Developmental Cognitive Neuroscience 9 (2014) 106–116

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Visuospatial working memory in very preterm and term born children—Impact of age and performance

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ARTICLE INFO

Article history:
Received 27 August 2013
Received in revised form 6 February 2014
Accepted 11 February 2014

Keywords:
fMRI
Children
Premature birth
Visuospatial
Short-term memory
Working memory

ABSTRACT

Working memory is crucial for meeting the challenges of daily life and performing academic tasks, such as reading or arithmetic. Very preterm born children are at risk of low working memory capacity. The aim of this study was to examine the visuospatial working memory network of school-aged preterm children and to determine the effect of age and performance on the neural working memory network. Working memory was assessed in 41 very preterm born children and 36 term born controls (aged 7–12 years) using functional magnetic resonance imaging (fMRI) and neuropsychological assessment. While preterm children and controls showed equal working memory performance, preterm children showed less involvement of the right middle frontal gyrus, but higher fMRI activation in superior frontal regions than controls. The younger and low-performing preterm children presented an atypical working memory network whereas the older high-performing preterm children recruited a working memory network similar to the controls. Results suggest that younger and low-performing preterm children show signs of less neural efficiency in frontal brain areas. With increasing age and performance, compensational mechanisms seem to occur, so that in preterm children, the typical visuospatial working memory network is established by the age of 12 years.

1. Introduction

Working memory refers to the ability to encode and actively process task relevant information in mind over a short period of time (Baddeley, 1986; Klingberg, 2006). Working memory is crucial for meeting the challenges of daily life and the performance of academic tasks, such as reading or arithmetic. Hence, working memory capacity is essential for the cognitive development throughout childhood.

In healthy term born children and adolescents, functional magnetic resonance imaging (fMRI) studies have detected a fronto-parietal working memory network (Klingberg, 2006; Klingberg et al., 2002; Thomason et al., 2009) involving the superior and middle frontal gyri and sulci, anterior cingulate cortex and large parts of the superior and inferior parietal lobes. The visuospatial working memory network is suggested to vary as a function of

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http://dx.doi.org/10.1016/j.dcn.2014.02.004
1878-9293

age, sex and working memory performance in childhood (Spencer-Smith et al., 2013).

The investigation of the impact of early brain development on later outcomes is particularly interesting in children who were born very prematurely (<32 gestational weeks) and/or with very low birth weight (<1500 g). Very preterm born children are at risk of reduced working memory capacity in the pre-school period (Woodward et al., 2005) and during school years (Anderson and Doyle, 2003). Even in very preterm born children without major neurological deficits and with normal cognitive abilities, working memory performance has found to be reduced (Vicari et al., 2004).

Very preterm born children demonstrate alterations in structural brain development with prolonged maturation of the frontal lobes, smaller cortical and cerebellar volumes, decreased corpus callosum size, larger lateral ventricles and reduced white matter volume (Nosarti et al., 2008; Parker et al., 2008). Particularly in the frontal regions, the structural maturation of white matter coincides with the formation and improvement of working memory performance (Klingberg, 2006). As structural maturation in fronto-parietal areas is associated with changes in brain activity in the working memory network (Olesen et al., 2003), it is likely that very preterm born children show differences in their working memory network when compared to term born controls.

The visuospatial working memory network has been rarely examined in very preterm born children. To the authors' knowledge, only Taylor et al. (2011) investigated neural processing during a visuospatial working memory fMRI task in very preterm born children ($n = 10$, 7–9 years) and term born controls ($n = 28$, 6–12 years). fMRI task performance did not differ between the groups, but while controls showed typical frontal activations, very preterm born children presented no frontal involvement and lower activation in the right parahippocampal gyrus and the left precuneus. Since the precuneus is linked to the monitoring of cognitive functions, the authors suggested that low precuneus activation was related to a reduction of organizational activity in very preterm born children, resulting in different cognitive strategies applied to solve the visuospatial working memory fMRI task (Taylor et al., 2011).

As the visuospatial working memory network in very preterm born children has not been investigated intensely yet, the developmental trajectories of the neural representation of working memory in these children are not fully known. On the one hand, it is possible that very preterm born children show persistent immature neural networks, resulting in lower working memory performance. One the other hand, potential alterations in structural and functional development might only exist initially (at younger age) and could be compensated through the recruitment of additional brain regions or enhanced neural effort, resulting in increased working memory performance (Jolles et al., 2012). To gain more knowledge on the development of the visuospatial working memory network, it is therefore important to investigate age and performance effects in very preterm and term born children.

The aim of the present study was to investigate the visuospatial working memory network in a relatively large sample of very preterm born and term born children comparable for age, gender and handedness, using an established fMRI task in children, with normative data available in the literature (Klingberg et al., 2002; Olesen et al., 2007; Spencer-Smith et al., 2013). We hypothesized that very preterm born children show alterations in visuospatial working memory activation when compared to term born controls. Specifically, based on the limited literature (Taylor et al., 2011), less involvement of frontal areas was expected in the working memory network of very preterm born children compared to term born controls. To shed light on developmental aspects of the working memory network we aimed to examine associations of brain activity during the fMRI task with age and fMRI task accuracy.

2. Methods

The present study reports on a subset of data from the NEMO (NEuropsychology and MeMOry) research program, a clinical trial examining cognitive development of very preterm born children and healthy term born controls. The study was approved by the ethics committee of the Children's University Hospital in Bern and the local ethics committee of Bern in Switzerland. All children and caregivers provided informed written consent prior to participation, consistent with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.1. Participants

2.1.1. Preterm born children

The medical reports of all very preterm (<32 weeks of gestation) and/or low birth weight (<1500 g) children born in the 1998–2003 cohort at the Children's University Hospital in Bern, Switzerland, were reviewed for study inclusion criteria. We included native German speakers aged between 7 and 12 years, who had normal or minimally abnormal neonatal ultrasound (no or mild periventricular leukomalacia, grade I and II; no or mild neonatal cerebral lesions, hemorrhage grade I) no chronic illness (e.g. no birth deformities, congenital heart defect, cerebral palsy, epilepsy), no medical problems influencing development (e.g. no history of meningitis, encephalopathy, traumatic brain injury, shaken baby syndrome, tumors, cancer), no reported neurodevelopmental disorders at the time of recruitment (e.g. autism, attention deficit hyperactivity disorder (ADHD)), and General IQ > 85. Fifty-five very preterm born children completed neuropsychological assessment and a working memory fMRI task. Four children were excluded because of technical problems and seven children were excluded due to low accuracy in the fMRI task (<50% correct responses). Three children were excluded due to AD(H)D (diagnosed during the neuropsychological assessment). A total group of 41 very preterm born children was included in the study (22 girls, 19 boys).

2.1.2. Term born control children

Term born controls (aged 7–12 years) were recruited using announcements on notice boards in the hospital and local schools. Forty-two healthy controls completed the neuropsychological assessment and the fMRI task, however