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Review

Neuroanatomical Differences Among Sexual Offenders: A Targeted Review with Limitations and Implications for Future Directions

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Abstract

As sexual assault and child sexual abuse continue to be worldwide public health concerns, research has continued to explore factors associated with sexual offending. Structural and functional neuroanatomical brain differences have been examined in an effort to differentiate sexual offenders and their behavior. This targeted review searched PubMed and Google Scholar for empirical studies using brain imaging techniques to examine possible structural or functional differences among control groups compared with at least one group of sexual offenders with contact offenses. This targeted review summarizes the structural and functional findings of 15 brain imaging studies (i.e., computed tomography, diffusion tensor imaging, magnetic resonance imaging, positron emission tomography, and functional magnetic resonance imaging), which suggest possible differences in brain size and gray matter volume, cortical thickness, white matter connectivity, and specific structural and functional differences among brain regions (fronto-temporal region, amygdala, prefrontal cortex, etc.). The methodological limitations of brain imaging studies and the associated findings with regard to sexual offenders are highlighted, as research indicates that many of the proposed differences in brain structure and function are not unique to this population. We further highlight several limitations to using neuroimaging studies to examine this population of interest, including publication bias, small sample size, underpowered studies, and all-male samples. As these results are mixed and findings are not seemingly unique to sexual offenders, we suggest future sexual offender research may benefit from focusing on more financially feasible options, such as neuropsychological assessment approaches, to assess for and attend to offenders' criminogenic and rehabilitative/therapeutic needs in alignment with the risk–need–responsivity model.

Keywords: sexual offenders, pedophiles, neuroanatomical differences, neuroimaging

Introduction

Sexual assault and abuse are public health concerns worldwide. Research estimates that worldwide, 7.2% of women over the age of 15 report experiencing sexual violence perpetrated by nonpartners (Abrahams et al. 2014), and 9% of women and 4% of men have experienced childhood sexual abuse (Barth et al. 2013). Within the United States alone, Finkelhor (2009) reported that 1 of 5 women and 1 of 20 men experience childhood sexual abuse. Furthermore, the National Intimate Partner and Sexual Violence Survey found that by 2012, in the United States, 17.1% of men and 36.3% of women have experienced sexual assault in their lifetime (Smith et al. 2017).

As experiencing sexual assault is associated with negative psychological health outcomes (Littleton et al. 2009; Smith et al. 2016; Yuan et al. 2006), understanding factors associated with potential perpetration is imperative. For over a century, researchers have theorized that criminal offense behavior may be linked to various neurological differences in the brain (Lombroso 2006; Savopoulos and Lindell 2018). Specific to sexual offenders, researchers have theorized that biological, neuropsychological, volitional, and environmental factors are likely at play regarding criminal sexual behaviors (Ward and Beech 2016). As a result, much research has focused on the ways in which neuroanatomical brain differences, both structurally and functionally, may be associated with sexual offending and may differentiate from nonsexual offenders or between types of sexual offenders.

Although structural and functional differences have been implicated in some samples, numerous limitations exist with regard to brain imaging studies. The goal of this review was to provide a targeted and selective summarization of neuroimaging techniques and findings associated with the attempt to

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differentiate sexual offenders from control groups. Although not an exhaustive review, this targeted review will summarize structural and functional neuroanatomical findings among samples of sexual offenders, will highlight limitations of previous studies, and offer suggestions for future directions of sexual offending brain imaging and evaluative research.

Neuroanatomical and Functional Findings

Structural findings

Brain imaging studies have been used to examine possible structural differences between sexual offenders and nonsexual offenders, and nonoffending controls, in effort to explain sexual offending behavior. Techniques include computed tomography (CT), diffusion tensor imaging (DTI), and magnetic resonance imaging (MRI). See Table 1 for imaging technique, sample size and participant demographics (i.e., age and sex) of the reviewed studies.

Computed tomography. Wright et al. (1990) used CT scans to compare the neuroanatomy of sexually aggressive offenders, pedophilic offenders, incest offenders, and nonviolent/nonsexual offenders. Results indicated differences in overall brain volume, with the nonviolent/nonsexual offenders having the greatest brain volume, followed by pedophilic offenders, sexually aggressive offenders, and incest offenders, respectively (Wright et al. 1990). The study further suggested that as a whole, the sexual offenders' brains were statistically smaller, particularly in the left frontotemporal regions, and had overall smaller brain widths than the nonviolent/nonsexual offenders' brains; however, no statistically significant differences in brain size were found between the three categories of sexual offenders (Wright et al. 1990).

Although Wright et al. (1990) suggested that their findings of smaller brain size may differentiate sexual offenders from nonsexual offenders, these results must be interpreted with caution. As Ovsepian (2019) summarizes, the size of one's brain does not reflect functional capabilities as numerous studies have found many individuals with underdeveloped brains are able to maintain daily and academic functioning (Ovsepian 2019). Moreover, decreased brain volume has been found among individuals with various diagnostic conditions, including Alzheimer's disease (Chan et al. 2003), attention-deficit/hyperactivity disorder (ADHD; Castellanos et al. 2002), schizophrenia (Harrison et al. 2003; Hulshoff Pol and Kahn 2008; Wright et al. 2000), alcohol use disorder (Fein et al. 2002), and panic disorder (Lai and Wu 2013; Sobanski et al. 2010). Therefore, overall brain size does not appear to be unique to offending behavior.

