Mental flexibility: An MEG investigation in typically developing children

Alexandra Mogadam\textsuperscript{a,b}, Anne E. Keller\textsuperscript{b,c}, Margot J. Taylor\textsuperscript{a,b,c,d,e}, Jason P. Lerch\textsuperscript{b,f,g}, Evdokia Anagnostou\textsuperscript{a,b,c,h}, Elizabeth W. Pang\textsuperscript{a,b,c,*}

\textsuperscript{a} Institute of Medical Science, Faculty of Medicine, University of Toronto, Canada
\textsuperscript{b} Neurosciences and Mental Health, SickKids Research Institute, Toronto, Canada
\textsuperscript{c} Division of Neurology, Hospital for Sick Children, Toronto, Canada
\textsuperscript{d} Department of Diagnostic Imaging, Hospital for Sick Children, Toronto, Canada
\textsuperscript{e} Departments of Psychology & Medical Imaging, University of Toronto, Canada
\textsuperscript{f} Mouse Imaging Centre, Hospital for Sick Children, Toronto, Canada
\textsuperscript{g} Department of Medical Biophysics, Faculty of Medicine, University of Toronto, Canada
\textsuperscript{h} Holland Bloorview Kids Rehabilitation Hospital, Toronto, Canada

\textbf{ARTICLE INFO}

Keywords:
Mental flexibility
Child
MEG
Functional neuroimaging
Set-shifting
Parietal lobe

\textbf{ABSTRACT}

Mental flexibility is a core property of cognitive executive functions, relying on an extended frontoparietal network in the brain. fMRI research comparing typically developing children and adults has found that children from an early age recruit the same “classic” brain areas associated with mental flexibility as adults; however, there is evidence that the timing of activation may be different. To investigate the temporal dynamics of brain activity associated with mental flexibility in children, we recruited 22 typically developing children (8–15 years) to complete a set-shifting task in the MEG. Our results showed that while the children relied on the same frontoparietal network of mental flexibility, there was a different emphasis on active brain regions, with children preferentially using their posterior parietal cortices. Additional areas such as the temporal pole and the premotor areas were also recruited, potentially playing a supporting role. Although children shared the same window of peak activity as adults, 75–350 ms, we found a significant decrease in activation latency with increasing age, suggesting the presence of developmental differences in timing of brain activity in areas supporting mental flexibility during childhood.

1. Introduction

Mental flexibility represents the executive ability to continuously alter and update cognitive and behavioural outputs in response to environmental changes, allowing one to effectively interact with, and adapt to one’s surroundings (Armbruster, Ueltzhöffer, Basten, & Fiebach, 2012; Dajani & Uddin, 2015). Prior research has established the neural correlates of mental flexibility in healthy adults (Armbruster et al., 2012; Dajani & Uddin, 2015; Ezekiel, Bosma, & Morton, 2013; Kim, Gilles, Johnson, & Gold, 2012; Oh, Vidal, Taylor, & Pang, 2014; Rubia et al., 2006; Wendelken, Munakata, Baym, Souza, & Bunge, 2012). However, less is known about this executive function in children. Given the disruption of mental flexibility in various mental illnesses (Airaksinen, Larsson, Lundberg, & Forsell, 2004; Cavedini, Zorzi, Piccinni, Cavallini, & Bellodi, 2010; Tchanturia et al., 2012; Waltz, 2016) and developmental disorders (Anderson, 2002; Dajani & Uddin, 2015; Ozonoff & Jensen, 1999; Shin et al., 2008), expanding our knowledge of the neurodevelopmental processes involved in mental flexibility may allow us to better understand the mechanisms when these processes go awry.

Various executive functions work in concert to achieve cognitive flexibility, including salience detection and attention, working memory, inhibition and switching (Dajani & Uddin, 2015). The first step in this cognitive process involves salience detection, followed by directed attention towards a change or novel feature in the environment. This change functions as a cue which calls on working memory to select an appropriate response, as well as on inhibitory processes to stop or adjust ongoing behaviour (Dajani & Uddin, 2015). There are various neuropsychological methods by which to assess mental flexibility, including the Wisconsin Card Sorting Task (WCST; Berg, 1948; Grant & Berg, 1948) and different types of task-switching or set-shifting exercises. The main shared feature across all these tests is a ‘switching’ component, between sets of responses or tasks, which allows for the behavioural assessment of cognitive flexibility skills (Dajani & Uddin, 2015). More specifically, task-switching requires switching between different tasks in response to a contextual cue (e.g., sorting stimuli from...
small to large in response to one cue, and doing the opposite in response to another cue type). In contrast, set-shifting represents a less complex test of mental flexibility, and refers to a task with multiple sets of responses, all fulfilling a singular task instruction. The task will invoke shifts, requiring different response sets to be used (e.g., matching stimuli based on the features of the stimuli). These types of tasks are often also used to investigate various degrees of cognitive control, a related albeit more complex feature of executive function, encompassing the ability for goal-directed, pro-active and flexible behaviour (Koechlin, Ody, & Koeunjeheri, 2003; Miller, 2000; Munakata, Snyder, & Chatham, 2012).

Dajani & Uddin (2015) reviewed the brain areas implicated in cognitive flexibility in adults, and identified multiple key hubs, all associated with the above executive subcomponents of cognitive flexibility. Based on these findings they concluded that mental flexibility in typical adults involves a network of active hubs, mainly spanning the frontal and parietal regions; these include the dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), inferior frontal gyrus (IFG), as well as both inferior and superior parietal lobules (IPL and SPL). The anterior insula (AI) and anterior cingulate cortex (ACC) additionally play an important role (Dajani & Uddin, 2015; Kim et al., 2012; Niendam et al., 2012).

