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"Facing" the Repercussions of Sexual Harm: A Scoping Review on Neuroimaging Studies Using Emotional Stimuli with Survivors of Sexual Violence

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Sexual violence (SV) is a public health issue that affects millions of Americans. SV survivors can experience a variety of physical and psychological symptoms, particularly when exposed to stimuli that triggers challenging emotions. The brain may be a key area to better understand survivor reactions to emotional stimuli and symptoms associated. While some research has attempted to understand SV survivor neural responses to emotional stimuli, no review has aggregated findings across these studies. The purpose of this review was to synthesize research findings of studies that used neuroimaging techniques to explore SV survivor responses to emotional stimuli. Studies that were published in PubMed prior to October 2021 were identified using key search terms including phrases relating to "sexual violence," "neuroimaging," and "emotional stimuli." Our PubMed search yielded 87 studies, with 11 studies meeting the full text review criteria. In general, SV survivors displayed significantly heightened brain response patterns when exposed to emotional stimuli compared to non-SV survivors (e.g. temporal lobe all areas (n=8), amygdala activation (n=5), parietal lobe activation (n=4), frontal lobe activation (n=5)). SV appears to have some effect on emotional brain responses, which may explain behavioral differences in emotional reactivity. Additional exploration is needed, however, to understand future neural intervention targets to better support survivor health and recovery.

***Keywords**: Neuroimaging, Sexual Violence, Emotional Stimuli*

Introduction

Sexual violence (SV) is a significant public health issue that affects millions of women, and a small percentage of men, worldwide.[1-3] SV can include any type of non-consensual sexual activity including but not limited to in-person, online, or other forms of technology.[2] More than 1 in 3 women have experienced some form of SV, with 1 in 5 experiencing an attempted or completed rape in their lifetime.[1-2] In most SV cases, the victim or survivor (for the purpose of this review we will refer to these individuals as survivors) knows the perpetrator, with approximately 99% of these perpetrators being men.[1-3]

Impact of SV on Health

SV has a range of short and long term consequences and is related to a number of physical and psychological conditions.[1] Physical injuries may include bruising and genital injuring.[2] Experiencing trauma, like SV, can also be linked to physical health outcomes like obesity,[4-6] diabetes,[6-7] chronic pain,[6, 8-10] and gastrointestinal disorders.[6, 10, 11] Psychologically, SV is linked to post-traumatic stress disorder (PTSD), anxiety, depression, eating disorders, sleep disorders and suicide ideation.[2, 10, 12] For example, around 75-80% of survivors have PTSD after the occurrence and 41% have PTSD after one year.[13-14] In addition, approximately 13-15% of survivors are living with depression and 12-40% are living with anxiety.[14] Suicide ideation occurs in 23-44% of survivors and up to 20% have attempted suicide.[14]

SV survivors use more medical services than their peers and incur 12-43% more in overall healthcare costs compared to the general population.[12] The cost of rape alone can total upwards of $122,461 per victim which includes but is not limited to medical costs as well as loss of productivity and criminal justice system fees.[2, 12] However, only 5% of SV survivors report their SV history to their primary care providers, which may limit engagement in treatment and care.[12]

Understanding the Impact of SV on the Brain

The experience of SV is also believed to impact brain functioning, with the temporal lobe seeming to be most commonly affected. The temporal lobe has a variety of functions from processing auditory signals like speech, processing visual information to send to the occipital lobe, and retrieving memory for semantic knowledge of objects.[15] Within the temporal lobe, the amygdala has been commonly studied in survivors, as it is primarily responsible for stress responses and the processing of emotional information including emotional behavior and motivation.[16-17] Studies have found amygdala volume differences,[18-20] hippocampal volume differences[20] as well as white matter and gray matter abnormalities[21-22] in survivors of SV. The cognitive impacts of SV have also been associated with emotion regulation difficulties and lower educational attainment.[23-24, 25-27]

There are several different types of neuroimaging technologies that can be used to understand how SV impacts survivors at the level of the brain. Some examples include functional magnetic resonance imaging (fMRI), positron emission tomography (PET) scans, and functional near-infrared spectroscopy (fNIRS) devices. An fMRI works by detecting the changes in blood oxygenation and flow during neural activity to create detailed scans.[28-30] During a PET scan radioactive material is injected or inhaled to create an image that displays brain activity.[30] An fNIRS is a portable headband technology that assesses regional tissue oxygenation, primarily detecting frontal lobe activity. The downside of fNIRS is that it lacks spatial resolution which makes it not as detailed as an fMRI or PET scan.[31] While all of these technologies have benefits and drawbacks, studies using any of these types of technologies were included in this review of neuroimaging studies.

