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Prefrontal Cortex and Limbic System Abnormalities in Pedophilic Disorder: A Review

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Abstract

Social stigma surrounding pedophilic disorder has restricted progress on research and prevented those suffering from the disorder from coming forward to receive help. Not all with the disorder go on to abuse children and of course, no one is born wanting to be a pedophile. It is important to understand why these reoccurring sexual fantasies involving children might occur, if there is abnormal brain functioning involved, and how these fantasies can be alleviated. Brain injury case studies, sexual stimuli reaction studies, and investigations into the structural and functional connectivity of the brains of pedophiles all show abnormal functioning within and between the prefrontal cortex and limbic structures. This indicates that irregular connections between brain regions involved in emotion, stimulus association, and impulse control are at work. With both more general research and brain research done on pedophilic disorder, important information can be provided to the public, reducing stigma, and more specialized treatments can be developed.

Prefrontal Cortex and Limbic System Abnormalities in Pedophilic Disorder: A Review

Pedophilic disorder is a paraphilia involving recurrent sexual interests in prepubescent children through persistent thoughts, fantasies, urges, and behaviors (American Psychiatric Association, 2013). While extensive research exists on child sexual abuse from the victim's point of view (e.g., Beach et al., 2013), research on perpetrators of child sexual abuse is not as common. Access to those exhibiting compulsive sexual behavior, especially those with pedophilic tendencies, is mostly limited to prisoners with histories of offending and fails to include non-offending pedophiles (e.g., Walter et al., 2007). Not everyone with pedophilic disorder goes on to offend. Many affected by the disorder do not seek help because of shame and stigma, ultimately leading many down the path of addiction, anxiety, depression, self-harm, and suicide (Stevens & Wood, 2019). Successful treatments cannot be developed until those suffering feel able to come forward.

Further research on this disorder can promote helpful resources and erase harmful stigma. Research investigating the brains of those with pedophilic disorder who have and have not offended can open the door to understanding possible underlying neurobiological mechanisms involved. Because there is almost no research

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available on non-offending pedophiles, this review focuses on brain abnormalities found in offending pedophiles. This means information found could be associated with pedophilic offending status rather than the actual disorder, though more research must be done to investigate this.

Irregular activation of certain regions of the prefrontal cortex and limbic system are seen in studies on pedophilic offenders (Habermeyer et al., 2013; Schiffer et al., 2008; Walter et al., 2007). These brain regions are involved in impulse control and emotional-behavioral responses, respectively (Braun, 2011; Hunt et al., 2015; Rolls, 2004). Altered activation in these regions contributes to faulty stimulus-outcome evaluations, resulting in irregular spatial and sexual maintenance when choosing proper actions (Hornak et al., 2004; Klein et al., 2020; Leon-Carrion et al., 2007). These faulty outcome evaluations show connections to child sexual offending and the association of children with sexual gratification (e.g., Habermeyer et al., 2013). Irregular activation in pedophilic offenders is associated with dysfunction in structural and functional connectivity also found in regions connecting the prefrontal cortex and limbic system (Cantor & Blanchard, 2012; Kärgel et al., 2015; Poeppl et al., 2013, 2015; Sartorius et al., 2008). Through improper connections in these areas, necessary brain regions involved in emotional and behavioral responses and impulse control may not communicate properly, leading to pedophilic offending.

This review will first explore several brain injury and brain tumor case studies indicating brain regions associated with the development of pedophilic tendencies in those previously unaffected. Next, the functions of regions seemingly involved in pedophilic disorder, including the dorsolateral and orbitofrontal regions of the prefrontal cortex and the amygdala of the limbic system will be observed. Lastly, directions for future research, as well as study limitations will be explored. By better understanding the underlying brain mechanisms involved in pedophilic disorder, better treatments can arise, stigma can reduce, and proper assistance can be provided to those affected.

Developed Pedophilic Tendencies in Patients with Frontal Lobe Brain Injuries

There are several case studies showing brain injury and brain tumor patients developing pedophilic tendencies after brain injury or before tumor removal (Alnemari et al., 2016; Burns & Swerdlow, 2003; Fumagalli et al., 2015; Gilbert & Vranič, 2015). Almost all known occurrences have involved areas of the prefrontal cortex, a region involved in complex social behavior (Braun, 2011). It is likely the general areas of the prefrontal cortex disturbed in these case studies are connected to sexual responses through their connection to other limbic structures in charge of emotions and behavioral responses (Braun, 2011; Burns & Swerdlow, 2003). Abnormalities in the orbitofrontal and dorsolateral regions of the prefrontal cortex and limbic structures like the amygdala have been found in other research on the disorder (e.g., Schiffer et al., 2008). These regions are involved in impulse control and conscious regulation of sexual urges (Burns & Swerdlow, 2003). However, not all changed sexual behavior stems from prefrontal damage, so it is possible pathways specific to pedophilic disorder exist between the prefrontal cortex, limbic structures, and other areas (Alnemari et al., 2016). Examining case studies associating some of these brain regions with pedophilic tendencies can provide insight into possible areas involved. It is important to note that case studies tend to be

ungeneralizable to the public. However, the multitude of these occurrences shows promise in supporting a brain-basis to pedophilic disorder.

