case in point is teaching rats to detect landmines. Presently landmines are found in over 70 countries and do great harm by denying people access to their homes and land in addition to causing bodily harm, death, and psychological duress (Landmine and Cluster Munitions Monitor, 2009). Over the past decade, personnel from Anti-Persoonsmijnen Ontmijnende Product Ontwikkeling (APOPO; Anti-Personnel Landmines Detection Product Development), a Belgian nongovernmental organization (NGO) headquartered in Morogoro, Tanzania, have developed operational procedures for landmine detection using giant African pouched rats (*Cricetomys gambianus*). This work, which is based on the use of operant discrimination training, has generated considerable media attention. For instance, it has been described recently in *National Geographic, Business Week,* the *New York Times, CNN News,* and *BBC News.* We describe herein how APOPO's staff train rats and use them to find mines. The information provided may interest practitioners because it illustrates the incredibly broad range of practical applications of operant conditioning and shows that training and using rats to find mines poses challenges similar to those encountered in more mainstream applications of applied behavior analysis.

## Using Animals for Scent Detection

Evolution has endowed many species with a good sense of smell, which they use to find food and mates, avoid predators, and communicate with one another. Humans have relied on dogs' keen noses to help us find food and detect intruders from the time dogs were domesticated, roughly 15,000 years ago to the present. In the past 20 years, dogs also have performed useful service in finding landmines and other explosive remnants of war (ERW; Geneva Center for Humanitarian Demining, 2003). At the beginning of this period a prominent behavior analyst, Jim Johnston, played a pioneering role in establishing Auburn University's Canine Detection Research Institute and in using behavior-analytic methods to study olfaction (e.g., Johnston, Myers, Waggoner, & Williams, 1994; Williams & Johnston, 2002; Williams et al., 1998 a, b).

Although dogs have an established and valuable niche in mine detection (Geneva Center for Humanitarian Demining, 2003), no demining strategy is appropriate for all applications. Recognizing this, and being committed to finding local solutions to local problems, Bart Weetjens, a Belgian product developer and the founder of APOPO, began to explore the possibility of using giant African pouched rats as mine detection animals for Africa in 1997. Mines and other ERW, such as unexploded artillery shells and grenades, are a problem across much of the continent.

For example, in 1998-2008 landmines inflicted casualties in 32 of the 53 African countries (Landmine and Cluster Munitions Monitor, 2009). Clearly, landmine clearance is a pressing humanitarian need for many Africans.

## African Pouched Rats as Mine Detection Animals

After considering many African species, Weetjens and his colleagues decided to evaluate pouched rats as demining animals because they are native to sub-Saharan Africa, hence resistant to local diseases and parasites. The rats, which are sometimes raised for food, are easy to maintain and live up to eight years in captivity. They are large enough to work on a lead (adults typically have body lengths of 25-45 cm and weigh 1-2 kg), but not heavy enough to activate most mines. Finally, over the years behavior analysts and other researchers have conducted extensive operant conditioning research with laboratory rats (*Rattus norwegicus*) and developed effective procedures for teaching them stimulus discriminations (e.g., Iverson & Lattal, 1991 a, b). Weetjens and the team he assembled reasoned that similar procedures would suffice to teach *Cricetomys* (African pouched rats) to discriminate the odor of landmines.

## Training Pouched Rats to Find Landmines

Elsewhere we provide detailed descriptions of how the rats are trained and used operationally (Poling, Weetjens, Cox, Beyene, & Sully, in press a, b; 2010). The training is aimed at producing rats that reliably emit an indicator response, which is pausing and pawing or biting at the ground, when they smell landmines or other explosive devices. Doing so is termed a "hit," whereas failure to emit an indicator response when a mine is present is termed a "miss." It is absolutely essential to obtain a zero, or near-zero, miss rate because failure to emit an indicator response when a mine is present is a major safety issue, with missed items potentially resulting in deminer or civilian injury. "False alarms," that is, indicator responses in locations where mines (or other ERW) are not present, create extra work for deminers, who must search the area with other means, typically metal detectors, but have no direct effect on safety. They may, however, make deminers "careless," and thereby reduce safety, but this possibility can be minimized with adequate supervision (Guelle, Smith, Lewis, & Bloodworth, 2003).