Impact of SV on Behavior

The experience of SV is also associated with a number of risk behaviors, including binge drinking, smoking, and high-risk sexual decision making.[23-24] Estimates range between 13-49% and 28-61% for SV survivors that develop alcohol use disorders and substance use disorders respectively.[13] For example, a study by Silva et al[32] revealed that undergraduates who experienced childhood SV used more tobacco products, marijuana, hypnotics, and sedatives compared to than their peers who had not experienced SV. These differences in behavior may be explained by the aforementioned impacts of SV on the brain.

The socialization of gender and sexuality may also play into the impact of SV on behavior, as one study found that women survivors of childhood SV are more likely to experience higher rates of binge drinking than their male counterparts with similar experiences.[33-34] In addition, for middle-school and high school youth, binge-drinking rates and surviving SV occurred at higher rates for LGBTQ+ women in comparison to their cisgender, heterosexual male peers.[35] Violence against women specifically has been linked to emotional dysregulation, avoidance, numbing, and dissociation.[36] This reveals the potential impact of emotional and cognitive processes on SV survivor wellbeing and functioning, as well as differences that may occur based on the way gender is reinforced in society.

Impact of SV on Emotional Reactivity

As mentioned previously, women who are SV survivors are twice as likely to develop PTSD than their peers,[37] which is associated with variations in the volume of different brain structures.[38] Even exposure to acute emotional stress on its own can increase spine synapse formation in the basolateral amygdala, leading to anxious and avoidant behaviors.[38] Continued exposure to emotional stressors, like SV, has a compounding effect on these symptoms and behaviors[38] and can lead to volumetric asymmetry (e.g., smaller left than right amygdala).[39] Volumetric asymmetry of the amygdala is related to many neurological disorders including anxiety and PTSD, which can manifest as agitation, irritability, hostility, hypervigilance, self-destructive behavior, or social isolation.[40] This illustrates just one example of how neural changes related to SV impact the reactions and behaviors of SV survivors.

Those who experience SV can experience a heightened startle response, even if they do not formally qualify as having PTSD.[41] For example, a study by Jovanovic and colleagues[42] measured startle responses in a sample of adults that experienced early life trauma, finding that those who reported high levels of physical or sexual abuse had an increased startle response compared to demographically similar control groups. Startle responses can be a biomarker for stress responsiveness that may follow survivors into adulthood. Other studies have found higher cortisol in those who have experienced SV or other types of gender-based harm, which could in turn impact emotional reactivity and behavior.[43]

Survivors of gender-based harm like SV experience challenges processing and identifying emotions compared to their peers.[44-46] For example, Young and Widom[46] found that those with a history of childhood maltreatment, including but not limited to SV, had less accuracy than their peers in recognizing positive and neutral images. Relatedly, Muñoz-Rivas et al[47] investigated the variability of emotional dysregulation among women who experienced different types of intimate partner violence, linking emotional dysregulation to lower levels of physical health and multiple episodes of intimate partner violence to greater psychopathology and poorer emotional regulation. In these studies, there is also some evidence to suggest that different types of trauma uniquely affect neural bases of emotional reactivity. Young and Widom[46] found individuals who experienced physical abuse during childhood indicated less accuracy for identifying "emotionally neutral" photos while those with a history of sexual abuse and neglect were less accurate in recognizing photos with a more "emotionally positive" theme. In addition, Muñoz-Rivas et al[47] found that when comparing PTSD symptoms in interpersonal violence to other survivors of trauma, those that experience interpersonal violence displayed more PTSD symptoms and related behaviors compared to their peers. Similarly, Jovanovic et al[42] found a difference in startle times for persons who reported greater physical or sexual abuse compared to those who had lower levels of abuse. This substantiates the need for this review to look at the impact of SV specifically, rather than generalizing to all forms of interpersonal or gender-based trauma.

