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CORRESPONDENCE

The contribution of brain volume to explain autonomous imbalance during recovery from acute stress in batterers

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Abstract

Aim Many authors have suggested that intimate partner violence (IPV) perpetrators present an imbalance between both branches of the autonomous nervous system when coping with acute stress. Concretely, there is a predominance of the sympathetic branches over the parasympathetic ones when recovering from stress. This imbalance can be explained by their tendency toward anger rumination, and more concretely, by their focus on thoughts of revenge during this period. Unfortunately, there is a gap in the scientific literature in terms of using magnetic resonance imaging (MRI) techniques to assess which brain structures would explain this tendency of IPV perpetrators when coping with acute stress.

Method The main objective of this study was to assess whether the gray matter volume (GMV) of relevant brain structures, signaled in previous scientific literature, moderates the association between thoughts of revenge and sympathetic activation during the recovery period, based on skin conductance levels (SCL) after being exposed to stress, in a group of IPV perpetrators ($n=58$) and non-violent men ($n=61$).

Results This study highlighted that the GMV of the left nucleus accumbens, right lobules of the cerebellum, and inferior temporal gyrus in IPV perpetrators moderated the association between thoughts of revenge and SCL during the recovery period. Accordingly, the higher the thoughts of revenge, the higher the sympathetic predominance (or higher SCL levels), especially among IPV perpetrators with the lowest GMV of these brain structures. Nonetheless, those variables were unrelated in the control group.

Conclusions Our study highlights the involvement of certain brain structures and how they explain the tendency of some IPV perpetrators to ruminate anger or, more precisely, to focus on thoughts of revenge when they recover from acute stress. These results reinforce the need to incorporate neuroimaging techniques during screening processes to properly understand how IPV perpetrators deal with stress, which in turn helps target their needs and design concrete intervention modules.

Keywords Brain volume · Intimate partner violence perpetrators · Neuroimaging · Skin conductance levels · Thoughts of revenge

Introduction

The application of psychophysiological and neuroimaging techniques in the forensic setting deepens our knowledge of the underlying foundations of violence perpetration (Glenn and Raine 2014; Lamsma et al. 2017). Intimate partner violence (IPV) represents a global health problem which has experienced a considerable increase, both during the COVID-19 pandemic lockdown (Ebert and Steinert 2021; World Health Organization 2020) and even after lockdown, with the number of women experiencing some form of violence perpetrated by their male partner still being high across the world (Sardinha et al. 2022). For these reasons,

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many scholars have dedicated important efforts to disentangling factors that may lead specific men to IPV perpetration given that the deeper the knowledge regarding these variables, the better the abilities of scholars and therapists to prevent it.

In recent years, psychophysiological studies assessing IPV perpetrators' response to acute laboratory stressors concluded that those men tend to be characterized by a marked imbalance between both branches of the autonomous nervous system (i.e., the sympathetic and parasympathetic nervous systems) when coping with different types of acute stressors (Pinto et al. 2010; Romero-Martínez et al. 2022). In fact, in humans, both branches of the autonomic nervous system tend to maintain a dynamic balance through a dual innervation of most organs. This helps individuals to adequately cope with a challenging context by employing or optimizing the body energy requirements (Porges 2011; Thayer et al. 2010; Wulsin et al. 2018). While the sympathetic nervous system (SNS) tends to activate the organism to effectively cope with acute stress by mobilizing energy, the parasympathetic nervous system (PNS) tends to return the body to the normal or initial state after stress, promoting restorative functions (recovery) (Critchley 2002; Porges 2011; Thayer et al. 2010; Wulsin et al. 2018). In IPV perpetrators, especially in those characterized by high impulsivity and emotionally driven violence, this imbalance or antagonistic association between both branches was especially evident during the recovery period or after acute stress. That is, during the restorative or recovery process of the organism. It seemed that instead of a predominance of PNS over SNS during recovery, these men showed higher or excessive SNS activation, measured with cardiorespiratory and electrodermal indicators, and lower PNS activation during this period when compared to non-violent men (Romero-Martínez et al. 2013, 2014, 2022; Sarrate-Costa et al. 2022; Vitoria-Estruch et al. 2018).

The predominance of SNS after ending laboratory stress tasks, which was indicated by high skin conductance (SCL) and reduced respiratory sinus arrythmia levels, might be indicative of the tendency of those men to reexperience and perseverate with angry thoughts focused on a concrete topic (i.e., negative events), more specifically, after the triggering stimuli disappears, which is known as anger rumination (Martin and Tesser 1996; Ray et al. 2008; Sarrate-Costa et al. 2022). This entails increases in SCL activation (or SNS predominance) during tasks in which subjects ruminate angry thoughts (Whinery et al. 2022). In this sense, the higher the anger rumination, including recurrent revenge thoughts, the higher the proneness to maintain and/or amplify the angry affect (Martin and Tesser 1996; Ray et al. 2008). This predominance of negative affect interferes with attention processing. Concretely, it can lead individuals to pay more attention to a stimulus that matches this emotional state and the source of provocation (Birkley and Eckhardt 2015; Yiend 2010). This, together with certain emotional instability and hostile cognitive attributions, facilitates violence intake under uncomfortable or uncertain circumstances (Alia-Klein et al. 2020). In this regard, the regulation of autonomic balance comprises different brain cortical and subcortical networks, with some of these brain areas overlapping to keep the balance between both branches (Beissner et al. 2013). Therefore, studying how the central nervous system (CNS) correlates with anger rumination beyond the analysis of the autonomic nervous system might help clarify our understanding surrounding this phenomenon.

Anger rumination processes, including revenge feelings, recruit different brain structures across the entire brain processes that underlie self-regulation, thought suppression, social cognition, arousal regulation, among others (Denson 2013). Some empirical research has highlighted that gray matter volume (GMV) alterations of the left middle frontal gyrus (left-MedFG) entails high scores in self-reports measuring anger rumination, and specifically reported a positive association between both (Wang et al. 2018). However, it is also necessary to contemplate other frontal structures, concretely the prefrontal cortex (PFC), and the role of the left orbitofrontal cortex (OFC) in inhibitory control, including inhibiting persistence of angry thoughts and revenge feelings (Romero-Martínez et al. 2019). Not only did these structures seem relevant for regulating anger rumination and/or processing anger emotions, so did the bilateral cerebellum, right lingual, angular and temporal gyrus (superior, middle, and inferior) (Alia-Klein et al. 2020; Klaus and Schutter 2021; Romero-Martínez et al. 2019), amygdala bilaterally (Nikolic et al. 2022; Romero-Martínez et al. 2019) and the left intracalcarine cortex (Jehna et al. 2011). Lastly, it is also necessary to keep in mind that feelings of revenge may bring a sense of satisfaction, depending on the outcome of such thoughts and the resulting consequences. In some cases, revenge feelings can sometimes lead to reinforcement, which tends to be associated with the differential activation and/or topography of structures such as the PFC and nucleus accumbens (bilateral). This helps maintain a negative association between both structures to regulate behavior (Chester and DeWall 2016). Thus, combining SNS measurements with the morphology of the previously mentioned brain structures could help develop a more comprehensive model for better understanding the tendency toward feelings of revenge (as part of an angry rumination processes) in IPV perpetrators after stress (or during the recovery period). Nonetheless, there is a gap in the scientific literature analyzing whether these brain structures would explain anger rumination, concretely, revenge feelings after coping with acute stress in IPV perpetrators.

