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Review

Bullying's anatomy: How it affects brain structure and function. A systematic review

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ABSTRACT

Bullying victimization is a common problem among adolescents with many catastrophic sequelae, as it has been associated with psychiatric disorders such as anxiety and depression. Identifying bullying print on the human brain could be useful in clinical practice, specifically in the secondary prevention of the disorders that are related to it. This review aims to explore the potential bullying-related changes of the human brain from a descriptive and functional anatomic perspective. A literature search was performed using the PubMed/Medline database, and, following meticulous screening, 16 articles were finally used. Our review included magnetic resonance imaging (MRI) and functional MRI studies, which were focused on gray and white matter structures of the brain. Bullying affects the morphology and function of gray and white matter structures in both victims and perpetrators. Victims seem to have atrophic hyperactive orbitofrontal cortex, hypertrophic hypoactive amygdalae, and increased cortical activation in almost all brain lobes. Bullies, on the other hand, have hyperactive accumbens nuclei. Fundamental nuclei of the limbic system, namely the nucleus accumbens and amygdala, are affected in both victims and perpetrators. Bullying changes the human brain morphologically and functionally, primarily affecting structures of the limbic system. Identifying these changes early could mainly help in the prevention of the expression of psychopathology and thus improve the quality of life of victims and even help bullies to seek medical help.

KEYWORDS: Amygdala, brain imaging, bullying, magnetic resonance imaging, nucleus accumbens, orbitofrontal cortex.

Introduction

Bullying is defined as a specific form of intentional, repeated aggression that involves a disparity of power between the victim and perpetrator. The aggression can take physical, verbal, or gestural forms.[1] One more common type of bullying is cyberbullying, as people tend to get full access to the internet from a young age. Regarding its prevalence, bullying is a very common phenomenon among adolescents, as has been shown in numerous cross-sectional studies in various areas around the world.[2,3] Bullying victimization is associated with numerous consequences, including poor mental health, low mood, irritability, nervousness, and sadness.[4] More important, however, is its correlation with many psychiatric disorders such as depression, anxiety, and personality disorders.[5] Attention-deficit hyperactivity disorder has also been related to bullying victimization as well as perpetration.[6,7] Remarkably, bullying

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is also a risk factor for suicidal ideation and death by suicide in youth.[8] It is, thus, clear that bullying severely affects worldwide health and societies.

From a neuroanatomic point of view, it would be interesting to approach how bullying affects the human brain. In a clinical context, an easy way to explore this would be via neuroimaging studies. Are there specific imaging findings that correlate with bullying victimization or perpetration? Are brain areas particularly affected? And if so, could these be associated with the above-mentioned vulnerability to psychopathological conditions? And even further, could brain imaging studies help in the prevention of the clinical expression of these psychopathologies? Functional magnetic resonance imaging (fMRI) studies could potentially indicate areas of the brain that are under- or overactivated in response to bullying, whereas regular magnetic resonance imaging (MRI) studies could show areas of the limbic system that underwent structural changes because of bullying. Aiming to find answers to our questions, the purpose of this review is to explore the bullying print on the human brain, as well as its potential usefulness in clinical practice. More specifically, we aim to describe the association between bullying victimization and perpetration of certain imaging findings to potentially help in the secondary prevention of the mental health consequences of it and to motivate bullies to seek medical help.

Material and Method

Our review follows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.[9] Our methodology includes a study selection process, and afterwards, a quality assessment procedure in which we assessed our selected studies for their quality and bias.

Study selection

A literature search was conducted using the PubMed/Medline database for the terms "bullying" and "brain imaging, which retrieved 61 articles. The authors screened all articles published until December 2024 for potential suitability. Exclusion criteria were (i) reviews, (ii) conference abstracts, (iii) letters to editors and (iv) case reports, and (v) publications for which we could not retrieve the full text. English language publications, including foreign language publications with English abstracts, were included in this review. Articles relevant to the topic concerning brain imaging in bullying, were further analyzed. Overall, 16 articles were finally used for the analysis of this narrative review (figure 1).