Similarly, Hucker and colleagues (1988) compared CT scans of sadist sexual offenders (those who inflict humiliation, bondage, or suffering on others; American Psychiatric Association 2013, p. 685), nonsadistic sexual aggressors, unclassified sexual offenders, and nonviolent/nonsexual offender controls. Their findings indicated that among this sample, particularly in the temporal regions, the sadistic offenders had significantly more abnormalities of the right temporal horn compared with the nonsadistic offenders and the control group (Hucker et al. 1988).

As the temporal lobes play an important role in memory and language processing, and are interconnected with various brain structures, systems, and functions (Weyandt 2018, p. 12), abnormalities in these structures may be associated with certain behaviors. For example, damage to the temporal lobes can result in memory impairment (Hawkins and Trobst 2000; Squire 2017), and increased irritability and anger (Hawkins and Trobst 2000). Therefore, it may be possible that abnormal temporal horn structures may be associated with sexual offenders' behavior through changes in the aforementioned domains, although further research is necessary to explore this hypothesis and it remains unclear if such structural brain abnormalities are unique to sexual offenders.

Diffusion tensor imaging. Research has used DTI to examine the white matter integrity (functional anisotropy [FA], which examines the diffusion of water molecules in myelinated axonal pathways; Weyandt 2018, p. 91) and gray matter connectivity (i.e., examining the connectivity among gray matter structures via DTI and MRI of white matter FA and gray matter regions; Bonilha et al. 2015) in sexual offender samples. For example, Chen et al. (2016) used DTI techniques with sexual offenders convicted of rape (and described as "rapists") compared with a control group (see Table 1 for sample characteristics). The study found significantly small FA in sexual offenders as a whole in several clustered areas including the left inferior fronto-occipital fasciculus of the occipital gyrus, the right superior longitudinal fasciculus of the supramarginal gyrus, and the right posterior cingulum of the parahippocampal gyrus (Chen et al. 2016).

Chen et al. (2016) noted that these brain structures are associated with moral decision-making, sexual over-arousal, fear conditioning, distorted cognitions related to social contexts, and reward sensitivity, thus hypothesizing that among rapists, decreased white matter integrity in these areas may be associated with offense behavior. At the same time, the sexual offenders were found to have greater FA in other areas (i.e., left superior longitudinal fasciculus adjacent to the angular gyrus, right posterior cingulate, and forceps minor adjacent to the medial frontal pole) also related to moral decision-making (Chen et al. 2016). Similarly, increased FA was found among the right internal capsule at the level of the thalamus, caudate, and Globus pallidus, and the researchers hypothesized that this greater FA in these areas may be related to overactivation of sexual arousal (Chen et al. 2016).

It is important to note that these findings are not exclusive to sexual offender samples. For example, decreased white matter integrity within the superior longitudinal fasciculus has been implicated in schizophrenia (Samartzis et al. 2014), ADHD (Hamilton et al. 2008), and panic disorder (Lai and Wu 2013). At the same time decreased white matter connectivity in the inferior fronto-occipital fasciculus has also been associated with diagnoses of schizophrenia (Samartzis et al. 2014).

In another DTI study, Cantor et al. (2015) examined the connectivity between gray matter regions in a sample of pedophilic individuals and control participants. Results indicated significantly greater gray matter FA in the pedophilic group, localized in the left hemisphere. Specifically, the differences in gray matter connectivity were located in the insula/operculum, temporal pole, occipital cortex, superior temporal gyrus, dorsolateral prefrontal cortex,

Table 1. Characteristics of the Structural and Functional Studies with Sexual Offenders

Participant sex and age, and sample size of studies examined in current review

	Study characteristics			
Study citation	*Imaging technique*	*Participant sex*	*Sexual offenders (age, mean/SD)*	*Control group (age, mean/SD)*
Hucker et al. (1988)[a]	CT	Male	22 Sadists (26.36/4.1) 21 Nonsadistic sexual aggressors (29.00/7.8) 8 Unclassified offenders (n.r.)	20 Nonviolent/nonsexual offenders (24.87/8.1)
Wright et al. (1990)[a]	CT	Male	34 Sexual aggressors (n.r.) 18 Pedophiles (n.r.) 12 Incest offenders (n.r.)	12 Nonviolent/nonsexual offenders (n.r.)
Cantor et al. (2015)[a]	DTI	Male	24 Pedophilic offenders (35.63/9.5)	32 Controls (37.00/10.7)
Chen et al. (2016)[a]	DTI	Male	15 Rapists (33.10/6.5)	15 Controls (33.00/6.8)
Gerwinn et al. (2015)[a,b]	DTI	Male	11 Heterosexual pedophiles (n.r.) 13 Homosexual pedophiles (n.r.)	18 Heterosexual controls (n.r.) 14 Homosexual controls (n.r.)
Lett et al. (2018)	MRI	Male	73 Pedophilic offenders (39.80/9.0) 77 Nonoffending pedophiles (34.20/9.4)	133 Nonpedophilic controls (33.60/10.2)
Poeppl et al. (2013)[a]	MRI	Male	9 Pedophiles (45.00/8.0)	11 Nonsexual offenders (29.00/6.0)
Schiffer et al. (2017)	MRI	Male	50 Pedophilic offenders (40.10/9.1) 60 Nonoffending pedophiles (34.40/9.2)	101 Teleiophilic controls (33.80/10.5)
Cohen et al. (2002)[a]	PET	Male	7 Pedophiles (38.00/8.0)	7 Healthy controls (37.00/10.0)
Fonteille et al. (2018)[a]	PET	Male	15 Patients with pedophilia (42.00/12.6)	15 Controls (41.20/16.20)
Kärgel et al. (2015)[a]	fMRI	Male	14 Nonoffending pedophiles (28.07/5.7) 12 Pedophilic offenders (43.67/7.1)	14 Healthy controls (32.86/9.9)
Kärgel et al. (2017)	fMRI	Male	37 Nonoffending pedophiles (37.00/8.8) 40 Pedophilic offenders (38.25/8.5)	40 Healthy controls (36.65/10.1)
Kneer et al. (2019)[a]	fMRI	Male	20 Nonpedophilic child sexual abusers (38.25/8.5)	20 Normal, healthy controls (45.20/11.2)
Massau et al. (2017)[a]	fMRI	Male	16 Pedophilic offenders (36.44/8.01) 15 Nonoffending pedophiles (31.73/6.5)	19 Healthy controls (33.47/10.2)
Sartorius et al. (2008)[a]	fMRI	Male	10 Pedophiles (31.10/8.9)	10 Heterosexual controls (35.30/8.3)

