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Original article

Developmental changes in autonomic emotional response during an executive functional task: A pupillometric study during Wisconsin card sorting test

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Abstract

Objective: The autonomic nervous system has a deep relationship with the cognitive network when performing cognitive tasks. We hypothesize that autonomic emotional responses can affect cognitive function, especially executive function. The aim of this study was to clarify the involvement of the autonomic system during an executive functional task via developmental changes assessed using pupillometry.

Subjects and methods: Subjects were 16 healthy children and 9 healthy adults. Children were divided into 3 groups (Group A, 7–9 years; Group B, 10–14 years; Group C, 15–17 years). Pupil diameter was recorded using an eye mark recorder during cognitive shift (CS) during the Wisconsin card sorting test (WCST). The rate of pupil variations was integrated and compared within each group, focusing on performance during CS.

Results: Categories achieved (CA) in the behavioral results of WCST increased with age, with significant differences between Group A and other groups. The change of pupillary diameter was increased with CS and decreased at the correct answers after CS in adults. Changes of pupillary diameter with CS showed a linear increase with age, and the pattern of the pupillary response at the age of 10–14 years was comparable to adults. The integrated rate of pupil diameter with CS increased with age, and there was a significant difference between Group A and adults. In addition, the degree of mydriasis correlated with the number of CA.

Conclusion: These findings suggest that autonomic emotional response play an important role as a part of the process for executive function.

Keywords: Executive function; Wisconsin card sorting test; Development; Autonomic emotional response; Pupillometry

1. Introduction

It is well known that pupil diameter increases when the sympathetic response is dominant in the autonomic nervous system and decreases when the parasympathetic response is dominant in that system [1]. Autonomic nervous system activity is recognized as a major component of emotional response [2]. Therefore, changes in pupil diameter can reflect emotional responses [3]. In recent studies, pupillometric methods were used to evaluate not only emotional processes but also cognitive processes. Hess et al. reported that the pupil constricted

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when subjects were shown unpleasant pictures and dilated when subjects were shown pleasant pictures [4]. Bradley et al. reported the pupil dilated and skin conductance response was increased for high-arousal visual emotional stimuli, whether the stimuli were pleasant or unpleasant [5]. In addition, for a complicated cognitive paradigm, such as the Stroop task, the pupil dilated for incongruent stimuli [6,7]. The pupil dilation evoked by a task reflects activation in processing modules in the brain, including emotions such as fear, alarm, surprise, arousal, and affective valance, as well as cognitive function, such as attention, stimulus identification, working memory, response organization, and motor output. Thus, pupillometry can be broadly applied in psychological research to identify normal or abnormal cognitive and emotional functioning.

The Wisconsin card sorting test (WCST) is widely used to measure the executive function of frontal lobe function [8]. Functional magnetic resonance imaging (f-MRI) studies demonstrated activation of the prefrontal cortex, basal ganglia, caudate nucleus, anterior cingulate cortex (ACC), and right dorsolateral prefrontal cortex during the WCST [9,10]. The projection to the prefrontal cortex reflects the emotional network through the amygdala to dorsomedial nucleus of the thalamus, and the amygdala projected to the hypothalamus. The hypothalamus is the center of emotional response [11]. As such, frontal projections may indicate the connection between executive function and emotional response. The WCST is a card matching task with feedback stimuli. However, after a fixed number of correct matches, the rule is changed without notice (cognitive shift [CS]). Therefore, the WCST investigates cognitive flexibility.

We have already reported about developmental changes of frontal lobe function using the verbal fluency task, Go/No-Go task, and anti-saccade task [12–14]. These results suggested that the second decade of life is the important age for maturation of frontal lobe function, especially executive function. However, few studies have examined developmental changes of emotion during cognitive tasks. Chatham et al. reported that developmental pupillometric changes to continuous performance tasks in 8-year-old children resembled those of adults more than those of 3.5-year-old children [15]. Moreover, previous studies had a limitation for the administered age and were not longitudinal.

In present study, we focused on this cognitive flexibility, which is important to achieve new strategies. Similarly, feedback of autonomic emotional responses is imperative to achieve new context. We hypothesize that an autonomic emotional response is a requisite part of the cognitive response, in particular, executive function. Thus, we investigated the change of pupillary size for an autonomic response during CS using the WCST, and the developmental changes of autonomic response for executive functions.

2. Methods

2.1. Participants

Seventeen children (mean age, 10.5 ± 3.0 years; 7 males, 10 females) and 9 adults (mean age, 31.4 $\pm$ 6.7 years; 8 males, 1 female) participated in the study. Children were divided into 3 groups (Group A: $n = 8$, 7–9 years, mean age, 8.13 ± 1.00 years; Group B: $n = 6$, 10–14 years, mean age, 11.2 ± 1.60 years; and Group C: $n = 3$, 15–17 years, mean age, 15.7 ± 0.58 years). All participants were healthy, native Japanese speakers and right-handed. All children attended regular schools and had no learning disorders, neurological deficits, or developmental problems, as reported by their parents. Their academic achievements were standard range in their school. Adult participants were healthcare workers. The procedures for informed consent and the study design were approved by the Medical Ethical Committee of Yamanashi University, and informed consent was obtained from each participant and from the children's parents.

2.2. Task procedures

We used the Keio version of the WCST as the task. The Keio version is a modified version of the WCST that contains a reduced number of stimulus cards and categories from which the subjects can select [16,17]. The reason we used the Keio version of the WCST was that we wanted to encourage a high success rate and to reduce the fatigue of subjects, because subjects in this research involved young children, and the pupillary response in children has been reported to be influenced by fatigue [3]. All subjects in this research performed the task successfully through 48 trials. During the WCST, subjects were asked to sit in front of a personal computer in a silent and modulated light room. Because pupil diameter changes with the amount of light, the illuminance of the room was set at a range of 75 ± 5 Lx using a luminometer. Changes in the brightness of the LCD monitor were reduced as much as possible. A computerized version of the WCST was administered on the LCD monitor. In the WCST, participants were presented with four stimulus cards with symbols that differ in shape, number, and color, and a pack of 48 response cards. Instructions were given to place each response card under one of the four stimulus cards. Only one of the dimensions was correct, for example, color in the first instance. However, the participant was not told which dimension was correct and therefore had to identify the matching card through trial and error, using the feedback provided. After six correct responses with color, the criterion was changed to shape without the participant's knowledge. When the sorting dimension was changed, the participant must shift

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