Quality assessment

To assess the methodological quality of our selected studies, we used the Newcastle-Ottawa Scale (NOS)[10] to identify potential sources of bias regarding selection, comparability, and bias in outcome assessment of the eligible reports. Given that we used different types of studies, including case-control studies, cohort studies, and cross-sectional studies, we used an adapted NOS for each type of study that we used. A study with an NOS score of 7 or more was considered a "good" study. A quality assessment of our studies can be found in our article's Supplementary Material.

Results

Imaging studies on bullying were either MRI or fMRI studies.

Bullying victimization

Regarding bullying victimization, there were two main categories of studies: those focusing on gray matter areas, mainly the cerebral cortex, and those focusing on white matter tracts.

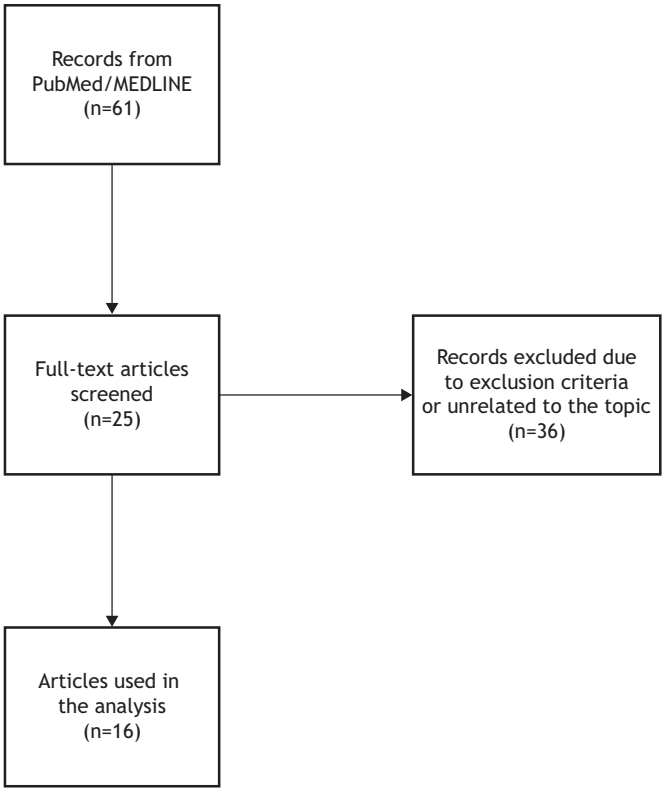

Figure 1. Study selection flowchart.

Gray matter areas

Structure

Delaney et al[11] studied bullying effects in brain structure and the role that family plays in minimizing them. More specifically, they reported greater amygdala volume in bullying victims across all family functioning levels, based on the results of the McMaster Family Assessment Device General Functioning Subscale[12,13] (higher score indicated healthier family environment), but the volume was less increased in those from a healthy family environment, indicating the importance of a healthy family environment in mitigating some of the effects of bullying victimization on the human brain.[11]

Without assessing the family environment, the study of Lee et al[14] found no statistically significant change in the volume of the amygdala and hippocampus. However, it was the only study we found that described an association between the volume of the nucleus accumbens and peer victimization. They found that peer problems were associated with adolescent depression through an increase in the volume of the nucleus accumbens, which could indicate increased sensitivity to social threat that resulted from repeated involvement with bullying.[14]

Nolfe et al[15] in their study, which involved patients who experienced bullying at their workplace and were diagnosed with psychiatric disorders (depression, anxiety, or a combination of symptoms), reported a statistically significant reduction in the size of both hippocampi, with a greater decrease in the left. A statistically significant reduction was also found in the volume of cortical Brodmann areas 18 (left inferior occipital gyrus), 19 (left cuneus), and 20 (right inferior temporal gyrus). Interestingly, no difference was found between the hippocampus volume and duration of the work distress, as well as the severity of the psychiatric symptoms.[15]

Quinlan et al,[16] was the first to describe a mechanism of anxiety in victimized peers and connected it to how bullying affects the developing brain. In their study in 2018, they found a connection between chronic peer victimization and reduction in the left putamen volume, which was also unique to peer victimization and unrelated to other types of stress.[16]

