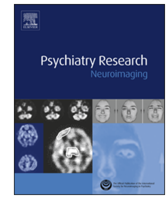
Psychiatry Research: Neuroimaging 223 (2014) 236–243

Contents lists available at ScienceDirect

Psychiatry Research: Neuroimaging

journal homepage: www.elsevier.com/locate/psychresns



Opposite brain emotion-regulation patterns in identity states of dissociative identity disorder: A PET study and neurobiological model

Antje A.T.S. Reinders [a,b,*], Antoon T.M. Willemsen [c], Johan A. den Boer [c], Herry P.J. Vos [d], Dick J. Veltman [e,1], Richard J. Loewenstein [f,1]

[a] Department of Psychosis Studies, Institute of Psychiatry, King's College London, United Kingdom
[b] Department of Neuroscience, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[c] Department of Nuclear Medicine & Molecular Imaging, University Medical Center Groningen, University of Groningen, The Netherlands
[d] Outpatient Department Addiction Clinic Groningen/Drenthe, The Netherlands
[e] Department of Psychiatry, VU University Medical Center, Amsterdam, The Netherlands
[f] Sheppard Pratt Health System, Department of Psychiatry, University of Maryland, Baltimore, MD, USA

A R T I C L E I N F O

Article history:
Received 8 December 2013
Received in revised form
27 April 2014
Accepted 13 May 2014
Available online 4 June 2014

Keywords:
Dissociative identity disorder (DID)
Posttraumatic stress disorder (PTSD)
Neuroimaging
Emotional undermodulation
Emotional overmodulation
Etiology

A B S T R A C T

Imaging studies in posttraumatic stress disorder (PTSD) have shown differing neural network patterns between hypo-aroused/dissociative and hyper-aroused subtypes. Since dissociative identity disorder (DID) involves different emotional states, this study tests whether DID fits aspects of the differing brain-activation patterns in PTSD. While brain activation was monitored using positron emission tomography, DID individuals ($n=11$) and matched DID-simulating healthy controls ($n=16$) underwent an autobiographic script-driven imagery paradigm in a hypo-aroused and a hyper-aroused identity state. Results were consistent with those previously found in the two PTSD subtypes for the rostral/dorsal anterior cingulate, the prefrontal cortex, and the amygdala and insula, respectively. Furthermore, the dissociative identity state uniquely activated the posterior association areas and the parahippocampal gyri, whereas the hyper-aroused identity state uniquely activated the caudate nucleus. Therefore, we proposed an extended PTSD-based neurobiological model for emotion modulation in DID: the hypo-aroused identity state activates the prefrontal cortex, cingulate, posterior association areas and parahippocampal gyri, thereby overmodulating emotion regulation; the hyper-aroused identity state activates the amygdala and insula as well as the dorsal striatum, thereby undermodulating emotion regulation. This confirms the notion that DID is related to PTSD as hypo-aroused and hyper-arousal states in DID and PTSD are similar.

1. Introduction

In dissociative identity disorder (DID) different emotional states can be maintained between alternate identity states (Reinders et al., 2003, 2006, 2012; Schlumpf et al., 2013). A large body of data supports the conceptualization of DID as the most severe, chronic, complex, childhood-onset form of posttraumatic disorder (PTSD) (Spiegel, 1984; Putnam, 1997; Van der Hart et al., 2006; Spiegel et al., 2011; Dalenberg et al., 2012; Reinders et al., 2012). In DID, repeated early traumatization may disrupt unification of identity through creation of behavioral and mental states associated with mitigating traumatic experiences and providing reparative experiences for the child (Putnam, 1997). Of note, the fantasy/sociocognitive model alternatively proposes that DID is an artefact mediated by high suggestibility, fantasy proneness and/or cognitive distortions (Lilienfeld et al., 1999; Kihlstrom, 2005; Giesbrecht et al., 2008; Lynn et al., 2012; Paris, 2012; Boysen and VanBergen, 2013). This controversy can be resolved by analyzing the neurobiological basis of the different identity states in DID, especially in comparison with other stress-related disorders such as PTSD.

Recent research on PTSD has identified a dissociative subtype affecting about 12–30% of the PTSD population (Lanius et al., 2010, 2012; Stein et al., 2012; Wolf et al., 2012b). When individuals in this subgroup are exposed to personal trauma scripts, they report high rates of dissociative symptoms, particularly depersonalization and derealization. The dissociative subtype is associated with a history of repeated childhood and adult interpersonal trauma,

* Corresponding author at: Department of Psychosis Studies, Institute of Psychiatry, King's College London, United Kingdom. Tel.: +44 20 7848 0966; fax: +44 20 7848 0287.
E-mail addresses: a.a.t.s.reinders@gmail.com, a.a.t.s.reinders@kcl.ac.uk (A.A.T.S. Reinders).

[1] Both authors contributed equally.

http://dx.doi.org/10.1016/j.pscychresns.2014.05.005
0925-4927/

primarily sexual abuse (Wolf et al., 2012a, 2012b). Individuals with the more common, hyper-aroused PTSD sub-type report reexperiencing and hyper-arousal symptoms in response to personal trauma scripts (Lanius et al., 2010). Imaging studies have shown differing neural network patterns between the putative hypo-arousal/dissociative and hyper-aroused PTSD subtypes (Lange et al., 2005; Frewen and Lanius, 2006; Hopper et al., 2007; Felmingham et al., 2008; Lanius et al., 2010, 2012; Weniger et al., 2013). PTSD individuals with dissociative responses to trauma cues show hyper-activation of cortical brain areas involved in emotion regulation, including the rostral/dorsal anterior cingulate and the medial, middle and superior prefrontal cortex (Felmingham et al., 2008; Lanius et al., 2010). These cortical regions appear to inhibit subcortical areas, including the amygdala, insula, and thalamic regions, that subserve posttraumatic emotional reactivity, and perception of aversive somatic and emotional states (Hopper et al., 2007; Lanius et al., 2010, 2012). This pattern is further characterized by autonomic hypo-arousal, as reflected in a decrease in heart rate and blood pressure during script-driven imagery for many subjects (Lanius et al., 2002). In contrast, PTSD individuals with the hyper-aroused subtype report subjective experiences of distressing intrusive trauma memories or flashbacks in response to trauma scripts. These subjects show decreased activation of frontal areas involved in emotion regulation, with failure to inhibit subcortical and limbic areas related to fear and perception of noxious stimuli. The latter pattern has been termed "undermodulation" of emotional response to trauma cues (Lanius et al., 2002, 2010, 2012; Hopper et al., 2007; Felmingham et al., 2008) and is generally accompanied by hyper-arousal and increase in heart rate and blood pressure, consistent with the more classical "fight-flight" pattern (Van der Hart et al., 2006).