Bearing all this in mind, the main objective of this study was to assess whether the structural or morphological analysis of the above-mentioned brain structures might moderate the association between revenge feelings, as a form of anger rumination, and sympathetic predominance, measured with the SCL, during the recovery period after acute stress exposure in a group of IPV perpetrators and another group of non-violent men. In accordance with previous empirical literature (Alia-Klein et al. 2020; Martin and Tesser 1996; Ray et al. 2008; Romero-Martínez et al. 2013, 2014, 2022, Sarrate-Costa et al. 2022; Vitoria-Estruch et al. 2018), we initially hypothesized that the higher the anger rumination, concretely, the tendency to experience revenge feelings, the higher the sympathetic predominance, higher SCL, during the recovery period in IPV perpetrators dealing with an acute laboratory stressor in a novel study with new data. Moreover, as stated above (Alia-Klein et al. 2020; Chester and DeWall 2016; Klaus and Schutter 2021; Nikolic et al. 2022; Romero-Martínez et al. 2019), the tendency to ruminate anger was associated with higher GMV in the left-MFG and OFC, but diminished GMV in the right lobules of the cerebellum, angular (AG), lingual (LG) and superior (STG) middle (MTG), and inferior temporal gyrus (ITG) amygdala bilaterally, left intracalcarine cortex (ICC) and nucleus accumbens. Therefore, we expected that the variations in GMV of these brain structures would moderate the association between anger rumination or revenge feelings and SCL during the recovery period in IPV perpetrators. Calculating these models would allow us to deepen our knowledge and comprehension of the underlying factors of IPV recidivism, while also targeting the future therapeutic focus of IPV interventions.

Method

Participants

From an initial sample of 125 participants, who were informed about the characteristics of the study and who voluntarily agreed to participate after written informed consent, six were removed from the statistical analysis. Concretely, three abandoned the study before completing it and the other three were removed due to failures during the fMRI acquisition (e.g., a considerable number of artifacts during acquisition…). Therefore, the final sample was composed of 58 IPV perpetrators and 61 controls.

All those male IPV perpetrators were recruited from the CONTEXTO Program. This is an intervention program, specifically a community-based psychoeducational intervention, which is mandatory for men convicted of gender-based violence (see Lila et al. 2018 for further details). Nonetheless, not all men convicted of gender-based violence receive this intervention program. In fact, only men with a gender-based violence sentence equal to or less than two years receive a sentence reduction on the condition that they attend this intervention program. This sentence includes causing injuries, mistreatment, threats with or without weapons or other dangerous instruments, coercion (physical, psychological, or sexual), insults, or minor unfair humiliation. In addition, another condition for the sentence reduction was for IPV perpetrators to have no previous criminal records, including IPV. It should be kept in mind that IPV perpetrators included in our study were classified as impulsive given that they committed IPV in reaction to marital conflicts without premeditation. Moreover, to take part in the study, not only was a sentence of less than two years necessary, but the absence of neurological (traumatic brain injuries, stroke, mild or severe cranioencephalic trauma, etc.) or mental disorders (e.g., schizophrenia, depression, alcohol and/or drug use disorder, etc.), current use of psychotropic medications as well as good comprehension of Spanish (i.e., writing and speaking skills), and an intelligence quotient (IQ) equal to or above 80 was also required, being measured with the Kaufman Brief Intelligence Test (Kaufman and Kaufman 1997). To check the criteria, all participants were interviewed and screened for neurological and mental disorders by two psychologists with an extensive experience in this field. To be included in the study, inter-rater agreement between the two qualitative interviewers had to be above 0.80 for the neurological and mental disorders. Additionally, it was necessary to meet additional criteria for the fMRI acquisition such as not having class III obesity (body mass index > 40), cranioencephalic metallic implants, and/or agoraphobia.

Except for the gender violence conviction, all the other inclusion criteria were the same for the control groups. That is, a group of men who presented similar anthropometric, socio-demographic (age, nationality, educational level, and/or laterality) and IQ to those of the IPV perpetrators. The absence of neurological or mental disorders, as stated above, was also required. Moreover, controls could have no previous criminal records (IPV or other type of conviction) or score below 1 on psychological abuse, physical assault, or sexual abuse on conflict tactics (Muñoz-Rivas et al. 2007; Straus et al. 1996). Controls were recruited in Valencia (Spain), and contact was made through advertisements posted on social networks and several advertisements published in the city of Valencia. After a first contact via e-mail, each control participant was interviewed and screened for neurological and/or mental disorders by two clinical psychologists. As in the case of IPV perpetrators, and inter-rater agreement above 0.80 between both raters was needed.

Finally, it should be kept in mind that the implementation and completion of this study was done in accordance with the Declaration of Helsinki and was also approved by the Ethics Committee of the University of Valencia (code: H1515749368278).

Procedure

To complete this study, participants needed to attend three experimental sessions, two of them in the Psychobiology laboratories at the University of Valencia and the third one in the Fe Health Research Institute (Supplementary Fig. 1).

Those who were included in the study after being screened (first session) and signed their informed consent were scheduled for the second session in the Faculty of Psychology between 4:00 and 7:00 p.m. This time frame was established due to the stability of several biological markers during this period (De Andrés-García et al. 2012). This session lasted approximately an hour and a half. Participants were taken to a noise-insulated room with a constant temperature of 22 ± 1 °C. First, socio-demographic characteristics were collected through a short, individual, and semi-structured interview and a set of self-reports, including the Anger Rumination Scale (ARS) (Ramos-Cejudo et al 2017; Sukhodolsky et al. 2001). Then, participants were submitted to a laboratory stress task, which lasted approximately 40 min. During this session, participants needed to respond to a set of neuropsychological tests to evaluate their cognitive performance in front of a committee of experts (of both genders). The experts tried to promote a social evaluative threat by offering negative feedback regarding participants' performance throughout the session (De Andrés-García et al. 2012; Romero-Martínez et al. 2013; 2014; 2022). SCL was registered continuously during four periods: resting (5 min), preparatory (5 min), stressor (20 min), and recovery (post-task; 10 min).