Furthermore, Vargas et al[17] in their study regarding bullying in typically developing and clinically high-risk adolescents, used MRI with diffuse tensor imaging (DTI) to examine both the structure of cortical areas of interest, as well as the fractional anisotropy (FA) of the uncinate fasciculus (white matter tract). Regarding gray matter, they found that increased bullying victimization was associated with smaller orbitofrontal cortex volume, whereas the hippocampi and amygdalae underwent no structural change.[17]

Function

Lim et al[18] performed a randomized control trial in which they observed the activation of specific brain areas during disgust processing in youth patients who had been victimized either by their peers or by their family, compared to controls. They reported significantly decreased activation in the right amygdala and bilateral posterior insula in bullying victims. They also reported lower activation in areas including bilateral hippocampi, thalamus, striatum, precuneus, inferior temporal areas, lingual and cerebellar regions, and other sensory and motor areas.[18]

Yang et al[19] reported a significant association between bullying and bilateral anterior insula activation, which was further associated with increased suicide risk. Other areas that were found to be activated apart from the insula involved visual regions such as the bilateral middle occipital and fusiform gyri, the supracallosal portion of the left anterior cingulate gyrus, and the medial portion of the left superior frontal gyrus.[19]

Kiefer et al[20] also studied the effect of previous bullying exposure and found that those who had experienced bullying victimization showed greater activation in the subgenual anterior cingulate cortex near the orbitofrontal cortex, pregenual anterior cingulate cortex, inferior frontal gyrus, left insula, dorsolateral prefrontal cortex, medial prefrontal cortex, superior temporal gyrus, and temporal pole. All those results were exhibited when the subjects were in an environment of social exclusion, which was created, meaning that bullying exposure had sensitized these areas.[20]

Finally, Swarz et al[21] in a cross-sectional study using fMRI reported patterns of amygdala activation for both bullying victims and perpetrators. More specifically, firstly, the participants were characterized as either bullying victims or bullies after completing the Peer Experiences Scale,[22] and then their amygdala activity was measured when they were exposed to angry and then fearful faces to see whether a certain pattern of activation could predict their self-reported status regarding bullying. As a result, they found that lower amygdala activity when exposed to both angry and fearful faces was associated with less relational bullying, meaning that bullying victims had higher amyg-

dala activity when exposed to either angry or fearful faces. Interestingly, their study involved only relational bullying, which is the type of aggression in which harm is caused by damaging someone's social status.[21] Table 1 summarizes the studies on gray matter areas affected by bullying victimization.

White matter tracts

Interesting results were also yielded from studies that focused on the white matter tracts of the brain. Lim et al,[23] apart from their findings on gray matter, also reported interesting findings on the white matter of the brain in another study. More precisely, they performed white matter tractography and tract-based spatial statistics in peer-victimized patients and controls and reported lower FA in the right uncinate fasciculus and bilateral inferior fronto-occipital fasciculi and higher FA in the bilateral inferior longitudinal fasciculi.[23]

Mulder et al[24] found greater global FA and lower global mean diffusivity (MD) in those who were victimized and socially excluded. They specifically reported greater FA in the corpus callosum, bilateral corona radiata, bilateral sagittal stratum, and left superior longitudinal fasciculus. They suggested that these findings could indicate accelerated white matter microstructure maturation in certain brain areas of children who are victimized.[24]

Graziano et al[25] studied 186 patients with depression, 88 of whom reported a previous history of bullying in their adolescence. DTI was obtained, and images with FA were produced, focusing on white matter tracts of major importance. The results showed that patients who had been bullied showed greater FA in the left posterior corona radiata and right medial lemniscus. These results could be explained by an overactivation of the fear network.[25]

Another study performed by Teicher et al[26] showed that those with exposure to verbal abuse, a major and common form of bullying, showed a significant dose-dependent increase in the MD in the splenium of the corpus callosum, as well as a positive association between exposure and both MD and radial diffusivity (RD) in the

Table 1. Summary of the studies on gray matter changes in bullying victims.

