Human and Primate Spatial Cognition through VR Experiments

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Virtual reality (VR) is the use of computer technology to create immersive simulated experiences. In evolutionary psychology, VR is used as an interactive technology to test spatial cognitive abilities such as learning, memory, and spatial navigation in primates and humans. Studies to date have mostly been conducted with adult chimpanzees and rhesus macaques, as well as humans aged 3-49. Paralleling Tinbergen's four questions, research has sought out to answer the questions of how spatial cognition has evolved, when and how it develops, and what cognitive mechanisms and strategies are used by humans and primates. Why spatial cognition has developed was less of a focus in these studies, probably because the answers found to this question in other primate studies were compelling.

VR primate studies examine navigation in mazes and paths of varying complexity that often have 3D or 2D landmarks. These landmarks can be positive or negative, representing if the paths lead the correct way or not. Virtual navigation is facilitated by joysticks, while the participants sit in front of a large monitor spanning their visual field. Chimps have been taught to use VR headsets and seem to enjoy games on them, but joysticks enable movement across longer distances and were therefore preferable (Treadmill VR might have safety issues but could be useful for future experiments). The studies tracked distance traveled in feet, eye movement, and neuron and hippocampal activity while the monkeys were in the simulations (Sato, Sakata, Tanaka, Taira, 2004)(Buffalo, Morrisoe, Jutras, Browning, McKinley, 2016). The chimpanzees and monkeys were given food or juice rewards and automated positive auditory feedback throughout the experiments. One study even made participation voluntary for the chimps by offering them the option to position themselves on the workstation if they wanted to. Children and adults, on the other hand, were given in-person verbal rewards during testing and presented with a small token gift upon reaching a goal (Dolins, Klimowicz, Kelly, Menzer, 2016).

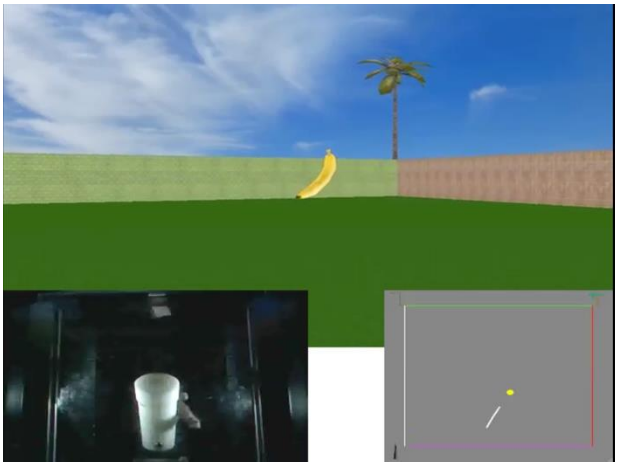

Fig. 1

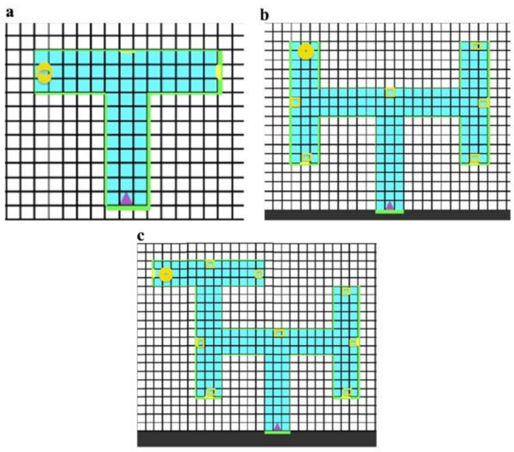

Fig. 2

One reason VR is used to examine spatial cognition is that the investigation of cortical mechanisms to construct cognitive maps is one of the most challenging themes in neuroscience (Sato et al., 2004). This is because it is technically challenging to perform neurophysiological recordings in freely moving and navigating primates, and virtual scenarios allow for innovative recording techniques. Additionally, VR offers greater control over landmarks and space to assess attention and behavior. Virtual environments can also vary in features, scale, and complexity. Research in VR has used built as well as simple naturalistic outdoor environments. The subjects had multiple trials to understand and navigate different settings within the encoding phase. Sato et al. (2004) reveal that it took thousands of trial rounds for the monkeys to learn how to use a joystick in virtual rooms in a building. The main finding of the experiments was that virtual reality enables cross-species investigations of spatial cognitive and developmental comparisons. Both chimpanzees and humans in the experiments translated images on a two-dimensional monitor into three-dimensional environments in their minds. Using the ground, walls, and ceilings as visual anchors, both species showed a "ground dominance effect" (Dolins et al., 2016, p.497). In addition, Wirth et al. (2017) found that the place fields of rhesus macaques were projecting spatial memory onto physical space (Wirth et al., 2017). This finding was based on the interpretation of place cell activity. As a result, monkeys were able to learn the foreign task of tracing a route in a virtual environment and research has found evidence for cognitive representations of the paths.