Brain Injury Case Studies

Case Study 1

A 40-year-old man was diagnosed with a right orbitofrontal tumor (Burns & Swerdlow, 2003). He was always interested in adult pornography but never sought out sexual favors. With the tumor present, he started collecting child-specific pornography and began molesting his prepubescent stepdaughter even when, in hindsight, he stated he knew it was inappropriate. The tumor was removed, and his impulses stopped. Several months later, he began collecting child pornography again. New brain scans showed that his right orbitofrontal tumor had regrown. This shows an irregular association with child-specific pornography and impulsive behavior during the presentation of the prefrontal cortex tumor.

Case Study 2

A 48-year-old man was incarcerated due to a pedophilic offense (Gilbert & Vranič, 2015). Two years later, he was diagnosed with a left prefrontal cortex tumor. After tumor removal, the pedophilic tendencies diminished. Developed pedophilia during tumor obstruction and diminished pedophilic tendencies after tumor removal suggest the prefrontal cortex has a strong connection to pedophilic disorder.

Case Study 3

A patient with an extensive lesion in areas of the prefrontal cortex and possibly the amygdala developed pedophilic tendencies 31 years after the brain injury (Fumagalli et al., 2015). Because the tendencies started happening 31 years after damage to an unspecified prefrontal area, the researchers suggest age-related changes through deteriorated inhibitory white matter pathways between the prefrontal cortex and limbic structures may have contributed to developed pedophilia.

Case Study 4

A patient with softening and loss of brain tissue in the prefrontal cortex following brain injury developed hypersexuality and a sexual preference for young children (Alnemari et al., 2016). Diminished brain tissue in the prefrontal cortex suggests interference in connectivity and informational transfer, possibly contributing to the development of pedophilic tendencies.

Relevance of Brain Injury Case Studies

These case studies showing developed pedophilic tendencies from prefrontal tumors and brain damage suggest that brain abnormalities in this area are associated with pedophilic disorder. However, the case studies mentioned do not define specific regions of the prefrontal cortex that are affected. This still leaves a broad range of potential target regions for future research to investigate. Luckily, other studies on the disorder point towards more specific regions of the prefrontal cortex that show abnormalities such as the orbitofrontal and dorsolateral prefrontal cortices (e.g., Habermeyer et al., 2013).

The Prefrontal Cortex

The prefrontal cortex involves stimulus-outcome association and reversal and shows importance in working memory functions (Rolls, 2004). Stimulus-outcome association occurs when the brain makes a connection between a stimulus and an outcome, whereas reversal involves relearning a new outcome for that stimulus. The prefrontal cortex receives input from many brain regions including the amygdala, a region in the limbic system involved in emotional responses (Rolls, 2004). The prefrontal cortex acts as a bridge between emotions and complex behaviors involved in social situations, which can be quite

important when studying offending pedophiles (Braun et al., 2011). Though the prefrontal cortex is divided into multiple regions, those that show the most involvement in pedophilic disorder are the orbitofrontal cortex and the dorsolateral prefrontal cortex (e.g., Schiffer et al., 2008; Walter et al., 2007).

The Orbitofrontal Cortex

A prominent function of the orbitofrontal cortex (OFC) (see Appendix A) is visual stimulus-outcome association and reversal (Rolls, 2004). When exposed to a reward paired with a stimulus, that stimulus arouses thoughts of reward when it is presented. Stimulus-outcome reversal comes into play when the visual stimulus no longer plays a reinforcing role and should no longer be associated with reward. This can happen through reassociation with punishment or a failure to produce reward when the stimulus arises. The OFC's job is to code all stimulus-outcome associations and send them to the dorsolateral prefrontal cortex and other regions to be evaluated for proper actions. Pedophilic patients' preferred sexual stimuli are children rather than adults. With increased OFC activation found in offending pedophiles when viewing pictures of children, irregularity in both stimulus-outcome association and stimulus-outcome reversal may be taking place somewhere along the way (e.g., Schiffer et al., 2008).

Damage or irregularity in regions of the OFC disrupts stimulus-outcome reversal, leading one to continue to associate a certain stimulus with negative or positive reinforcement even when their experience shows them otherwise (Hornak et al., 2004; Rolls, 2004). Patients with bilateral OFC damage fail to reverse their conditioned stimulus choice after outcome reversal (Hornak et al., 2004). That is, even when a stimulus is flipped to receive monetary loss rather than reward, patients continue to choose that stimulus, even when they note that monetary gain is the most important factor in their choices. This shows that those with impairments to the OFC have trouble coding stimulus-outcome associations, leading to irrational choices (Hornak et al., 2004). In the case of pedophilic offending, irrational choices can be detrimental. Interestingly, research on OFC activation in those with pedophilic disorder shows varying results with some finding increased and some finding decreased activation in both healthy controls and pedophilic participants.