Study profile	Type of study	Primary finding	Secondary findings	Comments
Delaney et al 2023[11]	MRI	Increase in amygdala volume	–	Healthy family environment prevents the increase
Lee et al 2020[14]	MRI	Larger nucleus accumbens	–	–
Nolfe et al 2018[15]	MRI	Reduction in hippocampus volume	Reduction in Brodmann areas [18–20]	–
Quinlan et al 2018[16]	MRI	Reduction in left putamen volume	–	Unique to peer victimization
Vargas et al 2018[17]	MRI, DTI	Smaller orbitofrontal cortex	–	–
Lim et al 2024[18]	fMRI	Reduced activation of right amygdala, bilateral posterior insula	Reduced activation of limbic–thalamic–striatal areas, precuneus/posterior cingulate, temporal, fusiform/lingual and cerebellar regions	–
Yang et al 2023[19]	fMRI	Anterior insula activation	Activation of middle occipital gyrus, fusiform gyrus, left anterior cingulate cortex, left superior frontal gyrus	Association with suicide risk
Kiefer et al 2021[20]	fMRI	Greater activation in orbitofrontal cortex	Activation of anterior cingulate cortex, inferior frontal gyrus, left insula, prefrontal cortex, superior temporal gyrus, temporal pole	–
Swartz et al 2019[21]	fMRI	Lower amygdala activity when exposed to either angry or fearful faces	–	–

fMRI: functional magnetic resonance imaging; MRI: magnetic resonance imaging; DTI: diffuse tensor imaging

splenium of the corpus callosum and right posterior corona radiata. Regarding FA of the corona radiata and corpus callosum, this was initially found to be negatively associated with exposure to verbal abuse, although it was later proved to be statistically non-significant.[26]

Finally, Vargas et al[17] reported no statistically significant difference in the uncinate fasciculus FA of bullying victims. Table 2 summarizes the studies on white matter areas affected by bullying victimization.

Bullying perpetration

The study of Mackey et al,[27] although unrelated to bullying, also indicates a connection between lower volume in the frontomedial cortex and bilateral insulae in accordance with greater volumes in the ventral striatum, hypothalamus, and anterior thalamus and impulsivity, which leads to adversity and antisocial behavior.

Swarz et al,[21] apart from their findings regarding bullying victims, also found a pattern of amygdala activation that predicted previously self-reported bullying perpetration. More specifically, they found that increased activity in the bilateral amygdala when exposed to angry faces, in combination with lower amygdala activity when exposed to fearful faces, is associated with bullying perpetration. Finally, they also described a negative association between the activity of the bilateral rostral anterior cingulate cortex and bullying, meaning that those who are less prone to engage in bullying perpetration had higher activation in this area.[21]

Perino et al[28] studied bullying imaging from the perspective of the perpetrator as well. They reported increased activation in the ventral striatum, amygdala, medial prefrontal cortex, and insula. These interesting findings highlight the pathways of reward learning and motivation that are activated in bullies when experiencing social hierarchy.[28]

Additionally, Kim et al[29] studied the effect of cognitive behavioral therapy in brain imaging of bullying perpetrators. Their results showed decreased fractional amplitude of low-frequency fluctuations (fALFF) in the left lingual gyrus, inferior parietal lobule, left and right inferior frontal gyri, and right middle occipital gyrus. This could indicate a possible association of these areas with bullying perpetration.[29] Table 3 summarizes the studies on brain areas potentially involved in bullying perpetration.

Discussion

This review approaches the print of bullying on the human brain from both a descriptive and functional anatomic perspective, based on MRI and fMRI data, not only from victimized peers but also from those with an innate tendency to be more impulsive and prone to engage in bullying perpetration.

Regarding bullying victimization, many studies agree on a volume reduction in the orbitofrontal cortex,[17] as well as on its increased activation.[20] The orbitofrontal cortex, which is an important part of the limbic system, plays a critical role in emotion and decision-making by representing the reward or affective value of primary reinforcers like taste and touch, and learning to associate these with other stimuli to predict rewards. It is essential for emotion-related learning, subjective emotional experiences, and modulating these processes through attention and cognitive input.[30] The orbitofrontal cortex has also been found to be affected by environmental stimuli and to be involved in regulating the neurological response to chronic stress.[31] Finally, it can also be affect-

Table 2. Summary of the studies on white matter changes in bullying victims.