Although the proposed frontoparietal network underpinning cognitive flexibility in adults seems robust, the question remains how this network develops during childhood. As an executive function, and thus heavily reliant on the prefrontal regions, cognitive flexibility develops through childhood, into adolescence (Anderson, 2002; Cragg & Nation, 2009; Dajani & Uddin, 2015; Dick, 2014). Behaviourally, children attain mature set-shifting capabilities by the age of eight years (Dick, 2014), with more general mental flexibility abilities peaking around 10–12 years (Anderson, 2002; Chelune & Baer, 1986; Dick, 2014). Functional MRI (fMRI) studies have examined the neural bases of cognitive flexibility in children compared to adults and reported that while there are potentially some differences in the extent of activation seen in specific frontoparietal hubs, with adults showing increased and more focal activation compared to children in certain studies (Casey et al., 2004; Crone, Donohue, Honovichl, Wendelken, & Bunge, 2006; Crone, Zanolie, Leijenhorst, Westenberg, & Rombouts, 2008; Dajani & Uddin, 2015; Morton, Bosma, & Ansari, 2009; Rubia et al., 2006), children aged eight years and above already recruit the same core areas as adults (Houdé, Rossi, Lubin, & Joliot, 2010; Wendelken et al., 2012). In addition to the core hubs of mental flexibility, some studies have found that children may also rely on the support of additional regions, such as visual and temporal areas (Ezekiel et al., 2013; Rubia et al., 2006).

The specific temporal dynamics of mental flexibility in children are still unclear. Using fMRI, Wendelken et al. (2012) found that while children and adults utilized the same cognitive network of “classic” regions when completing a task of mental flexibility; however, there was a significant difference in the temporal activity profile of the DLPFC, with children displaying delays in the updating of rule representations in these regions. This finding hints at the possibility that the timing of activation within the network plays a crucial role in differentiating the brain activation patterns associated with mental flexibility in children from adults (Ezekiel et al., 2013; Rubia et al., 2006; Wendelken et al., 2012).

To date, fMRI has been the method of choice with which to explore the neural correlates of cognitive flexibility in children. While fMRI is a powerful functional neuroimaging tool for spatial localization of brain activity, its temporal resolution is not as well suited for capturing fast-paced cognitive processes. Magnetoencephalography (MEG) is a functional neuroimaging method with excellent temporal (to the millisecond) and good spatial resolution (Hari & Salmelin, 2012). Previous related research by our group has demonstrated the unique contributions MEG can make in investigating and characterizing mental flexibility in various populations (da Costa et al., 2015; Dunkley et al., 2015; Oh et al., 2014; Pang, 2015; Pang et al., 2014; Taylor, Donner, & Pang, 2012). This precedence makes it an optimal technique with which to explore spatial-temporal brain activity in children.

To determine the temporal dynamics of the brain activity underlying mental flexibility in a developmental population, we recruited typically developing children to complete a set-shifting task while in the MEG scanner. We hypothesized that children would recruit the same classic mental flexibility areas as adults, with additional regions playing a supporting role. Additionally, we expected children to display a different temporal activation profile, potentially slower and more protracted than what is seen in adults.

2. Materials and methods

2.1. Participants and neuropsychological assessments

Twenty-two children participated in this study; demographic information can be found in Table 1. Children were recruited through flyers posted at the Hospital for Sick Children and Holland-Bloorview Kids Rehabilitation Hospital. An initial phone call was used to screen for exclusion criteria which included a history of learning disabilities, head trauma, premature birth, neurological/neurodevelopmental and/or psychiatric disorders, as well as standard exclusion criteria for MR/MEG imaging. All children had normal, or corrected-to-normal, vision. The study was conducted at the Hospital for Sick Children (SickKids) in Toronto and the test protocol was approved by the SickKids Research Ethics Board (REB). Informed written consent was obtained from all the parents and informed verbal assent from the children.

2.2. Set-shifting task and stimuli

Table 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Age range</th>
<th>Male: Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>8–15 yrs</td>
<td>9:13</td>
</tr>
</tbody>
</table>

We used a version of the Intra-Extra Dimensional Set Shift (IED) task (Fig. 1), previously adapted for MEG by our group at SickKids (Oh et al., 2014). Participants were presented with three stimuli, two in the top half of the frame and one below. The instructions were to match the bottom stimulus with one of two top ones. The stimuli either matched based on shape or colour, and only one answer per trial was correct. The stimuli appeared in 6 different shapes (circle, star, diamond, triangle, pentagon, cross), and 6 different colours (cyan, yellow, magenta, red, green, blue), combined for a total of 36 different stimuli (6 shapes × 6 colours). The task was self-paced (with each trial’s length a maximum of 4 s), and advanced by button-press as the participants indicated their answers, using a button box inside the MEG. Children were instructed to press the left button when they believed the bottom imaged matched the top left one, and similarly press the right button when the bottom image matched the top right one. A fixation cross appeared between trials and the inter-stimulus interval (ISI) was randomized between 1.0 and 1.5 s. The trials were organized into sets, with each set consisting of a minimum of 3 to a maximum of 8 trials. Each set started with a shift trial, followed by multiple repeat, or Non-Shift trials.

There were two types of shifts: Easy and Hard (Fig. 1). The Easy-Shift trials were intra-dimensional (ID), where the change in matching pattern stayed within the same dimension of either shape or colour, therefore upholding a colour-to-colour or shape-to-shape match. In contrast, the Hard-Shift trials were extra-dimensional shifts (ED), involving a shift in dimension, where there was a colour-to-shape or shape-to-colour shift. Non-Shift trials were trials where there was no
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات