ELSEVIER

Brain & Development 34 (2012) 799–805

BRAIN & DEVELOPMENT
Official Journal of the Japanese Society of Child Neurology

www.elsevier.com/locate/braindev

Original article

Developmental change of visuo-spatial working memory in children: Quantitative evaluation through an Advanced Trail Making Test

Naomi Kokubo [a], Masumi Inagaki [a,], Atsuko Gunji [a], Tomoka Kobayashi [a], Hidenobu Ohta [a], Osami Kajimoto [b], Makiko Kaga [a]

[a] *Department of Developmental Disorders, National Institute of Mental Health, National Center of Neurology and Psychiatry (NCNP), 4-1-1 Ogawa-higashi machi, Kodaira city, Tokyo 187-8553, Japan*

[b] *Department of Medical Science on Fatigue, Osaka City University Graduate School of Medicine, 1-4-3 Asahimachi, Abeno-ku, Osaka city, Osaka 545-8585, Japan*

Received 20 August 2011; received in revised form 29 December 2011; accepted 3 February 2012

Abstract

Aim: The present study aimed to investigate the developmental change in Visuo-Spatial Working Memory (VSWM) in typically developed children using a specially designed Advanced Trail Making Test for children (ATMT-C). Methods: We developed a new method for evaluating VSWM efficiency in children using a modified version ATMT to suit their shorter sustained attention. The ATMT-C consists of two parts; a number-based ATMT and a hiragana (Japanese phonogram)-based ATMT, both employing symbols familiar to young children. A total of 94 healthy participants (6–28 years of age) were enrolled in this study. Results: A non-linear developmental change of VSWM efficiency was observed in the results from the ATMT-C. In the number-based ATMT, children under 8 years of age showed a relatively rapid increase in VSWM efficiency while older children (9–12 years) had a more gradual increase in VSWM efficiency. Results from the hiragana-based ATMT-C showed a slightly delayed increase pattern in VSWM efficiency compared to the pattern from the number-based ATMT. There were no significant differences in VSWM efficiency for gender, handedness and test order. Interpretation: VSWM in children gradually matures in a non steady-state manner and there is an important stage for VSWM maturation before reaching 12 years of age. VSWM efficiency may also vary depending on developmental condition of its cognitive subsystems.

Keywords: Working Memory; Trail making test; Visuo-spatial; Development; Child

1. Introduction

Working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning [1–5]. The original view of working memory was that it consisted of a central executive function aided by two short term storage systems, namely, the phonological loop system, which stores and rehearses speech-based information and is necessary for language acquisition, and the visuo-spatial sketch pad system, which manipulates memories of visual images and spatial information. The central executive is assumed to be an attention-control system which processes information from these two short-term storage systems. This concept has been

Corresponding author. Tel.: +81 42 341 2712x6273; fax: +81 42 346 2158.

E-mail address: inagaki@ncnp.go.jp (M. Inagaki).

0387-7604/$ - see front matter © 2012 The Japanese Society of Child Neurology. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.braindev.2012.02.001

continuously developed over the past 30 years and working memory is now considered to employ other possible subsystems such as an "episodic buffer", which is in charge of long-term memory [6–8].

Concerning the phonological loop, there have been many previous studies examining its properties, and numerous kinds of tests evaluating phonological working memory are currently in use. The most popular test is the reading span test (RST), in which the participant is first ordered to listen to a sentence, words or numbers and then tested on their ability to recall a part of the presented stimuli. Other tasks including operation span tests, digit span tests, dual-task and other serial recall tests are also commonly used for evaluation of the memory span [9,10]. One of the basic functions of these tests is to estimate the participant's capacity to instantly memorize presently available phonological information.

In contrast, the performance of the visual spatial sketchpad, or visuo-spatial working memory (VSWM), has not been so systematically evaluated in previous studies. The visuo-spatial sketchpad is domain specific working memory and is considered to be activated when presently available information is categorized into color, shape, and spatial position. One of the most common tests for VSWM is the delayed saccade task, in which the eyes are made to move towards a visual stimulus [11]. Other psychological tests such as the Trail Making Test (TMT) [12], the Mapping and Directions Task [13], and the Spatial-Span Task [14] have been applied for both clinical and research use, as these can effectively detect cognitive deficits in patients with developmental disorders [15,16]. The basic component of such psychological tests is to make participants memorize and recall available visuo-spatial information within a certain period of time.

In the present study, we evaluated developmental change in efficiency of VSWM by means of the Advanced Trail Making Test. The ATMT is a computerized version of the Trail Making Test (TMT). The ATMT has been developed as a quantitative measure of visuospatial working memory (VWM) or mental fatigue originally by one of the authors (OK) [17,18]. Iwase et al. clearly showed a calculating method for utilization rate of spatial working memory in adult subjects on the basis of the results of ATMT, which was determined by the shortening of reaction time for touching circles [18]. It is useful and effective in detecting deficit in prefrontal functions such as sustained attention, working memory, and attentional set shifting in adult patients with psychiatric disorders [12,19,20]. To further suit our objective, we have modified it into a form more suitable for children, named, 'ATMT for Children' (ATMT-C). The ATMT-C consists of two parts, the number-based ATMT and the hiragana (Japanese phonogram) -based ATMT, both of which use symbols familiar to young children. In addition, the duration of the ATMT-C has been made shorter than the original ATMT taking into consideration the shorter sustained attention displayed by children.

2. Methods

2.1. Participants

A total of 94 healthy participants participated in this study. They ranged in age from 6 to 28 years of age. Children attended regular classes of elementary or junior high schools. All twelve participating adults were healthy volunteers. The gender characteristics were 47% male ($n = 44$) and 53% female ($n = 50$). Right handedness was observed in 91% of the subjects ($n = 86$), and 9% of the subjects were left handed ($n = 8$).

All of them were native Japanese and their principal language was Japanese. This study had ethical approval from the committee of the National Center of Neurology and Psychiatry. Written informed consent was obtained from the participants and parents. The test procedure was carried out under their consent.

2.2. Task

The Advanced Trail Making Test for Children (ATMT-C) is composed of two separate tests, both made up of a repeating series of 2 separate tasks designed to evaluate the efficiency rate of VSWM. One test is a number-based ATMT and another is a hiragana (Japanese writing characters)-based ATMT. Each test consist two parts: fixed-arrangement task (task A) and reshuffled-arrangement task (task B). Present ATMT-C was performed on a touch screen monitor (Totoku-CV515JP, Totoku Electric, Okubo, Shinjuku, Tokyo, Japan) connected to a laptop PC. In ATMT-C, encircled numbers or Hiragana (Fig. 1 and 2) have been scattered on a square (21.5 × 21.5 cm) on a 15 inch touch screen monitor (32 × 24 cm). Each subject was instructed to push the circles as quickly as possible in numerical order from 1 to 20 in number-based ATMT. In task B, subjects pushed 20 numbered black circles (buttons) displayed at randomly on the square in numerical order in number-based ATMT with the forefinger of their dominant hand.

In task A of number-based ATMT, participants were made to press in order a randomly scattered group of 20 numbered buttons (Fig. 1-A). In this task, each button disappears after being pressed and is replaced each time by a new dummy button elsewhere on the screen. In task B of number-based ATMT (Fig. 1-B), participants again had to press in order a randomly scattered group of 20 numbered buttons which also disappear as they are pressed and are replaced by a new dummy button elsewhere in the screen. This time, however, as each button is pressed and replaced, the other 19 buttons are