Study profile	Type of study	Primary finding	Secondary findings
Mulder et al 2022[21]	DTI	Greater global FA, Lower global MD	Greater FA in corpus callosum, corona radiata, sagittal stratum, left superior longitudinal fasciculus
Graziano et al 2019[22]	DTI	Greater FA in left posterior corona radiata	Greater FA in right medial lemniscus
Teicher et al 2010[23]	DTI	Greater MD, RD in corpus callosum (splenium) and right posterior corona radiata	Non-significant trend for decreased FA in corona radiata and corpus callosum
Vargas et al 2018[14]	MRI, DTI	No statistical significance in the uncinate fasciculus FA	--

DTI: diffuse tensor imaging; FA: fractional anisotropy; MD: mean diffusivity; MRI: magnetic resonance imaging; RD: radial diffusivity

Table 3. Summary of the studies on brain areas involved in bullying perpetration.

Study profile	Type of study	Primary finding	Secondary findings
Mackey et al 2017[24]	MRI	Lower volume in frontomedial cortex and insula	Greater volume in nucleus accumbens, hypothalamus, anterior thalamus
Swartz et al 2019[19]	fMRI	Increased amygdala activity in angry faces/ decreased in fearful faces	Negative association between the activity of rostral anterior cingulate cortex and bullying
Perino et al 2019[25]	fMRI	Increased nucleus accumbens activation	Increased activation of amygdala, medial prefrontal cortex, insula
Kim et al 2018[26]	fMRI	Decreased fALFF in left lingual gyrus and inferior parietal lobule	Decreased fALFF in right middle occipital gyrus and inferior frontal gyrus

fALFF: fractional amplitude of low-frequency fluctuations; fMRI: functional magnetic resonance imaging; MRI: magnetic resonance imaging

ed by other types of adversities during childhood, such as maltreatment.[32]

The hippocampus was a somewhat controversial structure regarding its association with bullying. Several studies suggested that its volume decreases in victimized peers,[15] while others report no significant change.[14,17] The duration of exposure to bullying could be the reason for this observation. Furthermore, the left putamen seems to suffer atrophy in child victims.[16]

The amygdala was another key nucleus with controversial results, while many studies were focused on it. Delaney et al,[11] studied its specific changes and described greater volume and increased activation in bullying victims. On the other hand, the studies of Vargas et al,[17] Yang et al,[19] Lee et al[14] and Lim et al[18] failed to confirm this finding. Again, the duration of exposure may play a role; however, it could not be proven since most studies did not specify the duration and degree of bullying victimization, and the one that did reported no association.[15] The amygdala was also associated with bullying perpetration, as the pattern of its activation that Swarz et al[21] described can lead to antisocial behavior. Additionally, their pattern of predicting antisocial behavior could potentially help those with the specific pattern of amygdala activation seek medical help and eliminate engagement in this behavior. The amygdala is important in regulating fear and has also been found to be overactive in depressed patients.[33,34]

Other areas that were possibly associated with bullying victimization include the insula and nucleus accumbens. The insula has many functions, including autonomic control, visceral sensations, etc. It also has a significant role in emotional experiences and feelings,[35] which indicates a potential link to bullying. The nucleus accumbens is the ventral portion of the striatum, receives cortical and limbic input, and is a major pleasure center and regulator of action selection.[36,37] Its overactivation that is suggested to be associated with bullying perpetration could be an interesting topic for future research to better understand how bullies are motivated towards their actions.[14]

Figure 2 shows a simplification of the current knowledge regarding structural and functional gray matter changes in bullying victims. Notably, these patients seem to have hypertrophic hypoactive amygdalae, atrophic hyperactive orbitofrontal cortex, and increased cortical activation in almost all brain lobes.

Regarding the white matter tracts of the brain, two of the studies showed greater FA (i.e., more homogenous fiber orientation, increased fiber density or axonal diameter, and increased ratio of intracellular/extracellular space) in the corona radiata, whereas another study did not confirm this finding (table 2). The corona radiata is a large white matter bundle that consists of ascending and descending fibers. Ascending fibers primarily connect the thalamus to the cerebral cortex, and descending fibers mainly connect the frontoparietal cortex to subcortical basal ganglia regions and the spinal cord.[38] It is not surprising that abnormalities in this tract have also been linked to other psychiatric conditions, such as depression.[39,40]

