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Research Report

Feedback-based versus observational classification learning in healthy aging and Parkinson's disease

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Previous studies underline the role of dopamine in cognitive reinforcement learning. This has been demonstrated by a striatal involvement in feedback-based probabilistic classification learning. In order to determine to which extent the dopaminergic loss of Parkinson's disease and aging affects the feedback aspect in classification learning, we applied two versions of the same visual classification task. One version had to be learnt by trial-by-trial feedback, the other by observing the correct assignment of stimulus and category. Performance was evaluated in test blocks that were identical under the feedback and the observational conditions. There were 31 patients with Parkinson's disease (PD), 30 older controls and 20 younger controls tested. The results show that younger healthy participants perform better than older participants in the classification task and this difference significantly interacts with the learning condition: both groups show nearly the same level of performance under the observational condition but younger participants show a better performance than older ones under the feedback condition. In contrast, PD patients and older controls did not differ in their performance in the classification task; both groups performed better under the observational than under the feedback condition. These results demonstrate that healthy aging affects feedback-based learning but does not affect learning by observation. The fact that PD patients showed no additional deficit in feedback-based learning is an indication that the loss of dopamine does not play the key role under the feedback condition of our classification task. This finding questions the general role of the striatum in feedback-based learning and demonstrates that healthy aging particularly affects feedback-based learning.

1. Introduction

The established taxonomy of memory systems distinguishes between a declarative (explicit) learning system that memorizes facts and events and a non-declarative (implicit) memory system (Squire and Zola, 1996). The latter refers to memory processes of unconscious and unintentional recollection of cognitive and motor skills and habits. In procedural or habit learning, the organism must learn sensory discriminations between items associated with different responses or outcomes (Seger and Cincotta, 2002). Animal studies and studies examining patients that suffer from a striatal

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dysfunction (e.g. Parkinson's disease and Huntington's disease) underline the role of the striatum in procedural or habit learning (Knowlton et al., 1996a; Packard et al., 1989). These implicit learning mechanisms are basically characterized by the following aspects: (i) amnesic patients are able to learn the task despite their hippocampal lesions, (ii) participants are not able to fully verbalize the cognitive strategy that are needed to solve the implicit learning task and (iii) implicitly learnt habits and skills are inflexible, which means subjects are not able to transfer their implicitly learnt skill to a new test situation assessing the same cognitive strategy (Dienes and Berry, 1997; Seger, 1994). An influential paradigm in the domain of striatal habit learning is probabilistic classification learning, in which patients with Parkinson's disease (PD) show impaired performance compared to control subjects (Knowlton et al., 1994, 1996a,b). In the so-called weather prediction task, participants learn to predict rain or sunshine from a set of four stimulus cards, so they can be said to learn sensory discriminations between the stimulus sets associated with the two different outcomes. After each prediction, participants get feedback (right or wrong). This is a form of category learning but stimulus sets and categories are associated in a probabilistic instead of a deterministic manner in order to prevent participants from learning the task in an explicit way. It is assumed that the task's sensitivity for striatal functioning is due to its probabilistic structure which makes it impossible to memorize explicitly the stimulus–category mappings (Knowlton et al., 1994). Another possibility is that PD patients are impaired in the probabilistic classification task because they must learn cue–outcome relations via trial-by-trial feedback (Reber and Squire, 1999). Thus, it is still a matter of debate which specific task characteristics (the probabilistic structure of the task or the fact that the task is learnt by feedback) enable learning by the striatal learning system in probabilistic classification learning (Witt et al., 2006a,b). There are several aspects that favor the latter possibility. Reinforcement learning is one task characteristic that is associated with striatal functioning. Dopamine neurons in the pars compacta of the substantia nigra and the ventral tegmental area play an important role in reward learning as these are activated by rewards – more strongly by unpredicted than by predicted rewards – and consequently, they can be said to code an error in reward prediction (Hollerman and Schultz, 1998). This can serve as a learning signal which is further processed in the striatum. Neurons in the striatum are activated in relation to the expectation and detection of reward and related to the preparation, initiation and execution of movements which reflect the expected reward (for a review, see Schultz et al., 2000). Based on this idea, several functional magnetic resonance imaging (fMRI) studies have been conducted. These studies confirmed the role of the striatum, especially the caudate nucleus, in reward-based behavioral learning (Aron et al., 2004; Delgado et al., 2000, 2005; Haruno et al., 2004; Rodriguez et al., 2006; Seger and Cincotta, 2005).

One strategy to elucidate the role of the striatum in feedback-based learning is to experimentally control the feedback aspect in a learning task, e.g. contrasting two parallel versions, a feedback version and an observational version, of the same task. This has been carried out with probabilistic classification learning: in the feedback version, participants saw the stimulus, made a decision and received feedback. In the observational version, they learnt by seeing correct pairings of stimulus and category and were instructed to classify by themselves only later. PD patients were impaired in the feedback, but not in the observational version of the task compared to matched controls (Shohamy et al., 2004). In an fMRI study, Poldrack et al. (2001) found that the striatum was active during the feedback version of the task, whereas the medial temporal lobe was implicated in the observational version. Activity in these regions was negatively correlated, suggesting competition between the striatal and the hippocampal memory systems.

In order to determine to which extent the activation of the striatal learning system depends on the fact that a task is learnt by feedback irrespective of the other task characteristics (e.g. the probabilistic nature of the task), it is necessary to contrast feedback and observational versions in a classification task other than probabilistic classification learning. Thus, we designed the study to test the hypothesis that the striatal learning system is enabled by the presence of feedback and not the probabilistic nature of a task and therefore needed a complex categorization task but which is not organized in a probabilistic manner. For this purpose, we used a modified category learning task called perceptual categorization task (Maddox and Filoteo, 2001). The task uses two categories with 50 stimuli per category that vary on two dimensions (the lengths of a horizontal and a vertical line that are connected at the upper left corner, forming a right angle), the categories are separated from each other by a complex nonlinear rule (see Figs. 1A and B).

Maddox and Filoteo (2001) studied performance of PD patients in a feedback-based version of the task and found impaired performance compared to control subjects. To examine the mechanisms of reinforcement-based learning in PD patients, we investigated PD patients and healthy controls under a feedback condition (providing feedback as to whether the answer was right or wrong after each decision in the learning trials) and an observational condition (showing the correct pairings) of the same task. In the learning trials, the two conditions differ (feedback-based learning versus learning by observation), but the test trials under both conditions are identical and provide the opportunity to express the acquired knowledge but disable the participants from further learning, e.g. the stimuli are shown and participants have to decide on the category membership without any further feedback. Four blocks of test trials (50 stimuli) and three blocks of learning trials (100 stimuli) alternate, beginning with a block of test trials (see Fig. 1D). We predicted that PD patients would be impaired in feedback processing and therefore would perform worse than controls under the feedback condition of this classification task. In contrast, they should be unimpaired in learning the observational version of the same task. In order to explore the explicit or implicit nature of our task according to the criteria mentioned above, we added a block of transfer trials in which the stimuli were rotated 90° (see Figs. 1C and D) to see if the participants were able to transfer their knowledge to stimuli which were slightly changed. If so, this would be an indication for flexible handling of the acquired information, which points to a more explicit rule learning process (Dienes