GLOBAL VOLUME REGISTRATION FOR MULTIPLE MOTION TYPES IN RESTING-STATE FUNCTIONAL MAGNETIC RESONANCE IMAGES

by

Jenna Marie Schabdach

B. S. Electrical Engineering, Drexel University, 2016

M. S. Electrical Engineering, Drexel University, 2016

M. S. Biomedical Informatics, University of Pittsburgh, 2018

Submitted to the Graduate Faculty of

the Department of Biomedical Informatics in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2019

UNIVERSITY OF PITTSBURGH

SCHOOL OF MEDICINE

This dissertation was presented

by

Jenna Marie Schabdach

It was defended on

January 30, 2019

and approved by

Dr. Ashok Panigrahy, Department of Biomedical Informatics

Second member's name, Dept. Aff.

Third member's name, Dept. Aff.

Dissertation Director: Dr. Ashok Panigrahy, Department of Biomedical Informatics

GLOBAL VOLUME REGISTRATION FOR MULTIPLE MOTION TYPES IN RESTING-STATE FUNCTIONAL MAGNETIC RESONANCE IMAGES

Jenna Marie Schabdach, PhD

University of Pittsburgh, 2019

INSERT ABSTRACT HERE

TABLE OF CONTENTS

1.0 BACKGROUND

The topics treated in this chapter can be somewhat obscure. For humanitarian considerations, the chapter will be subdivided.

1.1 RESTING-STATE NETWORKS

The idea of a neuronal network which operated when a person is at rest was proposed in 2001, and then confirmed in 2003 [Raichle et al., 2001] [Greicius et al., 2003]. Resting-state networks are recorded using resting-state functional magnetic resonance images (rs-fMRIs). rs-fMRIs are sequences of image volumes acquired over a period of a few minutes while the patient is in a task-free state. The image volumes themselves have relatively low spatial resolution when compared to structural MRIs, but their temporal resolution is significantly higher as a new volume is acquired every two to three seconds. Each volume records the blood oxygen level dependent (BOLD) signals within the brain at that point in time.

The BOLD signals in rs-fMRI image sequences are analyzed using a process called functional connectivity analysis. Functional connectivity analysis identifies patterns and networks of brain activity. Because the patient is not performing a specific task during a rs-fMRI acquisition, these resting-state networks have the potential to reveal valuable information about a patient's neurodevelopmental status. Some functional connectivity analysis studies have lead to the discoveries of links between specific disruptions in these naturally occurring networks and neurodevelopmental diseases such as autism and attention deficit hyperactivity disorder [Assaf et al., 2010] [Zang et al., 2007]. With further refinements of both acquisition techniques and characterization of these functional networks, clinicians may be

able to use rs-fMRI in early detection protocols to evaluate the neurodevelopmental status of infants and neonates, and in personalized care by identifying patients who may benefit from certain therapies or neuroprotective interventions.

1.2 MEASURING THE EFFECTS OF MOTION

Due to their low spatial and high temporal resolutions, rs-fMRIs are highly susceptible to motion. Even the smallest movement can alter the position of the patient enough to cause the voxels to record signals from different brain regions and tissue types. Even if the movement does not significantly change the recorded position of the subject, it impacts the established spin gradients, which introduces artifacts into the image sequence. Movements cause the orientation of existing spin gradients to change, and the gradients require time to realign to the magnetic field. This recovery time often results in a decrease in the global signal in frames obtained over the following 8-10 seconds, which can affect the functional connectivity analysis [Power et al., 2014].

The effects of motion on rs-fMRIs can be clearly divided into two categories: the effect on patient position and the effect on the recorded BOLD signal.

The effect of motion on patient position is measured in terms of the difference in position between temporally neighboring image volumes. The difference in position is determined using metrics calculated by performing rigid volume registration on the two volumes. In rigid volume registration, one volume is chosen as the reference volume and the other is considered the moving volume. The reference volume remains stationary while the moving volume is translated and rotated in three-dimensional space on top of it. The registration is considered successfully complete when the position of the patient in the moving volume matches the position in the reference volume. The three translation and three rotation parameters used to achieve this alignment are used to calculate the positional change between the image volumes, which is often called the framewise displacement (FD).