[a]The study had one or more participant group with <30 participants.
[b]The authors note that seven participants for the ‘‘paedophilia’’ sample were not exclusively attracted to children (i.e., sometimes attracted sexually to adults).
‘‘n.r.,’’ age information not reported in publication.
CT, computed tomography; DTI, diffusion tensor imaging; MRI, magnetic resonance imaging; PET, positron emission tomography; fMRI, functional magnetic resonance imaging; SD, standard deviation.

temporal–occipital junction, superior parietal lobule, left thalamus, and frontal pole (Cantor et al. 2015). With these findings, Cantor et al. (2015) hypothesized that pedophilic offenders may be differentiated from controls through exhibited decreased connectivity activation when shown adult sexual stimuli, while displaying increased connectivity among brain structures when exposed to child sexual stimuli. However, it remains unclear as to how these connectivity regions may be related to actual offending behaviors.

Of interest, while Chen et al. (2016) and Cantor et al. (2015) found white and gray matter connectivity and integrity differences in sexual offenders compared with controls, Gerwinn et al. (2015) found no significant differences in white matter FA among their sample of pedophiles compared with controls. It was hypothesized that the possible DTI differences between sexual offenders and nonsexual offenders may actually be smaller than previous studies suggest, or that additional covariates may have impacted the results of previous research (Gerwinn et al., 2015). Such incongruent findings further highlight the need for caution when interpreting structural imaging methods in an effort to differentiate between sexual offenders and nonsexual offenders, and drawing conclusions on whether structural differences are associated with offense behaviors.

Magnetic resonance imaging. In studies examining potential structural differences among pedophilic offenders compared with controls, several structural findings have been implicated. For example, in a sample of pedophile offenders compared with nonsexual offenders, MRI suggested structural differences among the pedophilic group in the prefrontal, insular, limbic, and parietal areas of the brain (see Table 1 for sample characteristics; Poeppl et al., 2013).

Specifically, reduced gray matter was seen in the right amygdala, left insular cortex, and dorsolateral prefrontal cortex in individuals with "strong pedophilic fixation" (p. 680), and decreased gray matter in the orbitofrontal cortex and angular gyri in those with a preference for younger children (Poeppl et al. 2013). The researchers suggested that their findings of amygdala abnormalities are consistent with previous studies. They hypothesized such abnormalities may indicate a common feature related to pedophilia while noting that amygdala changes and deficits are not likely to cause sexual preference for children, but might increase the risk of developing abnormal, pedophilic behaviors (Poeppl et al. 2013).

Additional research is needed to explore this hypothesis as, like the previously reviewed studies, structural differences in these brain regions are not unique to sexual offender samples. For example, the diagnosis of schizophrenia has been associated with decreased gray matter in the insula and dorsolateral prefrontal cortex (Wright et al. 1999). Moreover, reduced gray matter volume of the amygdala has also been implicated in schizophrenia (Del Bene et al. 2016; Wright et al. 1999; Xu et al. 2017), and major depressive disorder has been linked to gray matter reductions in the amygdala (Sheline et al. 1998; Stratmann et al. 2014) and orbitofrontal cortex (Koolschijn et al. 2009).

In a separate MRI study, reduced gray matter in the right dorsomedial prefrontal cortex and anterior cingulate cortex was found to be associated with a risk of reoffending in a sample of pedophilic offenders, pedophiles with no history of offending, and nonoffending controls exclusively attracted to adults (teleiophilic; Schiffer et al. 2017). Moreover, Schiffer et al. (2017) further found a significant difference in gray matter volume in the right temporal pole between the two pedophilic groups only, and found no differences between the pedophiles with no offense history group and the control group, overall.

It was hypothesized that gray matter volume in the temporal pole may moderate the risk for engaging in offenses against children between nonoffending and offending pedophiles, as the temporal pole is associated with responding sexually to visual stimuli (Schiffer et al. 2017). However, reductions in gray matter volume of the right temporal pole has likewise been indicated in individuals with diagnoses of schizophrenia (Wright et al. 1999).

