Supplementary document: Animals in Virtual Environments

Section S1: Discussion On Future Directions

In this section we have included some ideas for future development in behavior studies using XR and added supporting information relevant for Section 6 of the paper.

S1.1 Collective behavior experiments using mixed reality:

In a mixed reality scenario, projection mapping techniques can be used in a large tank or a cage (see figure S1). This method will provide a means to conduct experiments in larger areas with multiple animals. In a mixed reality setup a specific member of the group can be targeted for stimulus delivery. Based on the movement of the focal individual, a projector can be configured to trigger a stimulus to startle the focal individual and observe the response of the individual and the group. Such experiments are typically performed in open-loop scenarios with and offline processing, mainly due to lack of real-time tracking solutions for tracking a group of animals while maintaining individual identities. The problem is actively studied in computer vision and offline solutions are available for tracking individuals in a large group. Development of real-time methods may solve this problem and enable closed-loop MR experiments if the focal individual’s movements can be tracked in real-time, along with other individuals of the group.

Fig. S1. Mixed Reality with Multiple Animals: A school of fish in a large fish tank where bottom of the tank is illuminated with multiple projectors to provide desired visual stimulus to a group.

S1.2 Support from Computer vision community:

In the paper, we have mentioned that the computer vision community is paying more attention to challenging problems relevant to animal tracking. In the last 5 years, conferences like CVPR, ICCV, ECCV, WACV have published papers directly relevant to the identification and tracking of animals in the wild or in the lab. Most of these are covered by Mathis et al.[56] in a recent review focused on deep learning based methods for measurement of animal behavior. Workshops are organized with the theme of wildlife tracking to engage a dialogue between computer scientists and biologists [S1, S2, S3]. Additionally, various challenges are organized to motivate machine learning and computer vision-based applications for monitoring wildlife with large datasets e.g. LifeCLEF2020. This is a welcome change because animal tracking related methods are mostly published in the journals or conferences directly relevant to biologists (Fig S3) e.g. eLife [34,36], Nature methods [71].

We believe that the XR community will benefit greatly by starting a dialogue with biologists interested in developing new methods with XR. It will not only extend the reach of the XR community but also help in pushing fundamental research studies.
S1.2 Recent work in computer vision related to tracking animals:

Fig. S2. Keypoint based posture estimation: (Clockwise) 3D posture estimation of birds from 2D keypoints using C3DPO published in ICCV 2019 [66], Full 3D posture recovery of animals from images [86] published in CVPR 2018, 2D posture estimation using DeepPoseKit [34] published in eLife 2019, Locust tracking with markers [34].