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How and when do fetuses gather enough brain matter to be considered capable of developing a sense of self?

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AUTHOR BIO

Ugurcan Buyurgan is a junior high school student in Springfield, Missouri, at Central High School, and has a strong passion for medicine, specifically neurology. Trinity Lee is an Interlake High School senior interested in neuroscience. Prabhat Majji has always enjoyed neuroscience and is a university sophomore. Elizabeth Szeto goes to Olentangy Liberty High School, and she is currently a Junior. Ethan Zhou is a junior at Bullis School in Maryland. The five students collaborated during the Leadership Initiative Summer Neuroscience Internship to write this paper, merging their passion for medicine and ethics to explore the concept of self in a fetus.

ABSTRACT

When addressing the issue of abortion rights, the debate eventually reaches a standstill that is ultimately dependent upon the specifics of a fetus's developmental journey to gaining self-awareness. Concerning the idea of the "self" and its separation from the concept of simple "existence", we pivot to neuroscience to explore its relevance to this issue before examining specific theories. The definition of the "self" can be described as having "sensory awareness of the body, the self, and the world" (Lagercrantz & Changeux, 2009), while existence is simply the continuation of survival. The sense of self is unique, as it is our individuality that is constantly evolving throughout one's lifetime with experiences. The question is whether those experiences start during gestation. However, to address this question, we must determine what exactly a "self" is and also determine the specifics of a fetus achieving a "self". As a result, we must also strive to discover how self-awareness is achieved, and when it is achieved in the gestational process. This article describes current progress concerning this topic and discoveries regarding the default mode network region's (DMN region) ability to generate our sense of self. However, as novelty is not infallible, it is necessary to acknowledge the limitations of the new information surrounding the DMN region. This study will lastly specifically appeal to the ethical, legal, and social implications that it will have on the controversy of abortion. Additionally, this paper will provide a broader discussion of the literature that situates neuroscience in the context of the abortion debate.

Keywords*: Abortion rights, Fetal development, Self-awareness, Neuroscience, Neuroethics, Default Mode Network (DMN), Consciousness, Fetal sensory experiences, Cognitive development, Ethical implications, Neuroimaging, Abortion debate*

INTRODUCTION

In June 2022, the Supreme Court of the United States overturned the longstanding ruling of Roe v. Wade (1973), a decision that enforced the right of access to abortions up until the fetus reached the third trimester. However, the reversal of the original Roe v. Wade ruling gave rise to the inevitable debate regarding the ethicality of the court's decision. Those who believe in maintaining access to abortion rights believe that it is always the decision of the expecting individual to assess whether they want to terminate their unborn child, let alone one that may not even have achieved full sentience. Conversely, those who argue against giving individuals the choice of abortion express concerns that ending a pregnancy is the equivalent of murder. As this discussion has only become an increasingly prevalent topic, it has also proven to be heavily investigable through the lens of neuroscience. Despite this, existing research has not fully explored the connection between fetal neuroscience and the ethical discourse on abortion, making this paper a crucial contribution. Although the idea of fetuses developing awareness has garnered widespread interest as a result of the overturning of Roe v. Wade, this research proposal will not only approach the idea of how and when fetuses gather enough brain matter to be capable of developing their sense of self but also underscore the applicability of such information in the greater scope of neuroethics, law, and society.

ESTABLISHING THE "SELF"

Before even directly addressing the specifics of a fetus's development journey to gaining self-consciousness, the "self" and its separation from the concept of simple "existence" must be clearly defined. This section will also incorporate a broader discussion of competing theories of self-awareness beyond the Global Workspace Theory. In this specific study, *The Ethical Brain*, by Michael Gazzaniga, will be used as the template for interpreting the concept of "self". Gazzaniga's perspective aligns with the Global Workspace Theory, which suggests that self-awareness emerges from the brain's extensive connectivity rather than a single localized region. However, alternative theories such as Integrated Information Theory (IIT) and Higher-Order Thought Theory (HOT) provide different frameworks for understanding consciousness. IIT posits that consciousness arises from the integration of information across the brain, while HOT suggests that self-awareness depends on the brain's ability to form higher-order representations of its cognitive states. Additionally, in this article, a sense of self will be viewed as having the ability to experience sensory stimulation and process this experience. This also ties back to *The Ethical Brain*, which states that experience makes up the brain, and in turn, our "self" is defined by that experience.