In addition, Lett et al. (2018) examined MRI scans of pedophilic offenders, pedophiles with no history of offending, and nonpedophilic controls. Results indicated surface area reductions were found among the pedophilic abusers versus the control group (Lett et al. 2018). Furthermore, several areas of difference among the pedophilic abusers compared with the nonoffending pedophilic group were found, including decreased cortical thickness in the right motor and premotor cortices and left temporal lobe, and surface area reductions laterally in the prefrontal, cingulate, temporal, orbitofrontal, and occipital cortices (Lett et al. 2018).

The orbitofrontal cortex is important in regulating processes such as working memory, decision-making, and response inhibition (Bolla et al. 2003; Fettes et al. 2017), thus perhaps how abnormalities in the orbitofrontal cortex are hypothesized by some to be associated with sexual offending behaviors. However, abnormalities of the orbitofrontal cortex have been implicated in substance use disorders as well (Bolla et al. 2003), again indicating these results are not specific to sexual offending behaviors.

Lett et al. (2018) suggested that these aforementioned brain abnormalities may be specific to pedophilic offending behavior rather than pedophilia in general, as the frequency of child sexual offending behaviors was associated with reduced surface area in the left prefrontal and right superior frontal cortices (Lett et al. 2018). Yet, as previously mentioned, many of these structural differences (orbitofrontal cortex, temporal lobes global surface area reductions, etc.) are not specific to sexual offender populations. Thus, findings implicating structural differences differentiating sexual offenders from other populations should be considered with caution.

Functional findings

Beyond structural imagining techniques, research has used functional imaging techniques to further investigate potential brain differences between sexual offenders, nonsexual offenders, and control groups. These techniques include positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). See Table 1 for imaging technique, sample size and participant demographics (i.e., age and sex) of the reviewed studies.

Positron emission tomography. Cohen et al. (2002) utilized PET to examine possible functional brain differences in pedophilic offenders compared with a control group when participants viewed three sexual activation conditions (see Table 1 for sample characteristics). Results of the study indicated that in response to the activation conditions, the pedophilic offenders exhibited decreased glucose metabolism in the temporal and frontal cortices compared with the control group (Cohen et al. 2002). The authors noted that these areas are associated with the regulation of sexual arousal, and abnormalities in these regions within this sample suggest an association with oversexual arousal toward children (Cohen et al. 2002). However, widespread glucose metabolism reduction has been implicated in Alzheimer's disease (Jagust et al. 1991), and decreased glucose metabolism in the temporal cortices (Friedland et al. 1989; Jagust et al. 1991).

In a similar study during which participants viewed visual sexual stimuli of children or adults, PET imagining indicated that when patients with pedophilia were shown the child stimuli, they exhibited activation in the right inferior temporal gyrus and left middle occipital gyrus, compared with the control group that demonstrated activation of these areas only when shown the adult stimuli (Fonteille et al. 2018). Fonteille et al. (2018) hypothesized that the right inferior temporal gyrus may serve as a mediator of sexual arousal in the pedophilic group.

Such hypotheses require further investigation. Previous research has found that damage or impairment to the frontal lobes has been linked to impairments in controlling one's inhibitions, strategic planning, rigidity or perseveration, and/or increased inappropriate interpersonal behavior (Hawkins and Trobst 2000). Of note, with regard to sexual offenders, fronto-temporal abnormalities have been associated with impairments in important executive functions (Joyal et al. 2007). Moreover, Elliott (2003) summarized impairment in executive functioning processes are further associated with Alzheimer's disease, subcortical ischemic vascular disease, AIDS–dementia complex, schizophrenia, and depressive disorders. Thus, future sexual offender studies may wish to investigate and target specific functions and behavior related to functional brain abnormalities, with the caveat that such behaviors are not unique to sexual offenders.

Functional magnetic resonance imagining. In their study, Sartorius et al. (2008), examining functional activation of brain regions when participants viewed pictures of individuals in bathing suits, fMRI found that pedophilic offenders who were attracted to boys displayed significantly increased amygdala activation when viewing boys in bathing suits, compared with the heterosexual control group (see Table 1 for sample characteristics). The researchers hypothesized that the increased amygdala activation in the pedophilic offenders to the inappropriate stimuli may indicate an activation of a fear response or may indicate a sexual arousal response. In addition, Sartorius et al. (2008) suggested their findings may actually implicate a combination of both types of responses to such stimuli among the pedophilic offenders. However, one must consider such results are correlational in nature and it is unclear what an activation of this nature, within this sample, truly indicates.

Another study using fMRI to examine moral judgment in pedophiles, versus control individuals, found that when viewing scenarios depicting sexual offending against children, control participants exhibited greater activation in the left posterior insular cortex, left temporoparietal junction, posterior cingulate cortex, and precuneus, compared with the pedophilic group (Massau et al. 2017). Massau et al. (2017) hypothesized that these areas of activation among the control group are related to moral judgment, moral disgust, and theory of mind, which they suggest are implicated in important social cognitive abilities and may be impaired among the pedophilic group (Massau et al. 2017).

Indeed, previous research investigating moral judgment found the posterior cortex and precuneus may play a role in moral decision-making and judgment (Greene and Haidt 2002). However, such moral judgment and decision-making deficits are not specific to sexual offenders, as other antisocial behaviors are associated with impairment in these domains (Blair 1995; Greene and Haidt 2002).

