The amazing adventures of robotrat

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By using electrical brain stimulation to deliver both ‘virtual’ tactile cues and rewards to freely roaming rats, Talwar et al. have been able to instruct animals remotely to navigate through complex mazes and natural environments they have never visited before. These results provide both an elegant alternative way to train animals and a new approach to study basic neurophysiological principles of animal navigation.

Traditionally, neuroscientists interested in investigating the physiological properties of neural circuits in behaving animals have faced tremendous challenges when using routine operant-conditioning paradigms to instruct their subjects to learn a particular task. Not only are these classical training procedures very time-consuming, but they also impose significant physical constraints that limit their implementation to very restricted and controlled laboratory conditions. These serious shortcomings, combined with a natural reticence to incorporate state-of-the-art signal-processing technologies into neurophysiological studies, have seriously limited the range of electrophysiological measurements that can be made in behaving animals.

Remote control rats

A report by Talwar et al. [1] published early this year is likely to change this picture significantly in years to come. These researchers combined an ingenious and creative experimental paradigm – which significantly simplifies the operant-learning paradigm used to train their animals – with modern microelectronic tools and signal-processing techniques. Using this approach, Talwar and colleagues were able to use ‘virtual tactile cues’ and ‘virtual rewards’ to instruct rats remotely to navigate through extremely challenging mazes and environments, most of which the animals had never visited before. To accomplish this feat, the authors devised several elegant procedures. First, to instruct a rat which direction it should turn when navigating a maze, the authors designed a backpack containing a microprocessor-based, remote-controlled microstimulator. Then, using a laptop and a wireless interface to activate the backpack microstimulator, the authors took advantage of chronically implanted arrays of microwires to deliver brief trains of electrical pulses to the whisker representation area of either the left or right primary somatosensory (SI) cortex. Animals quickly learned to associate the target of these virtual ‘tactile’ stimuli (left or right SI cortex) with the direction they should turn (left or right) by receiving a ‘virtual’ but very powerful incentive: if they moved to the correct direction after the cortical stimulus they immediately received an electrical stimulus in the medial forebrain bundle, a brain region whose stimulation is thought to mimic the pleasure experienced by the animal following a powerful positive reward. Using this training paradigm, a remote operator was able to train freely roaming rats to learn how to navigate through a variety of daunting obstacles, placed either in a laboratory or even in outside environments.

‘...a remote operator was able to train freely roaming rats to learn how to navigate through a variety of daunting obstacles...’

Having witnessed the amazing achievements of ‘robotrat’ (as I referred to these animals since the first day I saw them in action), I believe that many areas of research will be influenced by the results obtained in these experiments. Of course, as pointed out by the authors, the use of intracranial electrical stimulation to mimic either a sensory cue or a reward is not a new idea. Several authors in the past have taken advantage of this method to study particular brain functions. The elegant recent studies of

References

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Romo et al. [2] illustrate this approach very well. However, the enormous potential of using brain stimulation as the main ‘vehicle’ for delivering both ‘virtual’ cues and reward in order to train animals more efficiently has received little attention previously. That is precisely the avenue that Talwar et al. decided to explore, and their results have attracted the attention of researchers in other fields besides neuroscience.

**From neuroscience to robotics**

Beyond neuroscience, these findings provide a renewed source of inspiration for roboticists interested in applying neurophysiological and ethological principles to build autonomous robots. In this context, I believe that robotrat represents much more than a technological or engineering feat. Indeed, this study may very well mark the emergence of a new design concept in the field of biomimetic robotics [3], an exciting area of research that has grown significantly in the last ten years. This design concept would rely on the idea of using hybrid brain–machine interfaces to endow robots with sensory, motor or even cognitive functions that have eluded the most sophisticated machines built so far.

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Indeed, recent progress in biomimetic robotics has solid foundations on the latest theoretical and experimental advances in brain research. As a result, system and cognitive neuroscience have continued to serve as powerful sources of inspiration for achieving the goal of endowing robots with the type of robust autonomous behavior and learning capabilities that abounds in the animal kingdom [3]. This is particularly true when one looks at several recent attempts to adapt what is known about animal navigation, and the brain mechanisms underlying these behaviors, to robot design. Despite a large number of serious and successful attempts, it is clear that much can still be learned by the continuous interaction among roboticists, neurophysiologists, and animal ethologists. In this context, the work of Talwar et al. significantly expands the research scope on biomimetic robotics and the potential range of future applications for hybrid robots.

Several interesting scenarios come to mind. For example, because rats have an exquisite sense of smell and touch, when trained, guided rats could one day become viable alternatives for search and rescue operations. In this scenario, guided rats could be used to help locate surviving victims buried in piles of rubble, which are normally inaccessible to larger animals, such as dogs. A few years ago such an idea would sound like wild speculation by a rat ethologist. The spectacular performance of guided rats in open environments reported by Talwar and colleagues has made this a serious testable hypothesis, far removed from the domain of science fiction.

**Clinical applications**

Important clinical applications might also emerge in the future through the implementation of hybrid brain–machine interfaces. By combining modern concepts of brain function with new neurophysiological, computational, microelectronic and robotics approaches, several laboratories are investigating the feasibility of designing neuroprosthetic devices aimed at helping patients regain neurological functions lost as a result of illness or trauma [4]. The results obtained with robotrat certainly represent one more demonstration supporting the notion that a cortical neuroprosthetic device for restoring upper limb motion in severely paralyzed patients could be built and implemented in the not-so-distant future. Although previous work by Chapin et al. [5] and Wessberg et al. [6] has demonstrated that rats and primates can learn to use their own cortical electrical activity to control the linear and 3-D movements of a robotic device (such as a prosthetic arm), the experiments by Talwar et al. have shown, for the first time, that sensory feedback signals (such as ‘virtual’ tactile or proprioceptive information) describing the movements of a robotic arm can be delivered back to the subject’s brain, via intra-cortical stimulation.

In fact, the possibility of closing the control loop between a monkey’s brain and a robotic arm using both large scale intracortical recordings as the source of motor control signals, and cortical microstimulation to provide the animal with sensory feedback, is currently being tested in our laboratory. Despite the fact that this task is likely to require the use of a multi-channel microstimulator capable of delivering spatiotemporal patterns into multiple somatosensory cortical areas, the principle neurobiological approach we and others are following is identical to that proposed by Talwar et al. Although it is much too early to know whether these experiments will materialize into clinical applications that can alleviate severe neurological deficits, there is reason to be optimistic [7].

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**A new era**

It is not every day that when reading a paper one gets the impression of having witnessed the beginning of a new era. Of course, it is impossible to predict the future, but the paper by Talwar et al. is in this category because it illustrates a new paradigm in neuroscience, one that will certainly cross the boundaries of brain research and influence developments in many other fields. In some fundamental sense, ‘the adventures of robotrat’ point in a new direction, one that clearly consolidates neuroscience as the ultimate multidisciplinary field of research of our time, and in which the frontier is quickly approaching the limits of one’s wildest imagination.

**References**


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