Several researchers have proposed different methods for calculating the FD. Power et al., Jenkinson et al., and Dosenbach et al. each propose a slightly different method for

calculating the FD [Power et al., 2012] [Jenkinson et al., 2002] [Dosenbach et al., 2017]. All three FD calculations produce correlated metrics: the FD metric proposed by Power et al. produces measurements approximately twice as large as the metric proposed by Jenkinson et al., and Dosenbach et al. reported a high correlation between their FD and Powers FD [Yan et al., 2013] [Dosenbach et al., 2017].

The effects of motion on the BOLD signal are a little more difficult to measure. They occur because motion disrupts the magnetic spin gradients present in the patient during the scan. The spin gradients need time to recover to the correct magnetic field orientation, and up to eight to ten seconds may pass before the recovery is complete [Power et al., 2014]. While the spin gradients are reorienting, the recorded BOLD signal may vary between temporally neighboring volumes. These changes can be measured using the temporal derivative of the variance in the BOLD signal intensity (DVARS) between the frames [Power et al., 2012].

Even though the effects of motion on the patient position and the recorded signal can be measured, we still need gold standard criteria to determine whether an image containing motion can be used. Patients move slightly due to breathing and cardiac function, and the BOLD signal naturally fluctuates over time. Some motion is expected; however, we need to know how much motion can be present in the image before it is considered to be corrupted by it. Power et al. established thresholds for FD and DVARS to determine the usability of a pair of images:

- FD less than or equal to 0.2 mm from previous volume, and
- DVARS less than or equal to 25 units on a normalized scale of [0, 1000] signal units [Power et al., 2014]

Image volumes that meet these criteria are considered to be low-motion. van Dijk et al. established that approximately five minutes of low-motion data is sufficient for use in functional connectivity analysis [van Dijk et al., 2012]. Unfortunately, it is often difficult to obtain enough low-motion data from patients to use in these analyses.

1.3 MOTION PREVENTION

Various techniques and protocols have been developed to prevent patients from moving during the image acquisition process. Not all of these techniques are suitable for all patient populations, and some techniques have been designed specifically for certain populations populations.

1.3.1 Sedation

Sedation can be used to help a patient tolerate an MRI scan. Murphy and Brunberg retrospectively analyzed seven weeks of data from the MR department and found that 14.2% of their adult patients some form of sedation [Murphy and Brunberg, 1997]. In a study about claustrophobia and MR acquisitions, ELEPHANTS report that out of 55,734 patients who underwent MRI scans, a total of 1,004 patients experienced claustrophobia and 610 of these patients required intravenous sedation before their scans [Dewey et al., 2007]. Even though sedation allowed the patients mentioned in this paragraph to undergo an MRI scan, the authors of both studies note that sedation can result in adverse events and advise the reader to avoid patient sedation if possible.

Sedation can be used with pediatric patients, though the risks are more significant than with adult patients. Studies have shown that sedation for pediatric imaging can lead to hypoxemia and inappropriate sedation levels during image acquisition [Malviya et al., 2000]. Some pediatric patients can also expect "motor imbalance and gastrointestinal effects," as well as agitation and restless for a period of hours after waking from sedation.

A report from the American Academy of Pediatrics and the American Academy of Pediatric Dentistry outlines the minimum set of criteria needed for a pediatric patient to be sedated for a procedure [Coté and Wilson, 2016]:

- The patient must be a suitable candidate for sedation based on their medical history and medical needs.
- At least one responsible person must be with the patient at the medical factility, though the report recommends that two adults are present for patients who use car seats to

travel to and from the facility. This practice ensures that one adult can monitor the patient after the procedure while the other adult drives.

- The clinician administering the sedation must have immediate access to emergency facilities, personnel, and equipment and should monitor the patient for adverse events including respiratory events, seizures, vomiting, and allergic reactions.
- There must be a clear protocol outlined for immediate access to these emergency services.
- Emergency equipment and drugs appropriate for the patient's size and age must be immediately available in case the patient needs to be resuscitated.
- Informed consent must be obtained prior to the procedure.
- Instructions for what to expect and how to transport the patient home safely must be provided to the patient's responsible adult.
- The patient may be held at the facility for prolonged monitoring after the procedure.
- The patient's food and drink intake prior to the procedure should be taken into account to minimize the risk of pulmonary aspiration.
- The patient's health status must be evaluated and verified by the sedation team prior to the procedure.
- The information about the procedure must be correctly documented.
- The facility should have a dedicated recovery area, and the status of the patient should be recorded when he is discharged. The patient should not be discharged if his level of consciousness and oxygen saturation do not meet recognized guidelines.

