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Attention in spina bifida myelomeningocele: Relations with brain volume and integrity

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ABSTRACT

This study investigated the relations of tectal volume and superior parietal cortex, as well as alterations in tectocortical white matter connectivity, with the orienting and executive control attention networks in individuals with spina bifida myelomeningocele (SBM). Probabilistic diffusion tractography and quantification of tectal and superior parietal cortical volume were performed on 74 individuals aged 8–29 with SBM and a history of hydrocephalus. Behavioral assessments measured posterior (covert orienting) and anterior (conflict resolution, attentional control) attention network functions. Reduced tectal volume was associated with slower covert orienting; reduced superior parietal cortical volume was associated with slower conflict resolution; and increased axial diffusivity and radial diffusivity along both frontal and parietal tectocortical pathways were associated with reduced attentional control. Results suggest that components of both the orienting and executive control attention networks are impaired in SBM. Neuroanatomical disruption to the orienting network appears more robust and a direct consequence of characteristic midbrain dysmorphology; whereas, executive control difficulties may emerge from parietal cortical anomalies and reduced frontal and parietal cortical–subcortical white matter pathways susceptible to the pathophysiological effects of congenital hydrocephalus.

1. Introduction

Two distinct frontoparietal attention networks underlie attentional relevance and salience (Petersen and Posner, 2012). The executive control network is predominantly responsible for cognitively driven attention functions including conflict resolution and attentional control. This network involves dorsolateral frontal and superior parietal cortices, and connections with the thalamus and anterior cingulate cortex (Posner, 2012). Abnormalities of the brain structures subserving the executive control network have been linked to response control deficits in developmental disorders such as attention deficit hyperactivity disorder (ADHD; Dennis et al., 2008).

The orienting network, responsible for engaging, disengaging, and shifting attention (Posner, 1980), is subserved by the frontal eye fields, superior parietal lobule, and intraparietal sulcus, and the superior colliculus of the midbrain tectum (Posner and Petersen, 1990). Covert orienting is associated with unobservable, internal shifts of attention without engaging eye, head, or body movements (Klein, 2004). Tectal and posterior cortical abnormalities have been linked to covert orienting deficits in a variety of adult neurological disorders (Rafal et al., 1988).

Covert orienting deficits are a major characteristic of spina bifida myelomeningocele (SBM). This neurodevelopmental disorder is of particular interest because in addition to covert orienting deficits, developmental dysmorphologies in SBM commonly include congenital abnormalities of the tectum and reduced volume and atypical cortical thickness of the parietal lobes due to hydrocephalus. However, the relation of these attentional difficulties and brain abnormalities has not been quantitatively examined. Because SBM has a range of both cognitive and neural variability, one cannot assume specific links, and so it is important to demonstrate such links directly in a hypothesis driven manner.

1.1. Spina bifida myelomeningocele

Spina bifida myelomeningocele, a neural tube defect, is associated with the Chiari II malformation, which involves a small posterior fossa and associated pathology of the cerebellum and brainstem,

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often contributing to obstructive hydrocephalus and compression of the midbrain (Juranek and Salman, 2010). In addition, hypoplasia or partial dysgenesis of the corpus callosum (Hannay et al., 2009) is common, along with, significant variations in cortical thickness: frontal regions are often enlarged and posterior regions thinned (Juranek et al., 2008). Fig. 1 demonstrates frequently observed neurostructural abnormalities in SBM.

As part of the spectrum of abnormalities associated with Chiari II malformation, the midbrain is often mechanically distorted. The majority of individuals with SBM and Chiari II malformation have a beaked tectum that is stretched posteriorly and inferiorly (Behramn et al., 2003). Williams et al. (2013) used diffusion tensor imaging (DTI) to investigate the frontal and parietal tectocortical attention pathways in individuals with SBM relative to typically developing (TD) individuals. Compared to TD individuals, those with SBM had reduced tectal volume, decreased fractional anisotropy in parietal tectocortical pathways, and a greater discrepancy between frontal and parietal tectocortical diffusion metrics. Those with SBM and tectal beaking had increased axial diffusivity across frontal and parietal tectocortical pathways compared to individuals with SBM and no tectal beaking.

1.2. Attention in SBM

Impairment of the orienting network in SBM is well-established (Dennis and Barnes, 2010). Individuals with SBM and a beaked tectum have more difficulty disengaging attention from a current stimulus and redirecting it towards a new stimulus when compared to TD individuals and individuals with SBM and no tectal beaking (Dennis et al., 2005). Similar findings have been found in infants with SBM, who require more time to disengage and shift their attention towards new stimuli relative to TD infants (Taylor et al., 2010). Although these findings suggest a relation between orienting deficits and tectum, this relation has not been quantitatively evaluated.