After ending the laboratory session, participants were scheduled within one week to undergo an MRI at the Fe Health Research Institute. This period of time between was established due to the considerable physical distance between the two research centers involved in the study and the working schedule of the participants. This lasted approximately 30 min, the participants were introduced to the MRI process and were asked to relax, keep their eyes closed, and remain awake, their heads empty of worries, that is, "not thinking about anything". Once the session ended, participants were thanked for their participation and received €100 to cover dietary and travel expenses.

Thoughts of revenge

This scale was part of the *Anger Rumination Scale (ARS)* developed by Sukhodolsky et al. (2001) and conveniently adapted to Spanish (Ramos-Cejudo et al 2017). Thoughts of revenge comprise several items which measure whether participants tend to present dreams and fantasies of a violent nature. Participants answer each item, rated on a four-point Likert scale (from 1 or almost never to 4 almost always), obtaining a total score by adding the score on each item. The higher the score, the higher the tendency to experience revenge feelings. Cronbach alpha for this study was 0.73.

Electrophysiological recording

For the recording of the psychophysiological signals, the Ambulatory Monitoring System (VU-DAMS) was employed, and the data were processed with data management and analysis software (DAMS) (http://www.vu-ams.nl/vu-ams/software/). For this study, the Biopac TSD203 was combined with isotonic gel (GEL101) to measure skin conductance levels (SCL), which was measured in microSiemens (μSi). Psychophysiological devices were placed in the medial phalanges of the index and ring finger. SCL has been widely employed as an indicator of sympathetic activation (Critchley 2002).

Magnetic resonance imaging data acquisition and analysis

For the brain volume measurement, magnetic resonance imaging (MRI) images were acquired on a 3 T magnet (Achieva TX, Philips Healthcare Best, The Netherlands) using an 8-channel head coil with parallel acquisition technology (SENSE). The acquisition protocol consisted of a T1-weighted high spatial resolution 3D gradient echo sequence with the following parameters: echo time = 3 s, repetition time = 6.2 s, flip angle = 100, voxel size = $1 \times 1 \times 1$ mm^3, and 6 min duration. The T2*-weighted MRI 2D echo planar BOLD sequence was acquired with the following main parameters TE = 35 ms, TR = 2000 ms, temporal dynamics = 265, pixel size = 1.8×1.8mm^2, slice thickness = 5 mm, and a total duration of 9 min.

All images were preprocessed with Statistical Parametric Mapping software, (SPM, https://www.fil.ion.ucl.ac.uk/spm/software/spm12/) from MATLAB (MathWorks, Inc., Natick, MA, USA), using the voxel-based morphometry (VBM) technique (Ashburner 2009; Salmond et al. 2002). The study atlas based on the Harvard Oxford atlas (https://scalablebrainatlas.incf.org/human/HOA06) was employed. We considered the following brain structures: left OFC, MedFG left, amygdala (bilateral), nucleus accumbens (bilateral), AG right, LG right, cerebellum lobules (bilateral), right temporal gyrus (STG, MTG and ITG), and ICC left.

Data analysis plan

Before applying moderation models, the pattern of significant zero-order correlations between the predictor (e.g., thoughts of revenge), moderators (gray matter brain region volume), and the predicted outcome (SCL recovery) had to be calculated for both groups separately, as stated by Hayes and Rockwood (2020). Then, when correlation analysis supported the interrelationship between variables, linear regression models were used to calculate moderation. Specifically, the existence of moderation was considered when the two-way interaction between predictor and potential moderator variables significantly increased the amount of explained variance of the predicted outcome. Finally, Hayes (2022) recommended that among significant moderation models it is important to test for simple slopes. That is, the interaction of each predictor and the moderators for "low (16th percentile)", "moderate (50th percentile)", and "high (84th percentile)" percentiles.

All statistical analyses were performed with IBM SPSS Statistics for Windows, Version 28.0, with the alpha level set at 0.05. Furthermore, to conduct the moderation analysis, we employed PROCESS 3.5 (Hayes 2022).

Results

Characteristics of participants are summarized in Table 1. Results of correlations between predictor, moderators, and predicted outcomes are summarized in Table 2 for IPV perpetrators and in Table 3 for controls. From all significant associated variables, it seemed that it would only be possible to test for four potential moderation models in IPV perpetrators. Initially, thoughts of revenge (predictor) were significantly and positively associated with SCL recovery. That is, the higher the tendency to ruminate anger, specifically presenting feelings of revenge, the higher the SCL during the recovery period. That is, IPV perpetrators exhibited increased sympathetic activation during a stage of the stress response that should be characterized by a shift to a dominant parasympathetic activation. Moreover, thoughts of revenge were significantly associated with the left nucleus accumbens, LG left, right lobules of the cerebellum and ITG which, in turn, were associated with SCL recovery.

Regarding the main objective of this study, we first applied a regression model (checking for moderation models) between thoughts of revenge and the potential moderators (nucleus accumbens left, LG left, cerebellum lobules right, ITG right, or ICC left) to predict SCL during recovery. From the five regression models that we conducted, three of them revealed a significant moderation model (Table 4), described below.

The interaction between both thoughts of revenge and nucleus accumbens left increased the amount of SCL recovery explained variance (R^2 change = 0.0693, F = 4.938, p = 0.0305, coeff = −92.29, SE = 41.53, t = −2.22; 95% CI −175.55 to −9.031), with the following values for the full model (R^2 = 0.2421, p = 0.0017). The Boostrap analysis revealed the following values for the interaction between predictor and moderator (coeff = −92.29, bootmean = −91.93, bootSE = 43.03, 95% CI −171.16 to −0.6460). The analysis of simple slopes highlighted the moderation to be exclusive to participants with 'low' nucleus accumbens volume (coeff = 0.0860, effect = 1.266, SE = 0.4073, t = 3.11, p = 0.0030, 95% CI 0.4497–2.082), but not moderate (standardized effect = 0.2503, SE = 0.3126, t = 0.8008, p = 0.4267, 95% CI −0.3763 to 0.8769) or high (effect = −0.4534, SE = 0.5436, t = −0.8341, p = 0.4079, 95% CI −1.543 to 0.6364). Hence, the higher the thoughts of revenge, the higher the SCL during recovery for IPV perpetrators with low volume in the left nucleus accumbens (Fig. 1).

