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Original article

Developmental changes in autonomic responses are associated with future reward/punishment expectations: A study of sympathetic skin responses in the Markov decision task

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Abstract

Objective: Autonomic nervous system activity is recognized as a major component of emotional responses. Future reward/punishment expectations depend upon the process of decision making in the frontal lobe, which is considered to play an important role in executive function. The aim of this study was to investigate the relationship between autonomic responses and decision making during reinforcement tasks using sympathetic skin responses (SSR).

Methods: Nine adult and 9 juvenile (mean age, 10.2 years) volunteers were enrolled in this study. SSRs were measured during the Markov decision task (MDT), which is a reinforcement task. In this task, subjects must endure a small immediate loss to ultimately get a large reward. The subjects had to undergo three sets of tests and their scores in these tests were assessed and evaluated.

Results: All adults showed gradually increasing scores for the MDT from the first to third set. As the trial progressed from the first to second set in adults, SSR appearance ratios remarkably increased for both punishment and reward expectations. In comparison with adults, children showed decreasing scores from the first to second set. There were no significant inter-target differences in the SSR appearance ratio in the first and second set in children. In the third set, the SSR appearance ratio for reward expectations was higher than that in the neutral condition.

Conclusions: In reinforcement tasks, such as MDT, autonomic responses play an important role in decision making. We assume that SSRs are elicited during efficient decision making tasks associated with future reward/punishment expectations, which demonstrates the importance of autonomic function. In contrast, in children around the age of 10 years, the autonomic system does not react as an organized response specific to reward/punishment expectations. This suggests the immaturity of the future reward/punishment expectations process in children.

Keywords: Reward/punishment expectations; Markov decision task (MDT); Autonomic responses; Sympathetic skin response (SSR); Prefrontal cortex (PFC)

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1. Introduction

In daily life, we constantly make choices, consciously or unconsciously, from among several options. Decision making and performance of tasks under uncertain circumstances requires deliberation about possible future consequences. Decision making research has demonstrated that the prefrontal cortex (PFC) is an important region involved in the long-term advantageous decision making process [1,2]. The processes involved are defined as the executive functions that determine one's goal-directed actions [3–5]. Although the details of its participation are as yet unclear, the PFC is considered to be the core area of performance of executive functions [3,6–10]. Damage to the PFC impairs daily decision making, which involves future reward anticipation [1,2]. Therefore, the PFC is thought to play an important role in the achievement of maximal efficiency in the cognitive process.

Recently, the somatic marker hypothesis (SMH) formulated by Damasio [11–13] has been postulated to explain the processes of human reasoning and decision making. The key idea of the SMH is that the process of decision making in the ventromedial PFC, insula, anterior cingulate cortex (ACC) and amygdala is influenced by marker signals that arise in autonomic responses, such as respiration, heart rate and diaphoresis [14,15]. Autonomic nervous system activity is recognized as a major component of emotional responses [14]. In particular, the sympathetic skin response (SSR) is one of the most useful methods of evaluation of the cooperation between central nervous system loops and internal organs [16]. Reportedly, autonomic responses play an important role in executive functions [17]. We previously reported that SSR amplitude habituation is lower with greater task involvement (i.e. attention, preparatory set) and that the cingulate cortex may play some part in modulating the SSR in the context of motivational behavior [18]. Deguchi also clarified the relevance of cognitive function in elicitation of the SSR [19].

The Markov decision task (MDT), which requires the subject to make decisions in different time scales in a dynamic context, is used as a reinforcement learning task [20]. Sutton et al. previously defined reinforcement learning as learning what to do to maximize a numerical value. The subject is not told what actions to take, but must decide by trial and error which actions yield the greatest reward [21]. Although the decision in this task is the result of probabilistic estimations of both reward and risk, it is, most often, emotionally biased [3]. Therefore, using SSRs, we evaluated autonomic emotional responses during MDT to investigate the role of the emotional system in the learning process.

We previously reported the developmental changes in frontal lobe function or executive function [22]. Frontal lobe function develops dynamically at approximately 10 years of age. However, developmental changes in the autonomic response associated with executive function is still unknown. Therefore, we hypothesized that SSRs would be elicited during efficient decision making tasks, which might demonstrate the importance of autonomic function. In this study, using SSRs, we evaluated autonomic emotional responses during a MDT, to investigate the role of the emotional system in learning processes that involve future reward/punishment expectations. In addition, we also evaluated the developmental changes in autonomic responses in association with future reward/punishment expectations that are required to achieve maximal efficiency in MDTs.

2. Methods

2.1. Participants

Nine healthy right-handed adults (mean age, 26.6 ± 7.1 years, 6 males and 3 females) and nine healthy right-handed children (mean age, 10.2 ± 1.9 years, 5 males and 4 females) participated in the study. The adult participants were all healthcare workers. The children's academic achievements were within the standard range in their school. The study design was approved by the Medical Ethics Committee of Yamanashi University. Informed consent was obtained from each participant and from the children's parents.

2.2. Task procedures

The MDT is a reinforcement learning task. In reinforcement learning, subjects are required to achieve a higher score by observing the environment, and their reward is their actual test score. In the MDT, the environment is a changeable target shape (i.e. square, vertical rectangle or horizontal rectangle) (Fig.1a). Each trial involved one of the three shapes being presented at the start of the trial. The subjects had to respond by pressing one of two buttons, left or right, with their left hand. The objective of the trials was not specified. Subjects had to determine their own contexts by trial and error and by observing their resultant score, aiming to obtain the highest score for each test.

Increases or decreases in scores depended on the combination of the target shape and button selection. Subjects needed to determine better selection rules by trial and error. The most efficient way to obtain a final high score involved continuously selecting the right button in spite of small transitory losses in scores. On the other hand, being attracted by smaller gains, and hence, continuing to press the left button resulted in a larger loss. The subjects sometimes needed to incur a transitory loss in order to obtain a higher reward. The target shape was changed by pressing a button under a constant rule (Fig.1a). For example, when the target shape was