In the current study, we investigate whether neural activation patterns to script-driven imagery in different identities in DID, compared with simulating controls, are consistent with the neurobiological model proposed for the two subtypes of PTSD. To be able to examine the neurobiological model for hypo-aroused/dissociative and hyper-aroused PTSD in a sample of individuals with DID, we re-analyzed previously obtained brain-imaging data from 11 individuals with DID (Reinders et al., 2003, 2006). Our goal was to specifically test the hypothesis that identity-state-dependent neural activation patterns in DID would fit the neurobiological model of differing neural network patterns for hypo-aroused/dissociative and hyper-aroused PTSD subtypes. Moreover, we included a group of healthy controls who were instructed to simulate dissociative identity states. Following the conceptualization of Van der Hart et al. (2006), we studied regional cerebral blood flow (rCBF) in authentic and simulated Neutral Identity States (NIS) and Trauma-related Identity States (TIS). The terms NIS and TIS are derived from the Theory of Structural Dissociation of the Personality (TSDP) (Van der Hart et al., 2006; Nijenhuis and van der Hart, 2011) and are analogous to that theory's constructs, the "apparently normal part of the personality (ANP)" and the "emotional part of the personality (EP)", respectively. Patients and controls underwent a script-driven imagery paradigm while brain activation was being monitored; in data analysis, within-subject comparison of (simulated) hypo-aroused and hyper-arousal identity-state-dependent brain activation patterns were conducted.

The *a priori* hypotheses with respect to participants' responses to personal trauma scripts were as follows: (1) the DID patients' NIS, the hypo-aroused identity state, would show hyper-activation in frontal areas and the rostral/dorsal cingulate, with hypo-activation in the amygdala and insula: the DID subjects' NIS will consequently show psychophysiological hypo-arousal; (2) the DID patients' TIS, the hyper-aroused identity state, will show hypo-activation in frontal areas and cingulate, with associated hyper-activation in the amygdala and insula: the DID subjects' TIS will consequently show psychophysiological hyper-arousal.

2. Methods

2.1. Participants

Participants comprised 11 patients with dissociative identity disorder (DID; all female, age: mean = 41.0, S.D. = 6.1) diagnosed with the Structured Clinical Interview for DSM-IV Dissociative Disorders (SCID-D) (Steinberg, 1993) and 16 healthy control subjects (CTRL; all female, age: mean = 41.1, S.D. = 10.7). The control subjects were free of psychiatric or current or past trauma-related problems evaluated with the Trauma Experience Checklist (TEC) (Nijenhuis et al., 2002) and the Somatoform Dissociation Questionnaire (SDQ-20) (Nijenhuis et al., 1996).

Individuals with DID included in the current study have been described previously (Reinders et al., 2003, 2006, 2012). In sum: exclusion criteria were pregnancy, traumatic experiences in a hospital setting, systemic or neurological illness, and no command of the Dutch language. Treatment had progressed to Phase II (Brown et al., 1998), which involves therapeutic exposure to trauma-related memories. They had to be capable of self-initiated and self-controlled switching between identity states (for definitions see Supplementary material) in an experimental situation with minimal guidance of their psychotherapist and had to have at least one TIS displaying signs of sympathetic nervous system activation when cued by trauma reminders and one NIS between which they could alternate if requested. Lanius et al. (2010) did not specifically relate their definitions for dissociation and hyper-arousal in PTSD subtypes to DID. Nevertheless, for the purpose of this study, we will use the concepts of Lanius et al. in addition to the terminology for different identity states in DID based on the TSDP (Van der Hart et al., 2006; Nijenhuis and Den Boer, 2009).

Control data are drawn from a subset of a previously published sample (Reinders et al., 2012). Control subjects were recruited, included and instructed (see Supplementary material) to simulate dissociative identity states as described previously (Reinders et al., 2012). Exclusion criteria were the presence of medical, neurological or psychiatric problems in the past or the present, the use of psychotropic medication 15 days before examination, participation in a positron emission tomography (PET) or other study that involved administration of radiation in the year before the study, and pregnancy. Two controls were found to be unable to maintain their roles during some of the study conditions: one listening as NIS to the trauma analog script, and one listening as TIS to the neutral memory script. Data from these conditions were excluded from the analysis. Furthermore, the PET data of one control subject were lost due to storage failure at the PET centre, leaving 15 controls with PET data available and the heart rate variability (HRV) data for two control subjects could not be obtained, leaving 14 control subjects with HRV data.

2.2. PET procedure and data processing

The PET (Siemens/CTI ECAT HR+) procedure for the controls was close to identical to that for the patients (Reinders et al., 2003, 2006). In contrast to patients, the controls did not habituate to the PET environment before the investigation as anxiety levels were expected to be low. No urine samples were obtained for the control groups; both medication and drugs use were verbally debriefed according to standard control research practice. For the controls one extra set of the four conditions was added to increase statistical power. The scanning sequence was therefore NISn, NISt, TISn, TISt, TISn, TISt, NISn, NISt, TISn, TISt, NISn and NISt. The last minor character (n or t) denotes the content of the memory script (MS: neutral or trauma-related). For patient comfort considerations, i.e., limiting the number of identity state switches, a fixed condition order was used, which was also used for the controls to minimize methodological differences. HRV segments 2 min in duration were obtained; after the scan, blood pressure (systolic and diastolic), and discrete heart rate frequency were measured.