This report clearly states that the levels of monitoring suggested within should serve as minimum levels of involvement: clinicians should increase patient monitoring as needed for complex cases. Rutman has a similar and detailed perspective on patient monitoring during and after sedation, suggesting that two independent medical personnel should be present during the scan and one should be present until the patient is discharged [Rutman, 2009]. Rutman also notes that all sedation and monitoring equipment must be MR compatible, which is a simple but important safety constraint. This constraint may make sedation less advisable if the appropriate equipment is not available.

Sedation in neonatal and infant populations is not recommended. The U. S. Food and Drug Administration (FDA) issued a warning in late 2016 about repeated use of sedation or

general anesthesia in patients under three years of age or in pregnant women in their third trimester [FDA, 2016]. The warning states that while a single, relatively short exposure to sedative and anesthetic drugs is unlikely to impact the patient, the effects of prolonged exposure to these drugs are still being studied. Studies of sedative and anesthetic drugs in multiple animal models have shown that these drugs can lead to loss of nerve cells in the brain when the animals undergo prolonged, repeated exposure to them during period of brain development. More data is needed to determine if this effect translates to humans.

1.3.2 Education, Distraction, and Behavioral Techniques

Educational material can be used to help the patient understand what to expect during an MRI scan as well as to teach the patient different behavioral coping strategies. The education materials can be used either before arrival at the imaging facility or upon arriving at the imaging facility.

Most of the formal literature focuses on educational, distraction, and behavioral techniques to use during pediatric MRI scans. Many of the following approaches could be adapted for use with adults.

In a review of the available literature, Alexander found several commonly used techniques to educate, comfort, and distract pediatric patients during radiology procedures. Tools such as educational coloring books and short videos can expose patients to the types of equipment they can expect to see using a familiar, engaging medium. Pediatric patients can learn coping strategies to employ during the scan such as breathing techniques, imagery, and positive statements. Alexander notes that allowing a pediatric patient to choose a behavioral coping strategy gives the patient a sense of control and may encourage the patient to cooperate during the MRI acquisition [Alexander, 2012].

Mock scanners and MRI simulators can also help the patient feel more comfortable during the scan. Barnea-Goraly et al. showed that both a commerical MRI simulator and a low-tech mock scanner desensitized pediatric patients between four and ten years of age to the MRI scanner with the results that 92.3% of the acquired images could be used in high-resolution anatomical studies [Barnea-Goraly et al., 2014].

During the MRI acquisition, headphones with music or stories and MR compatible video goggles can distract patients [Alexander, 2012] [Barnea-Goraly et al., 2014] [Harned and Strain, 2001]. Khan et al. found that a relatively simple moving light show can be helpful in distracting younger patients [Khan et al., 2007]. Garcia-Palacios et al. performed a case study comparing the efficacy of music and immersive virtual reality tools as distractions during a mock scan [Garcia-Palacios et al., 2007]. They suggest that immersive virtual reality may help decrease patient anxiety during a scan more effectively than music alone.

Another source of distraction for pediatric patients could be the patient's parent or parents. Having a parent involved with the scanning process may calm the patient and encourage him to cooperate; however, parental distress can further upset an anxious patient and complicate the scanning process [Alexander, 2012].

These techniques for educating the patient and helping the patient cope with the anxiety that can come with an MRI scan all depend on the ability of the patient to understand instructions and communicate with the scan team. Due to the gap in communication abilities, these techniques are not useful for young patients such as neonates, infants, and toddlers. Other patient populations, such as those with developmental delays and neurobehavioral disorders, may also have difficulty adhering to these protocols. Even in patients with developed and intact communication skills, the techniques outlined here do not actively prevent the patient from moving during the scan: they only help the patient feel more comfortable with the MRI environment.

1.3.3 Feed and Sleep Protocols

Neither sedation nor educational and behavioral techniques are appropriate to use with neonatal patients, but rs-fMRIs in neonates and infants are invaluable in studying early brain development and neurological diseases [Smyser and Neil, 2015]. A set of protocols have been developed specifically for scanning neonates without sedation. These protocols are referred to as "feed and sleep" or "feed and bundle" protocols.