Answering our aim's questions, as analyzed above, we did identify specific imaging findings that correlate with bullying victimization and perpetration, namely morphological and functional alterations in many brain areas. And indeed, there are cortical brain areas, nuclei (figure 3), and white matter tracts, particularly affected either morphologically or functionally. As expected, most of them are parts of the limbic system, which plays a crucial role in emotions and behavior and is disturbed in common psychopathologies such as anxiety and depression. It is therefore at least partially explained why alterations in areas like the amyg-

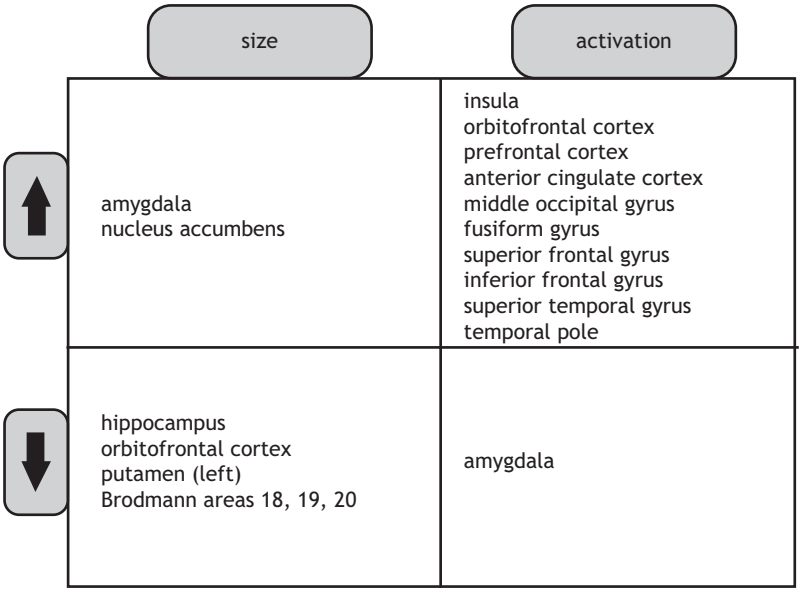

Figure 2. Simplification of gray matter (structural and functional) changes in bullying victims (↑, increase; ↓, decrease).

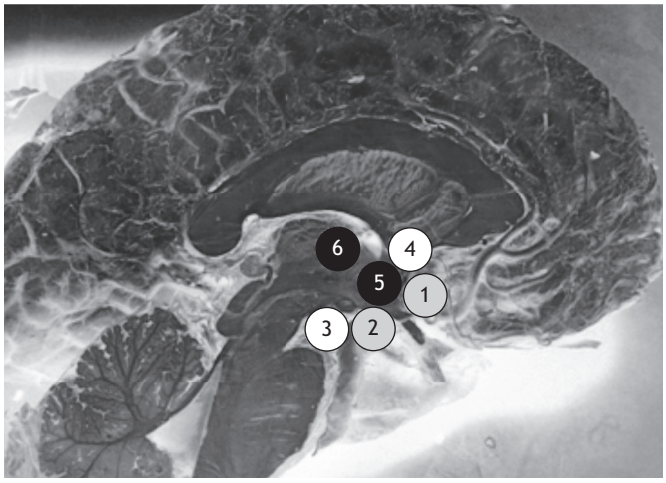

Figure 3. The human brain nuclei affected in bullying conditions (projection on the medial hemispheric surface). (1) nucleus accumbens; (2) amygdala; (3) hippocampus; (4) putamen (left); (5) hypothalamus; (6) anterior thalamus. White circles: nuclei affected in victims, black circles: nuclei affected in perpetrators, gray circles: nuclei affected in both victims and perpetrators (modified from Mavridis[37]).

dala and nucleus accumbens of bullying victims can make them vulnerable to depression and other anxiety disorders.

Given the fact that the imaging findings have been observed after bullying behaviors, it seems unlikely that these could be used in primary bullying prevention. However, they can be useful in secondary prevention by early identification of victims with brain imaging changes before the clinical manifestation of psychopathology. Early interventions could, thus, help in the avoidance of suicidal behaviors and other catastrophic sequelae of bullying on victims. Even for bullies, the evidence of overactive accumbens nuclei, for example, could be a red flag to seek medical help.