Data reconstruction, attenuation correction, spatial transformation, spatial smoothing (isotropic Gaussian kernel of 12 mm), global normalization and statistical analysis of the data were performed as usual (Reinders et al., 2002, 2003, 2006, 2012) with SPM5 (www.fil.ion.ucl.ac.uk/spm). The subjective reactions and the autonomic reactions were included as group-specific covariates in the general linear model (GLM: three-factor main effects (subject, condition and group), four conditions and the group × condition interaction) of SPM5 after PC analysis (Reinders et al., 2003, 2006, 2012); only the eigenvectors with an eigenvalue larger then 1 were included (DID:5, CTRL:9). Global cerebral blood flow (CBF) was included as a nuisance covariate (analysis of covariance by subject). Comparisons of interest included the following: *between identity state effects* and *within identity state effects*. Between identity state effects refer to differential processing of the trauma-related text and the neutral text between identity states. Within identity state effects refer to differential processing of the trauma-related and neutral text within the trauma-related or neutral identity state. All statistical analyses in SPM were analyses of variance (ANOVAs).

The psychophysiological data were subjected to missing value, principal components (PC) data transformation and statistical analysis (SPSS-PC 15.0 (2006)). The within subject subtractions for the between and within identity state effects were submitted to one-way ANOVAs.

2.3. Statistical inference and reporting

Statistical parametric maps were thresholded using an uncorrected threshold of $p<0.001$ (Friston et al., 1991) and explored for brain areas hypothesized *a priori*. Multiple comparisons correction was performed, using the false discovery rate statistical methodology (Genovese et al., 2002) included in SPM, for whole brain and for the *a priori* regions of interest (ROIs). In the latter case a small volume correction was applied using a sphere with radius of 9 mm (Reinders et al., 2005).

The *a priori* hypothesized ROIs were the cingulate (middle and anterior), the pre-frontal cortex (medial, middle and superior prefrontal gyrus), the amygdala and the insula. These areas were derived from the review by Lanius et al. (2010) and publications concerning dissociative responses in PTSD (Hopper et al., 2007; Felmingham et al., 2008). The coordinates were converted from Montreal Neurological Institute (MNI) space to Talairach space (Brett, 2006) to be defined in

Table 1
Overview of brain areas in which statistically significant cerebral blood flow changes were found in the between or within identity state comparisons.

R/L	Brain region	Brodmann area	MINI x	y	z	kE	T[a]
Within identity state							
Neutral identity state: differential processing of the neutral and trauma-related text							
DID(NISt–NISn)–CTRL(NISt–NISn)							
R	Middle frontal gyrus[b]	BA 8	44	18	46	38	3.40
L	Medial frontal gyrus[b]	BA 9	−12	32	36	41	3.73
R	S. frontal gyrus[b]	BA 9	24	50	38	100	3.53
L	S. frontal gyrus[b]	BA 9	−16	56	34	35	3.41
DID(NISn–NISt)–CTRL(NISn–NISt)							
	n.s.						
Trauma-related identity state: differential processing of the neutral and trauma-related text							
DID(TISt–TISn)–CTRL(TISt–TISn)							
L	Insula[b]	BA 13	−38	−14	14	177	4.25
L	Amygdala[b]		−10	−4	−24	126	3.87
DID(TISn–TISt)–CTRL(TISn–TISt)							
	n.s.						
Between identity states							
Processing of the trauma-related text							
DID(NISt–TISt)–CTRL(NISt – TISt)							
R	IPS (transition SPL/IPL)	BA 7/40	30	−38	40	298	4.30
L	IPS (transition SPL/IPL)	BA 7/40	−34	−50	34	49	3.96
R	Cingulate sulcus/S.Frontal sulcus	BA 4/6/24	16	−12	44	272	4.24
R	Cingulate gyrus	BA 32	6	16	40	100	3.95
R	Parahippocampal gyrus	BA 36	20	−52	2	79	3.87
L	Parahippocampal gyrus	BA 35	−40	−46	−4	77	4.12
L	Parahippocampal gyrus	BA 35	−24	−26	−16	11	3.52
R	M. temporal gyrus	BA 21	62	−6	−14	25	3.75
R	Occipitotemporal sulcus	BA 20/37	48	−40	−12	124	4.83
R	Fusiform gyrus	BA 19/37	38	−62	−20	32	3.60
L	Lingual gyrus	BA 18	−8	−90	−10	96	3.51
R	S. parietal lobule/precuneus/angular gyrus	BA 7/39	24	−64	36	564	4.53
L	(Pre-) cuneus	BA 7/31/18/19	−10	−64	28	838	4.48
R	S. occipital sulcus/Cuneus	BA 18/19	18	−90	38	411	4.45
L	S. occipital gyrus/angular gyrus	BA 19/39	−38	−82	30	176	4.33
DID(TISt-NISt)–CTRL(TISt-NISt)							
R	Caudate nucleus (dorsal part)		24	4	20	392	5.04
L	Caudate nucleus (dorsal part)		−12	4	16	98	4.90
L	Amygdala[b]		−4	−6	−26	50	3.92
L	Insula[b]	BA 13	−26	−10	20	241	3.86
Processing of the neutral text							
DID(TISn–NISn)–CTRL(TISn–NISn)							
	n.s.						
DID(NISn–TISn)–CTRL(NISn–TISn)							
	n.s.						