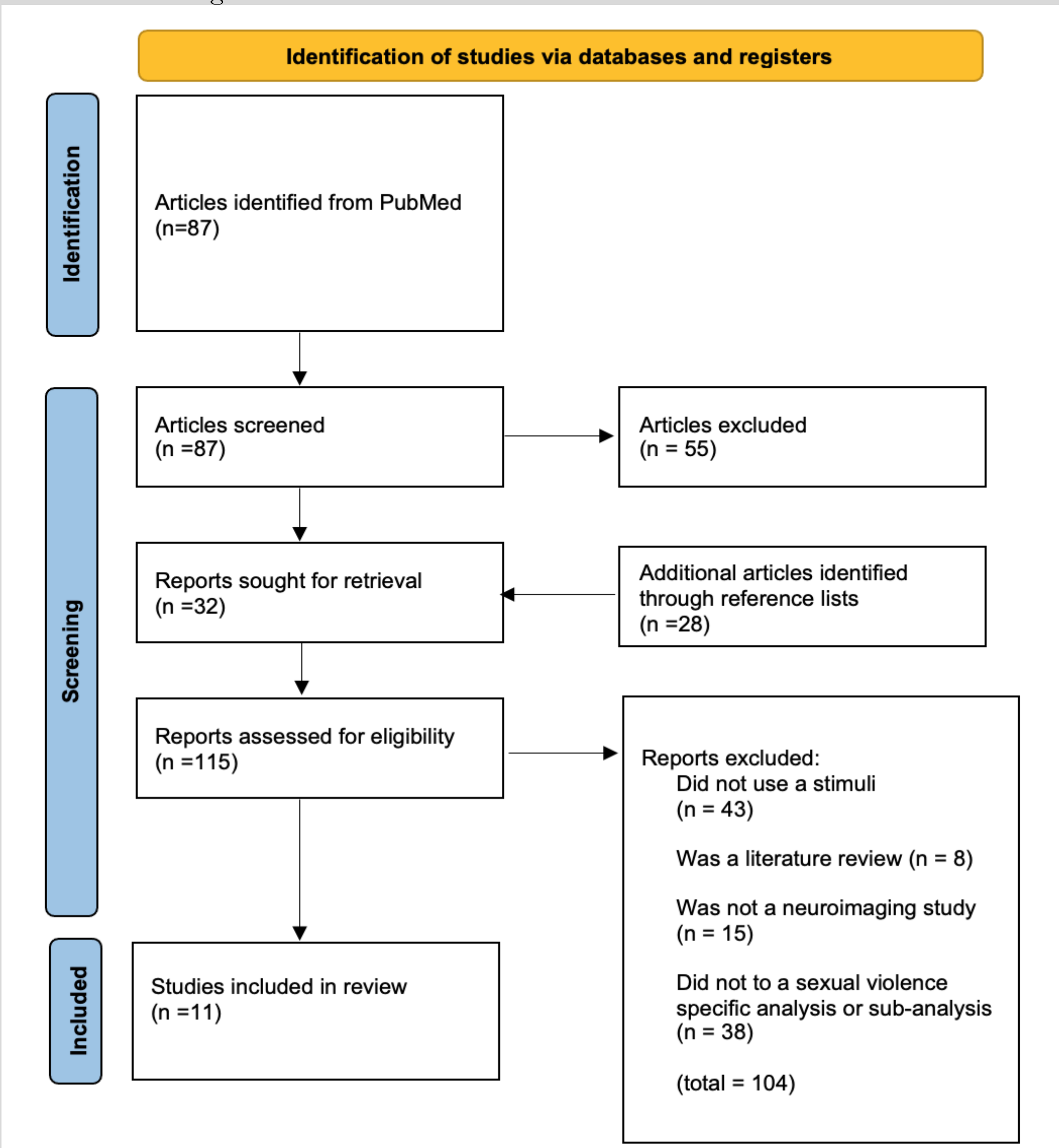
The Present Review

Given the need to better understand the links between SV exposure, the brain, emotional processing, and resulting behavior the present review seeks to aggregate articles that used neuroimaging techniques to explore SV survivor brain responses to emotional stimuli. A scoping review is ideal for beginning this endeavor, as scoping reviews serve to gather and examine the available evidence regarding emerging areas of science, such as neuroimaging with SV survivors.[48] This is a critical area of research, as understanding neural reactivity differences in survivors may lead to targeted interventions and additional brain exploration to create more multifaceted interventions designed to support the emotional and psychological health of survivors.

Methods

Our search was completed in October 2021. Studies published in PubMed before that date were identified using a search strategy created in collaboration with a library scientist. Key search terms included phrases relating to "sexual violence," "neuroimaging," and "emotional stimuli." See Appendix A for a detailed search. Studies were only included if they followed our aforementioned criteria, were empirical, and were written in English. Studies were excluded if they included samples of maltreatment or abuse generally and did not conduct SV-specific analyses. Our refined PubMed search yielded 87 studies. After reviewing titles and abstracts, 32 studies were included for full text review, with additional studies (n=28) added via selected studies reference lists. To screen the studies, one author reviewed all relevant abstracts and titles. Each study selected was then screened at the full-text level by the author and a senior author. The first and senior author made final decisions in collaboration on the included articles. Once final studies were selected, hand searching of their reference lists was done to identify any additional studies for inclusion that may have been missed. The end result yielded 11 studies (see Figure 1 for PRISMA diagram).

