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Exploring Neurodevelopmental Disorders and Broader Implications of MRI Technology

Introduction & MRI and fMRI Background

Since its inception in the 1970's (Hornak), Magnetic Resonance Imaging (MRI) technology has become a standard, widely-used radiology tool in clinical and research contexts ("What is fMRI?"). MRI technology essentially uses magnets to create a powerful magnetic field. Protons from molecules in the body align with the magnetic field. Then, the MRI machine sends radio waves to the body. In response, protons absorb and then release energy from the waves, thus generating a magnetic resonance signal. This magnetic resonance signal is then received by the MRI machine's sensors. Subsequently, the proton's magnetic resonance signals are translated into an image that a radiologist interprets ("Magnetic Resonance").

This non-invasive process has made MRI an especially popular diagnostic tool. In addition, MRI is appealing because it employs a strong magnetic field instead of the dangerous ionizing radiation involved in other radiological technologies such as CT scans and X-rays (Hartwig et al. 2009). Moreover, MRI provides three-dimensional, "high resolution" images with "good contrast between different tissues" which makes it useful for studying many different areas of the human body ("What is fMRI?"). While traditional MRI depicts anatomical structures, the closely related technology of fMRI – functional magnetic resonance imaging – depicts activity occurring inside these structures. In other words, fMRI employs "the same basic principles of atomic physics as MRI scans, but […] fMRI image[s] metabolic function"

(*Functional Magnetic*). In short, MRI illustrates the physical form of the brain and its component parts, while fMRI maps the neural activity occurring within the brain. Specifically, fMRI measures neural activity by detecting small changes in magnetic resonance signals in certain areas of the brain. These changes in magnetic resonance are caused indirectly by neural activity. To be precise, neural activity triggers a change in blood flow to particular regions of the brain. In turn, these changes in blood flow cause small changes in magnetic resonance (”What is fMRI?”). Thus, in an fMRI, changes in magnetic resonance illustrate whether and where brain activity is occurring.

In this paper, I will focus on current and future implications of using MRI and fMRI to scan the human brain. First, I will highlight the applications of MRI *and* fMRI to research the structural and functional components of a neurodevelopmental disorder: childhood-onset fluency disorder, also known as stuttering (Diagnostic and Statistical Manual of Mental Disorders, 5th edition). Then, I will discuss future implications of MRI and fMRI for scientific research, clinical treatment, and societal attitudes surrounding childhood onset fluency disorder and potentially other neurodevelopmental conditions. I will also explore how MRI research on stuttering has affected me and some personal implications of future MRI research.

Stuttering: A Brief Background and My Personal Connection

Stuttering, which is often called childhood onset fluency disorder in clinical and research contexts, is a neurodevelopmental speech disorder that affects 1% of the population and approximately 3 million Americans overall (Chang et al. 2015). The onset of stuttering begins while children are developing their language skills, and it can be a normal phase of language development lasting a few weeks to a few years. About 75% of children who stutter only do so temporarily, and recover during childhood; however, for those who do not recover in childhood, stuttering usually remains a constant and permanent communicative disability ("Stuttering"). Persistent stuttering – which describes those who stutter permanently – is widely misunderstood by those who do not study it or stutter themselves. Persistent stuttering is a complex disorder caused by dynamic interactions between genetic factors, epigenetic factors, and environmental (including both physiological and external) factors (Smith and Weber 2017 ["How Stuttering"]). The symptoms of stuttering are not simple or static, either. Rather, for persistent stutterers, symptoms are *always* present, but they fluctuate in *degree* over time and due to different physiological and external environments (Smith and Weber 2017). Contrary to popular belief, those who stutter persistently cannot control, treat, or improve their speech by will. There is no treatment for stuttering other than speech therapy, which only provides coping tools to mask speech abnormalities, manage emotions related to stuttering, or create a more comfortable environment for the stutterer. Any improvement or deterioration in fluency is arbitrary.