DID = dissociative identity disorder patients.
CTRL = normal DID simulating healthy controls.
TISt = trauma-related identity state exposed to the trauma-related memory script.
NISt = neutral identity state exposed to the trauma-related memory script.
TISn = trauma-related identity state exposed to the neutral memory script.
NISn = neutral identity state exposed to the neutral memory script.
L/R = left/right.
IPS = intraparietal sulcus.
SPL = superior parietal lobule.
IPL = inferior parietal lobule.
S = superior.
Note: T values and cluster sizes are given accompanied with the (x, y, z) coordinates in MNI space for the peak activation. The top section of the table presents the between identity state effects. These effects entail the comparison of the trauma-related state (TIS) to the neutral identity state (NIS) when processing of the trauma-related text (t) (DID(TISt vs. NISt)–CTRL(TISt vs. NISt)) and when processing the neutral text (n) (DID(TISn vs. NISn)–CTRL(TISn vs. NISn)), between DID patients and normal DID-simulating controls. The bottom section of the table presents the within identity state effects. These effects concern the comparison of the differential processing of the neutral (n) and trauma-related (t) text within the trauma-related identity state (TIS) (DID(TISt vs. TISn)–CTRL(TISt vs. TISn)) or within the neutral identity state (NIS) (DID(NISt vs. NISn)–CTRL(NISt vs. NISn)), between DID patients and normal DID-simulating controls.

[a] $p<0.05$, corrected for multiple comparisons.
[b] Region of interest, corrected for multiple comparisons using small volume correction (SVC).

Brodmann areas (BA) using both the Talairach atlas (Talairach and Tournoux, 1988) and Deamon (Lancaster et al., 1997, 2000). Activations in the sulci were defined using Brain Tutor (Goebel, 2013). The location was anatomically compared with and described using a second brain atlas (Mai et al., 1997). Activation localization was performed as usual (Reinders et al., 2012). Only clusters larger than eight voxels are reported, taking into account the spatial resolution of the PET camera. All peak voxels in clusters were explored and small volume correction was applied to the identified peaks as long as they were located within the *a priori* hypothesized regions.

For the psychophysiological data, the *F* and *p* values are reported as well as the mean and standard deviation. Bonferroni correction is applied to correct for the number of tests within the subjective or autonomic categories. Values with $p<0.006$ for the subjective measures and values with $p<0.003$ for the objective measures are reported as significant after correction for multiple comparisons.

3. Results

Significant differences in brain activation and psychophysiological measures between the DID patients and the controls are presented in Tables 1 and 2. The directionality of the neuronal responses and the most important brain areas are depicted in Fig. 1.

3.1. Within identity state effects

We found, when the participants in the neutral state listened to the trauma-related text, as compared with the neutral text, bilateral activation in the superior frontal gyrus was found accompanied by activation in the right middle frontal gyrus and the left medial frontal gyrus (see Fig. 1, top). A trend was found for an increase in subjective sensory perceptions, heart rate frequency, and systolic and diastolic blood pressure measurements (data not shown). No significant activations were found when participants in the NIS listened to the neutral text, as compared with the trauma-related text. Furthermore, when participants in the TIS condition listened to trauma-related information, the left insula (see Fig. 1, bottom) and the amygdala were activated. Concomitant significant increases in the subjective sensorimotor and emotional ratings, and of the objective heart rate frequency and systolic/diastolic blood pressure measurements were found, accompanied by a significant decrease in average HRV. No significant activations were found when participants in the TIS condition listened to the neutral text, as compared with the trauma-related text.

Table 2
Results of the statistical analysis concerning subjective sensorimotor and emotional experiences, and of the cardiovascular responses.

