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Distinct discrimination learning strategies and their relation with spatial memory and attentional control in 4- to 14-year-olds

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ABSTRACT

Behavioral, psychophysiological, and neuropsychological studies have revealed large developmental differences in various learning paradigms where learning from positive and negative feedback is essential. The differences are possibly due to the use of distinct strategies that may be related to spatial working memory and attentional control. In this study, strategies in performing a discrimination learning task were distinguished in a cross-sectional sample of 302 children from 4 to 14 years of age. The trial-by-trial accuracy data were analyzed with mathematical learning models. The best-fitting model revealed three learning strategies: hypothesis testing, slow abrupt learning, and nonlearning. The proportion of hypothesis-testing children increased with age. Nonlearners were present only in the youngest age group. Feature preferences for the irrelevant dimension had a detrimental effect on performance in the youngest age group. The executive functions spatial working memory and attentional control significantly predicted posterior learning strategy probabilities after controlling for age.

Introduction

The ability to learn from feedback is crucial in a changing environment. Using various paradigms in which learning from positive and negative feedback is essential, behavioral, psychophysiological, and neuropsychological studies have revealed large developmental differences in performance. Tasks used in these paradigms include a rule search and application task (van Duijvenvoorde, Zanolie, Rombouts,

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Raijmakers, & Crone, 2008; Zanolie et al., 2008), a rule switch task (Crone, Zanolie, van Leijenhorst, Westenberg, & Rombouts, 2008), the Wisconsin Card Sorting Test (WCST) (Heaton, Chelune, Talley, Kay, & Curtis, 1993), and the discrimination learning task (e.g., Block, Erickson, & McHoes, 1973; Kendler, 1979; Raijmakers, Dolan, & Molenaar, 2001). These tasks have in common that one or more underlying rules need to be inferred from feedback and that the correct solution may be found by testing hypotheses. The results of the studies mentioned above suggest the presence of distinct modes of learning and feedback processing.

In the current study, we used mathematical learning models to distinguish different learning modes on a discrimination learning task and to identify underlying strategies. Our specific aim was to examine the relation between these modes and the executive functions working memory and attentional control. In addition, we investigated the effect of preferences for stimulus features on learning performance.

All of the experimental rule learning tasks mentioned above can be solved by applying hypothesis testing strategies. The tasks differ, inter alia, in the size of the set of possible rules, the number of rule shifts, the presence of ambiguous feedback, and whether the set of possible rules is known to the participants. For instance, on the WCST, a series of unidimensional card sorting rules need to be inferred (from feedback) and applied. Children typically perform worse than adults on a number of measures on the WCST, including the number of perseverative errors (Chelune & Baer, 1986; Heaton et al., 1993; Huizinga, Dolan, & van der Molen, 2006).

In a discrimination learning task, a simple, unidimensional categorization rule needs to be learned from positive and negative feedback (e.g., Kendler, 1979). The set of rules is not explicitly mentioned. In developmental studies using discrimination learning tasks, two distinct modes of learning have been observed—a fast and a slow learning mode—with an age-related increase in the probability of using the fast mode (e.g., Kendler, 1979; Raijmakers et al., 2001). In her levels-of-functioning theory, Kendler (1979) posited that learning in the slow mode is incremental (based on associative stimulus–response learning), whereas the fast mode is based on a hypothesis testing strategy. However, the support for this theory is ambiguous (see Esposito, 1975, for a review). There is some evidence supporting the interpretation of the fast mode as a strategy of efficient hypothesis testing (e.g., Block et al., 1973; Kendler, 1979; Raijmakers et al., 2001). The interpretation of the slow mode in terms of a well-defined strategy is more difficult. A trial-by-trial analysis of discrimination learning performance revealed that learning in the slow mode was abrupt, not incremental (Schmittmann, Visser, & Raijmakers, 2006). This result suggests that learning in the slow mode originated in inefficient hypothesis testing. More specific, Schmittmann and colleagues (2006) hypothesized that the inefficiency in learning is due to inefficient feedback processing in combination with inefficient hypothesis selection due to preferences for the irrelevant dimension. Berkeljon and Raijmakers (2007) investigated this hypothesis in a neural network model of the development of discrimination learning. The combination of a weaker influence of negative feedback (and, therefore, a relatively higher impact of positive feedback) and variability of the initial dimension preference resulted in two modes of output that resembled fast and slow abrupt learning.

To further understand possible hypothesis testing strategies of children, it is useful to consider the following substrategies of efficient hypothesis testing (e.g., Dehaene & Changeux, 1991). A child using the *win–stay* substrategy randomly samples a rule from a set of rules and applies the rule until an error occurs. In addition, a child can use the *lose–shift* substrategy, meaning that a different rule is selected from the set of rules once an error is encountered. It is assumed that the new rule is sampled at random from the set.

Studies of the hypothesis testing behavior of children suggest that young children might not apply the strict win–stay and lose–shift substrategies (Gholson, Levine, & Phillips, 1972; Kemler, 1978; Phillips & Levine, 1975). However, these studies arrived at different conclusions, specifically concerning the use of the lose–shift substrategy in the age range of 4 to 10.5 years. This may be due in part to two indeterminacies. First, even if we observe lose–shift behavior on a given trial, we cannot conclude right away that a child actually applies a lose–shift substrategy. For instance, a child may forget to discard a falsified rule, so that the same rule may be sampled again on the subsequent trial, which is a *lose–sample* substrategy, or a child may use response *stereotypes*, which refer to position or stimulus feature-based responding that is insensitive to feedback (e.g., consistently choosing the left stimulus;