NeuroImage: Clinical 12 (2016) 442–450

Contents lists available at ScienceDirect

NeuroImage: Clinical

journal homepage: www.elsevier.com/locate/ynicl

Relation between functional connectivity and rhythm discrimination in children who do and do not stutter

Soo-Eun Chang[a,*], Ho Ming Chow[a], Elizabeth A. Wieland[b], J. Devin McAuley[c]

[a] Department of Psychiatry, University of Michigan, Ann Arbor, MI, United States
[b] Department of Communicative Sciences and Disorders, Michigan State University, East Lansing, MI, United States
[c] Department of Psychology and Neuroscience Program, Michigan State University, East Lansing, MI, United States

A R T I C L E I N F O

Article history:
Received 10 June 2016
Received in revised form 20 August 2016
Accepted 24 August 2016
Available online 25 August 2016

Keywords:
Rhythm
Stuttering
Resting state fMRI
Functional connectivity
Basal ganglia

A B S T R A C T

Our ability to perceive and produce rhythmic patterns in the environment supports fundamental human capacities ranging from music and language processing to the coordination of action. This article considers whether spontaneous correlated brain activity within a basal ganglia-thalamocortical (rhythm) network is associated with individual differences in auditory rhythm discrimination. Moreover, do children who stutter with demonstrated deficits in rhythm perception have weaker links between rhythm network functional connectivity and rhythm discrimination? All children in the study underwent a resting-state fMRI session, from which functional connectivity measures within the rhythm network were extracted from spontaneous brain activity. In a separate session, the same children completed an auditory rhythm-discrimination task, where behavioral performance was assessed using signal detection analysis. We hypothesized that in typically developing children, rhythm network functional connectivity would be associated with behavioral performance on the rhythm discrimination task, but that this relationship would be attenuated in children who stutter. Results supported our hypotheses, lending strong support for the view that (1) children who stutter have weaker rhythm network connectivity and (2) the lack of a relation between rhythm network connectivity and rhythm discrimination in children who stutter may be an important contributing factor to the etiology of stuttering.

1. Introduction

The ability to perceive and produce rhythmic patterns in the environment is fundamental to a number of human capacities including music and language processing, temporal control of attention, and coordination of purposeful action (Large and Jones, 1999; McAuley and Jones, 2003; Patel, 2006; Dilley and McAuley, 2008). Perception and production of auditory rhythms has been shown to engage a network of sub-cortical and cortical brain areas, including the basal ganglia, supplementary motor area (SMA), premotor cortices, auditory cortex, and cerebellum (Schubotz et al., 2000; Mayville et al., 2002; Lewis et al., 2004; Chen et al., 2006; Grahn and Brett, 2007; Chen et al., 2008; Bengtsson et al., 2009; Karabanov et al., 2009; Schwartze and Kotz, 2015).

Previous studies combining behavioral methods with functional magnetic resonance imaging (fMRI) have shown that better rhythm skills are associated with increased activity within regions of the rhythm network, including the SMA and pre-motor regions (Grahn and McAuley, 2009). Moreover, trained musicians with extensive experience perceiving and producing rhythms have been shown to have greater task-related functional connectivity between auditory-motor areas within the rhythm network (Grahn and Rowe, 2009). Individuals with Parkinson Disease (PD), in contrast, (for whom the basal ganglia, a major rhythm network region is affected) exhibit worse same-different rhythm discrimination compared to age-matched controls (Grahn and Brett, 2009).

Developmental stuttering is a speech disorder with a growing body of research suggesting a possible core deficit in rhythm processing. As a disorder, developmental stuttering is characterized by impaired rhythmic flow of speech (World Health Organization, 2004). Stuttering can be remarkably, albeit transiently, alleviated even in the most severe cases by providing individuals with an external pacing signal, such as an auditory metronome. This fluency inducing effect of a rhythmic pacing signal is similar to the effect of auditory pacing signals on symptom alleviation in PD. In one of the most direct examinations of a general rhythm perception deficit in developmental stuttering, Wieland et al. (2015) showed that children who stutter perform significantly worse on an auditory same-different rhythm discrimination task compared to typically developing children. Moreover, in a separate resting-state fMRI (rsfMRI) study, children who stutter exhibited attenuated functional connectivity within regions of the rhythm network relative to typically developing children (Chang and Zhu, 2013). Taken together,

* Corresponding author at: Department of Psychiatry, University of Michigan, Rachel Upjohn Building Rm 2541, 4250 Plymouth Rd., Ann Arbor, MI 48109, United States.
E-mail address: sooeunc@med.umich.edu (S.-E. Chang).

there is increasing evidence that individuals who stutter have aberrant function of the cortical-subcortical network that supports rhythm processing. One question that emerges from this work is whether there is a relation between functional connectivity within the rhythm network and rhythm perception and if so, how this relationship might be altered for children who stutter.

Previous studies have shown that temporally correlated, intrinsic neural activity measured using resting state fMRI (rsfMRI) offers a glimpse into intrinsic connectivity networks that often recapitulates task-related functional connectivity of the same networks (Hampson et al., 2002; Thomason et al., 2008; Koyama et al., 2010; Thomason et al., 2011; Allen et al., 2014). Moreover, individual differences in spontaneous cortical activity assessed with rsfMRI has been shown to reliably predict individual differences in learning a visual-motor task (Baldassarre et al., 2012). No studies to date, however, have examined whether strength of intrinsic functional connectivity within the rhythm network predicts behavioral performance in a rhythm perception task.

