FORUM Neuroscience

Virtual reality explored

Neuroscientists are increasingly using virtual reality to facilitate studies of animal behaviour, but whether behaviour in the virtual world mimics that in real life is a matter for debate. Here, scientists discuss the strengths and limitations of the approach.

THE TOPIC IN BRIEF

- Virtual-reality (VR) systems simulate real-world inputs to one or more of an organism's sensory neural circuits, then measure the subject's actions and apply updates to sensory stimuli in response.
- In most rodent set-ups, the animal receives visual information from an immersive screen that spans its field of vision. The animal's movements control the visual flow, thereby replicating the sensory–motor coupling of the real world.
- Typically, movement is restricted by fixing the rodent's head in position; this allows precise measurements of neural activity to be taken and correlated with motor actions in animals that are awake, rather than anaesthetized (Fig. 1).
- Many researchers think that VR is a valuable tool for studying both navigation and sensory systems.
- However, a body of work[1–3] indicates that the way in which mice navigate in real and virtual worlds is different.

The best of both worlds

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Virtual reality is a valuable tool for understanding neural function because it combines precise experimental control with natural behaviours. It allows experiments that are not possible using real-world approaches. As such, it has increased our understanding of neural processes in subjects ranging from humans to insects.

What are the experimental benefits of VR? First, the technology allows researchers to define explicitly and exhaustively the sensory cues that carry information about the virtual world. In real-world experiments, it is not possible to control all sensory cues. For example, when studying the contribution of visual cues to navigation, confounding information could be provided by unmeasured smells, sounds, textures and vestibular stimuli (internal information about balance and spatial orientation). VR offers the means to add or remove sensory cues to test the contribution of each one to a neural code, and to build up a 'minimal' set of stimuli needed to produce a given behaviour or neural activity pattern.

A second benefit comes from the ability to redefine the laws that link the subject's actions to changes in its world. When an animal explores the real world, it is difficult to disentangle which neural responses are attributable to the animal's actions and which are caused by sensory stimuli, because the two are rigidly linked by the laws of physics. In VR, this link can be modified in informative ways — sensory and motor features can be dissociated by changing the gain or lag between an action and a subsequent update of the virtual environment, or be made independent of one another for brief periods. Sensory and motor variables can therefore be separated while allowing the subject to interact naturally and actively with the sensory world.

Third, VR increases the range of tools available to measure neural activity. Because the subject is usually constrained, techniques can be applied that are either not possible or of poorer quality in freely moving subjects. These include functional magnetic resonance imaging, high-resolution fluorescence imaging and intracellular single-neuron electrophysiology.

Many studies have shown that animals can solve navigational tasks in virtual worlds[4–6]. But the aspects of navigation that can be studied in VR depend on the experimental set-up — for instance, the number of sensory cues simulated, the degree of sensory immersion and how naturally the subject interacts with the virtual world. In VR experiments that provide visual inputs and allow body rotations to trigger vestibular signals, neural activity patterns during navigation are consistent with those measured in real-world experiments[5]. Furthermore, studies[1–3] that remove key sensory inputs such as vestibular stimuli reveal which aspects of navigational neural activity depend on vestibular input and which can be supported by visual cues alone. Therefore, VR can recapitulate neural activity in real environments, and VR experiments can be designed to create informative differences between neural function in real and virtual worlds.

Overall, VR has yielded many insights into sensorimotor integration, decision-making and navigation[6]. But it is important to remember that, like all reductionist approaches, VR requires a trade-off between improved experimental accessibility and consistency with natural processes — the optimum set-up depends on the research question being asked. For instance, in studies of sensorimotor integration, it is crucial to dissociate sensory and motor variables. In navigation studies, convincing simulations are needed to probe the subject's internal model of the physical world. VR must be used judiciously, so that its implementation matches the needs of the question. Of course, this requirement applies to all experimental tools and is not specific to VR.

VR experiments can be designed to create informative differences between neural function in real and virtual worlds.

In summary, we consider VR as bridging the gap between natural behaviour and conventional reductionist approaches; this is a major step forward in the study of complex behaviours in many species. As the community of VR users grows and commercial VR technologies expand, we expect the range of applications for VR to continue to grow, enhancing our understanding of neural function.

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