Conclusion

In conclusion, bullying is a serious social and health issue that changes the human brain morphologically and functionally, primarily affecting the limbic system. Fundamental nuclei of the latter, namely the nucleus accumbens and amygdala, are affected in both victims and perpetrators. Bullying victims seem to have atrophic hyperactive orbitofrontal cortex, hypertrophic hypoactive amygdalae, and increased cortical activation in almost all brain lobes. Bullies, on the other hand, have hyperactive accumbens nuclei. These findings can be useful in the early identification of victims before the expression of psychopathology (secondary prevention). Subsequent early interventions could help in the preservation of the victims' lives and their quality. It is certain that we still have a lot to learn about the way that bullying affects the human brain, and further research is needed in this direction, especially at a neurochemical/molecular level. Of course, primary prevention is always better than secondary, and our societies have therefore to maximize their efforts in this direction, i.e., fighting bullying as a social disease.

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Ανασκόπηση

Ανατομία του εκφοβισμού (bullying): Πώς επηρεάζει τη δομή και λειτουργία του εγκεφάλου. Συστηματική ανασκόπηση

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ΠΕΡΙΛΗΨΗ

Ο εκφοβισμός (bullying) είναι ένα κοινό πρόβλημα στους νέους με πολλές καταστροφικές συνέπειες καθώς σχετίζεται με ψυχιατρικές διαταραχές όπως το άγχος και η κατάθλιψη. Ο προσδιορισμός του αποτυπώματος του εκφοβισμού στον ανθρώπινο εγκέφαλο θα μπορούσε να χρησιμεύσει στην κλινική πράξη, ιδίως στη δευτερογενή πρόληψη των διαταραχών που σχετίζονται με αυτό. Η παρούσα ανασκόπηση έχει ως σκοπό να διερευνήσει τις δυνητικές σχετιζόμενες με τον εκφοβισμό αλλαγές του ανθρώπινου εγκεφάλου από μία οπτική περιγραφικής και λειτουργικής ανατομίας. Πραγματοποιήθηκε έρευνα της βιβλιογραφίας χρησιμοποιώντας τη βάση δεδομένων Pubmed/Medline και, μετά από ενδελεχή έλεγχο, χρησιμοποιήθηκαν τελικά 16 άρθρα. Η παρούσα ανασκόπηση περιέλαβε μελέτες συμβατικών και λειτουργικών μαγνητικών τομογραφιών, οι οποίες εστίασαν σε δομές φαιάς και λευκής ουσίας του εγκεφάλου. Ο εκφοβισμός επηρεάζει τη μορφολογία και τη λειτουργία δομών φαιάς και λευκής ουσίας σε αμφότερους τους θύτες και τα θύματα. Τα θύματα φαίνεται να έχουν ατροφικό υπερδραστήριο κογχομετωπιαίο φλοιό, υπερτροφικές υποδραστήριες αμυγδαλές και αυξημένη ενεργοποίηση του φλοιού σε όλους σχεδόν τους λοβούς του εγκεφάλου. Οι θύτες, από την άλλη πλευρά, έχουν υπερδραστήριους επικλινείς πυρήνες. Θεμελιώδεις πυρήνες του μεταιχμιακού συστήματος, δηλαδή ο επικλινής πυρήνας και η αμυγδαλή, επηρεάζονται σε αμφότερους τους θύτες και τα θύματα. Ο εκφοβισμός αλλάζει τον ανθρώπινο εγκέφαλο μορφολογικά και λειτουργικά, επηρεάζοντας πρωτίστως δομές του μεταιχμιακού συστήματος. Η έγκαιρη ανίχνευση αυτών των αλλαγών θα μπορούσε κυρίως να βοηθήσει στην πρόληψη της εκδήλωσης ψυχοπαθολογίας και συνεπώς να βελτιώσει την ποιότητα ζωής των θυμάτων και ακόμη να βοηθήσει τους θύτες να αναζητήσουν ιατρική βοήθεια.

ΛΕΞΕΙΣ ΕΥΡΕΤΗΡΙΟΥ: Αμυγδαλή, απεικόνιση εγκεφάλου, επικλινής πυρήνας, κογχομετωπιαίος φλοιός, μαγνητική τομογραφία, εκφοβισμός.

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