The OFC, Sexual Stimuli, and Pedophilic Offenders

OFC activation is positively correlated with individual subjective ratings of sexual stimuli in healthy individuals (Klein et al., 2020; Ruesink & Georgiadis, 2017; Schiffer et al., 2008) and those with pedophilic disorder or compulsive sexual behavior (Habermeyer et al., 2013; Klein et al., 2020). Stronger differentiation in OFC activity between sexually preferred and non-preferred clips is also seen in non-pedophilic individuals with stronger problematic pornography use (PPU) (Klein et al., 2020). This indicates that reward valuation information is coded in the OFC in association with preferred sexual stimuli in both healthy and sexually compulsive individuals. However, stronger OFC activation with higher sexual arousal ratings in sexually compulsive compared to non-compulsive individuals furthers the proposal that reward valuation in the OFC plays an important role in impulse control as well (Klein et al., 2020).

A study by Habermeyer et al. (2013) found similar increases in OFC activation in pedophiles when exposed to child versus adult stimuli. Pictures of male and female children and adults were quickly shown while brain activity was recorded. Because all pedophilic participants were

heterosexual males, specific strong activation in the OFC was only found when exposed to pictures of prepubescent girls, whereas all other picture categories for both pedophilic and healthy participants showed deactivation of the lateral OFC (Habermeyer et al., 2013). This deactivation in controls is interesting because OFC activation in healthy controls has been consistently found in relation to sexually preferred stimuli (Ruesink & Georgiadis, 2017).

A similar study by Schiffer et al. (2008) found that, while brain responses were comparable, OFC activation to both adult and child sexual stimuli was significantly greater in controls compared to those with pedophilic disorder (Habermeyer et al., 2013). When exposed to both adult sexual stimuli and child stimuli, deactivation in the OFC, DLPFC, and other prefrontal regions was negatively correlated with their Child Molest Scale ratings. This means the lower their brain activation is in these areas when exposed to sexual stimuli in any condition, the higher their child molestation tendencies tended to be. This differs from the increased OFC activation found in pedophilic offenders in Habermeyer et al.'s (2013) study. Pictures were presented for a longer duration in Schiffer et al.'s (2008) study which could have affected brain regions activated in both studies due to prolonged or shortened processing opportunities. This may explain some variability in findings, though, future research should involve replicating these findings and exploring this anomaly.

Of course, sexual-stimuli studies involving pictures of children like these must undergo ethical considerations. Child pornography is unacceptable and it is unrealistic to ask for parents' consent to show pictures of their partially clothed children. Instead, digitally created images of children would allow for more ethical research. Only with these considerations should this research be allowed to take place.

These studies show a tendency for abnormal activation in the OFC when exposed to a sexual stimulus of choice in both controls and those with pedophilic disorder. However, healthy individuals have been shown to have increased OFC activation in relation to their preferred sexual stimuli (Ruesink & Georgiadis, 2017). Errors may have contributed to these variations, but pedophilic participants' responses seem to be wired towards preferred children whether it is through OFC activation or deactivation in association with ratings on the Child Molest Scale (Habermeyer et al., 2013; Schiffer et al., 2008). While many with pedophilic disorder understand and acknowledge that their tendencies are unacceptable, they still cannot refrain from sexual attraction to children (Stevens & Wood, 2019). Irregularity in the OFC points towards potential abnormalities in stimulus-outcome coding between thoughts of reward or arousal and children (e.g., Hornak et al., 2004). With further research on both healthy individuals and those with pedophilic disorder, OFC activity can be better understood.

The Dorsolateral Prefrontal Cortex

Through the OFC's connections to the dorsolateral prefrontal cortex (DLPFC) (see Appendix A), irregularity in OFC stimulus-outcome coding contributes to the choosing of irrational actions, creating impulsive behavior, and potentially contributing to child offense (e.g., Rolls, 2004; Hunt et al., 2015). The DLPFC and OFC seem to work together in choosing proper actions in response to visual stimuli (Hunt et al., 2015). The DLPFC region of the prefrontal cortex is involved in spatial short-term memory which involves the continuous firing of somatosensory and visual neurons indicating constant monitoring

and updating during the exposure of a stimulus (Rolls, 2004). This differs from the OFC which has fast reward association due to synaptic plasticity and neuronal strengthening (Rolls, 2004). The DLPFC's continuous firing contributes to the maintenance of spatial memory responses which means it is constantly receiving new information about the world around it through visual stimuli (Rolls, 2004). However, it also uses information from the OFC to flip through stimulus-outcome associations and choose proper responses (Hunt et al., 2015). With damage to the DLPFC, patients are unable to determine which stimuli are important or unimportant, making it hard to choose how and when to act on relevant stimuli (Hornak et al., 2013). In the case of offending pedophiles, these important choices are necessary for preventing offense.

Patients with DLPFC lesions generally perform worse on stimulus-outcome reversal tasks than healthy controls (Hornak et al., 2004). Unlike OFC lesioned patients who failed to associate old stimuli with new outcomes, Hornak et al.'s (2004) study found DLPFC lesioned patients had irregular selective attention to important information about monetary gain or loss during the task. Interestingly, a post-test questionnaire revealed that most individuals with this lesion did not even consider money to be an important motivator, whereas OFC lesioned participants still rated the money won or lost as the most important motivator, though they did not seem to connect this to stimuli while choosing options. This suggests that stimulus-outcome coding from the OFC plays a role in directing DLPFC attention to important stimuli and choosing proper actions. Because attentional direction depends on individual differences, some DLPFC patients did pay attention to the important information and were able to switch their chosen stimuli based on new reinforcement. In pedophilic offenders, deactivation of the DLPFC while viewing sexual stimuli provides evidence that impulsive sexual choices are taking place (Schiffer et al., 2008; Walter et al., 2007).