At the onset of the project, APOPO's personnel knew that their ultimate goal was to produce rats that were consistently accurate in detecting landmines. "Consistently accurate" is, of course, imprecise and some quantifiable, operationalized goal was badly needed. One was provided by International Mine Action Standard (IMAS) 09.42 (2008), which delineates testing conditions and performance standards for animals and handlers that are to be certified by National Mine Action Authorities. Almost all demining is done under the auspices of such authorities, and APOPO's personnel knew that their rats would have to be certified to be of value. Thus, meeting the IMAS 09.42 standards was identified as the training goal. It was, of course, a distal goal, and many proximal subgoals had to be established and met. Doing so posed challenges, as discussed subsequently, but the process of moving from a general goal to specific operations intended to produce clearly defined and quantitatively indexed responses was a logical and straightforward progression that is familiar to all good practitioners.

APOPO's staff began their work with wild-caught *Cricetomys*, but such rats proved difficult to manage and a captive-breeding program was soon initiated. All of APOPO's animals now come from its breeding colony. At a young age the rat pups begin to interact with humans and from three to six weeks of age trainers regularly handle them; expose them to a wide range of sights, sounds, and smells; and hand-feed them preferred foods like bananas and peanuts. Training begins when the rats are about six weeks old. The first step in training is establishing the sound of a clicker as a conditioned reinforcer, which trainers accomplish by repeatedly presenting the sound just before presenting mashed banana mixed with crushed commercial rat chow. The rat chow is used to increase nutritional value. Bananas are highly preferred foods and pilot studies in which rats were given a choice among a variety of foods in a scenario similar to that used in stimulus preference assessments with humans (e.g., DeLeon & Iwata, 1996; Fisher et al., 1992) revealed that the rats approached bananas first and consumed them before moving to other edibles. These outcomes suggest that bananas mixed with rat chow are likely to be potent positive reinforcers, a suggestion confirmed by repeated demonstrations that various operants could be demonstrably strengthened by response-dependent delivery of the mixture, as described later. To increase the reinforcing effectiveness of food delivered by trainers, the rats receive a major portion of their food during daily training sessions, which last about half an hour. They are food deprived for 17 hours when training starts, which serves as an establishing operation for food as a reinforcer (Laraway, Snycerski, Michael, & Poling, 2003).

Clicker training occurs in a metal cage. Trainers present food through a plastic tube attached to a syringe and the rats soon learn to approach the trainer when the click sounds, because doing so produces food. Thus, the click is established as a discriminative stimulus for approaching the trainer, as well as a conditioned reinforcer. When this is accomplished, as indicated by the rat immediately approaching the trainer following 10 consecutive clicks, training begins in APOPO's laboratory, which is located in Tanzania.

The target response for each rat is the emission of an indicator response. The first step in establishing the indicator response is teaching the rat to pause when it smells 2,4,6-trinitrotoluene (TNT), which is the main explosive charge in most landmines. This is accomplished in a small metal cage with a hole in the center of the floor. A plastic pot containing 2 g of sandy soil to which up to five drops of TNT dissolved in water (100 ng per microliter, a low concentration) is placed just below the hole. Initially, a reinforcer (click and food) is presented immediately when the rat places its nose in or just above the hole. This typically occurs quickly, but if not, shaping is used to engender the response. Over time, a progressively longer period of pausing at the hole is required for reinforcement. The final criterion is 5 s. When this criterion is met reliably, as demonstrated by the rat pausing at the hole within 5 s of being put in the box and staying there for 5 s on 10 consecutive trials, discrimination training begins.

Discrimination training at APOPO historically has been done manually, with data recorded and reinforcers delivered by the trainers. Although this approach can create difficulties with respect to intervention integrity and the accuracy of reported data (as can be the case in many applied settings), careful training and monitoring of staff keeps problems to a minimum. The rats' training begins in a metal cage with three holes in the floor. Pots containing soil with the TNT solution or soil with water are placed just below the holes. On average, half of the pots contain TNT and half do not. Pausing for 5 s above holes with TNT is reinforced and pausing at holes with no TNT has no programmed consequences. Training continues in this manner, with 60 to 90 pots presented each day, until a rat emits the indicator response (pausing for 5 s) on 100% of occasions when TNT is present and on no more than one occasion when TNT is absent on two consecutive sessions. When this criterion is met, the rat is trained in a more naturalistic setting.

