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Research article

Fronto–temporo–occipital activity changes with age during a visual working memory developmental study in children, adolescents and adults

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HIGHLIGHTS

- Working memory processing is characterized by a fronto–temporo–occipital network.
- Children showed more activation in posterior regions.
- Adults showed more activation in anterior regions.
- The delay period showed shared activated areas with the matching phase.

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ABSTRACT

The present report analyzes differences in cerebral sources among several age groups with respect to the encoding, maintenance and recognition of stimuli during a visual working memory task. Differential intensity of involvement of anterior and posterior areas during working memory processing is expected at different ages. For that, 168 subjects between 6 and 26 years old performed a visual delayed match-to-sample task. The sample was subdivided into 5 age groups, and the cerebral sources were analyzed with sLORETA, comparing the groups two-by-two.

The results showed that at younger ages more posterior regions are involved in working memory processing, while in adulthood more anterior regions are involved. Maintaining the visual item in memory showed some common activated areas with stimulus matching, indicating similar neural mechanisms involved in holding and selecting the target stimulus.

1. Introduction

Working memory (WM) consists of a cognitive cerebral function used on a daily basis that permits the temporary storage and processing of information for short periods of time in order to perform cognitive tasks [1].

Neuroimaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), have made it possible to develop a new line of research to determine the cerebral areas associated with WM function during delayed match-to-sample (DMTS) tasks. Through fMRI, several studies have analyzed cerebral maturation in heterogeneous age groups, showing that for WM processing in children, cerebral structures similar to those used by adults are involved (including the prefrontal cortex), although with a lower activation level [2–4]. The activity increase observed in adults in lateral areas of the prefrontal cortex (Brodmannís areas 9 and 46) during an item visuo-spatial recognition memory task was also observed in 5–6-year-old children [5], indicating that the cerebral areas involved in WM were similar in adults and kindergarten children. These authors showed that the dorsolateral prefrontal cortex of kindergarten children is activated during the WM process, revealing that at 5–6 years of age this cerebral structure has already developed its contribution to processing this important cognitive function. A study [6] using a spatial N-back task showed activation of the parietal and right dorsolateral prefrontal cortex in both 8–10-year-old children and adults.

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Using the same type of task, a visuo-spatial 2-back in subjects from 7 to 22 years old [3], the activation level of some areas of the parietal and prefrontal cortex of both hemispheres has been shown to increase with age. In this study, although the task performed was visuo-spatial, the enhancement of the left hemisphere activation was observed in areas related to the phonological loop, particularly Broca's area. The authors stated that this result was related to a developmental strategy that allows visual information encoding through verbal-related processes at the age of seven. These findings revealed that visual and verbal memory develop synchronously during childhood and adolescence and throughout young adulthood. In a similar way, studies have shown [7,8] that the increase in the visuo-spatial WM index, i.e., better performance on these types of tasks in the age range from 9 to 18 years old, is associated with an activity increase in intraparietal and superior frontal areas, as well as with the progressive maturation of the pathways that interconnect these two structures. With regard to the development of non-spatial WM (regarding WM objects) in three age groups (8–12, 13–17 and 18–25 years), findings have shown [9] that the youngest group performed worse than the other two age groups, but there were no differences among the three age groups in the activation patterns of the ventrolateral prefrontal cortex, a region associated with the online maintenance of the object. These results suggest that the crucial temporal–parietal–frontal networks in this WM process in adults begin to be recruited early by children from about the age of six.

The experimental paradigm used in this study was the DMTS task, which consists of one of the most widely used paradigms to study the short-term memory. The information about the target-stimulus has to be encoded during its presentation; the stimulus has to be retained in memory during the delay period; and the stimulus in memory has to be matched to one of those presented during the response period [10].

The low resolution of the hemodynamic techniques previously cited does not allow the sequential analysis of activation during DMTS tasks in humans. On the other hand, event related potentials (ERPs) allow the sequential temporal analysis of neural processing, but with a low spatial resolution. Current source computation is performed by standardized low resolution tomography analysis (sLORETA) [11], providing a low spatial resolution of the activated brain areas. Searching the literature, we did not find any data analysis performed with sLORETA during DMTS tasks in a sample with a broad age range that included children. The goal of this study is to compare the brain activation during a visual short-term memory task, using the DMTS paradigm, in a sample with an age range from 6 to 26 years, and more specifically, identify the possible differences in the cerebral sources used by children and adults in visual WM processing. The phases of encoding, maintenance and matching would be analyzed by means of the encoding P1 and P300 (encoding and matching) and slow wave (maintenance) [12]. These components were selected because they have been shown to be more associated with the phases of visual WM processing, and they stand out in the representation of the ERPs (see Fig. 1).

2. Methods

2.1. Subjects

One-hundred and seventy subjects between 6 and 26 years old (15.89 years ± 6.12) participated in this study. For more information, please see [12].

2.2. Stimuli and task procedure

Visual stimuli were cartoons and the paradigm used was a DMTS task. For a detailed description of the task procedure, please see [12]. Fig. 1A shows a typical experimental trial sequence.

2.3. EEG recording

The EEG was recorded at 32 scalp sites with 4 additional electrodes to record ocular movements. For a detailed description of the EEG recording, please see [12].

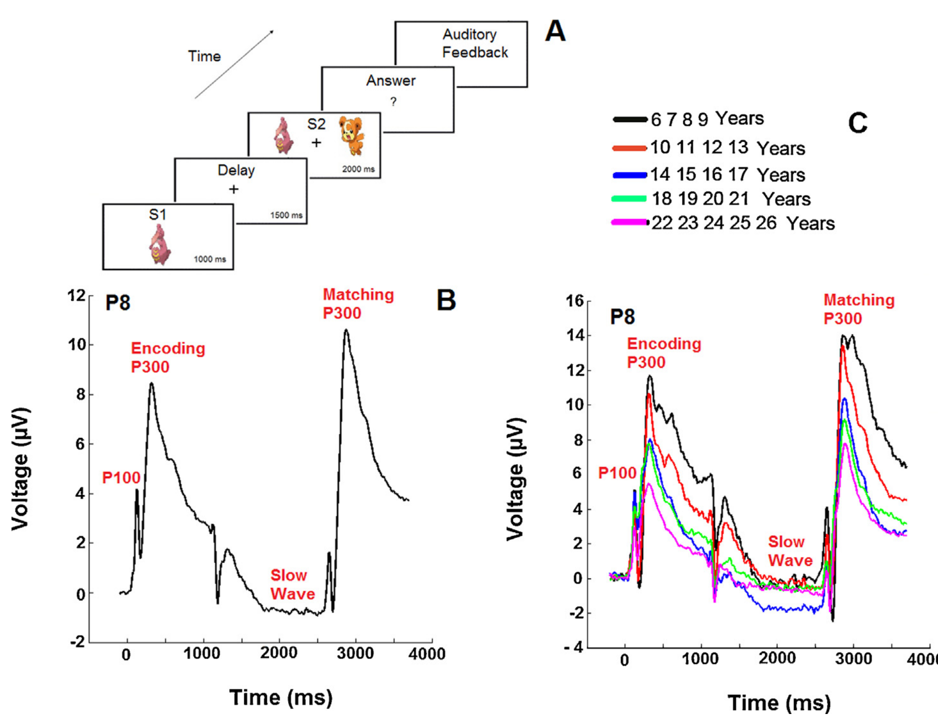

Fig. 1. Example of an experimental trial (A); ERPs observed during a trial for the total sample (B) and independently for the five age groups (C).