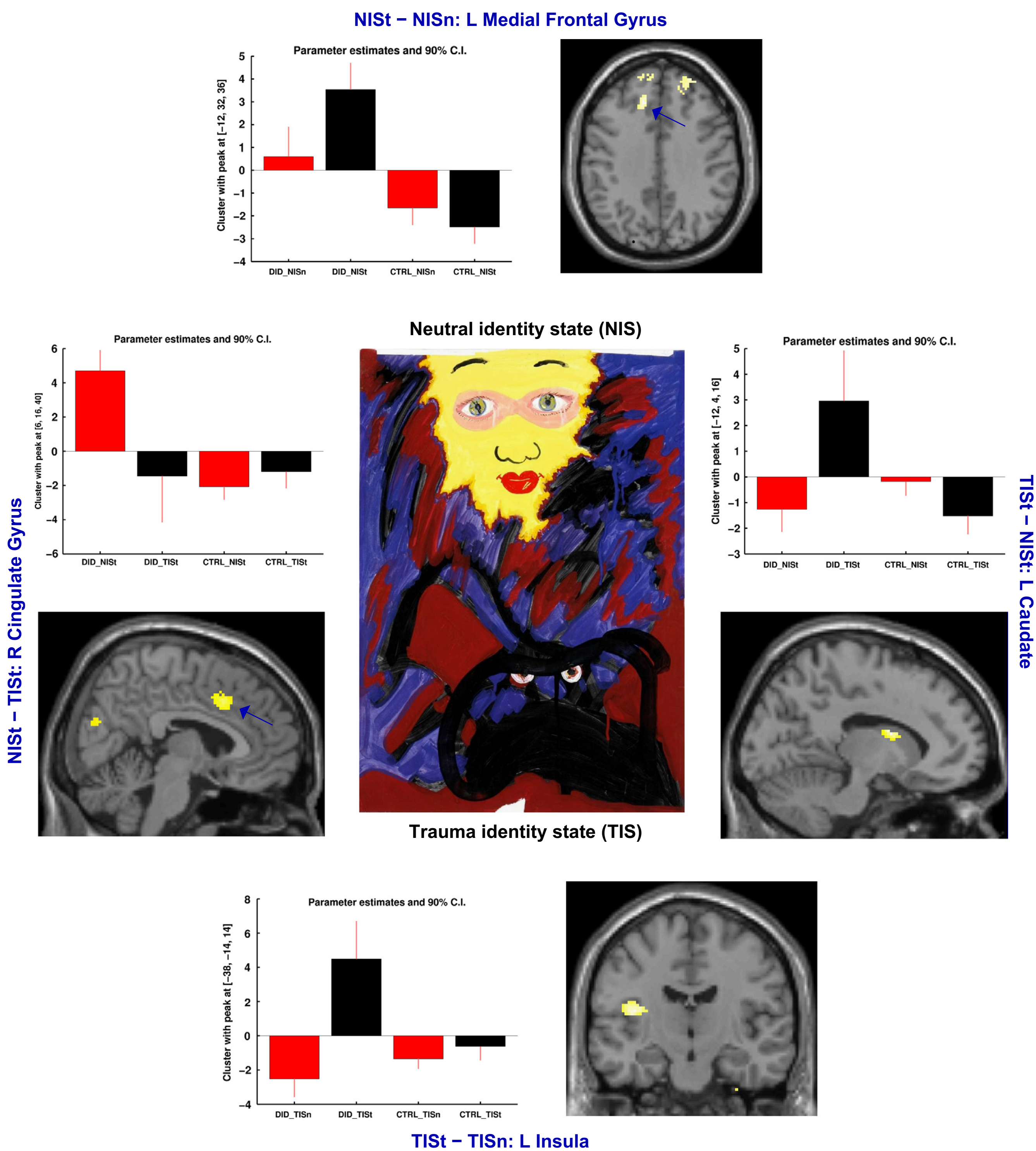
	Between identity state		**Within identity state**	
	DID(TISt–NISt) > CTRL(TISt–NISt)[a]	DID(TISn–NISn) > CTRL(TISn–NISn)[b]	DID(TISt–TISn) > CTRL(TISt–TISn)[c]	DID(NISt–NISn) > CTRL(NISt–NISn)[d]
Subjective ratings				
Sensory rating	$F(1,26)=28.55$, $P<0.001$**	n.s.	$F(1,26)=51.78$, $P<0.001$**	n.s.
	DID(M=4.10, S.D.=2.38)	DID(M=0.30, S.D.=0.64)	DID(M=4.39, S.D.=2.04)	DID(M=0.60, S.D.=1.24)
	CTRL(M=0.79, S.D.=0.64)	CTRL(M=0.22, S.D.=0.44)	CTRL(M=0.50, S.D.=0.64)	CTRL(M=−0.7, S.D.=0.24)
Emotional rating	n.s.	n.s.	$F(1,26)=24.79$, $P<0.001$**	n.s.
	DID(M=4.21, S.D.=3.05)	DID(M=0.11, S.D.=0.31)	DID(M=5.42, S.D.=1.88)	DID(M=1.32, S.D.=1.74)
	CTRL(M=1.80, S.D.=1.46)	CTRL(M=0.27, S.D.=0.47)	CTRL(M=2.03, S.D.=1.64)	CTRL(M=0.50, S.D.=1.15)
Autonomic reactions				
Heart rate frequency	$F(1,26)=18.67$, $P<0.001$**	n.s.	$F(1,26)=36.85$, $P<0.001$**	n.s.
	DID(M=9.64, S.D.=8.39)	DID(M=1.18, S.D.=4.71)	DID(M=11.45, S.D.=7.00)	DID(M=3.00, S.D.=3.46)
	CTRL(M=−0.26, S.D.=3.18)	CTRL(M=−0.79, S.D.=2.39)	CTRL(M=0.46, S.D.=1.73)	CTRL(M=−0.07, S.D.=2.61)
Systolic blood pressure	$F(1,26)=11.97$, $P=0.002$**	n.s.	$F(1,26)=14.34$, $P=0.001$**	n.s.
	DID(M=10.45, S.D.=11.92)	DID(M=2.00, S.D.=6.23)	DID(M=12.95, S.D.=12.45)	DID(M=4.50, S.D.=7.16)
	CTRL(M=−0.52, S.D.=3.82)	CTRL(M=−1.17, S.D.=4.38)	CTRL(M=0.85, S.D.=2.74)	CTRL(M=0.21, S.D.=2.99)
Diastolic blood pressure	n.s.	n.s.	$F(1,26)=14.87$, $P=0.001$**	n.s.
	DID(M=3.59, S.D.=7.59)	DID(M=1.14, S.D.=4.17)	DID(M=7.36, S.D.=5.37)	DID(M=4.91, S.D.=7.15)
	CTRL(M=1.37, S.D.=2.68)	CTRL(M=−0.21, S.D.=2.25)	CTRL(M=1.23, S.D.=2.88)	CTRL(M=−0.34, SD=2.87)
HRV-average	n.s.	n.s.	$F(1,26)=17.93$, $P<0.001$**	n.s.
	DID(M=4.67, S.D.=28.88)	DID(M=12.67, S.D.=43.26)	DID(M=−107.94, S.D.=95.30)	DID(M=−24.48, S.D.=54.63)
	CTRL(M=−70.79, S.D.=86.37)	CTRL(M=4.80, S.D.=35.03)	CTRL(M=0.74, S.D.=13.97)	CTRL(M=0.87, S.D.=14.84)

DID=dissociative identity disorder patients.
CTRL=normal DID simulating healthy controls.
TISt=trauma-related identity state exposed to the trauma-related memory script.
NISt=neutral identity state exposed to the trauma-related memory script.
TISn=trauma-related identity state exposed to the neutral memory script.
NISn=neutral identity state exposed to the neutral memory script.
n.s.=not significant.
M=mean.
S.D.=standard deviation.
Note: Results of the between and within identity state comparisons are presented. *F* and *p* values are given as well as the means and standard deviations from both groups. Significant results are shown in bold font. The two columns with the heading “between identity state” present the statistical results of the comparison of the trauma-related state (TIS) to the neutral identity state (NIS) when processing the trauma-related text (t) (first column: DID(TISt-NISt) > CTRL(TISt-NISt)) and when processing the neutral text (n) (second column: DID(TISn-NISn) > CTRL(TISn-NISn)), between DID patients and normal DID-simulating controls. The two columns with the heading “within identity state” present the statistical results of the comparisons concerning the differential processing of the neutral (n) and trauma-related (t) text within the trauma-related identity state (TIS) (first column: DID(TISt-TISn) > CTRL(TISt-TISn)) or within the neutral identity state (NIS) (second column: DID(NISt-NISn) > CTRL(NISt-NISn)), between DID patients and normal DID-simulating controls.