THE MECHANICS OF THE DEVELOPMENT OF A FETUS' SENSE OF "SELF"

Over the years, the question of *how* a fetus can achieve a "self" has been heavily investigated. As we analyze the logistics behind this process, Gazzaniga's definition of the "self" can be employed along with his general assessment of the fetus during the gestational stages. Gazzaniga seems to associate with the Global Workspace Theory, which states that one specific part of the brain is not responsible for the "self", but rather all four lobes, as shown in his firm statement that the vast connectivity and interactiveness of the brain make up who we are. However, alternative models, such as Integrated Information Theory and Higher-Order Thought Theory, also offer insights into the nature of self-awareness, and their implications for fetal development should be considered. At the stage when the corpus callosum, a large bundle of fibers that allows for communication between the two hemispheres of the brain, has begun to develop, Gazzaniga states that at this point, the fetus is not yet sentient, nor self-aware. It does not have a "sense of self" yet. Instead, the fetus can be described as a slug, "a writhing, reflex-bound hunk of sensory-motor processes that do not respond to anything in a directed, purposeful way" (Gazzaniga, 2005). By the time

the sensory systems start to develop, the fetus can experience stimuli such as pain, internal and external sounds, pressure, and heat, and can respond non-reflexively (Fagard, Esseily, Jacquey, O'Regan, & Somogyi, 2018). Experiences are not necessarily defined by language, sociality, or physical incidents. Exposure to different stimuli is an experience. For instance, look at a child who has gone through the basic developmental stages and their reaction to darkness. Upon experiencing the sensation of being in an environment without any light, the child formulates a unique reaction to the visual stimulus, such as crying out of fear. This unique response can be evaluated alongside the responses of fetuses to similar stimuli. As fetuses form individualized reactions to stimuli similar to those of a child with an already developed sense of "self", such as moving around in the uterus, it can be inferred that exposure to sensory stimuli is a processable experience. This ties into the sense of self, as a fetus's sensory experiences allow for their brains to develop, relating to Gazzaniga's idea of the "self". As a result, a fetus can process sensory experiences and therefore has self-developed these very experiences.

However, a recent experiment conducted in 2023 opened the possibility of attributing the source of the "self" to a certain part of the brain: the DMN region. Dr. Josef Parvizi, the director of the Stanford Program for Medication-Resistant Epilepsies and the principal investigator in the Laboratory of Behavioral and Cognitive Neuroscience, conducted a study by stimulating different areas of the brain using high-frequency pulses to demonstrate where dissociative changes in physical and spatial domains originate. While conducting his research, Dr. Parvizi discovered a correlation between different parts of the brain and our bodily and narrative selves. As a result, Dr. Parvizi was able to conclude that while the anterior precuneus (aPCu) is responsible for our physical "self", due to evidence of subjects experiencing dissociation and out-of-body experiences when the aPCu was stimulated, the DMN region was generally responsible for our narrative sense of self.

LIMITATIONS AND NEUROTECHNOLOGICAL METHODS

It is clear that self-consciousness is the product of different networks and regions of the brain working together, but it is also acknowledged that the DMN region is the main contributor to achieving consciousness. The DMN region, or the default mode network region, is regarded as one of the most important regions of the brain, and it forms the narrative sense of self. The DMN isn't just related to self-consciousness but also consists of areas of the brain that are typically more active during rest than during an active performance task.