The DLPFC, Sexual Stimuli, and Pedophilic Offenders

Healthy males show increases in DLPFC activation during and after exposure to erotic films (Leon-Carrion et al., 2007). A study by Leon-Carrion et al. (2007) found that, while viewing erotic clips, DLPFC activity in healthy males showed a rapid ascendant overshoot which became even stronger right after the clips disappeared. A strong undershoot was seen directly after viewing non-sexual clips. This shows the DLPFC is still processing information after exposure to specifically sexual stimuli and not non-sexual stimuli. The researchers suggest that interest in sexual stimuli plays a secondary role in the self-regulation of DLPFC activity. DLPFC activation maintains a representation of sexual stimuli after exposure, contributing to action, but not physical excitation (Leon-Carrion et al., 2007).

Unlike healthy males, males with pedophilic disorder show deactivation in the left DLPFC when exposed to both child and adult sexual stimuli (Schiffer et al., 2008; Walter et al., 2007). While both controls and pedophiles report higher sexual and emotional arousal for erotic pictures compared to non-erotic emotional pictures, those with pedophilic disorder show much lower signal intensity in the DLPFC, amygdala, and other regions while viewing adult sexual stimuli compared to controls (Walter et al., 2007). Deactivation of the DLPFC in these patients was shown only following erotic adult pictures and not neutral or emotional. The lower the DLPFC activation while viewing erotic adult stimuli, the

higher the pedophilic patients tended to score on measures of child offense tendencies.

Interestingly, Schiffer et al.'s (2008) study showed this same correlation between pedophilic offending and deactivation of the DLPFC while viewing their preferred stimuli. However, one difference was found in this study: those with pedophilic disorder also showed overactivation in the right DLPFC while viewing preferred sexual stimuli with only the left DLPFC deactivation pertaining to risk of offense. Surprisingly, these same activation patterns occur in individuals with depression and are associated with biased attention to negative stimuli with the inability to disengage (Disner et al., 2011). These activation patterns may reveal similar attention and reaction biases in pedophilic offenders in association with their negative stimuli (children), though more research must be done to explore this phenomenon.

The Prefrontal Cortex and Pedophilic Offenders

The patterns seen in the orbitofrontal and dorsolateral regions of the prefrontal cortex suggest the two work together (Hornak et al., 2013). Irregular activation in both regions points toward deficits in impulse control in those with pedophilic disorder (e.g., Rolls, 2004). Based on what is known of these regions, irregular OFC activation in pedophiles suggests irregular stimulus-outcome coding between children and sexual gratification (e.g., Habermeyer et al., 2013). In conjunction, decreased activity in the left DLPFC in accordance with both adult and child stimuli paired with increased right DLPFC activity only following preferred child stimuli indicates biases toward negative or arousing stimuli (children) (Disner et al., 2011). Decreased valence and uninterest towards adult sexual stimuli is also seen through deactivation of the left DLPFC (e.g., Disner et al., 2011; Walter et al., 2007). Overall, the DLPFC seems to play a role in attentional biases and proper response choices in pedophilic offenders.

Consciously choosing the proper responses to arousing stimuli can help prevent impulsive offending in those with pedophilic disorder. Though not all with the disorder commit crimes against children, more research on the prefrontal cortex's involvement is crucial in understanding why some act on their urges. It is necessary to note that many who are suffering from pedophilic disorder do not come forward. Therefore, almost all research is done on offending pedophilic patients from prisons or inpatient facilities rather than non-offending individuals. This can make it hard to associate brain regions with pedophilic disorder rather than just pedophilic offending. The prefrontal cortex seems to be dominant in coding and action over sexual excitation, which suggests that these irregularities in the prefrontal cortex are associated more with offending status than the presence of the disorder (e.g., Braun, 2011). However, these prefrontal regions are also connected to the limbic system, a system partly in charge of sexual pleasure. Exploring these connections in those with the disorder will reveal information about the relationship between impulsive behavior and sexual response.

The Limbic System

The limbic system (see Appendix A) is a large system including the amygdala and other cortical and subcortical regions (Braun, 2011). It is in charge of generating, integrating, and controlling a wide range of emotions and tying them to behavioral responses. Proper connections are crucial to learning and memory functions (Braun, 2011). Though brain research on pedophilic disorder shows variability in findings, a common limbic structure that shows activation and dysfunctional connectivity with the prefrontal

cortex is the amygdala (Cantor & Blanchard, 2012; Kärgel et al., 2015; Poeppl et al., 2013, 2015; Sartorius et al., 2008). The amygdala is the hub of aggression, fear, and other emotional responses in the brain and is directly connected to the OFC with indirect connections to the DLPFC (Braun, 2011). Alterations in functional connectivity between these areas manipulate input being received and sent, which affects outcomes in behavior and cognitive processes (Cantor & Blanchard, 2012; Kärgel et al., 2015; Poeppl et al., 2015). In pedophilic disorder, improper emotional information transferred between the amygdala, OFC, and DLPFC contribute to improper stimulus-outcome coding in the OFC, and therefore, improper recollection and action choices in the DLPFC (e.g., Poeppl et al., 2015). Though more research must be done, these connections between the prefrontal cortex and limbic system may contribute to the development of the disorder.