[a] Processing of the trauma-related text.
[b] Processing of the neutral text.
[c] Trauma-related identity state: differential processing of the neutral and trauma-related text.
[d] Neutral identity state: differential processing of the neutral and trauma-related text.
** Corrected for multiple comparisons.

3.2. Between identity states effects

We found that, when processing the trauma-related text, participants under the NIS condition activated bilateral parahippocampal and cingulate gyri (see Fig. 1: middle left); they additionally activated the posterior multimodal association areas: bilateral intraparietal sulcus, bilateral occipital areas (including (pre-) cuneus), accompanied by left lingual gyrus and right-sided (occipito-) temporal and fusiform gyrus activation. The TIS condition activated the bilateral caudate nucleus (see Fig. 1: middle right), left amygdala, and left insula. A concomitant significant increase in heart rate frequency, systolic blood pressure and subjective sensory perceptions was found. In addition, a trend was found for a decrease in HRV and for an increase in subjective emotional rating (data not shown). No significant differences were found in brain activation for the differential processing of the neutral text, and none of the subjective ratings or autonomic reactions showed a difference between the TIS and NIS.



4. Discussion

We have two major findings. The first finding of this study is that, in response to personal trauma scripts, DID patients' NIS and TIS alternate identities show opposite rCBF activation patterns, which are consistent with those previously found in the undermodulated (hyper-aroused) and overmodulated (dissociative) PTSD patient subtypes in separate individuals (Hopper et al., 2007; Felmingham et al., 2008; Lanius et al., 2010). The second finding is that important additional brain areas were revealed for identity state dependent emotion modulation in individuals with DID.

Our first finding concerns similarities between previously reported neural networks in PTSD involved in emotional undermodulation and overmodulation of affect and individuals with DID. In response to personal trauma scripts, and similar to individuals with the putative dissociative PTSD subtype (Felmingham et al., 2008), DID patients' NIS, compared to patients' TIS, on the within-identity state assessment, showed autonomic hypo-arousal with increased activation of the right mid/anterior cingulate cortex, and bilateral superior frontal gyrus, right middle frontal gyrus and left medial frontal gyrus. The current findings are in line with the neurocorrelates of dissociative PTSD, characterized by emotional overmodulation in response to exposure to traumatic memories. In both DID and dissociative PTSD patients, this state is associated with hyper-activation of similar brain areas that suppress the arousal of the sympathetic nervous system, leading to hypo-responsiveness of the psychophysiological system. Remarkably, there seems to be an overlap between the cortical mechanisms in dissociative PTSD individuals and those of the DID patients' NIS. These appear to control activation of subcortical systems related to fear, anguish, and nociception, as well as to dampen sympathetic responding to traumatic scripts (Nijenhuis and Den Boer, 2009). In contrast, in response to personal trauma scripts, the DID patients' TIS activated subcortical brain areas including left amygdala, bilateral caudate, and left insula but not prefrontal cortex and cingulate regions. In addition, DID patients' TIS showed significantly increased activation of the sympathetic nervous system, with increased heart rate and (systolic) blood pressure when listening to personal trauma scripts. Again, this shows a notable parallel to patterns found in individuals with hyper-aroused, undermodulated PTSD (Lanius et al., 2010, 2012).

Clinically, DID patients are similar to dissociative PTSD patients in having earlier and more severe childhood trauma experiences (Spiegel et al., 2011; Wolf et al., 2012b), as well as in treatment response (Van der Hart et al., 2006; Brand et al., 2012). However, there is still an on-going debate in the literature about the conceptual status of DID, either as a form of PTSD or a disorder related to suggestibility and iatrogenesis (Dalenberg et al., 2012; Boysen and VanBergen, 2013). The current findings do not support the latter view and represent a first step in investigating the shared neural substrate between DID and PTSD; they can thus guide future studies by providing the *a priori* hypothesized regions as included in the neurobiological model for DID.

Our second finding concerns differing neurobiological markers between previously reported neural networks in PTSD and the current findings in DID. DID is the most symptomatically complex dissociative disorder (American Psychiatric Association, 2013). Accordingly, it is not surprising that the neurobiology of DID involves additional patterns of brain activation when compared with those of non-DID individuals with hyper-aroused or hypo-aroused symptoms. For example, the DID NIS showed neural network patterns consistent with clinical and non-clinical models of Dissociative Amnesia (DA) (Simeon et al., 2000; Sar et al., 2007). In comparisons of the brain response of the DID patients' NIS to the patients' TIS in response to personal trauma scripts, they activated bilateral parahippocampal gyri (Schlumpf et al., 2013) and the posterior multimodal association areas, e.g., bilateral intraparietal sulcus, occipital cortex and the bilateral (pre-)cuneus. The posterior association areas are thought to mediate the process of subjective disengagement from the emotional content of trauma-related information and/or inhibition of recognition of the self-relevance of this information (Reinders et al., 2003, 2012). Anderson et al. (2004) suggested that these networks are involved in top-down suppression of unwanted autobiographical memories, and propose these as a neurobiological model for DA, a criterion symptom for the diagnosis of DID (American Psychiatric Association, 2013).

In addition, in this and related studies (Reinders et al., 2006, 2012), in response to personal trauma scripts, DID patients in the TIS condition have consistently shown activation in the dorsal striatum, particularly the caudate nucleus. The dorsal striatum has been found to correlate negatively with trait dissociation during stress-induced analgesia (Mickleborough et al., 2011), and to be involved in task switching and inhibition of irrelevant information (Yehene et al., 2005, 2008). We can speculate that the dorsal striatum is involved in dissociation (Mickleborough et al., 2011), particularly in switching between identity states (Tsai et al., 1999), as well as in maintaining state stability of a dissociative identity state (Reinders et al., 2006, 2012; Schlumpf et al., 2013). In a single subject functional MRI study, Savoy et al. (2012) reported the involvement of the ventral striatum (i.e., the accumbens area)