In recent studies examining resting state fMRI, results have suggested differences between offending and nonoffending pedophiles, whereas no significant differences were found between the pedophilic groups and the control groups (Kärgel et al. 2015, 2017). Specifically, pedophilic offenders demonstrated significantly reduced connectivity among the left orbitofrontal cortex and left medial superior frontal regions, and reduced connectivity between the dorsal medial prefrontal cortex and posterior cingulate cortex, compared with nonoffending pedophiles (Kärgel et al. 2015).

The findings implicate decreased abilities associated with emotion and cognition-related perspective taking, among pedophilic offenders (Kärgel et al. 2015), and these areas of decreased activation have been linked to aggressive behavior. Indeed, it has been hypothesized that among individuals committing aggressive acts, impairment within the frontal lobes region of the brain (e.g., damage or dysfunction of the orbitofrontal cortex) has been associated with lack of inhibition, engaging in socially unacceptable behavior, lack of insight into problematic behaviors, impaired decision-making (Strüber et al. 2008), increased risk taking behaviors, and difficulty learning from maladaptive decision-making (Rosenbloom et al. 2012).

Moreover, pedophilic offenders were further found to display decreased activation of the left caudal posterior cingulate cortex, medial parietal cortex, and left superior frontal cortex, compared with nonoffending pedophiles (Kärgel et al. 2017). Kärgel et al. (2017) suggested that these findings indicate pedophilic offenders may have decreased response inhibition abilities and abnormalities related to executive functioning, as the posterior cingulate cortex has been associated with inhibitive responses, whereas the superior frontal cortex is associated with executive functioning.

Finally, Kneer et al. (2019) found decreased connectivity between the left dorsolateral prefrontal cortex and the right central and medial nucleus among nonpedophilic child sexual abusers compared with healthy controls. The results were hypothesized to indicate that the impairment in these connections may impact the ability to control one's behavior, and that these specific connectivity impairments may serve to differentiate sexual offending against children (Kneer et al. 2019). However, as previously stated, such results must be interpreted with caution as a number of the aforementioned functional brain differences are associated with various disorders and behaviors, thus these findings are not exclusive to sexual offender populations.

Limitations of Brain Imaging Methods and Findings

Although neuroimaging techniques are utilized throughout the medical and neuroscience fields, caution is advised when using such techniques in an attempt to differentiate between sexual offender types. For example, CT, DTI, and MRI have often yielded mixed results when attempting differential diagnostic imaging and have shown varying consistency in identifying specific structural differences across psychiatric disorders (Alexander et al. 2007; Goulet et al. 2009; Weyandt 2018, pp. 91–92). Moreover, each imaging technique has unique limitations.

First, CT scans, although commonly used as a diagnostic tool for various medical purposes, have low resolution and make the differentiation of gray and white matter of the brain more difficult (Goulet et al. 2009; Lin and Alessio 2009). Because of these limitations, neuroimaging efforts, both diagnostically and in research endeavors, have moved toward more technologically advanced brain imaging techniques such as DTI and MRI. This has resulted in a body of literature utilizing these advancements in the hope of further elucidating the ability to differentiate sex offenders from other types of offenders and nonoffenders. As such, research studies utilizing CT scans in an effort to differentiate sexual offenders can be considered outdated and results should be interpreted with caution.

At the same time, Alexander et al. (2007) further argue that because of the multitude of DTI measures, of which FA is one type, interpreting DTI results is often difficult and suggest that several DTI techniques be used to increase the specificity of findings in both clinical and research settings. In addition, Weyandt (2018, pp. 91–92) summarized that although MRI is useful for gathering information related to brain structures, this technique cannot be used for identifying functional processes. Moreover, MRI has been held as more useful in better understanding and gathering information related to healthy neurotypical brain development through young adulthood (Gennatas et al. 2017; Meng et al. 2017), thus functional imaging techniques may be more useful in assessing potential differences among sexual offenders.

Regarding PET scans, this technique indirectly measures brain function at the cellular level, and therefore is not able to directly assess communication between neurons. Specifically, the glucose metabolism that measures neural activity is not a direct measurement of quantitative changes in brain functioning, but instead an indirect assessment (Papanicolaou 1998). This is further complicated by the temporal delay between initiation of the procedure and the metabolic processes resulting in data output as it takes many seconds for the changes in brain activity to be detected (Aguirre 2014; Bailey et al. 2005). Therefore, consideration must be given further to the fact that these methods may measure activation in the brain related to various processes, and not necessarily to the constructs or processes of interest (Weyandt 2018, p. 97).

Finally, functional imaging techniques have their own unique set of limitations (see Algermissen and Mehler 2018; Vul et al. 2009). Specifically, a commonly cited concern is the issue of Type I error as a result of uncorrected statistical analyses used in fMRI studies that often leads to inaccurate interpretations of results (Bennett and Miller 2010; Vul et al. 2009). Furthermore, fMRI is used to obtain a better understanding of the functional processes of the brain, spatially, yet is not useful temporally because of the time delay in the measurement process (Logothetis 2008). This can increase the likelihood that findings are interpreted as causal when, in fact, they are correlational (e.g., Farah 2014; Lyon 2017).