The Amygdala

The amygdala (see Appendix A) is connected to the prefrontal cortex and other areas of the brain (Braun, 2011). Its main role is control and regulation of emotions, especially fear, aggression, and reward sensations. Lesions or damage to the amygdala can diminish fear responses and aggressive behavior, while excitation can increase these responses (Braun, 2011). Studies looking at amygdala activation in pedophilic participants, compared to controls, have found increased amygdala activity in association with child stimuli and irregular functional connectivity between the amygdala and the prefrontal cortex (Cantor & Blanchard, 2012; Kärgel et al., 2015; Poeppl et al., 2013, 2015; Sartorius et al., 2008). Irregular functional connectivity suggests dysfunction in informational transfer between these brain regions, leading to disturbed arousal and emotional coding in the OFC and DLFPC after exposure to child stimuli.

The Amygdala, Sexual Stimuli, and Pedophilic Offenders

Activation patterns of the amygdala seem to be similar for both pedophilic participants and controls while viewing adult sexual stimuli; however, activation while viewing children is much higher in those with pedophilic disorder (Sartorius et al., 2008). Increased amygdala activation when viewing child sexual stimuli instead of adult stimuli could mean a few things. Sartorius et al. (2008) hypothesize that because the amygdala is involved in fear-specific facial cues, increased activation could show evidence for children-specific facial cue tuning in pedophilic patients. Amygdala activity could also indicate a combination of fear and sexual arousal when viewing children as sexual stimuli because the amygdala involves both. Lastly, increased activation could indicate a generally higher response to sexually salient stimuli, though this has not been found in the scarce amount of research available (Sartorius et al., 2008).

Though the OFC, DLPFC, and amygdala in pedophilic patients all show areas of activation, irregular connections between these areas can alter crucial information delivery (e.g., Braun, 2011). Dysfunctional connectivity or brain matter deficiencies between the prefrontal cortex and amygdala decrease the prefrontal cortex's ability to balance amygdala activity (e.g., Braun, 2011). Because increased amygdala activation creates a push for increased sexual and aggressive responses to motivational stimuli, improper wiring to regions of the prefrontal cortex, indicative of maintaining representations of sexual stimuli and stimulus-outcome reversal (i.e. the OFC and DLPFC), mean altered responses and reward-association to certain sexual stimuli (Braun, 2011).

Structural Abnormalities in Pedophilic

Offenders

Of the few studies available on the brain volume of individuals with pedophilic disorder, many show decreased grey matter volumes in the amygdala, OFC, DLPFC, and other regions (e.g., Poeppl et al., 2013). Grey brain matter mainly consists of neuronal cell bodies and dendrites with decreases in volume indicating decreases in neurons. Interestingly, correlations were found between grey matter reductions in the OFC and DLPFC and phenotypic characteristics associated with the pedophilic disorder (Poeppl et al., 2013). Stronger pedophilic fixation was found to be correlated with decreased grey matter in the left DLPFC. This is not surprising considering the DLPFC is involved in maintenance of and attention toward sexual stimuli, so irregularities in this area lead to more irrational activity (e.g., Hornak et al., 2004). Grey matter reduction in the OFC was correlated with lower sexual age preference, supporting the finding that the OFC assists with the coding of stimuli association and reversal (Hornak et al., 2004; Poeppl et al., 2013). Deficiencies in the grey matter of the right amygdala were also found but did not correlate with these characteristics. This suggests amygdala volume deficits are not the direct cause of sexual desire for children, but they increase the risk for developing pedophilic disorder (Poeppl et al., 2013).

Volume deficits in white matter regions connecting areas of the prefrontal cortex and limbic system have also been found in the brains of those with pedophilic disorder (Cantor & Blanchard, 2012). White brain matter consists of neuronal axons, the extensive strands that send connections to other neurons across the brain. White matter volume deficits affect the efficiency of informational transfer between brain regions and the integrity of the information. In Cantor and Blanchard's (2012) study they found that white matter regions connecting the prefrontal cortex and limbic system showed the lowest volumes in pedophiles, with volume increases positively correlated with sexual age preference. Because of this, Cantor and Blanchard believe white matter could be related to "pedophilia itself" while grey matter may be related to "propensity to break the law" or sexual offending, though more research must be done on the subject (Cantor & Blanchard, 2012). With decreased white and grey matter volumes within and between the prefrontal cortex and limbic system, it is also expected that functional connectivity between these regions is affected in pedophilic disorder.