Table 1 Means, standard deviations, percentages, and means comparisons for socio-demographic and psychological variables

	IPV perpetrators (n = 58)	Controls (n = 61)	t-test or chi-square
Age (*M, SD*)	41.40 (11.55)	38.57 (13.98)	1.19
BMI (M, SD)	22.73 (3.49)	22.69 (3.36)	0.06
Nationality (%)			
Spanish	91.4	89	3.27
Latin Americans	1.7	8	
Others	6.9	3	
Educational level (%)			
Primary/lower secondary	56	39	3.69
Upper secondary/vocational training	35	48	
University	9	13	
Laterality (%)			
Right-handed	91	89	0.267
Left-handed	9	11	

BMI body mass index, *IPV* intimate personal violence, *M* mean, *SD* standard deviation

Table 2 Correlations of brain regions volume and thoughts of revenge with skin conductance levels during recovery period for IPV perpetrators

	Thoughts of revenge	OFC left	MedFG left	Amygdala left	Amygdala right	Nucleus accumbens left	Nucleus accumbens right	AG right	LG right	Cerebellum lobules left	Cerebellum lobules right	Cerebellum vermis	STG right	MTG right	ITG right	ICC left
SCL recovery	0.341**	−0.268*	0.294*	−0.319*	−0.342**	−0.326*	−0.334*	0.014	−0.290*	−0.419**	−0.480**	−0.297*	0.076	0.070	−0.331*	−0.279*
Thoughts of revenge		−0.177	0.252	−0.180	−162	−0.289*	−0.222	0.141	−0.313*	−0.251	−0.274*	−0.067	0.056	−0.050	−0.289*	−0.290*

IPV intimate partner violence, *SCL* skin conductance levels, *OFC* orbitofrontal cortex, *MedFG* Medial frontal gyrus, *AG* angular gyrus, *LG* lingual gyrus, *STG* superior temporal gyrus, *MTG* middle temporal gyrus, *ITG* inferior temporal gyrus, *ICC* Intracalcarine cortex. Statistical significance *$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 3 Correlations of brain regions volume and thoughts of revenge with skin conductance levels during recovery period for controls

	Thoughts of revenge	OFC left	MedFG left	Amygdala left	Amygdala right	Nucleus accumbens left	Nucleus accumbens right	AG right	LG right	Cerebellum lobules left	Cerebellum lobules right	Cerebellum vermis	STG right	MTG right	ITG right	ICC left
SCL recovery	−0.073	0.053	−0.056	−0.136	−0.086	−0.078	−0.146	0.141	−0.020	−0.060	−0.010	−0.076	−0.116	−0.156	−0.090	0.101
Thoughts of revenge		−0.053	−0.142	0.063	0.048	−0.264*	−0.212	−0.239	−0.063	−0.227	−0.151	−0.133	−0.156	0.019	0.065	−0.043

SCL skin conductance levels, *OFC* orbitofrontal cortex, *MedFG* Medial frontal gyrus, *AG* angular gyrus, *LG* lingual gyrus, *STG* superior temporal gyrus, *MTG* middle temporal gyrus, *ITG* inferior temporal gyrus, *ICC* Intracalcarine cortex. Statistical significance *$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 4 Regression models testing the interaction between predictors thoughts of revenge with brain region volume to predict skin conductance levels during recovery period in intimate partner violence perpetrators

Skin conductance levels during recovery					
Effect	Estimate	SE	95% CI		*p*
			LL	UL	
Thoughts of revenge	9.201	3.883	1.416	16.98	0.0214
Nucleus accumbens left	341.21	217.5	−94.82	777.2	0.1225
Thoughts of revenge x nucleus accumbens left	−92.29	41.52	−175.5	−9.031	0.0305
Thoughts of revenge	−0.6707	4.596	−9.886	8.554	0.8845
LG right	−18.76	25.25	−69.38	31.85	0.4606
Thoughts of revenge x LG right	1.295	4.637	−8.003	10.59	0.7811
Thoughts of revenge	13.16	4.970	3.189	23.12	0.0106
Cerebellum lobules right	10.59	6.557	−2.557	23.74	0.1121
Thoughts of revenge x cerebellum lobules right	−3.178	1.246	−5.676	−0.6788	0.0137
Thoughts of revenge	10.64	4.622	1.374	19.91	0.0252
ITG right	26.89	18.93	−11.08	64.86	0.1614
Thoughts of revenge x ITG right	−7.299	3.351	−14.02	−0.5821	0.0337
Thoughts of revenge	3.381	4.043	−4.725	11.49	0.4068
ICC left	12.66	52.54	−92.68	118.01	0.8105
Thoughts of revenge x ICC left	−7.184	10.51	−28.26	13.89	0.4973

SE standard error, *CI* confidence interval, *LL* lower limit, *UL* upper limit, *LG* lingual gyrus, *ITG* inferior temporal gyrus, *ICC* intracalcarine cortex

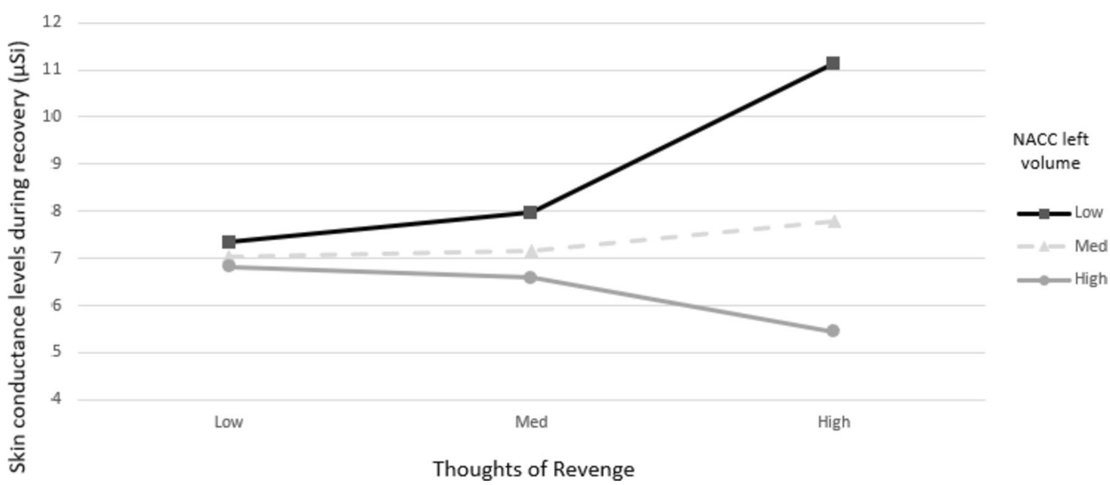

Fig. 1 Thoughts of revenge as a predictor of skin conductance levels during recovery moderated by NACC left volume in IPV perpetrators

Regarding the interaction between thoughts of revenge and the right lobules of the cerebellum, their interaction increased the amount of explained variance for SCL during recovery (R^2 change = 0.0776, F = 6.499, p = 0.0137, coeff = −3.178, SE = 1.246, t = −2.549; 95% CI −5.676 to −0.6788), the following values for the full model being (R^2 = 0.3556, p < 0.0001). Boostrap analysis revealed the following values (coeff = −3.177, bootmean = −3.072, bootSE = 1.378, 95% CI −5.626 to -0.2247). The analysis of simple slopes highlighted the moderation to be exclusive to participants with 'low' (coeff = 3.798, effect = 1.085, SE = 0.3397, t = 3.194, p = 0.0023, 95% CI 0.4040–1.766), but not to IPV perpetrators with 'moderate' (effect = 0.4584, SE = 0.2502, t = 1.832, p = 0.0724, 95% CI −0.0431 to 0.9600), or 'high' volume in the right lobules of the cerebellum (effect = −0.5536, SE = 0.4821, t = −1.148, p = 0.2559, 95% CI −1.520 to 0.4129). The SCL during the recovery period was higher in IPV perpetrators with a high tendency to ruminate thoughts of revenge, specifically, among those presenting lower volume in the right lobules of the cerebellum (Fig. 2).