Functioning of the executive control network in SBM is less clear. Individuals with SBM have demonstrated executive control difficulties on measures of top-down attention processes such as attention control and response inhibition (Ou et al., 2013). In contrast, on continuous performance tasks, several studies found that individuals with SBM make more commission errors relative to TD individuals (Swartwout et al., 2008), implicating response inhibition difficulties, although such findings have not been unequivocal (Colvin et al., 2003).

1.3. Objectives and hypotheses

The objective of the present study was to investigate the relations of tectal and superior parietal cortical volume, and tectocortical diffusivity metrics, with functioning of the orienting and executive control attention networks in SBM. Given the role of the superior colliculus in the orienting network, we hypothesized that lower tectal volume would be associated with poorer covert orienting, but not with executive control functions. Because the superior parietal cortex subserves both the orienting and executive control networks, we hypothesized that lower volume of the superior parietal cortex would be associated with poorer performance on both covert orienting and executive control tasks. Finally, we did not have any a priori expectations concerning the understudied relations of tectocortical pathways and attention outcomes. The present study is novel due to a large clinical sample, the simultaneous analysis of both the orienting and executive control attention networks, and the implementation of robust correlations and bootstrap procedures to increase the reliability of findings.

2. Materials and methods

2.1. Participants

Participants included 80 individuals with SBM (also reported in Williams et al., 2013) who had undergone structural MRI of the brain. These participants were recruited through clinics in Houston. Of these individuals, 74 had complete neuroimaging, orienting, and conflict resolution data (except for the superior parietal cortex, orienting, conflict resolution data where $n = 73$), and 59 had complete neuroimaging and attentional control data. Inclusion criteria consisted of a myelomeningocele at birth, evidence of hydrocephalus, and adequate upper limb control. Participants had no evidence of major psychiatric disorder. All participants had an IQ score of at least 70.

The sample was 13.70 years in age (SD = 4.81, age range: 7.90–29.11 years), 55% male, and 53% Hispanic. The sample was representative of other samples of SBM, with most showing the Chiari II malformation (88%), thinning (61%) or partial dysgenesis (35%) of the corpus callosum, lower spinal lesions (86%), ambulatory difficulties (68%), no seizure history (64%), and two to four shunt revisions (49%). Tectal beaking was present in 47 out of 74 participants with SBM. The study was approved by the human participants review boards at all institutions. Parents and participants gave written consent unless the participant was under 13, in which case the parent consented and the child assented.

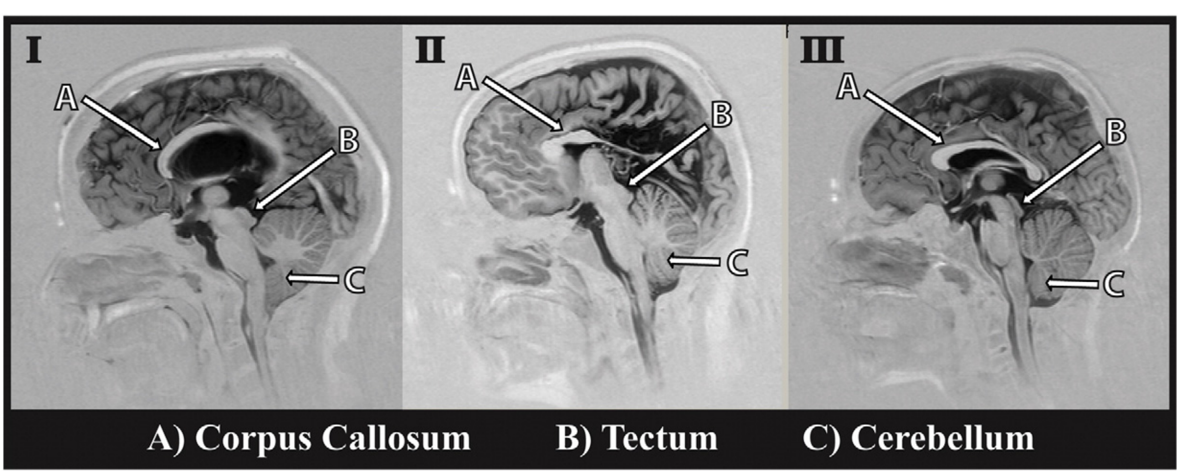

Fig. 1. Depiction of variations in corpus callosum (A), tectum (B), and cerebellum (C) in SBM compared to typically developing individual. I) Individual with SBM showing partial dysgenesis of the corpus callosum, a normal appearing tectum, and downward herniation of the cerebellum; II) individual with SBM showing partial dysgenesis of the corpus callosum, beaking of the midbrain tectum and normal cerebellum; III) typically developing individual showing a fully formed corpus callosum, with normal appearing tectum and cerebellum.