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Right prefrontal cortex specialization for visuospatial working memory and developmental alterations in prefrontal cortex recruitment in school-age children

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HIGHLIGHTS

- Right-lateralized pre-frontal cortex (PFC) activity was observed with near-infrared spectroscopy during sequential presentation in a visuospatial working memory (VSWM) task in school-age children.
- In 11–12 but not 7–10-year-old children, PFC activity was right-lateralized for simultaneous presentation in the VSWM task.
- Findings indicate right-dominant developmental changes in the recruitment patterns of the PFC during VSWM tasks.

ABSTRACT

Objective: The right prefrontal cortex (PFC) plays an essential role in active processing within visuospatial working memory (VSWM). The aim of this study was to examine developmental changes in the recruitment patterns of the PFC during visuospatial memory tasks in school-age participants.
Methods: We recruited 80 school-age children who were classified into three age groups: 7- to 8-year-old, 9- to 10-year-old, and 11- to 12-year-old children. We used near infrared spectroscopy (NIRS) to measure PFC activity during visuospatial memory task. Memory stimuli were presented either sequentially or simultaneously.
Results: In all three groups, right-lateralized PFC activity was observed during sequential presentation, suggesting specialization of the right PFC for VSWM. During simultaneous presentation, right-lateralized PFC activity was not observed in 7- to 8-year-old children or 9- to 10-year-old children. In contrast, PFC activity was right-lateralized in 11- to 12-year-old children.
Conclusions: We suggest that specialization of the right PFC for VSWM is already present before school-age, but widely distributed activity in response to visuospatial memory tasks changes to more focal activity in VSWM-specific regions during the early school years.
Significance: Using NIRS, we showed developmental changes in the recruitment patterns of the PFC during visuospatial memory tasks.

1. Introduction

Working memory (WM) is a system for maintaining and manipulating information (Baddeley and Hitch, 1974), which has a subsystem that specifically processes visuospatial information (i.e., visuospatial WM: VSWM). Cornoldi and Vecchi (2004) have proposed a continuity model of WM assuming the existence of two dimensions: a horizontal continuum comprising different content types (e.g., verbal or visuospatial information) and a vertical continuum distinguishing between passive storage and active processing. Passive storage is the retention of information that is not modified after encoding, whereas active processing is associated with integration, transformation, modification, and/or manipulation of stored information (Cornoldi et al., 2000; Cornoldi and Vecchi, 2004). Previous studies using neuroimaging techniques

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(e.g., functional magnetic resonance imaging, fMRI) have reported that the prefrontal cortex (PFC) plays an essential role in active processing (Smith and Jonides, 1999; Wager and Smith, 2003; Owen et al., 2005).

Many cognitive functions are supported by hemispheric specialization, in which the right hemisphere is superior for visuospatial processing, whereas the left hemisphere is superior for verbal processing (Hervé et al., 2013; Badzakova-Trajkov et al., 2015). Consistent with this hemispheric specialization, PFC activity shows right lateralization in visuospatial memory tasks, whereas it shows left lateralization in verbal memory tasks (Smith and Jonides, 1999; Wager and Smith, 2003; Owen et al., 2005). Therefore, it is thought that right PFC activity is specialized for active processing within VSWM.

Much attention has been paid to the development of PFC function in neuroimaging studies. In previous studies using near infrared spectroscopy (NIRS), preschool children showed PFC recruitment during visuospatial memory tasks, similar to adults (Tsujimoto et al., 2004; Buss et al., 2014). Furthermore, there was greater activity in the right than the left PFC during a spatial item recognition task in 7-year-old children (Tsujii et al., 2009). Hence, specialization of the right PFC for VSWM appears to be present in young school-age children.

In contrast, activity in the PFC during visuospatial memory tasks appears to show developmental changes after entering school. For example, bilateral activity in the PFC in response to visuospatial memory tasks increases between childhood and adulthood (Klingberg et al., 2002; Kwon et al., 2002). Scherf et al. (2006) also reported that right PFC activity during a memory-guided saccades task was greater in adolescents than in school-age children. Furthermore, in memory tasks with visual stimuli, patterns of activity in the PFC differed between school-age children and adolescents (Crone et al., 2006). However, developmental changes in PFC activity have differed among previous studies (Klingberg et al., 2002; Kwon et al., 2002; Crone et al., 2006; Scherf et al., 2006). Behavioral studies have shown that task conditions determine the use of VSWM or other WM domains (e.g., verbal WM) during visuospatial memory tasks (Simons, 1996; Postle et al., 2005). Hence, we suggest that different results reported by previous studies stem from differences in task conditions, i.e., task conditions differently influence recruitment patterns in VSWM-specific regions (i.e., the right PFC) and non VSWM-specific regions (i.e., the left PFC), with differing influences among different ages.