The final model checked the interaction between thoughts of revenge and ITG right to predict SCL during recovery. Accordingly, the interaction of both

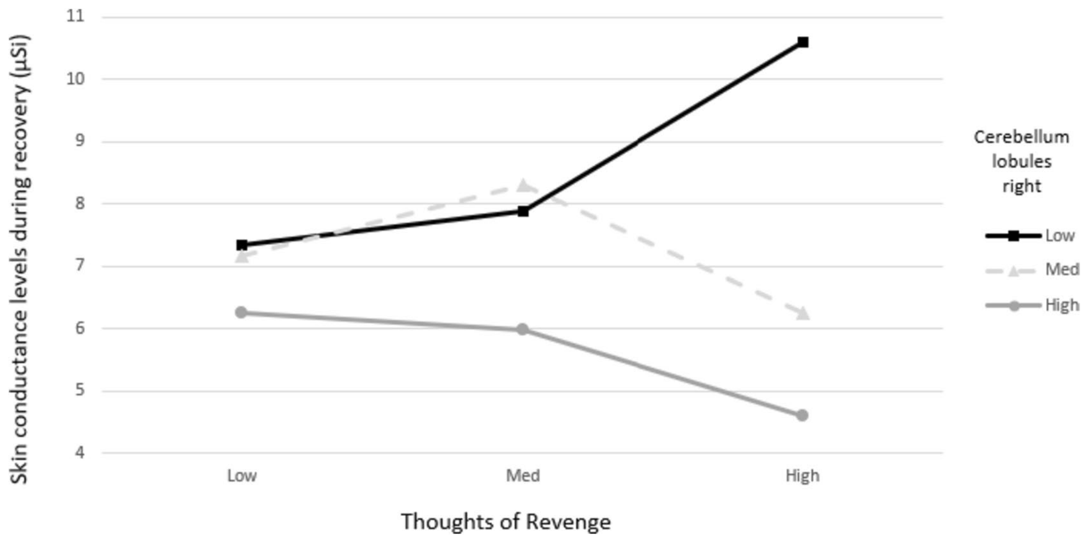

Fig. 2 Thoughts of revenge as a predictor of skin conductance levels during recovery moderated by right lobules of cerebellum in IPV perpetrators

variables increased the amount of explained variance (R^2 change = 0.0666, $F = 5.740$, $p = 0.0337$, coeff = −7.229, SE = 3.351, $t = -2.178$; 95% CI −14.02 to −0.5821), the following values for the full model being ($R^2 = 0.2418$, $p = 0.0017$). Boostrap analysis revealed the following values (coeff = −7.299, bootmean = −7.513, bootSE = 3.767, 95% CI −16.23 to −0.1987). The analysis of simple slopes highlighted the moderation to be exclusive to participants with 'low' (coeff = 1.134, effect = 0.3697, SE = 0.3697, $t = 3.068$, $p = 0.0034$, 95% CI 0.3931–1.875), and 'moderate' (effect = 0.6579, SE = 0.2739, $t = 2.401$, $p = 0.0189$, 95% CI 0.1087–1.207), but not to IPV perpetrators with 'high' volume of the right ITG (effect = −0.0493, SE = 0.3998, $t = -0.1232$, $p = 0.9024$, 95% CI −0.8508 to 0.7523). The SCL during the recovery period was higher in IPV perpetrators with a high tendency to ruminate thoughts of revenge, concretely, among those IPV perpetrators with a low and moderate volume in the right ITG (Fig. 3).

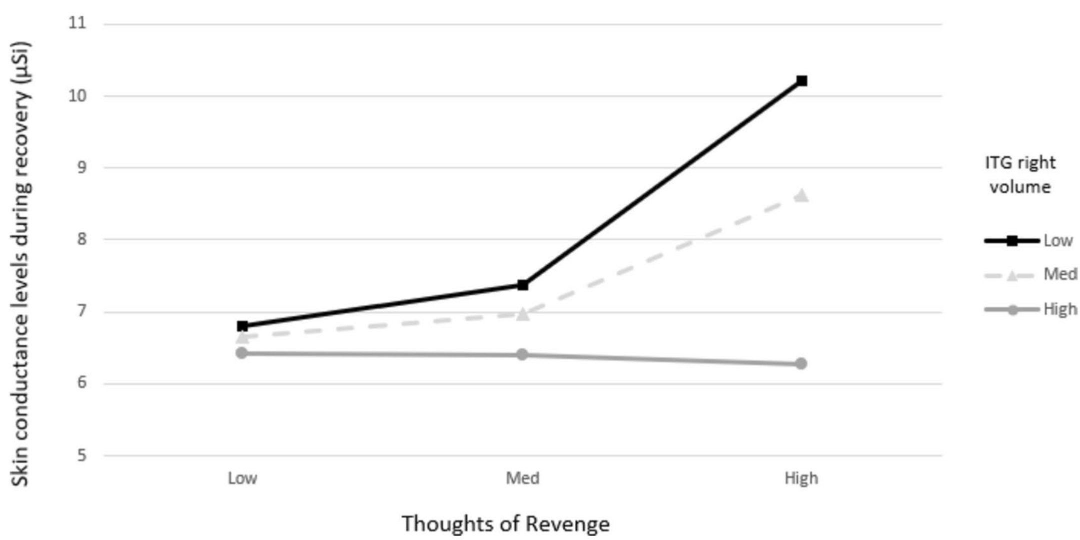

Fig. 3 Thoughts of revenge as a predictor of skin conductance levels during recovery moderated by ITG right volume in IPV perpetrators

Discussion

This study showed that the GMV of three brain structures (e.g., left nucleus accumbens, right lobules of cerebellum and ITG) in IPV perpetrators moderated the association between thoughts of revenge and SCL during the recovery period. In this sense, the higher the thoughts of revenge, the higher the sympathetic predominance (or higher SCL levels), especially among IPV perpetrators with the lowest GMV of these brain structures.