Figure 1: PRISMA Diagram



Inclusion Criteria

Participants. All races, genders, age groups, sexualities, and socioeconomic statuses were considered, given the global public health nature of this issue. All participants had to have had some type of sexual violence encounter in their lifetime.

Concept, Context, and Types of Studies. Sexual violence was operationalized as any non-consensual sexual harm that someone experienced. Key terms included, but were not limited to: sex offenses, sexual child abuse, sexual assault, rape, and adult survivors of child abuse. Emotional stimuli was operationalized as any sort of lab derived task intended to perpetuate frequent or intense emotional activity or arousal. Emotional stimuli included emotions, emotional correlates, cognition, emotion processing, and emotional faces. Lastly, the MeSH term "neuroimaging" included terms like fMRI, in addition to terms like fNIRS and PET scans. Only papers published in English were included.

Results

Eleven studies met the criteria after full text review. See Table 1 for a summary of the studies found. Ten of the 11 studies used an fMRI to measure brain responses, while Bremner et al[49] was the only study that used a PET scan. Five studies used facial stimuli.[50-54] Six studies used some other type of emotional stimuli.[49, 55-59] All studies were published between 2005-2019.

Table 1: Abbreviated Evidence Table of Articles Synthesized

Citation	Country	Emotion-related Tasks Used	Purpose/ Aims	Study Population	Type of Violence Experienced By Participants
Quidé, Y., Cléry, H., Andersson, F., Descriaud, C., Saint-Martin, P., Barantin, L., Gissot, V., Carrey Le Bas, M. P., Osterreicher, S., Dufour-Rainfray, D., Brizard, B., Ogielska, M., & El-Hage, W. (2018). Neurocognitive, emotional and neuroendocrine correlates of exposure to sexual assault in women. Journal of psychiatry & neuroscience : JPN, 43(5), 318–326. https://doi.org/10.1503/jpn.170116	France	**Facial stimuli & other tasks:** * emotional go/no-go task with face matching neutral, happy and sad facial expressions * N-Back working memory task with letters (1-back, 2-back, 3-back, 4-back) * Mental imagery task where participants were instructed to rest, or remember positive or negative memories.	This study investigated changes in cognition, emotional processing and brain function in the early stages after sexual assault.	Total (n=47), Female survivors of sexual assault within 4 weeks of the traumatic event (n=27), Age-matched controls (n=20), age range: 18-52, race/ethnicity: not specified	Sexual assault
van den Bulk, B. G., Somerville, L. H., van Hoof, M. J., van Lang, N. D., van der Wee, N. J., Crone, E. A., & Vermeiren, R. R. (2016). Amygdala habituation to emotional faces in adolescents with internalizing disorders, adolescents with childhood sexual abuse related PTSD and healthy adolescents. Developmental cognitive neuroscience, 21, 15–25. https://doi.org/10.1016/j.dcn.2016.08.002	Netherlands	**Facial stimuli:** Emotional face-processing task with fearful, neutral or happy faces of constrained conditions (""how afraid are you?"", ""how happy are you?"", and ""how wide is the nose?) and one unconstrained conditions passive viewing.	The current study examined habituation patterns of amygdala activity to emotional faces (fearful, happy and neutral) in adolescents with a DSM-IV depressive and/or anxiety disorder (N=25), adolescents with CSA-related PTSD (N=19) and healthy controls (N=26).	Total (n=71), Adolescents with a DSM-IV depressive and/or anxiety disorder (n=26), female (n=22), male (n=4),Adolescents with CSA-related PTSD (n=19), female (n=17), male (n=2), healthy controls (n=26), female (n=23), male (n=3), age range: 13-17, race/ ethnicity: not specified	Sexual abuse with PTSD, internalizing disorders, and healthy controls