In Dolins et al.'s (2016) study, chimpanzees' average shortest path ratios were comparable with that of 3 to 6-year-old humans', and humans above 11 years of age outperformed the chimps on average. Strategies used in locating the most efficient path to a goal were either to look around and then move the joystick every time or to follow the circumference of the walls. 80% of the participants used the "wall-hugging" (Dolins et al., 2016, p.511) method, but the strategies used by the subject changed randomly in different environments. The spread of distance traveled among children's age groups were consistent, whereas some chimpanzees traveled double the path length of others to find the correct way. In the experiments, both humans and chimpanzees discriminated effectively between positive and negative landmarks (Dolins et al., 2016). Following this, primates' viewing patterns and eye movements showed significant similarity (Wirth et al., 2017). However, an interesting detail was that chimpanzees showed faster and more regularly changing eye movements and visually explored more locations than humans. (Dolins et al., 2016). Another key finding of the studies was that maze complexity reduces path efficiency both in chimpanzees and in humans. Markedly, the reduction of efficiency was more prominent in younger children. The researchers found that young children lacked attention to directional cues and landmarks to locate a goal.

Questions and controversies in the field of spatial cognition and VR studies focus on concerns of ecological validity, comparative spatial-cognitive strategies, and testing methods. The researchers had to make sacrifices in the ecological validity of the experiences to have experimental control. The joysticks only allowed for 90º turns, meaning the subjects could not move diagonally or circularly. Furthermore, the environments lacked specific goals such as seasonally available fruits and other primates/humans that the participants would observe for social directional cues. This might not have caused human participants difficulty, but for wild chimps who are social navigators, being separated from their community would be an unnatural condition. In addition, the findings in small-scale environments may not translate to large-scale environments, and vice versa. As a result, there is a question of whether or not the observed behaviors would be different in the real world and if the results can be generalized to the trained chimps' wild counterparts (Dolins et al., 2016). There is also a considerable difference in the background in technology use and cognition between humans and primates. Modern humans are very used to seeing symbolic representations and animated environments, but a virtual banana floating in mid-air would probably be quite shocking to a monkey. This might positively or negatively affect their memory, and is a question to explore.

The second controversy was on the strategies used for spatial navigation and cognition. There was a comparison between the motor sequence theory, maintaining that primates might be memorizing joystick positions to get to their goals, and the flexible cognitive mapping strategy, setting forth the idea that the primates have mental maps just like humans. The motor sequence strategy was ruled out by Sato et al. (2004) and then Wirth et al. (2017) since they observed corrective navigation behaviors, and brain scans that supported the flexible mapping strategy. However, an unresolved issue is the relative cognitive map development process and transformation in humans versus nonhuman primates. Unfortunately, it was not possible to test young chimpanzees at an equivalent stage in development on the same tasks to determine age and development related effects on performance (Dolins et al., 2016). An added challenge was that human children were allowed to opt-out of or stop the experiments at any time. As a result, many children did not complete the challenging mazes, leaving the researchers without a significant percentage of data points. Another developmental and cognitive psychology question is how Panzee, the female adult chimpanzee, outperformed all chimps and humans, who remarked the mazes were complicated, in the complex maze condition. All we know is that Panzee used shorter distances to localize the goal position (Dolins et al., 2016).

When it comes to methods of the experiments, one of the chimpanzee studies uses only four adults and four chimpanzees, and another two only had two macaque monkeys. These numbers do not provide representative samples of the species and must increase in later trials. In addition, without averaging data, performance among the chimps was so different that the experimenters factored out half the data from their chimpanzee sample. One final ethical controversy online included the debate about putting chimpanzees in VR environments. Animal rights activists press that since the chimpanzees do not know the reality is virtual and are taught to comply with experiments for rewards, they would not escape the simulations even when distressed (Toliver, 2016). The method that Dolins et al. (2016) used against this concern was to end the trials as soon as the chimps showed any sign of frustration or discomfort. In addition, it is parsimonious to claim that the chimps know the experience is simulated since they need to enter a separate room or wear glasses in order to experience them.

In sum, the experiments on primates and humans served more as tests of VR for spatial cognition and memory studies than studies that dramatically impacted the understanding of chimpanzee navigation and spatial cognition. They did, however, give some insight into the learning and viewing patterns of primates that previous studies could not access. Wirth et al.’s (2017) study was particularly promising in its analysis of hippocampal activity. The big questions to consider in further studies are How can we increase the sample sizes of these experiments to be more inclusive? Would changes in foraging strategies and spatial cognition occur under different social and ecological constraints and information sets? Or in other words, can we render more realistic simulations to wild/familiar environments for the chimps and monkeys? And do human and primate cognition and spatial problem solving develop similarly?

References

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Fig.1 Buffalo, E. A., Morrisoe, K., Jutras, M., Browning, Y., &; McKinley, M. K. (2016). Using Virtual Reality to Assess Navigation and Spatial Memory in Nonhuman Primates.

Fig. 2 Dolins, F. L., Klimowicz, C., Kelly, J., &; Menzer, C. R. (2014). Using Virtual Reality to Investigate Comparative Spatial Cognitive Abilities in Chimpanzees and Humans. American Journal of Primatology.