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Characterizing rule-based category learning deficits in patients with Parkinson's disease

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Abstract

Parkinson's disease (PD) patients and normal controls were tested in three category learning experiments to determine if previously observed rule-based category learning impairments in PD patients were due to deficits in selective attention or working memory. In Experiment 1, optimal categorization required participants to base their decision on a single stimulus dimension and ignore irrelevant variation on another dimension, thus emphasizing selective attention processes. In Experiment 2, optimal categorization required participants to base their decision on both stimulus dimensions using a conjunction of unidimensional decisions. Thus, this task placed less emphasis on selective attention and more on working memory. In Experiment 3, optimal categorization again required participants to base their decision on both stimulus dimensions using a disjunction of two unidimensional decisions in which an additional verbal operation was needed, thereby placing even greater emphasis on working memory. Results indicated that PD patients were impaired in the unidimensional rule-based condition, but not the other two rule-based conditions. These results are consistent with previous studies that demonstrate that PD patients are impaired in learning rule-based categories when selective attention demands are greatest, whereas these patients are normal in learning rule-based tasks when working memory demands are emphasized. Overall, these findings help to delineate the conditions under which PD patients display rule-based category learning deficits.

Keywords: Parkinson's disease; Category learning; Rule-based; Selective attention; Working memory

A growing body of research indicates that patients with Parkinson's disease (PD) are impaired in their ability to learn new categories (Ashby, Noble, Filoteo, Waldron, & Ell, 2003; Filoteo, Maddox, Ing, Zizak, & Song, 2005; Filoteo, Maddox, Salmon, & Song, 2005; Knowlton, Mangels, & Squire, 1996; Maddox, Aparicio, Marchant, & Ivry, 2005; Maddox & Filoteo, 2001; Shohamy, Myers, Grossman, et al., 2004; Shohamy, Myers, Onlaor, & Gluck, 2004; Witt, Nuhsman, & Deuschl, 2002). However, not all studies have identified a generalized category learning deficit in these patients (Filoteo, Maddox, Ing, et al., 2005; Filoteo, Maddox, Salmon, et al., 2005; Maddox & Filoteo, 2001; Peigneux, Meulemans, Van der Linden, Salmon, & Petit, 1999; Reber & Squire, 1999; Smith, Siegert, McDowall, 2001; Witt, Nuhsman, & Deuschl, 2002). One potential reason for this discrepancy is the likelihood that there are multiple category learning systems (Asbhy & Maddox, 2005; Keri, 2003; Smith, Patalano, & Jonides, 1998), with some of these systems being impacted by the pathological changes to the striatum that occur in PD and other category learning systems not being affected. For example, PD patients' category learning abilities may be impaired to a greater extent when learning is based on trial-by-trial feedback (Filoteo, Maddox, Ing, et al., 2005; Shohamy, Myers, Onlaor, et al., 2004), but not when learning is based on simple observation of category exemplars (Reber & Squire, 1999). This difference may be due to PD patients experiencing a deficiency in the dopamine-mediated reward signal that likely drives trial-by-trial feedback learning (Aron et al., 2004), but having an intact perceptual priming system that is likely responsible for certain aspects of observational learning (Reber, Stark, & Squire, 1998).

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Another area that PD patients might experience a deficit is in their ability to learn *rule-based* categories. Rule-based categories are thought to be learned via an explicit *hypothesis-testing* system that seems to rely on hypothesis generation and testing, logical reasoning, working memory and executive attention. Rule-based categories are those where the rule defining category membership is salient and verbalizable, and can often be based on a single stimulus feature (e.g., the stimulus goes into one category if it is a certain color and another category if it is a different color; Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Bruner, Goodnow, & Austin, 1956; Smith et al., 1998). These tasks are often referred to as unidimensional rule-based tasks because information on a single dimension defines category membership. Perhaps the most well-known rule-based category learning task is the Wisconsin Card Sorting Test (WCST; Heaton, 1981), on which PD patients have been shown to be impaired in a number of previous investigations (Alevriadou, Katsarou, Bostantjopoulou, Kiosseoglou, & Mententopoulos, 1999; Bowen, Kamienny, Burns, & Yahr, 1975; Brown & Marsden, 1988; Caltagirone, Carlesimo, Nocentini, & Vicari, 1989). Although these studies might suggest a deficit in the learning of rule-based categories, one potential confound with the WCST is that the level of performance is often based on the ability to switch to a new rule after another rule has been established. The index measuring this sort of 'set-shifting' on the WCST is the number of preservative responses (i.e., the number of times a participant responds with a previously correct category although that category is no longer correct), and it is on this index that most studies report impairment in patients with PD. Thus, although PD patients are impaired on this test, their deficit may be due primarily to an inability to switch between rules and not necessarily in rule acquisition (see also Cools, Barker, Sahakian, & Robbins, 2001; Owen, Roberts, et al., 1993).