Functional Connectivity Abnormalities in Pedophilic Offenders

Abnormal functional connectivity between the prefrontal cortex and limbic structures has been recorded (Kärgel et al., 2015; Poeppl et al., 2015). Functional connectivity (FC) is a measurement of how correlated the activation is between and within certain brain regions while at rest or while doing a task (Ryan Webler, personal communication, December 11, 2020). Another way to think of this is how well brain regions communicate with each other under certain circumstances. Decreased FC between regions implies decreased communication.

In a meta-analytical study on potential task-based FC in pedophilic offenders, possible alterations in FC were found between critical regions involved in healthy sexual stimuli processing such as the amygdala and DLPFC (Poeppl et al., 2015). When FC studies are "task-based", this means brain responses are being recorded while the subject is completing a task. Because the amygdala is involved with processing emotion, the researchers suggest that altered connectivity between the DLPFC and the amygdala contributes to irregular emotional evaluation of sexual characteristics (Poeppl et al., 2015). This

would lead the DLPFC to misclassify stimuli (children) as sexual. The OFC, on the other hand, was found to be more involved with response inhibition than sexual functioning, but it still showed FC alterations in pedophilic disorder (Poeppl et al., 2015). This indicates that the amygdala, DLPFC, and OFC work together in pedophilic disorder, and irregularities in one individual region do not directly contribute to the disorder as a whole. However, irregular FC between them promotes the development of the disorder or offending tendencies.

Further research has continued to find alterations between these areas of the prefrontal cortex and amygdala in both offending and non-offending pedophiles (Kärgel et al., 2015). Resting-state functional connectivity (RSFC) of offending and non-offending pedophilic participants seems to be diminished between the left amygdala, OFC, and other prefrontal regions (Kärgel et al., 2015). However, the effects were most extreme in pedophiles with offending status, while those without offending status showed more RSFC, and controls showed the most. Like Poeppl's (2015) FC study, this indicates a connection between offending and FC between these regions.

As mentioned, almost all studies on pedophilic disorder involve offending patients, but Kärgel et al.'s (2015) study includes those with no background of offending. The differences in RSFC between these regions in those with and without a background of offending further emphasize the importance of separating offending from non-offending pedophiles when studying FC as well as other abnormalities in the disorder.

Conclusion

Though there is limited research, promising data shows brain abnormalities in pedophilic patients with and without a history of offending (e.g., Gilbert & Vranič, 2015; Kärgel et al., 2015; Poeppl et al., 2013; Schiffer et al., 2008). Abnormal activation of the OFC, decreased left and increased right DLPFC activation, and increased amygdala activation during exposure to child sexual stimuli compared to healthy controls indicates increased arousal and sexual response to children, possible abnormal coding of children with feelings of arousal, and attentional biases to child stimuli (e.g., Habermeyer et al., 2013; Sartorius et al., 2008; Walter et al., 2007). Irregular wiring of sexual stimuli occurs through diminished white and grey matter and abnormal or reduced FC in the OFC, DLPFC, amygdala, and connecting regions (e.g., Cantor & Blanchard, 2012). Reduced FC between these networks prevents the amygdala's sexual and emotional input from properly acting on stimulus-outcome coding from the prefrontal cortex, ultimately skewing sexual responses to favor irregular stimuli (children) (e.g., Kärgel et al., 2015).

With this evidence, pedophilic offending seems to be associated with dysfunctional connections between the prefrontal and limbic regions. However, with little research done on non-offending pedophilic samples, it is hard to say if dysfunction in these specific regions is associated with pedophilic disorder or child-offending status. In either case, this review demonstrates that investigating abnormal functional connectivity between the prefrontal cortex and limbic structures, as well as further studying the regions on their own, will prove helpful in aiding research on pedophilic disorder.

Ethics & Limitations

The study of pedophilic disorder may have been delayed due to ethics and limited access to pedophilic individuals. Many of these studies involve exposing convicted child sexual abusers to pictures of sometimes partially clothed or naked prepubescent children. Of course, this is not ideal.

Though these pictures are not forms of child pornography because of the absence of sexual content and having no relation to these experiments prior to them being taken, many researchers find it unethical to use them for sexual excitation of participants, and rightfully so. However, this disorder must be studied if interventions are to be created. As mentioned, using digitally created pictures of children will solve many of the ethical downfalls of these experiments.

With limited access to participants and funding, many of these studies included very small sample sizes (usually less than 20 pedophilic participants) with only one brain scan per patient. Because of this, the data collected from these experiments is far less generalizable to larger populations. Out of the pedophilic patients who participated, almost all were from prisons with histories of offending, making it hard to distinguish between brain abnormalities concerning the offending status or the disorder in general. Lastly, fMRI, a popular brain scanning technology used to measure real-time functioning in the brain, is still a fairly new technology. It is not meant to record high-resolution, specific activity in real time, which can damage replicability (Constable, 2006). Because of these technological limitations and individual brain variations in patients, findings on precise brain activity can be variable. Therefore, those with pedophilic disorder must not be profiled solely based on brain abnormalities, especially those without a history of offending. This review explored general regions potentially involved in pedophilic disorder, so further research may find differences.