Initially, small perforated stainless steel balls (tea eggs) containing TNT are placed on a platform covered with soil and the rats receive reinforcers for stopping and scratching at them. Subsequently, the balls are buried up to 1 cm deep and other balls containing nothing or chemicals other than TNT are added. Indicator responses (pausing and digging or biting for 5 s) at tea eggs containing TNT are reinforced and all other indicator responses have no programmed consequences. Such training continues each weekday until a rat emits the indicator response to all tea eggs containing TNT and not to a tea egg without TNT during two consecutive sessions, then the rat moves to field training.

Note that pausing for 5 s upon encountering TNT is the required operant in the one- and three-hole cages, but pausing and digging or biting for 5 consecutive s is the operant in more naturalistic settings. Digging and biting the ground are natural food-procurement responses for *Cricetomys.* Because the smell of TNT predicts food (in the sequence TNT>click>food), through respondent conditioning, it soon comes to elicit these responses in the same way that tokens followed by food elicited rooting in domestic pigs in Breland and Breland's (1961) seminal demonstration of elicited species-typical responses intruding on required operant responses. Rather than allowing it to intrude on some arbitrary operant, we take advantage of the rats' easily observed and consistently engendered species-typical

*photograph by Xavier Rossi*

response of scratching and biting as the indicator response in our field work. Making the task as easy as possible and taking advantage of existing repertoires are gainful strategies as useful in animal training as in mainstream applied behavior analysis.

Field training occurs on a 70-acre simulated minefield, which contains 1,533 defused landmines of several types planted by the Tanzanian military between 2001 and 2004. The field is divided into 100 square meter rectangular area, termed "boxes." Each box contains 0-4 landmines and the locations of all mines are recorded in terms of x and y coordinates, which are indicated by metal stakes along box boundaries. All boxes are regularly hand-cleared of tall vegetation.

In the first step of field training, the rats learn to move along a rope stretched between two trainers, who move slowly down the length of the box being searched. The rats wear a nylon harness with a metal snap connector to which one end of a thin nylon harness cord is attached. A snap on the other end is fastened around the rope between the trainers, which allows the rat to move from side to side. The trainers hold in their hands thin lines that are attached to the rat's harness cord. They can gently direct the rat to move in either direction along the rope by pulling on one line and feeding out the other. After a very short time pulling is rarely necessary, however, because the rats are already leash-trained and learn quickly to move independently from side to side along the rope.

As they move, the rats sniff the ground. Their target (i.e., discriminative stimulus) now, of course, is a landmine, not a tea egg. But both contain TNT and the indicator response readily generalizes such that landmines engender pausing and digging or biting. To increase the probability that generalization occurs, trainers first expose rats to partially-buried landmines in small boxes with bare soil. When such mines are reliably detected (i.e., accuracy is 100% for two consecutive boxes), training progresses to larger boxes (100 square meters) with mines fully buried and covered with vegetation. Correct indicator responses, which are those occurring within 1 meter of a landmine, are reinforced by a click and, when the rat moves to the trainer, a mouthful of food. The importance of clicks as conditioned reinforcers and as discriminative stimuli for approaching trainers is evident in this stage of training, because indicator responses frequently occur some distance from trainers, who cannot deliver unconditioned reinforcers (food) immediately. Clicks can, however, instantaneously follow correct indicator responses, allowing for immediate, albeit conditioned, reinforcement. Regardless of the application, arranging effective reinforcement is a critical, and frequently difficult, aspect of operant behavior change.

Rats are trained on APOPO's simulated minefield five days a week, typically searching one or two 100 square meter boxes per day. When they reliably (i.e., on at least two consecutive tests) find all of the mines with zero incorrect indicator responses, the rat is given a blind test, in which the trainers do not know the location of mines. To pass, the rat must correctly identify all of the mines in four 100 square meter boxes with no more than two false alarms. A rat that passes this test is considered ready for operational service and is designated a "Jackpot" rat because its trainers receive a financial bonus. Rats that fail the blind test are retrained. In 2009, APOPO's trainers produced 60 rats that passed the final blind test. On average, 188 training days (range 143 to 320 days) were required for each rat to progress from the end of clicker training to Jackpot status.

Although the rats initially are trained to detect TNT (i.e., the smell of TNT is established as a discriminative stimulus for pausing at holes in the laboratory), when they move to more naturalistic settings their task is to detect *landmines*. From a human perspective, the most important chemical in a landmine is that which makes it explodes, which in most mines is TNT. It therefore seems reasonable to establish the smell of TNT as a training stimulus. The odor of one or more other chemicals uniquely associated with mines may, however, be easier for a rat to detect, and if so, stimulus control could shift from the smell of TNT to that of another chemical or combination of chemicals, unbeknownst to trainers. If the relevant chemical is uniquely associated with mines in settings where the rats will be used operationally, this is no problem. For example, it is practically irrelevant if a rat's consistent indicator responses to M14 and M16 type mines on APOPO's minefield are controlled by the smell of the plastic cases of those mines or the smell of the TNT inside those cases, so long as such responses occur consistently both in training and in operational use in real minefield. It is, however, a huge problem if rats learn to respond to an odor arising from the smell of the plastic case of the mines in combination with the red clay soil that surrounds them. Such soil will not be found in many minefields, and when it is not, the rats will not respond accurately.

Although published reports may make it seem easy, training animals to detect landmines is a complex and difficult undertaking in which seemingly trivial procedural details can dramatically influence success. Training a rat to emit a specific response when they detect a specific odor is not unlike training a verbal person to report some private event such as pain because, in both cases, the stimulus that we want to acquire control over a particular response cannot be sensed by the trainer who is attempting to reinforce the response in the presence of only the target stimulus. Consequently, in both cases, we run the risk of poor stimulus control by the target stimulus, and greater control by some other stimulus. In the case of the person, a teacher will generally use accompanying public collateral behavior or other public stimuli as evidence that the private event is occurring (e.g., crying and a bleeding wound should accompany the sensation of pain) and reinforce verbal reports of its occurrence when those or similar accompaniments are present. In training an animal to detect an odor, we use only our confidence that the odor must be present if the target item (e.g., a mine) is present as a basis for deciding whether or not to reinforce an indicator response. While this might often be true, it is also likely that numerous other odors correlate with the target and might overshadow stimulus control by the target.

Moreover, determining how close an indicator response must be to a mine to be reinforced poses problems, because it is always difficult, and in operational work impossible, for humans to determine how far a scent plume extends around a target. Because IMAS standards define a hit as an indicator response within 1 m of a mine, in training rats, APOPO's staff reinforce responses within this distance. But in truth the standard is somewhat arbitrary and may be less than ideal. We currently are conducting a detailed analysis of where rats' indicator responses occur in relation to landmines in actual minefields and its findings may lead to a better operational definition of the target response. It is critically important to ensure that accurate performance is established at every training step and, most importantly, that accuracy is high in the operational setting even though the current definition is arbitrary. The logic we follow and the steps we take in doing so are not fundamentally different than those taken by, for example, a behavior analyst who teaches a person with autism to emit a desired response in increasingly naturalistic settings. Just as a practitioner might teach a child with autism a novel skill (e.g., a social greeting) in one-on-one setting, then program for the occurrence of the response around a school with prompting if necessary, and finally strengthen the behavior in a variety of public settings without prompting, we start in the lab, move to the training platform, then to the simulated minefield, and finally to actual minefields. In both cases, performance is continuously monitored and training is adjusted as appropriate and desired results are usually, but not always easily, attained.