In Dr. Parvizi's study regarding the DMN region, the patients tested already had a developed sense of self due to their experiences throughout life, making them different from fetuses. Does this mean that the same results apply in this situation? There are two possibilities: the fetus' encounters with sensory stimulation can also be considered as life experiences, therefore allowing us to simply track when the DMN region develops in the fetus' brain develops and deduce that its creation is the development of fetal self-awareness, or the fetus' experiences simply are not enough in comparison with the subjects of Dr. Parvizi's study to allow the results of his research to apply to fetuses. If we consider Dr. Parvizi's research applicable to fetuses, fMRI can prove to be the technology that can help us pinpoint when in the gestational process a fetus gains "self". fMRIs have been proven capable of reading pre- and postnatal brain activity, so if the sensory stimuli that a fetus receives proves to be enough experience, allowing us to apply Dr. Parvizi's findings to fetuses, we can use fMRIs to assess when they gain a sense of self. Since it must be taken into consideration both the sensory experiences of the fetuses and also the development of their DMN region to pinpoint when they form a "self", we can automatically assess that the narrative self cannot manifest before the 24th gestational week when the thalamocortical connections are created because this part of the brain relays sensory and motor

information, creating experiences for the fetus. However, there are also limitations to the applications of Dr. Parvizi's research. From the very beginning of this article, the established principle has been the idea that experiences shape the brain, and since the brain as a whole contributes to our sense of "self", our experiences eventually develop and form what we perceive as the "self".

The possible inapplicability of Dr. Parvizi's results can ultimately cast doubt on the idea that our experiences create individual "selves". In the specific experiment that Dr. Parvizi performed, he applied electrical stimuli to patients that have passed the basic developmental stages. However, in the case of the fetus, *it*, despite being able to undergo experiences, has only been subject to the most rudimentary of experiences. This leaves the uncertainty of whether the underdevelopment of the fetus in establishing self-awareness can prevent Dr. Parvizi's research from being equally applicable to fetuses.

However, whether or not the results of Dr. Parvizi's research apply to fetuses, neither of the two possibilities addresses the limitation of determining whether the DMN or experiences are mainly responsible for generating self-awareness. In his study, Dr. Parvizi addresses that the DMN was specifically responsible for our "narrative selves" (Correa et al., 2023). However, it can arguably be said that the subjects he employed have already fully developed a sense of self due to the number and diversity of their experiences, and that the DMN simply maintains this "self", therefore provoking a response when electrically stimulated. As a result, the consequence is a classic chicken-and-egg dilemma. We must address whether it is the DMN that maintains who we are by relying upon our experiences that generate our "self", or if the DMN automatically generates a covert consciousness as soon as it develops, with the experiences acting as a crutch that helps our sense of "self" becomes more refined over time.

Besides this uncertainty, another limitation lies within the actual determination of what the "self" is. As this study established its definition of "self" using *The Ethical Brain* as a template, the possibilities and limitations that have been addressed are centered around this very doctrine. However, it must be acknowledged that the true definition of "self" relies on the consensus of what people view as having achieved a sense of awareness, especially when applying such information in reality to influence situations such as the abortion debate.

ETHICAL, LEGAL, AND SOCIAL IMPLICATIONS

The challenge arises when we pose the question of whether discovering the existence and development of a "self" is even necessary. After all, regardless of having self-awareness, is it within our moral code to protect all life, even if it has no perception of itself and its existence? It may seem that the question of whether the difference between mere existence and a "self" is too uncertain a boundary for human morality to be able to determine the fate of unborn infants. More ethical concerns arise when considering procedures that could potentially impact the sense of self or alter the trajectory of the fetus's consciousness. What if the fetus's brain is not fully developed? Do we still consider this baby to have a self? Is it still deemed worth saving? From a legal standpoint, being able to determine when a fetus gains self-awareness may be very well employed in the laws that govern us. Discovering when a fetus gains the concept of "self" is critical, as it may fully modify the abortion restrictions currently in place. Knowing when and if self is gained in the fetus may show that abortion is ethical to a certain point before the fetus has a sense of self. This knowledge has the potential to influence the political perspectives of countries and states, particularly within the U.S., leading to shifts in their stance on abortion. Determining a consensus on what "self" is in the broader scope of the public has the potential to cause more division in our society, pushing the debate on abortion rights to further discourse. However, if we can prove the presence of the