Directions for Future Research

Far more general research and brain scan studies are needed on non-offending pedophilic individuals so a more definite brain network can be investigated and past findings can be replicated. Because fMRI is quite expensive, many studies attempt to gather basic data from bigger sample sizes, which may hurt replicability. Instead, gathering in-depth individual-level data throughout multiple sessions could produce more consistent replicability and should be implemented into future brain research, especially if future pedophilic sample sizes will continue to be limited (Nee, 2019). Unfortunately, with harmful stigma still in place, finding non-offending pedophiles willing to participate in research will prove challenging. Contacting counseling centers with research opportunities for clients experiencing pedophilic fantasies could be the first step in recruitment.

Pedophilia is of global concern and it is necessary to focus on this as a disorder with specialized treatment options. As of now, common treatments for pedophilic disorder are serotonin reuptake inhibiting medication (SSRIs) or chemical castration integrated with cognitive-behavioral therapy (Hall & Hall, 2007; Dr. Michael Miner, personal communication, December 7, 2020). While these lower general libido to reduce recidivism and promote a healthy lifestyle, they do not help diminish attraction to children. Those who offend see increased recidivism when taken off medication, further emphasizing the importance of developing a more disorder-specific treatment on top of therapy (Hall & Hall, 2007).

The first step in diagnosis is the patient admitting sexual attraction towards children. Brain abnormalities cannot individually diagnose someone with a disorder, but general trends, as seen in this review, provide a base for further research. If FC variations are seen in pedophiles, Transcranial Magnetic Stimulation (TMS) might be a viable tactic to use in research and treatment (Hampson & Hoffman, 2010). With more knowledge on the subject, more resources and information will be available to the general public. This will hopefully

reduce stigma and create a greater push for those suffering from the disorder to seek treatment and volunteer for research.

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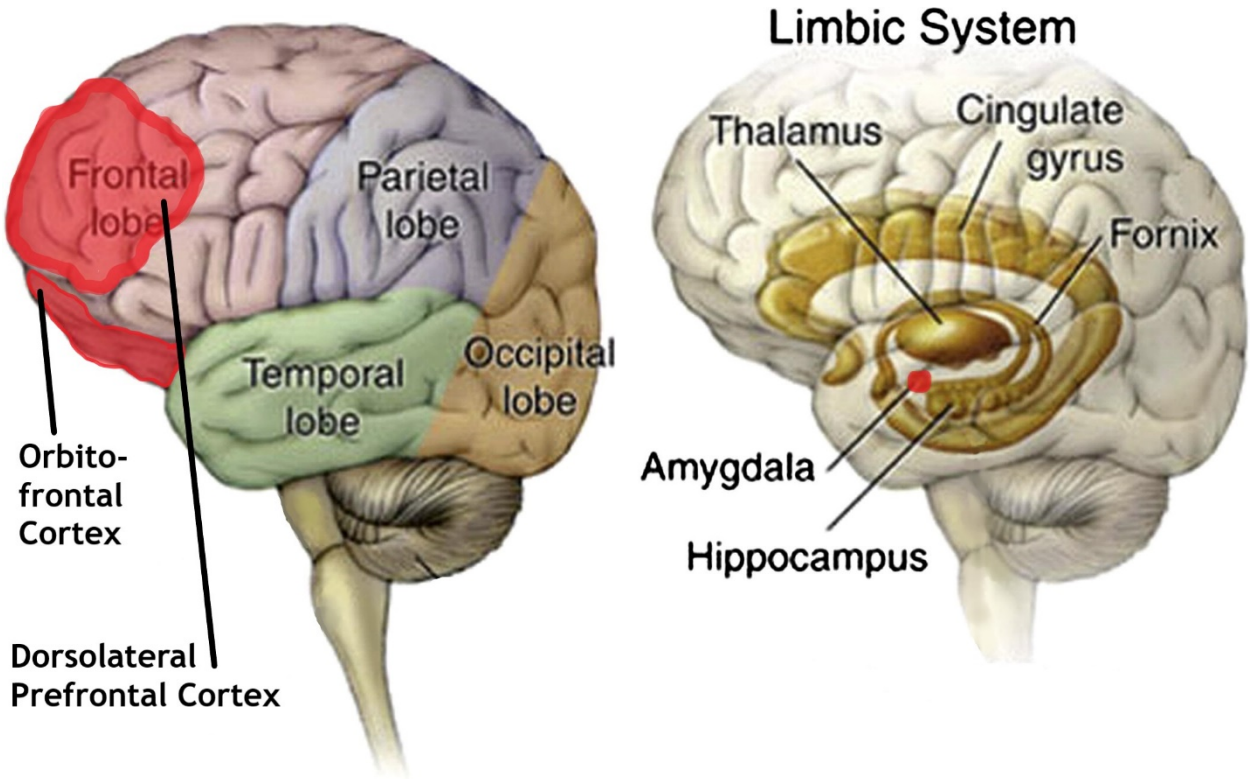
Appendix A

Edited Map of the Prefrontal and Limbic Systems



Note. This map presents the locations of the orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (DLPFC), amygdala, and other regions of the brain and limbic system. It was taken from Braun (2011) and edited to show the specific regions this review is investigating.