Overall, these limitations with neuroimaging techniques are important when considering findings that suggest structural and/or functional differences differentiating sexual offenders from nonsexual offenders. Although the aforementioned studies have suggested structural and functional differences among sexual offenders, it is clear that the interpretation of sexual offender neuroimaging results must be considered carefully as several psychiatric and neurodegenerative disorders have similar structural or functional abnormalities. Thus, it is not clear if any specific pathology is leading to these structural or functional differences, and in turn leading to specific behavioral patterns.

Further limitations exist concerning study designs. Like the majority of neuroimaging studies in general, among the studies in the current review the methods and design procedures differed greatly, including exclusion criteria. Among these studies, differing exclusion criteria included, but were not limited to current use of psychotropic medication, current major mental illness (whereas other studies excluded past psychiatric diagnosis or treatment), substance abuse in the past 6 months (whereas other studies excluded a history of substance abuse or dependence), substance use during the offense, certain medical issues (e.g., seizures), or job history (e.g., metal grinding). Moreover, some studies had different exclusion criteria for the offender group versus the control group, whereas others did not report exclusion criteria. Without uniform methodological approaches, it is unclear if the findings of the individual studies can be generalized to larger sexual offender populations or can be replicated with other samples.

Another limitation prevalent in the research, perhaps particularly with neuroimaging studies, is publication bias. Over the past decade, research has investigated potential factors contributing to a large number of neuroimaging studies obtaining statistically significant results (see Jennings and Van Horn 2012; Vul et al. 2009; Yarkoni 2009). It has been found that a great number of neuroimaging studies are conducted with small sample sizes (Jennings and Van Horn 2012). Small sample sizes result in studies with insufficient power that are not able to detect medium or small effect sizes (Algermissen and Mehler 2018; Turner et al. 2018). Furthermore, underpowered neuroimaging studies tend to result in low reliability (Button et al. 2013) and decreased replicability of findings (Turner et al. 2018).

Moreover, results of neuroimaging studies, particularly fMRI studies, suggest very large correlational outcomes that are often inflated (Vul et al. 2009; Yarkoni 2009) and the result of questionable data analytic methods (Vul et al. 2009). Of importance, such large correlations are not likely to accurately reflect the true estimate of population effect sizes (Yarkoni 2009). Yet, the implications of these studies are often framed as reflecting causality and consequence; erroneously so, given that these implications are being drawn from large, potentially spurious correlations. Furthermore, Yarkoni (2009) noted, as sample sizes increase, the magnitude of previously large correlations decrease, again calling into question the true association between the variables of interest.

These aforementioned conclusions indicate that although neuroimaging studies are often underpowered, the articles reaching publication are reporting significant findings. Such findings are considered problematic as there are a great number of unpublished studies that found null or inconclusive findings (Jennings and Van Horn 2012), which may contradict the significant findings of some published studies. These considerations are important regarding neuroimaging assessment in the effort to differentiate sexual offenders and offending behaviors from control groups, given that the studies examined in this review often had small sample sizes, many of which were unequal in size across group conditions. In fact, 80% ($n = 12$) of the reviewed studies had one or more underpowered group of participants (Table 1). Therefore, it is critically important that when interpreting neuroimaging findings, large correlations are considered carefully and that correlation does not become conflated with causation and consequence.

Future Directions

Power and sample size

To address some of the methodological issues associated with neuroimaging studies, future research must consider adequate sample sizes and statistical power. Although it has been noted that small sample sizes in neuroimaging studies are often the result of the extremely high cost associated with neuroimaging techniques (Turner et al. 2018), researchers must conduct power analyses *a priori* (Mumford 2012; Yarkoni 2009) to guide appropriate research questions and to find an adequate sample size needed for analyses to be conducted (Mumford 2012).

In general, current estimates suggest neuroimaging studies require a minimum of ~ 30 participants per group to have an adequately powered study (Pardoe et al. 2013; Yarkoni 2009). An additional factor that is likely to impact sample size is the ability to recruit a sufficient sample meeting specific inclusion criterion. To address such sampling issues, future collaboration between researchers with the support of grant funding agencies will likely make such recruitment possible allowing for adequately powered studies.

Future adequately powered brain imaging studies are critical as such studies are likely to prove useful in generating hypotheses regarding sexual offending behavior and offender characteristics. Indeed, Mier and Mier (2015) suggested the bimodal, simultaneous use of functional and structural brain imaging techniques (e.g., PET and fMRI) to examine both spatial and molecular processes in conjunction, rather than separately. Applying such an approach through adequately powered sexual offender studies may enable the development of rigorous and methodologically consistent approaches to sexual offender hypothesis testing.

Participant sex

Future studies must consider female sexual offending to address an important gap in the literature. Although female sexual offenders are less common than male offenders (Denson et al. 2018; Williams and Bierie 2015), Williams and Bierie (2015) summarized that in the United States in 2011 alone, 8.1% of forcible sexual offense arrests, and 1.2% of forcible rape arrests, involved women. Moreover, in their study examining data from the National Incident-Based Reporting System, Williams and Bierie (2015) found that from 1992 to 2011, 43,018 sexual offenses involved female offenders and 773,118 offenses involved male offenders. Although the female sexual offender rate is much lower than the male rate, 43,018 offenses are arguably significant from a public health and safety concern. Furthermore, these rates of offending, particularly female offending, are very likely because of underreporting (Williams and Bierie 2015).