I am a persistent stutterer, so this subject is important and personal for me. Although my stutter was severe throughout childhood, it became mild to moderate during mid-adolescence. I still feel and hear my own stutter every day, but to other people, my abnormal speech patterns have become much less noticeable overall. For stutterers who do not recover, stuttering is not an intermittent challenge that only occurs sometimes. Instead, it is an ever-present challenge for the stutterer that is only *sometimes noticeable* to the listener. This is an important distinction to understand how persistent stutterers differ from people who are normally fluent. MRI and fMRI scans of stutterers' brains have sharpened this distinction by revealing some of the neurological basis for stuttering (Chang 2014). Consequently, these MRI findings provide insight into my personal experience as well as into scientific and clinical understandings of stuttering. Perhaps most importantly, the data from MRI scans has laid the foundation for future treatment and diagnosis. Certainly, this suggests a hopeful future for stutterers, who have only recently had any research to explain the nature of their disorder.

Present Applications and Future Implications of MRI for Stuttering Research

Neurological research into stuttering using MRI began in earnest just within the past twenty years (Chang 2014). MRI and fMRI scans have been crucial tools for researchers trying to understand the differences between individuals who stutter and those who do not (Chang and Zhu 2013). In fact, MRI technology has facilitated the scientific basis for understanding the very nature of stuttering as a neurodevelopmental disorder in the first place (Smith and Weber 2016 [“Childhood”]). Some of the most potent and groundbreaking findings in stuttering research have been discoveries of subtle differences in brain anatomy and function in stutterers as demonstrated by MRI imaging. One scientific study summarized the “underlying nature” of stuttering as neurological due to the “altered brain structure and function” of stutterers (Loucks, et al. 2011). For example, in the “largest pediatric neuroimaging study of stuttering to date” in 2015, researchers used structural MRI scans to study white matter – a particular type of brain tissue – in normal and stuttering children’s brains (Chang et al. 2015). These MRI scans indicated “extensive white matter structural differences in children who stutter” compared to non-stuttering children (Chang et al. 2015). More precisely, the structural MRIs depicted anatomical differences in the white matter that “interconnect auditory and motor structures” in the brain, underscoring the connection between brain anatomy and speech production (Chang et al. 2015). In an earlier study, fMRI was used to examine neural activity in the brains of stuttering adults, with results suggesting that there was not an overall *lack* of brain activity. Rather, the fMRI scans showed that levels of overall activity were the same, but the stutterers' language activity occurred in different locations in the brain relative to non-stutterers (Loucks, et al. 2011). In the study's analysis of stuttering and non-stuttering adults, stutterers had had "aberrant increases in brain activity" in certain areas of the brain compared to fluent speakers, while some "speech relevant brain regions" in stutterers' brains had less activity (Loucks, et al. 2011).

A later study in 2013 used fMRI to measure the neural connectivity of stuttering and non-stuttering children's brains in an effort to understand neurological conditions closer to the onset of stuttering. The data illustrated that stuttering children also had weakened "functional and structural connectivity" in certain speech-related areas of the brain (Chang and Zhu 2013). However, the brain scans also suggested that girls, "who are more likely to recover than boys who stutter in future years" had higher connectivity than boys in certain neural networks. Therefore, since girls are more likely to recover from stuttering, researchers suggested these better-connected networks might "undergo dynamic changes during development that may underlie natural recovery from stuttering" (Chang and Zhu 2013). In other words, the use of functional MRI in this study might have revealed one reason why some children are able to recover from stuttering, which is one of the most elusive and poorly understood aspects of the disorder (Chang and Zhu 2013).

Most recently, a July 2019 study using MRI brain scans corroborated previous studies that showed stutterers have abnormal anatomical structures in speech and auditory regions of the brain (Koenraads, et al. 2019). The study points out, however, that "[f]uture research is needed to explore the causal nature of this association" (Koenraads, et al. 2019), suggesting the exact interaction between brain structure and function and stuttering is still unclear. Despite this, researchers in the aforementioned 2011 study suggest that the *difference* between the brains of stutterers and non-stutterers is subtle, but certain. Namely, the scientists asserted that differences "have been observed across studies and during fluent speech production or silent verbal processing" (Loucks, et al. 2011). Ultimately, because MRI and fMRI are highly precise tools for imaging brain anatomy and function, it is an ideal tool for examining the neurological aspects of stuttering. Furthermore, the connection between stuttering and the brain's structure and function makes MRI data essential to understanding stuttering, as well as other neurodevelopmental disorders.

