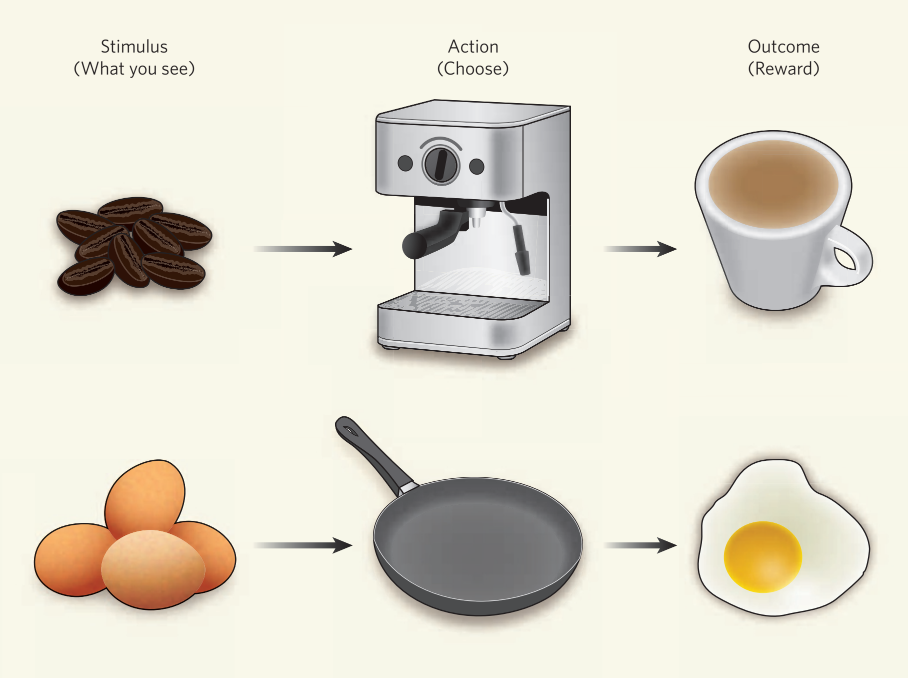

Figure 1 | Stimulus–action–outcome associations. Histed and colleagues[2] study how the brain stores information about the relationship between a stimulus, an action and its outcome. Their work shows that learning the outcomes of specific actions might be facilitated by persistent neural activity in the prefrontal cortex and basal ganglia.

experience the same sequence of sensory stimuli, actions and outcomes repeatedly. Moreover, the sensory and motor events that need to be remembered together are often transient, whereas the outcome of an action may be revealed only after a long delay. Therefore, the information about various sensory and motor events must be stored temporarily before the long-lasting memory about their relationship can be formed.

At least two mechanisms have been proposed to store such information in the brain. First, the relationship between two events, such as the tendency for separate sensory stimuli to occur together, might be reflected in the strength of synapses within a population of neurons[3,4]. Although the properties of such synaptic plasticity are becoming better characterized, how they encode behaviourally relevant information during the learning of a specific task is poorly understood. In addition, this mechanism requires the activity of the pre-synaptic and post-synaptic neurons to overlap within a relatively narrow time window, and therefore might not be able to deal with a long delay between relevant events[3]. A second, alternative mechanism for storing information about the relationship between multiple events might be persistent neural activity, which is sustained beyond the duration of the initiating event[5,6].

The best-known example of persistent neural activity is the 'delay activity' observed during the delay period of a working-memory task[5,6]. The activity of neurons in the primate prefrontal cortex often alters while the animal remembers the location or identity of a particular stimulus in order to use this information for guiding subsequent behaviour. The results from more recent studies[7–11], however, suggest that persistent activity might serve broader functions than working memory. For example, persistent activity is observed[7] in the prefrontal cortex, even when the animal is not performing a working-memory task. Also, during a dynamic decision-making task in which the animal has to discover an optimal behavioural strategy by trial and error, the activity of neurons in the prefrontal cortex and parietal cortex often changes according to the outcomes of the animal's previous choices[8–11].

Histed and colleagues' work[2] shows that persistent neural activity might have an important role in learning the correct actions, even when the animal needs to repeatedly revise the associations between a sensory stimulus, an action and its outcome. In their study, monkeys learned which of two alternative actions (looking to the left or to the right) was required to gain a reward after viewing a particular visual stimulus. Once the animal learned the rewarded or 'correct' actions, the associations between stimuli and the correct actions were unpredictably reversed, requiring the animal to re-learn the relationship. The authors found that individual neurons in the prefrontal cortex and basal ganglia showed changes in activity depending on whether the action was correct or incorrect. And these neurons often displayed persistent activity during the inter-trial interval, signalling whether the animal had performed correctly or not in the preceding trial. Histed *et al.* also found that the activity in the prefrontal cortex and basal ganglia that is related to the animal's upcoming choice was enhanced, and the animal was more likely to choose the correct action when its choice in the previous trial was correct.

Histed and colleagues' results indicate that persistent neural activity might have more diverse roles in relating multiple events separated in time than previously thought. Studies have shown that some neurons in the prefrontal cortex and basal ganglia carry information about previous actions[8,11–13]. Combined with the authors' findings[2], these data suggest that the prefrontal cortex and basal ganglia might be essential brain areas for storing information about action–outcome associations[12–14]. However, how the signals related to an action and its outcome can be bound to a particular stimulus remains unknown. For example, in the task used by Histed *et al.*, the animal had to learn the relationship between a particular stimulus and an action. But neurons in the prefrontal cortex and basal ganglia predominantly encoded the outcome of the animal's choice between trials rather than the corresponding stimulus or action. To build on these findings, more studies are needed to further characterize the neural circuitry responsible for forming appropriate associations necessary for adaptive and flexible behaviours. ■

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Correction

The News & Views article "Chemical physics: Electronic movies" by Marc Vrakking (*Nature* **460,** 960–961, 2009) stated at the end of the fifth paragraph that "A similar conclusion was recently reached in a study of harmonic generation from nitrogen molecules", and incorrectly cited reference 8 of the article. This should have cited B. K. McFarland *et al. Science* **322,** 1232–1235 (2008).