Moreover, in neuroscience research, various studies have found that male and female participants differ with regard to certain psychiatric disorders, and structural differences linked with specific behaviors (Gatzke-Kopp 2016). Indeed, regarding studies of aggression, Denson et al. (2018) concluded that, behaviorally, women display aggression more indirectly (intentionally harming another through nonphysical or violent actions such as expressing undue criticism, spreading rumors, engaging social exclusion of others, etc.) compared with men.

However, brain studies related to aggression have largely neglected female participants (Denson et al. 2018). It is important to note, perhaps not surprisingly, the neuroimaging studies examined in this review did not include female sexual offender or control groups (Table 1). As such, it is greatly important that future sexual offender studies include female offenders, as potential correlational, and possibly causal, factors may differ across male and female offender populations.

Legal considerations

The surge of increased technological advances in neuroimaging has resulted in more frequent incorporation of such results as evidence in court. For example, one article cited that there are an estimated 130 legal cases in which neuroimages have been included as evidence (Yang et al. 2008). However, the ways in which neuroimaging results are presented are inconsistent and often chosen subjectively. At present, there are no standardized methods for color-coding results and scales indicating significant neuroanatomical differences, as such these visual details are often arbitrarily selected (Reeves et al. 2003). Despite this, these random color-coded neuroimages presented in the courtroom, can impact the jury or judge's perception of the importance of findings (Perlin 2009).

For example, research has shown that individuals tend to find the logic of an explanation describing psychological phenomena as more satisfying when presented with neuroscientific information, even when such information is logically irrelevant, than explanations that do not present neuroscientific information (Weisberg et al. 2008). This is problematic as these results indicate that nonexperts (i.e., jury members) may be more likely to consider neuroscientific evidence, such as neuroimaging results, as highly explanative, despite inaccurate and potentially irrelevant information related to the specific psychological phenomena being investigated. Thus, the use of neuroimaging findings as evidence in the courtroom should be considered with caution.

Are there other assessment options?

The risk–need–responsivity (RNR) model of offender treatment (Bonta and Andrews 2007) is commonly used in correctional settings, aimed at rehabilitation based on individual risk factors, criminogenic and noncriminogenic needs, and factors associated with responsivity to treatment (Bartol and Bartol 2019, p. 473; Bonta and Andrews 2007). The RNR model inherently relies on utilizing various scientifically validated evaluation methods and assessment measures to classify, manage, and treat criminal offenders (Bonta and Andrews 2007). A large body of literature has amassed over the past few decades examining sex offenders through the RNR framework with the assistance of a combination of assessment tools and techniques (Hanson and Morton-Bourgon 2009; Joyal et al. 2014; Olver et al. 2018; Tully et al. 2013). Thus, approaching the evaluation of sexual offenders based on the RNR model may prove advantageous.

Neuropsychological assessment may be one promising evaluation approach to understanding neurological and cognitive functioning in sexual offenders. Compared with the general population, sexual offenders as a whole, have been found to exhibit significant cognitive deficits in various cognitive domains (Joyal et al. 2007, 2014), such as Intelligent Quotient scores compared with the general population (Joyal et al. 2007). Research has further suggested that there may be differences between differing types of sexual offenders.

For example, in their meta-analysis of the neuropsychology of sexual offenders, Joyal et al. (2014) found those having offended against children obtained significantly lower scores on a measure assessing cognitive flexibility and deduction skills. Meanwhile, these same individuals scored significantly higher on measures of verbal fluency and internal control interference, compared with both sexual offenders against adults and nonsexual offenders (Joyal et al. 2014). At the same time, offenders with adult victims were found to obtain scores similar to nonsexual offenders on measures assessing for impairment of inhibition and verbal abilities (Joyal et al. 2014).

These findings regarding cognitive deficits suggest that neuropsychological differences among sexual offenders may play a role in sexual offending behavior for some individuals, indicating that specific assessments and interventions may be warranted for offenders based on individual needs. Therefore, neuropsychological assessment may prove to be a useful and more cost-effective method, compared with neuroimaging techniques, of examining differences among offenders.

Another form of evaluation that is likely to be useful and relatively more cost-effective compared with imaging studies, is personality assessment. Research examining personality characteristics of sexual offenders have found that sexual offenders may respond differently during assessment and some characteristics are more likely to be related to certain offender types and to reoffending (Boccaccini et al. 2017; Tarascavage et al. 2018).

For example, Carvalho and Nobre (2019) found that compared with nonconvicted sexual offenders, convicted rapists and convicted child sexual molesters have greater levels of neuroticism, convicted child sexual molesters exhibit less openness compared with convicted rapists and nonconvicted sexual offenders, and convicted rapists have greater overall psychopathological traits compared with convicted child sexual molesters (although not significantly different from nonconvicted sex offenders). Moreover, sexual offenders are at a greater likelihood, compared with normative samples, to exhibit response styles on personality measures that are indicative of defensiveness, suggesting the minimization of symptoms and behaviors (Boccaccini et al. 2017) and underreporting of problematic behaviors (Tarascavage et al. 2018).

Such response behaviors, particularly among a sample of male sexual offenders against children, suggest that this type of offender may be overtly managing others' impressions of them (Tarascavage et al. 2018). What is more, minimizing symptoms and behaviors through defensive response styles has been indicated as a predictor of sexual offenders receiving diagnoses of Antisocial Personality Disorder (Boccaccini et al. 2017). These findings are important given that antisocial traits and personality characteristics are predictive of both general and sexual recidivism (Hanson and Morton-Bourgon 2005).