## Using Rats in the Minefield

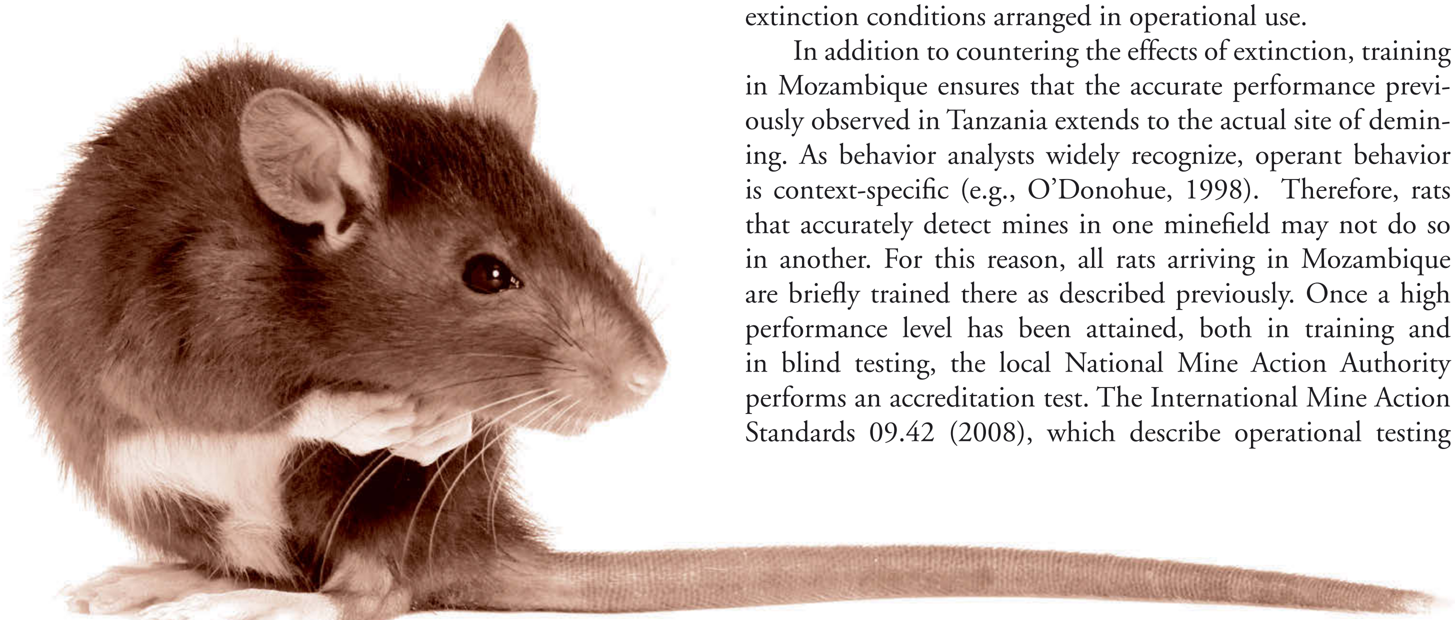
APOPO recently has been involved in demining operations in Gaza Province, Mozambique where mines were placed in the civil war that ended in 1992. A team of 34 rats and 50 APOPO personnel, outfitted with a variety of equipment, worked on the project in 2009. In field operations, an armored bush cutter removes vegetation from the area to be checked by the rats. Humans (manual deminers) wearing protective gear and equipped with metal detectors then manually clear well-marked safe lanes. The rats search along a rope stretched between two trainers wearing protective equipment who move down parallel safe lanes. Pictures and videos of the rats working in the field and related activities are available online at the APOPO (www.apopo.org) and HeroRat (www.herorat.org) web sites. Two rats search each area and the location of every indicator response is recorded on a grid. All locations where at least one rat made an indicator response are checked by a manual deminer using a metal detector. Deminers dispose of all located mines and ERW. In 2009, the rats cleared 199,318 square meters, finding 75 landmines and 62 ERW and allowing more than 750 families to return to their land. Those mines were buried at depths of 0 to 10 cm, with an average burial depth of 7 cm below the surface.

During 2009 and 2010 APOPO personnel used metal detectors to check every box searched by the rats in Mozambique, including boxes with no indicator responses because it is absolutely crucial that rats do not miss mines. This project is ongoing, but to date no mines have been missed by the rats (Poling et al., in press b).

## Challenges in the Field

An obvious challenge in using demining rats is that it is impossible for a handler to know whether an indicator response is correct (i.e., emitted near an explosive device) or incorrect. Therefore, it is impossible to arrange differential reinforcement, which is required to maintain the discrimination. APOPO's team deals with this by beginning each training day with a test in which each rat is worked across an area known to contain a defused mine. If an indicator response occurs, a reinforcer is delivered and the rat is used in field operations. This reinforcer, plus reinforcers received on a simulated minefield in Mozambique, is sufficient to maintain performance under the extinction conditions arranged in operational use.

In addition to countering the effects of extinction, training in Mozambique ensures that the accurate performance previously observed in Tanzania extends to the actual site of demining. As behavior analysts widely recognize, operant behavior is context-specific (e.g., O'Donohue, 1998). Therefore, rats that accurately detect mines in one minefield may not do so in another. For this reason, all rats arriving in Mozambique are briefly trained there as described previously. Once a high performance level has been attained, both in training and in blind testing, the local National Mine Action Authority performs an accreditation test. The International Mine Action Standards 09.42 (2008), which describe operational testing



for mine detection dogs and handlers, is applied to rats. The animal and its handlers, who are blind to mine locations, must detect every mine in a 400 square meter field containing five to seven mines with two or fewer false alarms, which are defined as indicator responses located further than 1 m from the nearest mine. Only after a rat has been accredited by the National Mine Action Authority can it be used operationally.