Skokauskas, N., Carballedo, A., Fagan, A., & Frodl, T. (2015). The role of sexual abuse on functional neuroimaging markers associated with major depressive disorder. The world journal of biological psychiatry : the official journal of the World Federation of Societies of Biological Psychiatry, 16(7), 513–520. https://doi.org/10.3109/15622975.2015.1048723	Ireland	**Emotional Stimuli:** Emotional attention shifting task: asked to process visual stimuli and answer yes or no questions like "was it positive?," "was it negative?," and "was it neutral?" or to its shape "was it horizontal" or "was it vertical?."	This study aimed to clarify the role of sexual abuse (SA) on functional imaging markers associated with mdd.	Total (n=93), MDD without sexual abuse (n=37), female (n=25), male (n=17), MDD with sexual abuse (n=13), female (n=6), male (n=7), Healthy controls (n=43), female (n=23), male (n=20, age range: 18-65, race/ethnicity: not specified	Sexual abuse, Major Depressive Disorder (MDD)
Noll-Hussong, M., Otti, A., Laeer, L., Wohlschlaeger, A., Zimmer, C., Lahmann, C., Henningsen, P., Toelle, T., & Guendel, H. (2010). Aftermath of sexual abuse history on adult patients suffering from chronic functional pain syndromes: an fMRI pilot study. Journal of psychosomatic research, 68(5), 483–487. https://doi.org/10.1016/j.jpsychores.2010.01.020	Germany	**Emotional Stimuli:** Participants underwent an interview, imagining themselves to be in the painful situations depicted in the photos (“self”-perspective) and were instructed to rate the pain intensity from a “self”-perspective on a scale from 0 (no pain) to 9 (strongest pain imaginable).	This preliminary study investigates the neural-substrates of empathy-induced pain in multisomato-form pain patients “with vs. without” a history of sexual abuse during childhood.	Total (n=16), History of SV and suffer from multisomato-form pain disorder (n=8), female (n=7), male (n=1), non-abused, matched controls with multisomato-form pain disorder (n=8), female (n=7), male (n=1), age range: 22-67, race/ethnicity: German-speaking	Sexual abuse
New, A. S., Fan, J., Murrough, J. W., Liu, X., Liebman, R. E., Guise, K. G., Tang, C. Y., & Charney, D. S. (2009). A functional magnetic resonance imaging study of deliberate emotion regulation in resilience and posttraumatic stress disorder. Biological psychiatry, 66(7), 656–664. https://doi.org/10.1016/j.biopsych.2009.05.020	USA	**Emotional Stimuli:** In an event-related paradigm, neutral and negative pictures were presented. All pictures chosen for this study depicted human content, and during each trial, subjects received one of three auditory regulation instructions via headphones, to “diminish,” “enhance,” or “maintain” responses to negative pictures.	In this project, we examined the neural mechanisms underlying differences in response to sexual violence, focusing specifically on the deliberate modification of emotional responses to negative stimuli.	Total (n=42), Women with PTSD (n=14), Trauma-exposed women non-PTSD (n=14), Non-traumatized healthy women (n=14), age range: 20-55, Race/Ethnicity: Hispanic (n=12), African American (n=12), Caucasian (n=12), Asian (n=3), Other (n=2)	Sexual violence

Landré, L., Destrieux, C., Andersson, F., Barantin, L., Quidé, Y., Tapia, G., Jaafari, N., Clarys, D., Gaillard, P., Isingrini, M., & El-Hage, W. (2012). Working memory processing of traumatic material in women with posttraumatic stress disorder. Journal of psychiatry & neuroscience : JPN, 37(2), 87–94. https://doi.org/10.1503/jpn.100167	France	**Emotional Stimuli:** * For the identity task participants were sequentially presented 15 pairs of words for 2 seconds each, and they were instructed to determine whether words were identical or different on each trial. * For the 3-back task participants were presented 10 words for 3 seconds each, and they had to determine whether the item was identical to the one from 3 trials previous.	This study investigated the effects of trauma-related words processing on working memory in patients with PTSD.	Total (n=34), Women with PTSD (n=17), Controls (n=17), age range:18-40, race/ethnicity: not specified	Sexual abuse related PTSD
Bremner, J. D., Vermetten, E., Schmahl, C., Vaccarino, V., Vythilingam, M., Afzal, N., Grillon, C., & Charney, D. S. (2005). Positron emission tomographic imaging of neural correlates of a fear acquisition and extinction paradigm in women with childhood sexual-abuse-related post-traumatic stress disorder. Psychological medicine, 35(6), 791–806. https://doi.org/10.1017/s0033291704003290	USA	**Fear Stimuli:** Subjects were told at the beginning of the study that they would be exposed to electric shocks on their left wrist and viewing images on a screen during collection of PET and psychophysiology data. During habituation subjects were exposed to a blue square on a screen followed by a blank screen. One PET image of brain blood flow was obtained starting from the beginning of each of the blocks. During active fear acquisition exposure to the blue square (CS) was paired with an electric shock to the forearm.	We hypothesized increased amygdala function with fear acquisition, and decreased function or failure of activation in medial prefrontal cortex during fear extinction, in women with abuse-related PTSD compared with controls.	Total (n=19), Women with early childhood sexual-abuse-related PTSD (n=8), Women without abuse or PTSD (n=11), age range: 25-48, race/ethnicity: not specified	Childhood sexual-abuse-related post-traumatic stress disorder