Windram et al. describe a protocol in which the infant is deprived of food for four hours prior to the scan [Windram et al., 2011]. At the scanning facility, the patient is fed by his

mother, swaddled, and placed in a vacuum-bag immobilizer for the duration of the scan.

Rather than deprive the patient of food prior to the scan, Gale et al.'s protocol recommends timing the scan so that the patient is fed after arrival on site and less than 45 minutes before the scan [Gale et al., 2013]. The patient's ears are protected from the noise of the MR scanner by a layer of dental putty, followed by headphones, and held in place by a hat. The patient is the swaddled and placed in the scanner once he is asleep. Additional foam padding is used to cushion the patient's head and provides extra noise protection.

Mathur et al. describe a protocol similar to the previous two: the patient's feeding schedule is adjusted so that he feeds 30-45 minutes before the scan time, and he is swaddled, given ear protection, and placed in a vacuum-bag immobilizer [Mathur et al., 2008].

These protocols are generally successful: when performed correctly, the neonatal patient usually sleeps for the duration of the MRI scan. However, the patient may shift slightly while asleep or may wake up and move mid-scan.

1.4 PROSPECTIVE MOTION CORRECTION

Since motion cannot be completely eliminated from rs-fMRI scans, different approaches have developed for correcting for the effects of motion after the scan. These approaches can be divided into two groups: those that monitor the patient's motion during the scan and those that work solely on the acquired sequences.

1.4.1 Optical Motion Correction

Several groups have developed methods for actively recording the patient's position during an MRI scan. These methods usually involve a combination of markers placed on the patient and one or more MR compatible optical cameras placed the scanner bore. Throughout the scan, the optical cameras record the position of the markers on the patient. Changes in the patient position are used to update the MR parameters in real-time, resulting in less motion corruption in the acquired sequences.

The first report of successful prospective motion correction using optical cameras and markers was by Zaitsev et al. in 2006 [Zaitsev et al., 2006]. Their dual camera system was located outside of the MRI scanner and focused on the patient inside the system. Four reflective markers were attached to a modified mouthpiece originally designed for patient immobilization. Changes in the translation and rotation of the patient were recorded and processed during the exam. The processed changes were sent in real-time to the MRI scanner which used them to update the gradient orientations and RF frequences and phases at every time point during the acquisition process.

Aksoy et al. simplify this approach by using a single in-bore optical camera and replacing the 3D markers with a small 2D chessboard grid [Aksoy et al., 2008]. Properties intrinsic to the camera as well as information about the camera's placement within the MRI scanner were recorded prior as part of a calibration process. During the scan, patient movements recorded using the optical camera were used to calculate the relationship between the patient's position at the current time point in the physical space and the patient's position at the initial time point in the MR space. The transformation needed to translate between these two positions was calculated on a laptop and passed to the MRI scanner to correct for motion in real-time.

The methods discussed above have a few limitations due to the optical camera setups. For precise real-time motion correction, the camera or cameras must be carefully placed so that the position of the marker on the patient can be recorded. They must have a clear line of sight, which means they will be in the same room as the MRI scanner. The cameras and markers must be MR compatible, but the positions of the cameras and markers in physical space relative to the MRI scanner must be known. The changes in position that are recorded and used to adapt the scan parameters will only be true for rigid body motion of the body part to which the markers are attached: any distortion of soft tissue may not be accurately accounted for during the motion correction.

1.4.2 Within Sequence Motion Monitoring

Dosenbach et al. have developed a tool to evaluate motion in rs-fMRI sequences as they are acquired][Dosenbach et al., 2017]. It registers each frame to the initial frame of the rs-fMRI

sequence immediately after the new frame is recorded. The parameters produced by this registration are used to calculate the framewise displacement between pairs of frames, which is then compared to a set of displacement thresholds associated with the scan quality. The number of frames that meet each threshold is used to determine how many more frames are needed to obtain five minutes of low-motion frames. This method for assessing the quality of a scan in real time is useful for ensuring images are acquired with a sufficient number of low-motion frames. It can also aid the technologists in determining whether to prematurely terminate a scan, which may be desirable if the amount of time needed to obtain enough low-motion frames is greater than the amount of time remaining for the patient in the scanner.