Fig. 1. The artwork centralized in this figure is entitled "The Mask" and can be seen as depicting the neutral identity state (NIS) in the top part and the trauma-related identity state (TIS) in the bottom part, where the NIS "masks" the TIS and thereby the traumatic experiences (interpretation by: AATSR). It is surrounded by the within and between identity state comparisons between the dissociative identity disorder (DID) patients and normal DID-simulating controls. The within identity state comparisons at the top (NIS) and the bottom (TIS) are in alignment with the representations within the artwork. The bar graphs show the directionality of effect and represent the average effect of the cluster. The first two bars represent the DID patients and the other two bars represent the healthy DID-simulating controls. The red bars represent a more neutral condition, whereas the black bars represent a trauma-related condition (identity state or text). The picture of the brain in the top right of the figure shows the activation in the bilateral superior frontal gyrus and the activation in the left medial frontal gyrus. The latter activation is indicated with a blue arrow and coincides with the bar graphs on the top left side. The bottom part of the figure shows the activation in the left insula and the magnitude of effects in the accompanying bar graphs. The two graphical displays on the left show the activation in the left cingulate gyrus and the magnitude of effects in the bar graphs. The activation, both location and magnitude, in the dorsal part of the left caudate nucleus is depicted in the middle right part of the figure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure subscript

NISt	neutral identity state exposed to the trauma-related memory script
NISn	neutral identity state exposed to the neutral memory script
TISt	trauma-related identity state exposed to the trauma-related memory script
TISn	trauma-related identity state exposed to the neutral memory script
R	Right hemisphere
L	Left hemisphere
DID	dissociative identity disorder patients
CTRL	normal DID-simulating healthy controls

during identity state switching. In addition, the dorsal striatum is involved in memory systems (Quirarte et al., 2009; Sánchez-Resendis et al., 2012). Stress-impaired functioning of the hippocampal system coincides with higher activation of the dorsal striatum (Schwabe et al., 2008), leading to the hypothesizes that a similar shift from hippocampal to striatal memory functioning takes place in DID under certain stress-related conditions. Or, taking both the switching and memory hypotheses together, in DID the dorsal striatum may be involved in the regulation of memory access by modulating the presence of neutral or trauma-related identity states. However, further research is needed to replicate the current findings and to investigate the hypothesis of identity state switching and memory.

A limitation of the current study is that neither clinical nor psychometric assessment of PTSD was obtained on DID subjects. However, it is likely that the DID subjects met diagnostic criteria for co-morbid PTSD, as do the large majority of DID patients, and given the TIS responses to personal trauma scripts, which included intense subjective distress and flashback-like experiences (Reinders et al., 2003, 2006, 2012). One might argue that the current brief practice of DID simulation is insufficient to simulate the psychobiological profiles of NIS and TIS. Even if years of practice could generate these profiles, our findings are in line with our *a priori* hypotheses that similar, but extended, networks are involved in emotion regulation in DID and dissociative PTSD. This result has not been predicted by holders of the sociocognitive and fantasy based view. Other limitations are that the DID data only involve females, the data have been published previously, and the neurobiological model for hypo-aroused/dissociative and hyper-aroused PTSD is based on findings in the literature rather than on the inclusion of PTSD subjects (Hopper et al., 2007; Felmingham et al., 2008; Lanius et al., 2010). However, we believe that the current study provides important information on the similarities between DID and the putative PTSD subtypes, especially as empirical research into dissociative PTSD and DID is in an early phase.

Although our results support and extend the model that DID is a severe, childhood-onset form of PTSD, some have conceptualized PTSD as fundamentally a dissociative process (Van der Hart et al., 2006; Nijenhuis and Den Boer, 2009). Hence, the neurobiological similarity between DID identity states within a single human being, and the PTSD subtypes may be explained in both directions, and raises the question whether dissociative PTSD is a specific form of PTSD or whether all forms of PTSD are fundamentally dissociative, as postulated by Nijenhuis and others (e.g., Van der Hart et al., 2006; Nijenhuis and Den Boer, 2009). Indeed, DID may occur without co-morbid PTSD, and PTSD may occur without dissociative symptoms such as depersonalization, derealization, dissociative amnesia, and subjective self-division, albeit DSM-5 defines flashbacks as “dissociative reactions” (American Psychiatric Association, 2013). Also, DSM-5 did not include dissociative disorders (DD) under the Trauma- and Stressor-Related Disorders, as the diagnostic criteria for dissociative disorders do not include a stressor criterion (Criterion A), although the DDs in DSM-5 were deliberately placed just after the Trauma- and Stressor-Related Disorders group to indicate that most DD are associated with traumatic experiences. Future research to help resolve this question will be needed on DID, PTSD, and, in particular, the dissociative PTSD subtype. DSM-5 has been developed to be an evolving structure that can be more rapidly amended than earlier editions of the DSM. Thus, the current study opens avenues to further study of the conceptual status and nosological classification of both DID and PTSD.

In conclusion, the current study shows similarities in neurobiological network patterns between patients with DID functioning as a NIS alternate identity and PTSD patients with the dissociative or hypo-aroused subtype of PTSD. On the basis of the current results, we propose an extended neurobiological model for emotion modulation in DID. For the hypo-aroused NIS, we suggest the posterior association areas and parahippocampal gyri play a pivotal role in the suppression of unwanted (trauma-related) autobiographical memories. For the hyper-aroused TIS, we propose the dorsal striatum to be crucial in the regulation of memory access by modulating the presence of different identity states. Finally, our study supports the notion that DID is closely related to PTSD and is not a disorder related to suggestibility.

Acknowledgments

A.A.T.S. Reinders is supported by the Netherlands Organization for Scientific Research (www.nwo.nl), NWO-VENI Grant no. 451-07-009. The authors are greatly indebted to all the participants and extend thanks them for participating. They also thank Margo Jongsma for her assistance and participant recruitment. Ellert Nijenhuis, Paola Dazzan and Carmine Pariante are thanked for their comments on the manuscript. Jaap Haaksma is thanked for the HRV data collection. Borden Armstrong is thanked for psychophysiological data-analysis support and proofreading. Esther Veerman is thanked for her kind permission to use her artwork, which is entitled “The Mask” in which she expresses her inner experiences (kunstuitgeweld.nl and www.exto.nl). All authors report no financial relationships with competing interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.pscychresns.2014.05.005.