In a series of recent studies, we examined PD patients' ability to *learn* rule-based categories. In one study (Maddox & Filoteo, 2001), non-demented PD patients were normal in learning a rule-based task that required participants to compare the length of two lines and categorize the stimuli into one category if the vertical line was longer than the horizontal line, or into another category if the horizontal line was longer than the vertical line. These findings gave the initial impression that PD patients are normal at rule-based category learning. However, in a follow-up study (Ashby, Noble, et al., 2003) we found contradictory results. In that study, participants were asked to categorize single cards that consisted of colored geometric figures on a colored background. Each stimulus varied from trial-to-trial along four binary-valued dimensions. In the rule-based condition, category membership was defined by the value on a single dimension (e.g., color of the stimuli), thus the task was unidimensional. Interestingly, PD patients were impaired in learning, with fewer PD participants than controls being able to meet a specific learning criterion. Maddox et al. (2005) recently found that PD patients are impaired in learning a unidimensional rule-based task when correct categorization is based on either the distance between two lines or the length of a single line, results that again suggest PD patients are impaired in rule-based category learning. Thus, unlike our original finding in which PD patients were normal in rule-based category learning (Maddox & Filoteo, 2001), two subsequent studies indicate that PD patients are impaired in learning unidimensional rule-based tasks.

One possible explanation for these discrepant results is that the various rule-based tasks differ in terms of the presence or absence of irrelevant dimensional variation. That is, in our original study (Maddox & Filoteo, 2001), both of the stimulus dimensions were relevant to category membership (i.e., participants had to base their decision on the length of both lines), so there was no irrelevant dimensional variation. In contrast, in the study by Ashby, Noble, et al. (2003), one dimension of the stimulus was relevant, and three dimensions could vary randomly from trial-to-trial, and in the study by Maddox et al. (2005), one stimulus dimension was relevant but the other irrelevant dimension varied from trial-to-trial. Thus, the latter two studies potentially required greater selective attention than did the former study. Indeed, the WCST, on which PD patients are often impaired, also requires that the participant attend selectively to a single stimulus dimension when other irrelevant dimensions vary on a trial-by-trial basis. As such, a selective attention deficit might also underlie their impairment in shifting from one rule to another.

To examine the role of selective attention in PD patients' rule-based category learning more directly, we conducted a follow-up study (Filoteo, Maddox, Ing, et al., 2005) in which we systematically manipulated the selective attention requirements during the learning of a rule-based task. Specifically, participants were administered a rule-based task in which they were presented with stimuli that had 4 binary-valued dimensions (similar to those used in the study by Ashby, Noble, et al. (2003)) in four different conditions. In each of the conditions, one of the binary-valued dimensions determined category membership, and zero, one, two, or three irrelevant dimensions varied from trial-to-trial. Thus, there was a systematic difference among the four conditions in terms of the degree of irrelevant dimensional variation, and as such, the need for selective attention. PD patients' ability to learn the rule-based categories was impacted to a greater extent than controls as the number of varying irrelevant dimensions increased, suggesting that deficits in selective attention might contribute to the PD patients' rule-based category learning deficit. This characterization of the rule-based category learning deficit in PD is consistent with the observation that these patients are impaired on direct tests of selective attention (Dujardin, Degreef, Rogelet, Defebvre, & Destee, 1999; Filoteo & Maddox, 1999; Maddox, Filoteo, Delis, & Salmon, 1996; McDowell & Harris, 1997; Sharpe, 1990, 1992). In fact, in two previous studies using similar methods as those in the present study, we demonstrated that PD patients were impaired in attending selectively to a single dimension of a two-dimensional stimulus, whereas they were normal in attending to two relevant stimulus dimensions (Filoteo & Maddox, 1999; Maddox et al., 1996). The only difference between the present study and our two previous studies was that, in our previous work, we told the participants the categorization rule prior to the start of the experiment, thereby eliminating the need for learning.

Taken together, these findings raise the possibility that a selective attention impairment might contribute to any observed