In our study, correlations revealed a positive association between the MedFG left and a sympathetic predominance (SCL levels during recovery period), while the rest of the brain structures (e.g., nucleus accumbens, amygdala, cerebellum, LG, ITG, and ICC) maintained a negative association with SCL, which is in line with previous results (Alia-Klein et al. 2020; Chester and DeWall 2016; Klaus and Schutter 2021; Nikolic et al. 2022; Romero-Martínez et al. 2019). Contrary to previous findings (Romero-Martínez et al. 2019), our data also highlighted that the OFC maintained a negative association with SCL. Moreover, the superior and middle temporal gyrus as well as the AG were unrelated to SCL and/or thoughts of revenge. For all of this, it should be kept in mind that not all previous empirical research employed the same instruments to measure anger rumination (i.e., self-reported anger rumination instead of laboratory procedures) or paid attention to GMV instead of brain activation. Therefore, we should be cautious when interpreting these conclusions.

The main objective of this study was to clarify whether the GMV of specific brain structures, previously highlighted by scientific literature, explained the association between anger rumination (i.e., thoughts of revenge) and SNA imbalance during the recovery period. The hypothesis was that a higher GMV of the left-MFG and OFC and a lower GMV of the right lobules of the cerebellum, angular (AG), lingual (LG) and temporal gyrus (superior, middle, and inferior) amygdala bilaterally, left intracalcarine cortex (ICC) and nucleus accumbens would moderate the association between rumination and sympathetic predominance, as concluded before in different violent and non-violent samples (Alia-Klein et al. 2020; Chester and DeWall 2016; Klaus and Schutter 2021; Nikolic et al. 2022; Romero-Martínez et al. 2019). Regarding the moderation models, we checked for five models, but only three of them were significant. Particularly, the lowest GMV of the left nucleus accumbens, right lobules of the cerebellum and ITG seemed relevant to anger rumination, which partly explained sympathetic predominance in IPV perpetrators. The main interest of nucleus accumbens was its relevance in the rewarding processes (Chester and DeWall 2016). It has been highlighted that the role of revenge thoughts toward their couples is particularly important in terms of maintaining this type of violence among IPV perpetrators (Stuart et al. 2006). Hence, the reinforcing role of revenge feelings might be a key point for certain modules in IPV interventions. In other words, focusing on models to deconstruct these cognitive schemas that sustain the relevance and pleasure of revenge and looking for alternative ways of dealing with couple conflicts, which in turn might diminish participants' desire for revenge (e.g., Nonjustice System Intervention) (Rowe et al. 2018).

Regarding the association with the right lobules of the cerebellum, this was the most relevant model as it explained the highest variance (around 36%) compared to the rest of the regression models (less than 25%). In line with previous research, it has been pointed out that reductions in GMV of the right cerebellum explained interpersonal violence proneness (Coccaro et al. 2016; Soloff et al. 2008; Wolfs et al. 2023; Zhang et al. 2018). Their facilitator role of violence was explained by its contribution to non-planning impulsivity. In addition, certain evidence has suggested that the cerebellum presents a specificity for processing angry stimulus, but not those with a positive content (e.g., happiness) (Park et al. 2010). In any case, the role of vermis should be clearly differentiated from the lobules of the cerebellum for violence proneness; whereas GMV of vermis maintained a positive association with interpersonal violence, reductions of lobules entailed a high risk. In our study, we not only concluded a differential role of lobules and vermis through revenge thoughts, but also differences between right and left lobules, being especially important the role of the right lobule of the cerebellum. Thus, it would be important not to neglect the role of the cerebellum to properly understand violence proneness in IPV perpetrators. That is, by not only stating that violence is the result of failures in the cortical circuit (PFC) and limbic structures, but also, to incorporate the cerebellum in this circuit (e.g., cortical (PFC)–limbic–cerebellar) due to its role in impulsivity and emotional stimulus processing.

The third model pointed out the importance of a reduced GMV of ITG for explaining sympathetic predominance during the recovery period. This brain structure presented an important contribution for visual perception and recognition as well as for semantic multimodal sensory integration, which affect lexical and phonological decisions (Buckley et al. 1997; Mesulam 1998; Tek et al. 2002). Moreover, this structure also presented a differential activation depending on the emotional content of lexical (Hsu et al. 2015), with its activation being especially accused in violent individuals when processing stimulus with violent content (Nikolic et al. 2022). In this study, the reduced GMV was relevant to explain the tendency of some IPV perpetrators to ruminate anger (revenge).

This is the first study that has tried to introduce neuroimaging techniques together with other psychobiological indicators to explain the main reasons some IPV perpetrators present an ANS imbalance when they recover from an acute stressor. Despite its novelty and the strength of incorporating biological markers in laboratory procedures and self-reports, it is necessary to keep in mind some limitations that might impact the external validity of our conclusions which, in turn, might help guide future research in the field of IPV. First, we applied regression models to explain sympathetic imbalance, but this was employed to a relatively homogeneous and reduced sample, mainly Spanish men with no psychopathologies, which directly impact the generalizability of these findings. Furthermore, if we attend to the cross-sectional nature of the study, we cannot establish a causal association between variables. Additionally, regression models explain approximately 40% of the variance in the sympathetic imbalance, so we should assume the involvement of other factors which are not contemplated in our study. That is, we need a multidisciplinary approach beyond biological factors to better understanding the complex phenomenon of IPV. Regarding the instruments employed in our study, thoughts of revenge were measured with a self-report instead of a laboratory procedure. Thus, to reliably replicate our conclusions, future research should include a larger sample size as diverse as possible, which would increase external validity. Second, we only paid attention to specific brain structures instead of incorporating all brain divisions of the Oxford atlas. Although this could be considered as a potential limitation, we reinforce the need to focus on concrete brain structures to reduce the number of comparisons in a reduced number of participants, which considerably increases the risk of type 1 error. That is, future studies should include the volume measurements of other brain regions which are critical for anger modulation such as the entorhinal cortex, cingulate gyrus, and the regions of the PFC that are not contemplated in this research. Third, there are inherent limitations in the psychophysiological (transduction of galvanic signals, etc.) and MRI instruments (e.g., resolution, statistical models employed for preprocessing images, etc.), which should be considered when building complex models to properly understand IPV perpetrators' proneness to violence. In fact, for future research, it would be important to combine SNS and PNS (e.g., respiratory sinus arrhythmia) by employing appropriate instruments. Finally, it is important to note that we did not design a concrete laboratory produce to measure thoughts of revenge, which could be important for future research.

In summary, our study offers valuable information with a clear application in forensic practice to design therapeutic modules focused on appropriately dealing with stress and reducing anger rumination tendencies. Nevertheless, it is still important to be cautious about the interpretation of our results and to combine these techniques with other behavioral instruments to clarify the importance of anger rumination in IPV proneness. Moreover, our results highlight the existence of differential profiles of IPV perpetrators when dealing with acute stress, given that statistical models explained less than 40% of the explained variance. Therefore, future studies should consider all these questions when conducting adequate research and conducting it in clinical practice.