Future Implications of MRI Technology

The implications of this research for stutterers and non-stutterers alike are potent. By comparing the differences between these two groups of brains, we learn more about the neural structures, connections, and activity that facilitate language generally. The human brain is complex and there are still aspects of it that we do not completely understand. So, comparing normal and abnormal brains could reveal insights we might not currently have by only studying normal brains. For instance, the MRI scans illustrating how stutterers use different regions of the brain for speech function (Loucks, et al. 2011) could provide more information about the varying purposes and versatility of certain components of the brain. We also may gain more specific understanding about the anatomical basis of language ability. Hence, the MRI and fMRI scans in stuttering research can help us better understand the brain overall.

For stutterers, though, the future of MRI presents the possibility to predict which child stutterers will recover and which will not. The 2013 study identifying the particular neural network that was stronger in stuttering girls – who recover from stuttering more than boys do – could lead to progress in identification of more of these structures in stutterers using MRI. A possible implication is that it could lead to a misguided inclination to “fix” stuttering in favor of fluent speech. However, there are many cases, such as mine, where stuttering is permanent but manageable. It is true that I will never be able to speak in the same way as a fluent person and that speaking will always be more difficult for me. On the other hand, stuttering itself is not inherently bad. Instead, the negative perceptions of stuttering (Amick, et al. 2017) must be questioned, not stuttering itself. Some cases of stuttering – along with some cases of other neurodevelopmental disorders – do not need to be predicted or cured. Therefore, our society should critically examine the use of MRI technology as a diagnostic and predictive technology in the future.

For example, MRI could also lead to identifying neuroanatomical structures that indicate neurological traits, abnormalities, or disorders other than stuttering persistence. This could lead to attitudes that disadvantage or discriminate against neurologically atypical and disabled people in general. Moreover, this could contribute to a tendency to “correct” or “cure” neurological abnormalities. I believe this correctional impulse could present some serious ethical implications. In an ethical society, most would agree that the principles of pluralism, diversity, and tolerance should be valued. So, if a neurological abnormality such as autism, dyslexia, or stuttering is not detrimental enough to incapacitate an individual or significantly diminish her quality of life, then it should not necessarily be “cured.” Even though stuttering is at times debilitating and difficult, I would not have wished for my stutter to have been "cured." With my stutter, I am still productive, independent, and I have a good quality of life. However, social norms still cause hostility to difference and "abnormality." Screening and selecting for (or against) certain traits in embryos is already underway in certain parts of the world. Thus, a continued cultural and clinical shift toward pursuing biological "control" in the future is plausible.

As MRI's precise imaging capabilities become more advanced and accurate, so could scientists' ability to detect certain anatomical abnormalities. Ultimately, it may be difficult for advanced diagnostic technologies and a genuine tolerance of difference to coexist. Consequently, ableism and other forms of discrimination might increase. From a social and clinical perspective, in order to prevent this, our society should encourage compassion, respect, and inclusion for disabled and physically and mentally atypical individuals. In order to avoid this issue today and in the future, patients, scientists, and doctors must strive to use MRI and other diagnostic technology for the purpose of addressing the patient's clinical needs as a unique, inherently valuable individual. Perfecting the patient is not the end of medicine.

Ultimately, the possible implications of MRI are diverse and wide-ranging. There are certainly many applications and consequences of MRI that are unpredictable at this point in time. However, the available information about current clinical and medical use of MRI technology can alert us to some of the potential conflicts that might arise in the future. By focusing on a very specific application of MRI – stuttering research – I sought to demonstrate the ways in which MRI will impact me, the scientific community, the medical community, and society broadly. Also, my analysis of MRI in the context of stuttering research highlighted the unique nature of MRI technology. In other words, it revealed how the technology of MRI *itself* is responsible for advancements in science, medicine, and individuals' lives. Indeed, the stuttering research I described would not have been possible without MRI and fMRI technology. Lastly, evaluating a specific application of MRI also provides a sound basis for extrapolating future applications of the technology and the potential consequences of those applications. With a technology as versatile and complex as MRI, a narrow analytical scope can help us project ourselves into the future to gain a more comprehensive and accurate understanding of how MRI might change our world.

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