All operational rats are continuously trained and tested because consistent accuracy is essential. Training typically occurs each day and every week handlers conduct blind tests like those described previously for Jackpot rats. Only those rats that exhibit 100% detection and less than 5% false alarms are considered for operational use.

Although the rope system works well, in some settings obstructions such as large trees and rocks make it unfeasible. APOPO has developed a system for directing the rats by attaching their harness cord to the end of a long pole held by the handler that works well in such situations (Poling et al., 2010), as well as for clearing to the sides of previously demined roads or paths. This system can even be used to clear large open areas and has the advantage of requiring only one handler per rat.

## Advantages and Disadvantages of Rats as Mine Detectors

APOPO's work in Mozambique illustrates that *Cricetomys* are robust and accurate mine-detection animals. They are easy to maintain at a field site making it possible to have a sizeable colony. Their small size allows them to walk over mines and ERWs without activating them and no accidental discharges have occurred. The rats do not bond with individual handlers and perform well for any competent person. All of these are points in the rats' favor.

The main disadvantage of rats is that they do not work well when it is extremely hot and sunny. Therefore, in warm weather—which is characteristic of Gaza Province—demining with the rats is limited to the cool of morning. Later in the day, handlers shift to other activities, such as clearing brush and manually demining. Although pouched rats play an invaluable role in APOPO's mine clearance activities, they are by no means the sole weapon in the arsenal.

In the early stages of training and testing *Cricetomys* outside, some of the animals developed cancers on their ears, apparently as a result of exposure to the sun. Handlers now coat the rats' ears and tails, which are also sensitive to sunlight, with sun block before field work, which obviates this problem. We have explored the possibility of having the rats work under lights at night, because they are nocturnal animals and should be most active at night. Safety concerns and the difficulty of seeing indicator responses rendered this strategy unworkable under the present circumstances. Fortunately, the rats' high accuracy during daylight makes it unnecessary. It appears that the rats have a number of strengths as mine-detection animals and no overwhelming weakness. They are not *better than* dogs in this role, but *different from* them and especially well-suited to some applications. For example, mine-detection dogs are widely employed in Afghanistan and some of the territory they search is steep and covered with rocks, including small ones that roll under a dog's feet. This is difficult terrain for the dogs, which have to maintain their balance while sniffing the ground, but seemingly would pose no problem for the rats, whose small size and light weight would let them easily pass between large rocks and over small rocks without rolling them. In other terrain, the dogs might be faster and more cost-effective.

## Concluding Comments

In closing, it is important to note that biologists, ethologists, and product designers, not behavior analysts, were and are responsible for most of APOPO's research and development, as well as its operational mine-detection activities. Behavior-change strategies based on principles of operant conditioning have become common knowledge in a number of areas, which should be heartening to any confirmed behavior analyst. In applying these strategies to solve significant problems, people often encounter similar challenges in a wide range of settings. For example, devising an effective strategy for immediately reinforcing appropriate behavior posed a challenge for APOPO's personnel and the same challenge often faces practicing behavior analysts who work, for example, to aid people with developmental disabilities. Another problem both encounter is dealing with extinction in the "natural environment," whether a minefield for a pouched rat or a school classroom for a child. A third is ensuring "intervention integrity," that is, getting the individuals responsible for a given behavior-change strategy to implement that strategy as intended by its designer (Poling, Methot, & LeSage, 1995). Devising appropriate response definitions, recording data accurately, and setting useful performance criteria are other common challenges.

All of these challenges are magnified in APOPO's work by the use of KiSwahili, the official language of Tanzania, by most local employees, who constitute over 90% of APOPO's workforce. Although everyone at APOPO speaks some English, Tanzania's second language, many people do not understand it well enough to share information regarding procedures and findings. Because some ex-patriates' grasp of KiSwahili is even more limited, there is real risk for miscommunication. The probability of miscommunication can be increased by cultural variables, notably the general reluctance of Tanzanians to bear bad news or to disappoint another person. For example, a researcher who asks a Morogoro trainer "How is your rat doing? (*Panya anaendeleaje?*)" is apt to hear "Very well (*Nzuri sana*)" regardless of its actual performance. Such miscommunication can lead to inappropriate decisions by subject-matter experts. Becoming familiar with the language and culture of the people with whom one works, and making decisions based on real data, not verbal reports, prevents this from occurring. Behavior-analytic practitioners who work with professionals from other disciplines know well the wisdom of taking this tack.

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