Even though it is important to be cautious regarding the clinical applications of our conclusions, due to important limitations of the current research, our research reinforces the need for clinical psychologists and specialists in forensic settings, especially in the field of IPV, to combine their efforts with other professionals such as psychobiologists, medical doctors, among others, to adopt a multidisciplinary approach that allows us to better understand a complex phenomenon such as IPV which, in turn, would allow us to design different screening tools and therapeutic programs. The better our knowledge regarding characteristics of IPV perpetrators, the better our ability to attend to their therapeutic needs which, in turn, would positively impact the reduction of recidivism.

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Author contributions AR-M and MB wrote the main manuscript text. AR-M, BS and CS-C, administered the project and applied statistical analysis. All the rest of the authors critically reviewed the manuscript."

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Data availability The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that have no conflict of interest.

References

Alia-Klein N, Gan G, Gilam G, Bezek J, Bruno A, Denson TF, Verona E (2020) The feeling of anger: from brain networks to linguistic expressions. Neurosci Biobehav Rev 108:480–497. https://doi.org/10.1016/j.neubiorev.2019.12.002

Ashburner J (2009) Computational anatomy with the SPM software. Magn Reson Imaging 27(8):1163–1174. https://doi.org/10.1016/j.mri.2009.01.006

Beissner F, Meissner K, Bär KJ, Napadow V (2013) The autonomic brain: an activation likelihood estimation meta-analysis for central processing of autonomic function. J Neurosci

33(25):10503–10511. https://doi.org/10.1523/JNEUROSCI.1103-13.2013
Birkley EL, Eckhardt CI (2015) Anger, hostility, internalizing negative emotions, and intimate partner violence perpetration: a meta-analytic review. Clin Psychol Rev 37:40–56. https://doi.org/10.1016/j.cpr.2015.01.002
Buckley MJ, Gaffan D, Murray EA (1997) Functional double dissociation between two inferior temporal cortical areas: perirhinal cortex versus middle temporal gyrus. J Neurophysiol 77(2):587–598. https://doi.org/10.1152/jn.1997.77.2.587
Chester DS, DeWall CN (2016) The pleasure of revenge: retaliatory aggression arises from a neural imbalance toward reward. Soc Cogn Affect Neurosc. https://doi.org/10.1093/scan/nsv082
Coccaro EF, Fitzgerald DA, Lee R, McCloskey M, Phan KL (2016) Frontolimbic morphometric abnormalities in intermittent explosive disorder and aggression. Biolog Psychiatry 1(1):32–38. https://doi.org/10.1016/j.bpsc.2015.09.006
Critchley HD (2002) Electrodermal responses: what happens in the brain. Neuroscientist 8(2):132–142
De Andrés-García S, Moya-Albiol L, González-Bono E (2012) Salivary cortisol and immunoglobulin A: responses to stress as predictors of health complaints reported by caregivers of offspring with autistic spectrum disorder. Horm Behav 62(4):464–474. https://doi.org/10.1016/j.yhbeh.2012.08.003
Denson TF (2013) The multiple systems model of angry rumination. Pers Soc Psychol Rev 17(2):103–123. https://doi.org/10.1177/1088868312467086
Ebert C, Steinert JI (2021) Prevalence and risk factors of violence against women and children during COVID-19, Germany. Bull World Health Organ 99(6):429
Glenn AL, Raine A (2014) Neurocriminology: implications for the punishment, prediction and prevention of criminal behaviour. Nat Rev Neurosci 15(1):54–63. https://doi.org/10.1038/nrn3640
Hayes AF (2022) Introduction to mediation, moderation, and conditional process analysis: a regression-based approach, 3rd edn. The Guilford Press, Newyork
Hayes AF, Rockwood NJ (2020) Conditional process analysis: Concepts, computation, and advances in the modeling of the contingencies of mechanisms. Am Behav Sci 64(1):19–54. https://doi.org/10.1177/0002764219859633
Hsu YC, Lo YC, Chen YJ, Wedeen VJ, Isaac Tseng WY (2015) NTU-DSI-122: a diffusion spectrum imaging template with high anatomical matching to the ICBM-152 space. Hum Brain Mapp 36(9):3528–3541. https://doi.org/10.1002/hbm.22860
Jehna M, Neuper C, Ischebeck A, Loitfelder M, Ropele S, Langkammer C, Enzinger C (2011) The functional correlates of face perception and recognition of emotional facial expressions as evidenced by fMRI. Brain Res 1393:73–83. https://doi.org/10.1016/j.brainres.2011.04.007
Kaufman A, Kaufman N (1997) K-BIT Test Breve de Inteligencia [K-BIT Brief Intelligence Test]. TEA
Klaus J, Schutter DJ (2021) Functional topography of anger and aggression in the human cerebellum. Neuroimage 226:117582. https://doi.org/10.1016/j.neuroimage.2020.117582
Lamsma J, Mackay C, Fazel S (2017) Structural brain correlates of interpersonal violence: systematic review and voxel-based meta-analysis of neuroimaging studies. Psychiatry Res 267:69–73. https://doi.org/10.1016/j.pscychresns.2017.07.006
Lila M, Gracia E, Catalá-Miñana A (2018) Individualized motivational plans in batterer intervention programs: a randomized clinical trial. J Consult Clin Psychol 86(4):309. https://doi.org/10.1037/ccp0000291
Martin LL, Tesser A (1996) Some ruminative thoughts. In: Wyer RS (ed) Ruminative thoughts: advances in social cognition. Erlbaum, Hillsdale, NJ, pp 1–47
Mesulam MM (1998) From sensation to cognition. Brain 121(6):1013–1052. https://doi.org/10.1093/brain/121.6.1013
Muñoz-Rivas MJ, Andreu Rodríguez JM, Graña-Gómez JL, O'Leary DK, González MP (2007) Validation of the modified version of the Conflict Tactics Scale (M-CTS) in a Spanish population of youths. Psicothema 19:693–698
Nikolic M, Pezzoli P, Jaworska N, Seto MC (2022) Brain responses in aggression-prone individuals: a systematic review and meta-analysis of functional magnetic resonance imaging (fMRI) studies of anger-and aggression-eliciting tasks. Prog Neuropsychopharmacol Biol Psychiatry. https://doi.org/10.1016/j.pnpbp.2022.110596
Park JY, Gu BM, Kang DH et al (2010) Integration of crossmodal emotional information in the human brain: an fMRI study. Cortex 46(2):161–169. https://doi.org/10.1016/j.cortex.2008.06.008
Pinto LA, Sullivan EL, Rosenbaum A, Wyngarden N, Umhau JC, Miller MW, Taft CT (2010) Biological correlates of intimate partner violence perpetration. Aggress Violent Beh 15(5):387–398. https://doi.org/10.1016/j.avb.2010.07.001
Porges SW (2011) The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation (Norton series on interpersonal neurobiology). WW Norton & Company, New york
Ramos-Cejudo J, Salguero JM, Kannis-Dymand L, García-Sancho E, Love S (2017) Anger rumination in Australia and Spain: validation of the anger rumination scale. Aust J Psychol 69:293–302. https://doi.org/10.1111/ajpy.12154
Ray RD, Wilhelm FH, Gross JJ (2008) All in the mind's eye? Anger rumination and reappraisal. J Pers Soc Psychol 94(1):133. https://doi.org/10.1037/0022-3514.94.1.133
Romero-Martínez A, Lila M, Williams RK, González-Bono E, Moya-Albiol L (2013) Skin conductance rises in preparation and recovery to psychosocial stress and its relationship with impulsivity and testosterone in intimate partner violence perpetrators. Int J Psychophysiol 90(3):329–333. https://doi.org/10.1016/j.ijpsycho.2013.10.003
Romero-Martínez A, Nunes-Costa R, Lila M, Gonzalez-Bono E, Moya-Albiol L (2014) Cardiovascular reactivity to a marital conflict version of the Trier social stress test in intimate partner violence perpetrators. Stress 17(4):321–327. https://doi.org/10.3109/10253890.2014.919448
Romero-Martínez Á, González M, Lila M, Gracia E, Martí-Bonmatí L, Alberich-Bayarri Á, Moya-Albiol L (2019) The brain resting-state functional connectivity underlying violence proneness: is it a reliable marker for neurocriminology? A systematic review. Behav Sci 9(1):11. https://doi.org/10.3390/bs9010011
Romero-Martínez A, Lila M, Moya-Albiol L (2022) Sympathetic nervous system predominance in intimate partner violence perpetrators after coping with acute stress. J Interpers Violence 37(11–12):NP10148–NP10169
Rowe M, Kimmel J, Pavlo AJ, Antunes KD, Bellamy CD, O'Connell MJ, Kimmel JP (2018) A pilot study of motive control to reduce vengeance cravings. J Am Acad Psychiatry Law 46(4):486–497. https://doi.org/10.29158/JAAPL.003792-18
Salmond CH, Ashburner J, Vargha-Khadem F, Connelly A, Gadian DG, Friston KJ (2002) Distributional assumptions in voxel-based morphometry. Neuroimage 17(2):1027–1030. https://doi.org/10.1006/nimg.2002.1153
Sardinha L, Maheu-Giroux M, Stöckl H, Meyer SR, García-Moreno C (2022) Global, regional, and national prevalence estimates of physical or sexual, or both, intimate partner violence against women in 2018. Lancet 399(10327):803–813. https://doi.org/10.1016/S0140-6736(21)02664-7
Sarrate-Costa C, Lila M, Comes-Fayos J, Moya-Albiol L, Romero-Martínez Á (2022) Reduced vagal tone in intimate partner violence perpetrators is partly explained by anger rumination. Curr Psychol. https://doi.org/10.1007/s12144-022-03994-z