The assessment of risk for reoffending is a further important method of evaluation to assess sexual offenders' risk, needs, and potential responsivity to treatment. Risk assessment tools allow for the assessment of various factors that have been shown to be predictive of future reoffending, such as static (unchanging) and dynamic factors. The assessment for static factors, such as the history of previous sexual offending, previous convictions for nonsexual offenses, or age at the time of the index offense (e.g., under the age of 25), to name a few, have been found to be associated with a greater probability of future sexual reoffending (Waisanen and Ackerman 2010).

Static factors are useful for identifying offenders' potential for long-term risk (Hanson and Thorton 2000), whereas the examination of dynamic factors, such as appropriate social support, prosocial peers, mental health, substance use, and coping abilities, to name a few, is integral for developing treatment plans, measuring cognitive and behavioral change over time, and assessing the effects of treatment (Waisanen and Ackerman 2010). Indeed, research indicates that some risk assessment tools, such as the Static-99, the Sex Offender Risk Appraisal Guide (SORAG), and the Rapid Risk Assessment for Sexual Offense Recidivism, have significant predictive validity of recidivism for child molestation offender type compared with predictive validity of rapist offender type, whereas the Static-99 and SORAG near significance for predicting recidivism among rapist offender type (Bartosh et al. 2003).

Although neuropsychological, personality, and risk assessment are promising evaluation methods in examining distinctive factors unique to sex offenders, they are not without their own limitations. Similar to the criticisms of neuroimaging, these assessment approaches exhibit limitations such as, identifying functioning capacities found present across an array of psychological disorders, difficulty differentiating groups of individuals, and a lack of empirical evidence. For example, neuropsychological assessments have rendered deficits in cognitive flexibility seen in individuals with unhealthy eating (Fagundo et al. 2012), substance abuse (Cunha et al. 2010), traumatic brain injury (Rabinowitz and Levin 2014), and sex offenders (Adjorlolo and Egbenya 2016).

Similarly, objective personality measures may have a single scale within a measure that may discriminate sex offenders from nonsexual offenders, but simultaneously may be actually capturing general antisocial behaviors rather than characteristics unique to sex offenders (Davis and Archer 2010). Finally, there is a dearth of research examining the predictive validity of some risk assessment tools for certain subgroups of sexual offenders (e.g., hands-off offenders or offenders with adult male victims) resulting in the clinical utilization of risk-needs assessments tools that have not been validated for all sex offender types (Barbaree et al. 2006; Bartosh et al. 2003).

Perhaps one potential remedy for the limitations of each individual assessment approach, including neuroimaging, is the use of multimodal assessments in the evaluation of sex offenders. The use of the combination of neuropsychological, personality, and risk assessment is likely to provide a more comprehensive understanding of sexual offenders behavioral and cognitive functioning, levels of defensiveness, minimization, and underreporting of specific traits and behaviors, risk for reoffending, and responsivity to treatment; all of which lend themselves to diagnosing, managing, and treating sex offenders in line with the RNR model.

Using data gathered from such methods are likely to provide useful evaluative information, and insight into sexual offender behavior and characteristics. Such an approach is also warranted for researchers as investigation into the differentiation and etiology of sexual offending continues. Future research examining differential factors associated with sexual offending should focus on implementing a combination of assessment and evaluation methods as they may have lower relative costs, may provide greater diagnostic utility, and ideally enhance the efficacy of clinical service delivery with this population.

Conclusions

Overall, the findings of the aforementioned literature highlight the heterogeneous nature of neuroanatomical differences among sexual offenders. These studies suggest that many sexual offenders exhibit neuroanatomical abnormalities compared with normative samples and nonsexual offenders and suggest possible associations between these differences and offending behavior. However, these findings must be considered with caution given the potential limitations associated with each type of neuroimaging technique, the prevalence of small sample sizes, research only including male samples, and the shared structural abnormalities among other conditions and psychiatric disorders.

Future brain imaging studies should continue to focus on functional differences with consideration given to plausible covariates and mediating or moderating neuropsychological, environmental, biological, and volitional factors, and researchers may want to begin to focus their efforts on other forms of assessment. Indeed, a multimodal approach, such as neuropsychological, personality, and risk assessment may likely prove to be beneficial and align with the RNR model as such assessments allow for targeting individual risk factors and needs, whereas neuroimaging studies are largely inconclusive, have not yet been proven to differentiate between groups, diagnoses, and clinical factors effectively and with certainty.

Because of these limitations, neuroimaging results do not lend themselves to treatment recommendations or legal proceedings, at this time, thus exemplifying a lack of clinical utility with various populations, such as forensic populations, where individualized evaluation, treatment, and rehabilitative strategies are critical. However, neuroimaging methods should continue to be used in research endeavors to continue to better understand the etiology of sexual offending and to formulate testable hypotheses, which in turn will likely provide a more nuanced and complete picture of sexual offenders. Although the role of neuroimaging within the assessment and evaluation of sexual offenders remains to be determined, increased technological advances and statistical analyses of imaging techniques may yet prove useful beyond hypothesis generation. Until then, caution is advised.

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Podcast

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Supplementary Material

Podcast

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