Grant, M. M., Cannistraci, C., Hollon, S. D., Gore, J., & Shelton, R. (2011). Childhood trauma history differentiates amygdala response to sad faces within MDD. Journal of psychiatric research, 45(7), 886–895. https://doi.org/10.1016/j.jpsychires.2010.12.004	USA	**Facial stimuli:** The task was designed to identify the influence of valence on the efficiency of selective attention by emotion (positive, sad, and neutral) and level of task difficulty (non-conflict, congruent and incongruent). Participants were instructed to respond with a predetermined button press (index or middle key) to identify either male or female centralized target faces and asked to respond as quickly and accurately as possible.	We sought to determine whether heightened amygdala response is a core feature of depression or a general risk factor for psychopathology secondary to early life stress.	Total (n=36), Major Depressive Disorder (n=10), Major Depressive Disorder (n=10), healthy controls (n=16), female (n=21), male (n=15), race/ethnicity: not specified	Depression and early life trauma
Zhu, J., Lowen, S. B., Anderson, C. M., Ohashi, K., Khan, A., & Teicher, M. H. (2019). Association of Prepubertal and Postpubertal Exposure to Childhood Maltreatment With Adult Amygdala Function. JAMA psychiatry, 76(8), 843–853. https://doi.org/10.1001/jamapsychiatry.2019.0931	USA	**Facial stimuli:** The implicit emotional face-matching paradigm consisted of 3 blocks of negative faces and 3 blocks of neutral faces interleaved with 7 blocks of sensorimotor control (geometric shapes).	To identify the type and age of exposure to childhood maltreatment that are associated with hyperactive and hypoactive amygdala responses in young adulthood.	Total (n=202), total with childhood maltreatment (n=150), male (n=84), women (n=118), race/ethnicity: White (n=140), Asian (n=32), Black (n=18), Hispanic (n=26), Other (n=12)	Childhood Maltreatment

The majority of studies included adult participants. Van den Bulk et al[53] studied adolescents and Zhu et al[51] studied young adults. Four of the studies sampled adult women.[49, 52, 57, 59]

Countries of Publication. The studies were conducted in six different countries. Four studies came from the USA,[49, 51, 54, 59] two were from France,[52, 57] two were from Germany,[50, 58] one came from the Netherlands,[53] one came from Ireland,[56] and one was from Mexico.[55]

Emotional Facial Stimuli Used. Five studies used facial stimuli with positive, neutral, and negative faces. The negative faces varied from being described as fearful faces, sad faces, or negative faces. All studies used at least one type of negative face. Van den Bulk et al,[53] Grant et al,[54] and Quidé et al[52] all used happy or positive faces, neutral faces, and a negative face. Van den Bulk et al[53] used a face-processing task with fearful, neutral, or happy faces followed by randomly presented questions to participants about how afraid they were, how happy they were, and how wide the nose of the person they were viewing was on a four-point scale. While Van den Bulk et al[53] used fearful faces, Grant et al,[54] and Quidé et al[52] used sad faces as their "negative" stimuli. Grant et al[54] used a task to identify how positive, sad, and neutral faces influence the efficiency of selective attention and level of task difficulty. Participants were instructed to press a button and identify either male or female target faces. Similarly, Quidé et al[52] used happy, sad, and neutral facial expressions and presented participants with a target category of male or female and then asked to press a button only when the face matched their target category.

Zhu et al[51] and Dannlowski et al[50] used a related approach. Zhu et al[51] used an emotion face-matching paradigm with negative and neutral faces. Meanwhile, Dannlowski et al[50] had participants view a trio of faces expressing anger or fear and instructed them to select one of two faces on the bottom of the screen that was identical to the target face on top. Dannlowski et al[50] also used the same activity but with shapes like circles and ellipses.

Other Forms of Emotional Stimuli Used. Six studies that used other forms of emotional stimuli. One assessed emotions in social situations,[55] three showed emotional words and or pictures,[56-57, 59] and two used a fear-related task.[49, 58] One study had participants watch a video illustrating social situations where the participants' emotions, thoughts, and social intentions were assessed.[55]