However, this method cannot be used to recover motion-corrupted data in existing repositories.

1.5 POST-ACQUISITION MOTION CORRECTION

1.6 VOLUME REGISTRATION

Liao et al. suggested that a rs-fMRI sequence could be viewed as a hidden Markov model, and reflected this idea in their suggested registration framework [Liao et al., 2016]. Their framework uses the transformation of the previous volume to the reference volume as the initial transformation for the current volume and the reference volume.

BIBLIOGRAPHY

[FDA, 2016] (2016). Drug Safety and Availability - FDA Drug Safety Communication: FDA review results in new warnings about using general anesthetics and sedation drugs in young children and pregnant women. Technical report.

[Aksoy et al., 2008] Aksoy, M., Newbould, R., Straka, M., Holdsworth, S. J., Skare, S. T., Santos, J. M., and Bammer, R. (2008). A Real Time Optical Motion Correction System Using a Single Camera and 2D Marker. *Proceedings of the 16th Scientific Meeting of ISMRM*, 16:3120.

[Alexander, 2012] Alexander, M. (2012). Managing Patient Stress in Pediatric Radiology. *Radiologic Technology*, 83(6):549–560.

[Assaf et al., 2010] Assaf, M., Jagannathan, K., Calhoun, V. D., Miller, L., Stevens, M. C., Sahl, R., O'Boyle, J. G., Schultz, R. T., and Pearlson, G. D. (2010). Abnormal functional connectivity of default mode sub-networks in autism spectrum disorder patients. *NeuroImage*, 53(1):247–256.

[Barnea-Goraly et al., 2014] Barnea-Goraly, N., Weinzimer, S. A., Ruedy, K. J., Mauras, N., Beck, R. W., Marzelli, M. J., Mazaika, P. K., Aye, T., White, N. H., Tsalikian, E., Fox, L., Kollman, C., Cheng, P., and Reiss, A. L. (2014). High success rates of sedation-free brain MRI scanning in young children using simple subject preparation protocols with and without a commercial mock scanner - the Diabetes Research in Children Network (DirecNet) experience. *Pediatric Radiology*, 44(2):181–186.

[Coté and Wilson, 2016] Coté, C. J. and Wilson, S. (2016). Guidelines for Monitoring and Management of Pediatric Patients Before, During, and After Sedation for Diagnostic and Therapeutic Procedures: Update 2016. *Pediatrics*.

[Dewey et al., 2007] Dewey, M., Schink, T., and Dewey, C. F. (2007). Claustrophobia during magnetic resonance imaging: Cohort study in over 55,000 patients. *Journal of Magnetic Resonance Imaging*, 26(5):1322–1327.

[Dosenbach et al., 2017] Dosenbach, N. U., Koller, J. M., Earl, E. A., Miranda-Dominguez, O., Klein, R. L., Van, A. N., Snyder, A. Z., Nagel, B. J., Nigg, J. T., Nguyen, A. L., Wesevich, V., Greene, D. J., and Fair, D. A. (2017). Real-time motion analytics during brain MRI improve data quality and reduce costs. *NeuroImage*, 161(January):80–93.

[Gale et al., 2013] Gale, C., Jeffries, S., Logan, K. M., Chappell, K. E., Uthaya, S. N., and Modi, N. (2013). Avoiding sedation in research MRI and spectroscopy in infants: our approach, success rate and prevalence of incidental finding. *Arch Dis Child Fetal Neonatal Ed*, 98:F267–F268.

[Garcia-Palacios et al., 2007] Garcia-Palacios, A., Hoffman, H. G., Richards, T. R., Seibel, E. J., and Sharar, S. R. (2007). Use of Virtual Reality Distraction to Reduce Claustrophobia Symptoms during a Mock Magnetic Resonance Imaging Brain Scan: A Case Report. *CyberPsychology and Behavior*, 10(3):485–488.

[Greicius et al., 2003] Greicius, M. D., Krasnow, B., Reiss, A. L., and Menon, V. (2003). Functional connectivity in the resting brain: A network analysis of the default mode hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, 100(1):253–258.