Appendix B

Interview with Dr. Michael Miner, Ph.D., LP

Dr. Miner is a licensed practitioner and professor involved in the Human Sexuality program at the University of Minnesota. His research focuses on Attachment Theory in child sexual abuse perpetration in adolescent males through a sexuality perspective. He provided insight on current sex offender and child sex offender treatments and what may set offenders apart from non-offenders.

According to Dr. Miner, a factor that may drive sexual behavior in child sexual abusers compared to all other sexual abusers is insecure anxious attachment to parents. Motives for offending are hard to understand, but most seem to be for sexual gratification. Non-offending pedophiles seem to have an intact moral compass that drives their behavior. They never want to act on their sexual urges, and they realize the consequences. Offending pedophiles, however, do not have this moral compass for reasons unknown. We do not have a good handle on what proportion (usually men) have a sexual preference for children and have not acted on it which is usually due to stigma preventing those suffering from coming forward.

Current treatments for adult and child sex offenders are the same, except more focus is placed on motives involved in child sexual offending. Many use a cognitive behavior perspective in hopes of pushing offenders to think through their thoughts and emotions before acting, and in turn, developing a healthy lifestyle not conducive to crime. Testosterone-blocking medication is rarely used except in extreme cases and opiate antagonists are used for more compulsive individuals. If there is a comorbid condition such as anxiety or depression, SSRIs are used. Unfortunately, we do not understand pedophilic disorder well enough to have interventions to influence pedophilic sexual preference. Behavioral interventions are used, but the effectiveness is unclear.

Cognitive-behavioral therapy along with medication seems to be effective in preventing re-offense. However, little research has been done on how pedophilic disorder develops specifically, and more must be done to understand this. That is why this review focuses on neurobiological factors involved.

Appendix C

Interview with Ryan Webler, 3rd Year Clinical Psychology Ph.D. Student

Ryan is a graduate student working under Dr. Shmuel Lissek in the A.N.G.S.T. Lab at the University of Minnesota. He is familiar with the DLPFC in relation to anxiety and depression and has performed transcranial magnetic stimulation (TMS) on this area prior to graduate school. He discussed the roles of the DLPFC and how TMS may improve dysfunctional connectivity (as seen in pedophilic disorder).

Ryan described the DLPFC as a node of the central executive network involved in executive functioning, cognitive control, direction of attention, and more. Its job is mainly to inhibit responses and guide more flexible behavior. It also works to control initial emotional responses and facilitate reinterpretation. Weak left DLPFC activation seen in pedophilic disorder has been linked to poor cognitive control and inability to regulate behaviors and thoughts. TMS is often applied to the DLPFC in depression patients because it is easily accessible, and it is functionally connected to other regions involved.

When thinking about dysfunctional connectivity in association with depression, it does not seem to arise purely through stimulus associations. Rather, depression is a global mood state and consistent experiences may contribute to the exacerbation of already dysfunctional networks. This may also be the case in pedophilic disorder. By continuing to activate already dysfunctional networks in association with children, the disorder may be developed.

TMS applied to definite brain region targets facilitates excitation or inhibition of neurons, ultimately helping certain networks tip back to normal functioning over continued treatment. This tip is seen even more when the brain is stimulated during certain states, helping only certain networks activated during a task to evolve back to normal functioning. TMS may prove helpful when studying pedophilic disorder. It seems dysfunctional connectivity between the prefrontal cortex and limbic system may contribute to the disorder or offending status. TMS through the DLPFC would help activate neurons in this network to increase connections over time.

Appendix D

Interview with Hannah Berg, 5th Year Clinical Psychology Ph.D. Student

Hannah Berg also studies fear processes under Dr. Shmuel Lissek in the A.N.G.S.T. Lab at the University of Minnesota. She discussed the OFC's and amygdala's roles in stimulus-outcome reversal and association.

In Hannah's opinion, increased amygdala activation with decreased FC between the OFC in pedophilic disorder makes sense. The amygdala is known in pop-science as the "fear center" of the brain, but, she said, it is more accurate to say it is involved in general salience detection, not just fear. It is activated in exposure to reward cues and it tells your OFC and DLPFC which stimuli are important. There may be a possible fear or threat aversion component in amygdala activation in pedophilic disorder if the individual also has the awareness that attraction to children is frowned upon and action may prove detrimental. Activity between the amygdala and OFC seems to be crucial in reversing these detrimental stimulus-outcome associations. If you do not have both the amygdala and OFC in-tact, you may acquire certain associations, but you will not be able to switch those associations when the environment changes.

When looking at brain studies, it is important to remember that some brain regions are more like discrete structures. For example, compared to other brain regions, you can see the amygdala is a discrete structure from its small size and unique tissue. The DLPFC and other prefrontal cortex regions are not discrete structures. They are very large, involved in many functions, and work in terms of whole systems which can make it hard to relate them to certain situations.

In Psychology, there is a lot we do not know, and for ethical reasons, there is a lot we cannot explore. Because of this, further theoretical and physical investigation is needed if we are going to dive deeper into human brain research. Many brain pathways are intertwined, and it can be hard to understand individual systems. This review looked at general theory. More research and theoretical investigation must be done on healthy brains and the brains of those with pedophilic disorder for further progression.