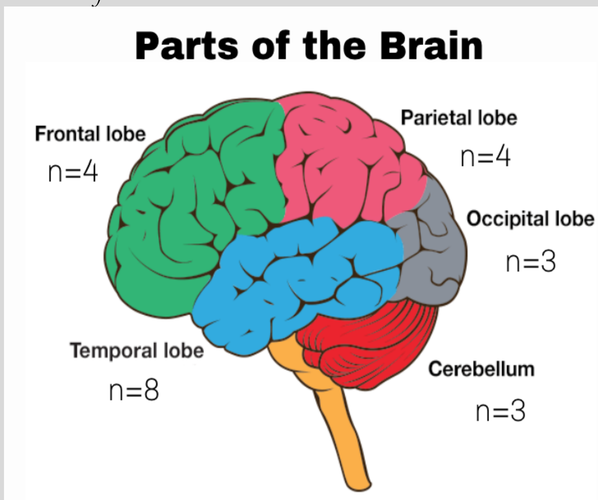
Similar to the facial tasks, Skokauskas et al[56] showed participants a picture and had them answer a yes or no question that referred either to the emotional valence of a picture and used the questions "was it positive?," "was it negative?," "was it neutral?" or to its shape "was it horizontal," or "was it vertical?." Likewise, New et al[59] used a similar event-related paradigm with neutral and negative pictures depicting human content to assess nontrauma-specific emotional processing. Participants were asked via headphones to do one of three regulation instructions to "diminish," "enhance," or "maintain" responses to negative pictures. In contrast, Landré et al[57] used a variety of tasks involving emotional or traumatic and neutral words.

Fear stimulating tasks were used during two different studies.[49, 58] In the study conducted by Bremner et al,[49] participants were randomly assigned into the active condition or control condition. Participants were exposed to fear acquisition and given electric shocks while viewing shapes on a screen. Noll-Hussong et al[58] had participants familiarize themselves with the stimuli and procedure before the neuroimaging. After the neuroimaging participants were told to imagine themselves to be in the painful situations depicted in the photos as a self-perspective exercise and rated the pain intensity on a scale from 0 (no pain) to 9 (strongest pain imaginable).

Brain Response Findings. Table 2 summarizes the brain responses studies synthesized found (see Figure 2 for a diagram indicating brain areas where response patterns were found). Findings displayed that in all of the studies, SV survivors displayed significantly heightened brain response patterns when exposed to emotional stimuli compared to control groups. Most commonly when displayed a stimuli, there was a heightened temporal lobe response (n=8) with the amygdala response being the most common within the temporal lobe (n=5).[49-51, 53-55, 57-58] Noll-Hussong et al[58] found lower activation in the left hippocampus. Three studies found an overall increase in amygdala activation.[50-51, 53] Grant et al[54] found activation of the right amygdala and Bremner et al[49] found activation of the bilateral amygdala. In addition to overall activation of the amygdala, van den Bulk et al[53] also found a left amygdala response.

Eleven studies met the criteria after full text review. See Table 1 for a summary of the studies found. Ten of the 11 studies used an fMRI to measure brain responses, while Bremner et al[49] was the only study that used a PET scan. Five studies used facial stimuli.[50-54] Six studies used some other type of emotional stimuli.[49, 55-59] All studies were published between 2005-2019.

Figure 2: Results in Different Parts of the Brain



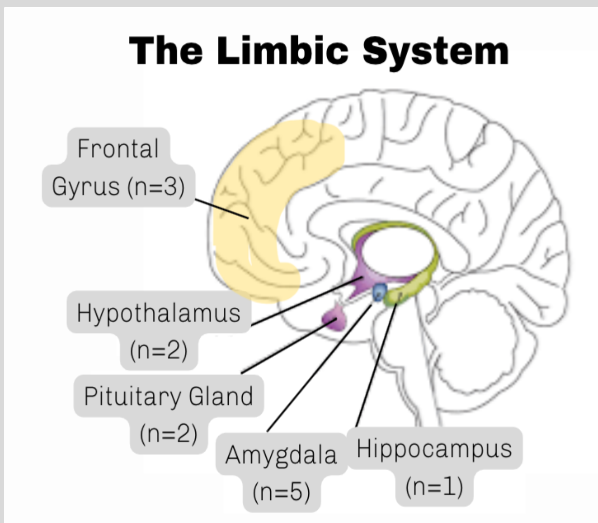


Table 2: Summary of Brain Responses to Emotional Stimuli

Parts of the Brain	# of Articles	References
Temporal Lobe	8	31-32, 34-37, 39-40
Amygdala Specific (found in temporal lobe)	5	31-32, 34-36
Parietal Lobe	4	31, 38-39, 41
Frontal Lobe	5	31, 37, 39-41
Frontal gyrus (found in frontal lobe)	3	31, 39-40
Occipital Lobe	3	31, 36, 39
Cerebellum	3	31, 33, 39
Cortisol (Hypothalamus, pituitary gland, adrenal glands)	2	32, 33

Skokauskas et al,[56] Landré et al,[57] and New et al[59] found higher activation in the parietal lobules. Skokauskas et al[56] identified higher responses specifically in the left inferior and superior parietal lobe. New et al[59] found activation of the intraparietal sulcus. However, Bremner et al[49] found a decreased function in inferior parietal lobule function.