Based on previous findings, we hypothesized the following: (i) specialization of the right PFC for VSWM is already present by school-age; (ii) the conditions of visuospatial memory tasks influence the recruitment pattern of the PFC; and (iii) the influence differs among different school ages. To test these assumptions, we examined recruitment patterns of the PFC during visuospatial memory tasks in school-age groups (7- to 8-year-old, 9- to 10-year-old, and 11- to 12-year-old children). Memory stimuli were presented within two conditions, sequential and simultaneous presentation (Fig. 1A), which place different demands on active processing within VSWM. During sequential presentation, participants were required to integrate the encoded information (Lecerf and De Ribaupierre, 2005). Hence, we assumed that active VSWM processing was required more in this condition than during simultaneous presentation, which strongly recruits the right PFC (Smith and Jonides, 1999; Wager and Smith, 2003; Owen et al., 2005). Thus, we expected different recruitment of the PFC for sequential and simultaneous presentations.

In this study, we used NIRS because it has some advantages over fMRI. During fMRI, participants must lie still in the MRI scanner with restricted movement, which is difficult for children. In previous studies using fMRI, the number of school-age children was too low to allow classification into narrower age range groups (Klingberg et al., 2002; Crone et al., 2006). In contrast, NIRS does not require restriction of movements (Cutini and Brigadoi, 2014),

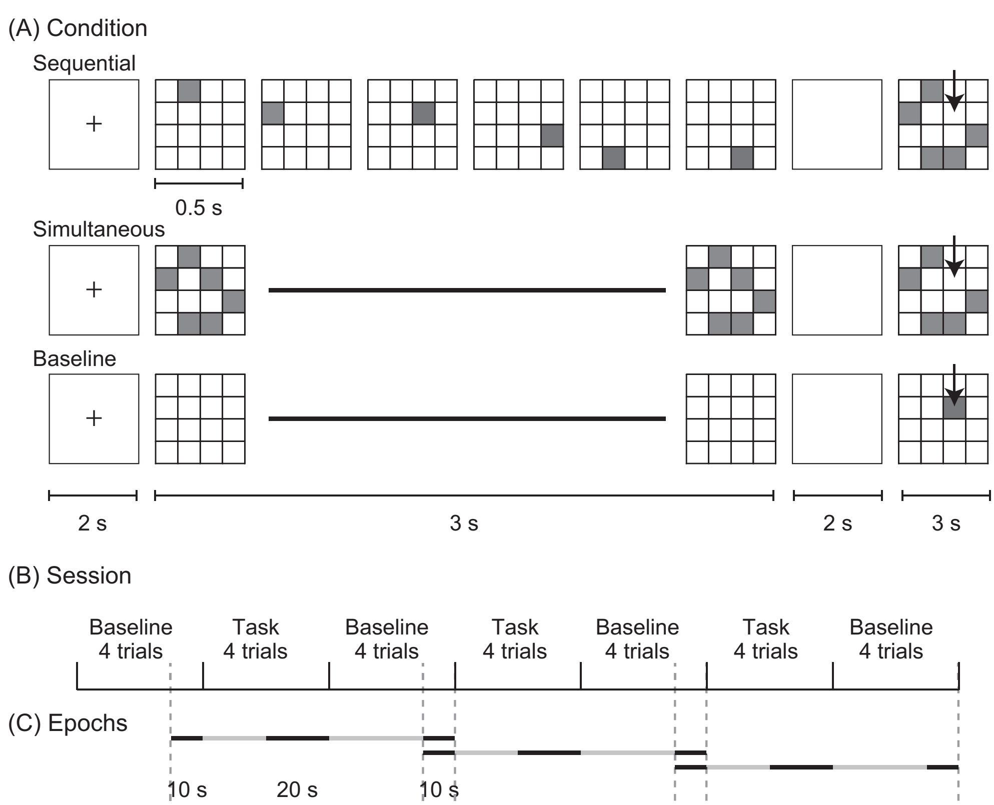

Fig. 1. Task and procedure (revised from the previous our work (Oi et al., 2017)): (A) Conditions; (B) Session; (C) Epochs.