self in a fetus and when it develops through neuroscience and professionally conducted experiments into the mix, the irrefutability of factual science may become the foundation that allows society to come to a consensus about the ethicality of abortion. These ethical dilemmas must be thoroughly addressed if and when the self can be identified. In the end, what we really must determine for ourselves is whether we can imagine living in a society where the blurred line between a fetus simply "existing" and living with a developed concept of "self" is the defining factor of not only what we do to our bodies, but also the possible futures of the fetuses.

FUTURE WORK

In the future, fetal magnetoencephalography (fMEG) could be the key to prepartum fetal cognitive monitoring. The activity of all brain cells naturally produces electricity, which in turn produces magnetic fields. A MEG machine detects minute changes in these magnetic fields and reports changes back (Sheridan et al., 2010). MEG is a rapidly advancing technology, with many leaps having been made since 1972 when it was invented by physicist David Cohen. At the time, he was simply theorizing the existence of these magnetic fields in active tissues such as the brain, however, he quickly realized the validity of his theory after the invention of the SQUID device (superconducting quantum interference device): a highly sensitive magnetometer (Doherty, 2014). Today, there are a few dozen MEG sites around the world, one of which is located at MIT. The site has a thirteen-ton shield to block background magnetic field noise and contains more than 306 SQUID detectors in a helmet that sits on a patient's head as they are being scanned. The recorded data is then processed by a machine learning classifier that learns to recognize patterns in brain activity (Doherty, 2014).

At the moment, the University of Arkansas is the first medical center to adopt this technology for fetuses. fMEG is the sole existing non-invasive method for investigating evoked fetal brain responses and spontaneous brain activity. Utilizing the technology of previous MEG machines, SARA (superconducting quantum interference device array for reproductive assessment) is a unique device developed by the University of Arkansas that works when the pregnant person sits under a shield covering their abdomen for a maximum of about 30 minutes while more than 100 sensors collect data from both the fetus and uterus. This data can tell us how the fetus responds to certain stimuli, general brain activity, and more. This process is similar to the SQUID machine (UAMS Department of Obstetrics and Gynecology, n.d.) process.

This technology concerning fetal life is incredibly new and unexplored. The possibilities of fMEG technology with sufficient refinement are endless, especially considering the lack of other non-invasive prenatal assessments for cognitive development. At the moment, some of the drawbacks of this technology include the difficulty of blocking out background magnetic "noise", the short period a pregnant individual can be scanned for at one time, as well as determining the source in the brain of any recordings received by the machines (Sheridan et al., 2010). Should these issues be resolved in the future and fMEG machines become more researched and prevalent, not only could pregnancies become safer for the mother and the fetus through the prevention of medical emergencies, but they could also help us know exactly when certain parts of the brain become active in a fetus. Eventually, with check-ins similar to an ultrasound, we could see when and how prepartum brains begin to respond to stimuli, as well as when regions of the brain, such as the DMN, start producing magnetic fields from activity. As a result, fMEG technology has the potential to change our understanding of cognitive development before birth. Of course, however, neuroscience is developing every day, and we can only speculate the lengths to which our current technology will take us.

CONCLUSION

Abortion is a very sensitive and prevalent topic with many layers. One majorly disputed topic is the fetus's sense of self. Using neuroscience, we can use technologies such as fMRI, EEG, and fMEG to measure various factors and variables that can hint at fetal "self" or consciousness. However, these technologies can help us in assessing only when we have developed what we see as a "self". Additionally, many ethical, legal, and social implications are considered.

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