Toward this end, the current study investigated the relation between spontaneous fluctuations in children's intrinsic functional connectivity using rsfMRI and individual differences in the ability to make same vs. different judgments about auditory rhythms in typically developing children and children who stutter. We hypothesized that for typically developing children, intrinsic functional connectivity in the rhythm network during rsfMRI would correlate with individual variation in the performance of an auditory rhythm discrimination task. In contrast, given past data showing an attenuated and different pattern of functional connectivity in the rhythm network in children who stutter (Chang and Zhu, 2013), as well as significantly worse performance on same-different auditory rhythm discrimination (Wieland et al., 2015), we expected that children who stutter would show a reduced, or possibly no relation between intrinsic functional connectivity in the rhythm network and rhythm discrimination performance.

2. Materials and methods

2.1. Participants

Twenty-one children who stutter and 19 typically-developing children (hereafter controls) were recruited in this study. Four children who stutter (19%) and two controls (11%) were excluded due to severe head moments during rsfMRI. The final analyses included 17 children who stutter and 17 controls ranging from 6.08 to 11.42 years of age (8 F, 9 M in each group). The children were recruited through the Speech Neurophysiology Lab at Michigan State University. Many of these children also participated in the study reported in Wieland et al. (2015) with the exception of 6 children (3 controls, 3 children who stutter), who did not overlap in the two studies. Further, a total of 15 controls and 12 children who stutter (out of 17 in each group) overlapped between the current study and Chang and Zhu (2013). However, the fMRI data analyzed and reported in the current study were based on datasets that had little overlap with those reported in Chang and Zhu (2013). The participants included in both studies were recruited as part of a larger longitudinal study, and hence we were able to acquire fMRI datasets on multiple time points from each participant. For the current study, we selected the individual scans that were closest to the time when the rhythm discrimination experiment was conducted. As a result, fMRI datasets from only 5 controls and 1 stuttering child were those that were acquired in the same year in both studies. Namely, fMRI datasets from 12 controls and 16 children who stutter of the current study are distinct from those reported in Chang and Zhu (2013) study.

All children underwent careful screening to ensure normal speech and language development and typical developmental history except for the presence of stuttering in the stuttering group. Participants were monolingual, native speakers of English, with normal hearing, and without concomitant developmental disorders such as dyslexia, ADHD, learning delay, or other confirmed developmental or psychiatric conditions. Parents also confirmed that no child was taking any medication affecting the central nervous system. Children who stutter and controls did not differ in chronological age or socioeconomic status (Hollingshead, 1975).

Research procedures were approved by the Michigan State University Institutional Review Board. Parents received nominal remuneration and children received small rewards (i.e., stickers) for their participation.

2.2. Speech, language, hearing, and cognitive evaluation

Prior to participation, all children were given a battery of standardized speech, language, and cognitive tests, audiometric hearing screening, oral-motor screening, and cognitive evaluations. Tests included the Peabody Picture Vocabulary Test (PPVT-4), Expressive Vocabulary Test (EVT-2), Goldman-Fristoe Test of Articulation (GFTA-2), Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III, ages 3;0–7;0; or Wechsler Abbreviated Scale of Intelligence, WASI, ages 7; 0–12; 0) and receptive language test (subtests within the Test of Language Development, TOLD-P:3, ages 4; 0–8; 11; TOLD-I4, ages 9; 0–12; 0; or Test for Auditory Comprehension of Language, TACL-3, ages 4; 0 to 8; 11). Potential participants were excluded from the current study if their scores on any of these standardized tests were below two standard deviations of the mean.

Stuttering severity was assessed off-line by reviewing video recorded samples of speech, elicited through storytelling and conversational tasks with a certified Speech-Language Pathologist or a trained graduate student assistant. These speech samples were transcribed for further off-line analyses. The Stuttering Severity Instrument (SSI-4) was used to assess stuttering severity by considering percent frequency and duration of stuttering-like disfluencies, and physical concomitants associated with stuttering, derived from a minimum of 500 syllable speech sample recorded while the child engaged in conversations with a clinician. To be considered stuttering, children had to score at least very mild according to the total score on the SSI-4, stuttering judged to be present by a Speech-Language Pathologist, and the parent(s) had to express concern due to stuttering behavior. These measures were incorporated into a composite stuttering severity rating (SSI total score range: 8–29). To determine measurement reliability of the SSI score ratings, an intraclass correlation (ICC) coefficient was calculated based on the two independent judges' ratings of SSI on a larger sample of children, from which pool the current participants were recruited. The ICC based on 37 samples was very high, with Cronbach's alpha = 0.97 (absolute agreement; unadjusted). All children who stuttered were tested to be persistent at the time of behavioral testing. The average duration of stuttering was 5.14 years (range 2.1–8 years; SD 2.0).

2.3. MRI acquisition

Functional and anatomical MR images were acquired on a GE 3 T Signa® HDx MR scanner (GE Healthcare) with an 8-channel head coil. Functional images were acquired using echo-planar sequence with the following parameters: 38 contiguous 3 mm axial slices in an ascending, interleaved order, echo time = 27.7 ms, repetition time = 2500 ms, flip angle = 80°, field of view = 22 cm, matrix size = 64 × 64, ramp sampling. In total, 164 volumes were acquired during wakeful rest with subjects' eyes closed. Whole brain anatomical images were acquired using inversion recovery fast spoiled gradient recalled echo sequence with CSF suppressed, time of echo = 3.8 ms, time of repetition of acquisition = 8.6 ms, time of inversion = 831 ms, repetition time of inversion = 2332 ms, flip angle = 8°, field of view = 25.6 cm × 25.6 cm, matrix size = 256 × 256, slice thickness = 1 mm, and receiver bandwidth = ±20.8 kHz. During the scans, one staff member sat inside the scanner room next to the child at all times to monitor the child's comfort and to ensure cooperation during scanning.