[Harned and Strain, 2001] Harned, R. K. and Strain, J. D. (2001). MRI-compatible audio / visual system : impact on pediatric sedation. *Pediatric Radiology*, pages 247–250.

[Jenkinson et al., 2002] Jenkinson, M., Bannister, P., Brady, M., and Smith, S. (2002). Improved Optimization for the Robust and Accurate Linear Registration and Motion Correction of Brain Images. *NeuroImage*, 17:825–841.

[Khan et al., 2007] Khan, J. J., Donnely, L. F., Koch, B. L., Curtwright, L. A., Dickerson, J. M., Hardin, J. L., Hutchinson, S., Wright, J., and Gessner, K. E. (2007). A program to decrease the need for pediatric sedation for CT and MRI. *Applied Radiology*, April:30–33.

[Liao et al., 2016] Liao, R., Turk, E. A., Zhang, M., Luo, J., Ellen Grant, P., Adalsteinsson, E., and Golland, P. (2016). Temporal registration in in-utero volumetric MRI time series. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 9902 LNCS:54–62.

[Malviya et al., 2000] Malviya, S., Voepel-Lewis, T., Prochaska, G., and Tait, A. R. (2000). Prolonged Recovery and Delayed Side Effects of Sedation for Diagnostic Imaging Studies in Children. *Pediatrics*, 105(3).

[Mathur et al., 2008] Mathur, A. M., Neil, J. J., McKinstry, R. C., and Inder, T. E. (2008). Transport, monitoring, and successful brain MR imaging in unsedated neonates. *Pediatric Radiology*, 38(3):260–264.

[Murphy and Brunberg, 1997] Murphy, K. J. and Brunberg, J. A. (1997). Adult claustrophobia, anxiety and sedation in MRI. *Magnetic Resonance Imaging*, 15(1):51–54.

[Power et al., 2012] Power, J. D., Barnes, K. A., Synder, A. Z., Schlagger, B. L., and Petersen, S. E. (2012). Spurious but systematic correlations in functional connectivity MRI networks arise from subject motion. *NeuroImage*, 59(3):2142–2154.

[Power et al., 2014] Power, J. D., Mitra, A., Laumann, T. O., Snyder, A. Z., Schlaggar, B. L., and Petersen, S. E. (2014). Methods to detect, characterize, and remove motion artifact in resting state fMRI. *NeuroImage*, 84:320–341.

[Raichle et al., 2001] Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., and Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences*, 98(2):676–682.

[Rutman, 2009] Rutman, M. S. (2009). Sedation for emergent diagnostic imaging studies in pediatric patients. *Current Opinion in Pediatrics*, 21(3):306–312.

[Smyser and Neil, 2015] Smyser, C. D. and Neil, J. J. (2015). Use of resting state functional MRI to study brain development and injury in neonates. *Seminars in Perinatology*, 39(2):130–140.

[van Dijk et al., 2012] van Dijk, K. R., Sabuncu, M. R., and Buckner, R. L. (2012). The influence of head motion on intrinsic functional connectivity MRI. *NeuroImage*, 59(1):431–438.

[Windram et al., 2011] Windram, J. D., Grosse-Wortmann, L., Shariat, M., Greer, M.-L., and Yoo, S.-J. (2011). The Feed and Sleep method: how to perform a cardiac MRI in the 1st year of life without the need for General Anesthesia. *Journal of Cardiovascular Magnetic Resonance*, 13(Suppl 1):P224.

[Yan et al., 2013] Yan, C.-G., Craddock, R. C., He, Y., and Milham, M. P. (2013). Addressing head motion dependencies for small-world topologies in functional connectomics. *Frontiers in Human Neuroscience*, 7(December):1–19.

[Zaitsev et al., 2006] Zaitsev, M., Dold, C., Sakas, G., Hennig, J., and Speck, O. (2006). Magnetic resonance imaging of freely moving objects: prospective real-time motion correction using an external optical motion tracking system. *NeuroImage*, 31(3):1038–1050.

[Zang et al., 2007] Zang, Y. F., Yong, H., Chao-Zhe, Z., Qing-Jiu, C., Man-Qiu, S., Meng, L., Li-Xia, T., Tian-Zi, J., and Yu-Feng, W. (2007). Altered baseline brain activity in children with ADHD revealed by resting-state functional MRI. *Brain and Development*, 29(2):83–91.