Sir,

The case study by Vo and colleagues (2014) aims to address the differential roles of ventral versus dorsal striatum in learning, specifically, whether they are essential for learning or simply involved in it. The authors reported a dissociation between action-value (based on the outcomes, values will be assigned to actions) and stimulus-value learning (values will be associated with the stimuli), and how impairment of the dorsal striatum will affect each of these processes.

To achieve this, Vo and colleagues tested a patient (known as XG) who has bilateral damage to the dorsal striatum, while the ventral striatum including the nucleus accumbens is spared. To compare XG’s performance in different tasks with a healthy population statistically, the researchers tested 11 matched control subjects. Among the seven reinforcement learning tasks employed, three could be solved only by learning stimulus-values, one only by learning action-values, and the remaining tasks, with either strategy. Surprisingly, they found that Patient XG was able to learn all the tasks involving action-value learning and his performance resembled those of healthy controls. However, he was impaired at learning the tasks which could only be learned using stimulus values; his performance in those tasks was significantly poorer than controls and was no different from random.

Vo et al. also analysed learning and performance processes using computational models. Regression modelling of current choice based on the previous choice and the history of rewards revealed the following: in action-value learning tasks, both Patient XG and healthy controls demonstrated normal patterns of reinforcement learning (i.e. exponential decline in weight of past trials). In contrast, Patient XG (compared to controls) did not show this pattern in stimulus-value tasks. In fact, the regression weights were not significantly different from zero, which indicated lack of learning. Consistent with this, a three-parameter reinforcement learning model explained choice behaviour better than the null model for controls in both tasks. For Patient XG, the model explained choice behaviour better for the action-value tasks, but could not explain the behaviour in stimulus-value tasks.

These results address two different aspects of reinforcement learning: (i) the anatomical dissociation of the ventral striatum and dorsal striatum in learning; and (ii) the behavioural dissociation between stimulus-value versus action-value learning. These two aspects are addressed separately hereafter.

Studies investigating functional segregation of the striatum suggest that the ventral striatum is more involved in goal-directed learning, whereas the dorsal striatum is more involved in action related habitual learning (Balleine et al., 2007; Balleine and O’Doherty, 2010; Redgrave et al.,...
2010); this is consistent with findings in anatomical connectivity of the striatum. Moving in the ventral-dorsal axis, the corticostriatal connectivity changes from limbic/cognitive areas (ventromedial prefrontal cortex, orbitofrontal cortex) towards associative (dorsal anterior cingulate cortex, dorsal prefrontal cortex) and finally motor areas (supplementary motor area) (Postuma and Dagher, 2006; Haber and Calzavara, 2009). These theoretical findings have been validated in rodent addiction studies where goal-directed behaviour subserved by the ventral striatum shifts towards habitual behaviour by the dorsal striatum as addiction progresses (Porrino et al., 2004; Everitt and Robbins, 2013). These findings can explain Patient XG’s spared performance in tasks involving action-value learning, but fails to address the impaired stimulus-value learning.

Stimulus- and action-value learning dissociations have also been studied in cortical areas. Orbitofrontal cortex lesions disrupt stimulus-value but not action-value learning, whereas dorsal anterior cingulate lesions show the opposite effects (Camille et al., 2011). Based on these findings and the previously discussed anatomical connections between dorsal striatum and dorsal anterior cingulate cortex, dorsal striatum impairment in Patient XG should result in action-value learning impairment while stimulus-value learning remains intact, i.e. the exact opposite of what was observed by Vo et al. Using functional and structural connectivity analysis and functional MRI during task performance in Patient XG can enhance our knowledge about the cortico-striatal connectivity and the brain structures involved in each learning process and clarify the source of this contradiction.

In the striatum, stimulus- and action-value learning dissociation has been studied using conditioning paradigms including Pavlovian (stimulus-outcome association) and instrumental (stimulus-action-outcome association) as well as Actor/Critic models. The Actor/Critic model of the striatum suggests that ventral striatum plays a similar role to the ‘critic’ by calculating the prediction errors, and dorsal striatum is similar to the ‘actor’ that is involved in action selection (Joel et al., 2002; Niv, 2009). Consistent with these results, O’Doherty et al. (2004) found that dorsal striatum is involved in instrumental conditioning while ventral striatum is involved in both instrumental and Pavlovian conditioning. Schonberg and colleagues also showed a selective impairment of prediction error-related activity in dorsolateral but not ventral striatum in patients with Parkinson’s disease, confirming dissociation between the two areas (Schonberg et al., 2010). In contrast, a meta-analysis by Garrison and colleagues found that the ventral striatum was chiefly responsible for instrumental condition specific activity, whereas mainly cortical areas were identified in Pavlovian condition (Garrison et al., 2013). These findings suggest that the ventral striatum may be responsible for intact action-value learning but does not explain the impaired stimulus-value learning in Patient XG suffering from bilateral dorsal striatum damage. Investigations of the potential alterations in cortico-striatal connections in Patient XG may elaborate on this knowledge gap.

Various theoretical models suggesting dissociation between stimulus- and action-value learning have been proposed. However, existing models contradict findings reported by Vo et al. For example, Piray and colleagues (2014) provided evidence for dissociation in patients with Parkinson’s disease ON/OFF dopamine medication, those with impulse control disorders and controls using an Actor/Critic model. Their findings suggest that the ventral striatum plays a role in stimulus-value learning while the dorsal striatum in action-value learning whereas Vo et al. suggest dorsal striatum being necessary for stimulus-value learning process and not involved in action-value learning.

Differences in findings might be due to the structure of the task used in the study by Vo and colleagues. In action-value learning tasks, Patient XG was presented with a single state (trial type) whereas the stimulus-value learning tasks consisted of multiple states. Impairment in the latter task may therefore reflect the involvement of the dorsal striatum in state representation, and its interaction with working memory and not necessarily in learning stimulus-value learning. Future study designs should introduce multiple state action-learning tasks and examine whether the impairment occurs in state representation or stimulus-value learning.

References