Soloff P, Nutche J, Goradia D, Diwadkar V (2008) Structural brain abnormalities in borderline personality disorder: a voxel-based morphometry study. Psychiatry Res 164(3):223–236. https://doi.org/10.1016/j.pscychresns.2008.02.003

Straus MA, Hamby SL, Boney-McCoy SUE, Sugarman DB (1996) The revised conflict tactics scales (CTS2) development and preliminary psychometric data. J Fam Issues 17(3):283–316. https://doi.org/10.1177/019251396017003001Stuart

Stuart GL, Moore TM, Gordon KC, Hellmuth JC, Ramsey SE, Kahler CW (2006) Reasons for intimate partner violence perpetration among arrested women. Violence Against Women 12(7):609–621. https://doi.org/10.1177/1077801206290173

Sukhodolsky DG, Golub A, Cromwell EN (2001) Development and validation of the anger rumination scale. Personal Individ Differ 31:689–700. https://doi.org/10.1016/S0191-8869(00)00171-9

Tek C, Gold J, Blaxton T, Wilk C, McMahon RP, Buchanan RW (2002) Visual perceptual and working memory impairments in schizophrenia. Arch Gen Psychiatry 59(2):146–153. https://doi.org/10.1001/archpsyc.59.2.146

Thayer JF, Yamamoto SS, Brosschot JF (2010) The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. Int J Cardiol 141(2):122–131. https://doi.org/10.1016/j.ijcard.2009.09.543

Vitoria-Estruch S, Romero-Martínez Á, Lila M, Moya-Albiol L (2018) Could alcohol abuse drive intimate partner violence perpetrators' psychophysiological response to acute stress? Int J Environ Res Public Health 15(12):2729. https://doi.org/10.3390/ijerph15122729

Wang Y, Zhu W, Xiao M, Zhang Q, Zhao Y, Zhang H, Xia LX (2018) Hostile attribution bias mediates the relationship between structural variations in the left middle frontal gyrus and trait angry rumination. Front Psychol 9:526. https://doi.org/10.3389/fpsyg.2018.00526

Whinery ED, Musleh A, Brown EA, Alford Z, Anigbogu JC, Ellingwood L, Espinoza M-A, Hawkins G, Kammer K, Krause K, Olson LE (2022) Physiological responses to narrative anger recall and correlates to anger, forgiveness, and rumination. J Psychophysiol 36(4):231–240. https://doi.org/10.1027/0269-8803/a000297

Wolfs EM, Klaus J, Schutter DJ (2023) Cerebellar grey matter volumes in reactive aggression and impulsivity in healthy volunteers. Cerebellum 22(2):223–233. https://doi.org/10.1007/s12311-021-01337-5

World Health Organization. (2020). COVID-19 and violence against women: what the health sector/system can do. WHO. https://www.who.int/reproductivehealth/publications/emergencies/COVID-19-VAW-full-text.pdf.Accessed 26 March 2020

Wulsin L, Herman J, Thayer JF (2018) Stress, autonomic imbalance, and the prediction of metabolic risk: a model and a proposal for research. Neurosci Biobehav Rev 86:12–20. https://doi.org/10.1016/j.neubiorev.2017.12.010

Yiend J (2010) The effects of emotion on attention: a review of attentional processing of emotional information. Cogn Emot 24(1):3–47. https://doi.org/10.1080/02699930903205698

Zhang J, Liu W, Zhang J, Wu Q, Gao Y, Jiang Y, Huang B (2018) Distinguishing adolescents with conduct disorder from typically developing youngsters based on pattern classification of brain structural MRI. Front Hum Neurosci 12:152. https://doi.org/10.3389/fnhum.2018.00152

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