Five studies found responses in the frontal lobe. Bremner et al[49] and Duque-Alarcón et al[55] found responses in the medial prefrontal cortex (MPFC). Bremner et al[49] found connectivity of the left MPFC with other parts of the brain and Duque-Alarcón et al[55] found decreased function in MPFC. New et al[59] found activation of the lateral prefrontal cortex. Landré et al[57] found overactivation of the left pars orbitalis. Landré et al[57] also found activation in the motor cortex with activations in supplementary motor areas and activations in premotor cortex. Noll-Hussong et al,[58] Landré et al,[57] and Bremner et al[49] found higher activation of the frontal gyrus. Noll-Hussong et al[58] and Landré et al[57] found higher activations in the left lateral and medial superior frontal gyrus while Bremner et al[49] found increased activation in the right inferior frontal gyrus.

Three studies identified cerebellar activation.[49, 52, 57] Quidé et al[52] found deactivation in the dorsal anterior cingulate cortex. Both Quidé et al[52] and Zhu et al[51] found cortisol responses. Quidé et al[52] found lower levels of morning cortisol while Zhu et al[51] found an increased adrenocortical response.

Activation in the occipital lobe was found by Landré et al[57] and Dannlowski et al.[50] Specifically, Landré et al[57] found activation of the superior and middle occipital gyrus. Bremner et al[49] found a decreased function in the visual association cortex.

Discussion

The findings of these studies suggest that a history of SV is associated with neurocognitive changes in response to emotional stimuli. SV survivors displayed significantly heightened brain response patterns in the temporal lobe (n=8), parietal lobe (n=4), and frontal lobe (n=5). Ten of the 11 studies used functional magnetic resonance imaging (fMRI) to measure brain responses, while one[49] used a PET scan. The emotional stimuli used varied greatly across studies, making it difficult to draw definitive conclusions on relationships between emotional stimuli and brain reactivity.

This review revealed that brain differences were most often seen in the temporal lobe, with the most studied areas being the amygdala and hippocampus. This could explain differences in learning and memory (hippocampus) and heightened incidences of anxiety, depression, and PTSD (related to amygdala dysfunction) that is frequently seen in SV survivors compared to their peers. SV.[2, 17, 60-62] In addition, activation in the parietal lobes was seen in several studies, which has been linked to differences processing somatosensory information.[63] This could explain why trauma from SV has been associated with physical pain, chronic pain, and disability.[64]

Five studies found responses in the frontal lobe,[49, 55, 57-59] with three of these studies finding activation in the frontal gyrus, a large brain region with a variety of functions mostly related to cognition.[65-66] Responses in this area could indicate decreased cognitive functioning, which has been found in survivors of SV in other studies.[67]

The emotional stimuli used varied across studies, making it difficult to draw definitive conclusions in this review. In addition, many studies lacked accompanying behavioral data, making it difficult to discern how these brain differences impacted subsequent behavior. Future research should attempt to repeat the studies synthesized with larger and more diverse SV survivor samples to better articulate connections between survivor brain responses, emotions, and behavior.

This review revealed several gaps in this area of research. For example, men and non-binary people who experienced SV were not studied in any of the research synthesized. In addition, many of these studies had primarily white samples or did not take note of the races and ethnicities included. Third, sample sizes were small across studies, although this may be a function of the expense associated use of fMRI and PET scans. By using newer, cost-effective, and less invasive technology like fNIRS in future work, researchers can collect larger sample sizes on diverse trauma survivors.

This scoping review has several strengths and weaknesses. The weaknesses include reviewing articles available in English only, having only one researcher review titles and abstracts, and only using one database to retrieve scientific literature. While we used PubMed due to consultation with a library scientist who indicated that this was the most comprehensive database for this topic, there may be other databases with studies that are not indexed in PubMed that could give us additional results. In addition, due to the limited number of articles found and the wide variety of emotional stimuli used, caution should be used when interpreting the overall findings of this review. Additional research is needed to better understand not only how SV impacts the brain, but how this impact manifests as behavior or adverse health outcomes.

Conclusion

SV appears to impact reactivity in several areas of the brain. The amygdala appears to be the area most frequently affected and showing the most changes in response to emotional stimuli. Future research should build on these findings with the goal to develop behavioral, cognitive, and neurological interventions to support SV recovery. By understanding the impact of SV on the brain and behavior, we can provide better psychoeducation to patients, understand intervention targets, and measure the impact of interventions at the level of the brain.

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Conflicts of Interest
The authors have no conflicts of interest to declare.

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Statement of Contributions
Elizabeth Pierson led the literature investigation and analysis. She also was responsible for data curation and writing the original manuscript draft. Laura Sinko conceptualized the project and supervised the review methodology. She also supervised the drafting of the manuscript and critically reviewed and edited the final document.

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