References

American Psychiatric Association, 2013. Diagnostic and Statistical Manual of Mental Disorders: DSM-5. APA, Washington, DC (DSM-5 Task Force).

Anderson, M.C., Ochsner, K.N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S.W., Glover, G.H., Gabrieli, J.D.E., 2004. Neural systems underlying the suppression of unwanted memories. Science 303, 232–235.

Boysen, G.A., VanBergen, A., 2013. A review of published research on adult dissociative identity disorder: 2000-2010. Journal of Nervous and Mental Disease 201, 5–11.

Brand, B.L., Myrick, A.C., Loewenstein, R.J., Classen, C.C., Lanius, R.A., McNary, S.W., Pain, C., Putnam, F.W., 2012. A survey of practices and recommended treatment interventions among expert therapists treating patients with dissociative identity disorder and dissociative disorder not otherwise specified. Psychological Trauma: Theory, Research, Practice, and Policy 4, 490–500.

Brett, M., 2006. The MNI Brain and the Talairach Atlas ⟨http://imaging.mrc-cbu.cam.ac.uk/imaging/MniTalairach⟩.

Brown, D., Scheflin, A.W., Hammond, D.C., 1998. Memory, Trauma Treatment, and the Law. Norton, New York.

Dalenberg, C.J., Brand, B.L., Gleaves, D.H., Dorahy, M.J., Loewenstein, R.J., Cardeña, E., Frewen, P.A., Carlson, E.B., Spiegel, D., 2012. Evaluation of the evidence for the trauma and fantasy models of dissociation. Psychological Bulletin 138, 550–588.

Felmingham, K., Kemp, A.H., Williams, L., Falconer, E., Olivieri, G., Peduto, A., Bryant, R., 2008. Dissociative responses to conscious and non-conscious fear impact underlying brain function in post-traumatic stress disorder. Psychological Medicine 38, 1771–1780.

Frewen, P.A., Lanius, R.A., 2006. Toward a psychobiology of posttraumatic self-dysregulation: reexperiencing, hyperarousal, dissociation, and emotional numbing. Annals of the New York Academy of Sciences 1071, 110–124.

Friston, K.J., Frith, C.D., Liddle, P.F., Frackowiak, R.S., 1991. Comparing functional (PET) images: The assessment of significant change. Journal of Cerebral Blood Flow and Metabolism 11, 690–699.

Genovese, C.R., Lazar, N.A., Nichols, T., 2002. Thresholding of statistical maps in functional neuroimaging using the false discovery rate. NeuroImage 15, 870–878.

Giesbrecht, T., Lynn, S.J., Lilienfeld, S.O., Merckelbach, H., 2008. Cognitive processes in dissociation: an analysis of core theoretical assumptions. Psychological Bulletin 134, 617–647.

Goebel, R., 2013. Brain Innovation: Home of the BrainVoyager Product Family ⟨http://www.brainvoyager.com⟩.

Hopper, J.W., Frewen, P.A., van der Kolk, B.A., Lanius, R.A., 2007. Neural correlates of reexperiencing, avoidance, and dissociation in PTSD: symptom dimensions and emotion dysregulation in responses to script-driven trauma imagery. Journal of Traumatic Stress 20, 713–725.

Kihlstrom, J.F., 2005. Dissociative disorders. Annual Review of Clinical Psychology 1, 227–253.

Lancaster, J.L., Rainey, L.H., Summerlin, J.L., Freitas, C.S., Fox, P.T., Evans, A.C., Toga, A. W., Mazziotta, J.C., 1997. Automated labeling of the human brain: a preliminary report on the development and evaluation of a forward-transform method. Human Brain Mapping 5, 238–242.

Lancaster, J.L., Woldorff, M.G., Parsons, L.M., Liotti, M., Freitas, C.S., Rainey, L., Kochunov, P.V., Nickerson, D., Mikiten, S.A., Fox, P.T., 2000. Automated Talairach atlas labels for functional brain mapping. Human Brain Mapping 10, 120–131.

Lange, C., Kracht, L., Herholz, K., Sachsse, U., Irle, E., 2005. Reduced glucose metabolism in temporo-parietal cortices of women with borderline personality disorder. Psychiatry Research 139, 115–126.

Lanius, R.A., Brand, B., Vermetten, E., Frewen, P.A., Spiegel, D., 2012. The dissociative subtype of posttraumatic stress disorder: rationale, clinical and neurobiological evidence, and implications. Depression and Anxiety 29, 701–708.

Lanius, R.A., Vermetten, E., Loewenstein, R.J., Brand, B., Schmahl, C., Bremner, J.D., Spiegel, D., 2010. Emotion modulation in PTSD: clinical and neurobiological evidence for a dissociative subtype. American Journal of Psychiatry 167, 640–647.

Lanius, R.A., Williamson, P.C., Boksman, K., Densmore, M., Gupta, M., Neufeld, R.W.J., Gati, J.S., Menon, R.S., 2002. Brain activation during script-driven imagery induced dissociative responses in PTSD: a functional magnetic resonance imaging investigation. Biological Psychiatry 52, 305–311.

Lilienfeld, S.O., Lynn, S.J., Kirsch, I., Chaves, J.F., Sarbin, T.R., Ganaway, G.K., Powell, R. A., 1999. Dissociative identity disorder and the sociocognitive model: recalling the lessons of the past. Psychological Bulletin 125, 507–523.

Lynn, S.J., Lilienfeld, S.O., Merckelbach, H., Giesbrecht, T., Van Der Kloet, D., 2012. Dissociation and dissociative disorders challenging conventional wisdom. Current Directions in Psychological Science 21, 48–53.

Mai, J.K., Assheuer, J.K., Paxinos, G., 1997. Atlas of the Human Brain. Academic Press, Inc., San Diego.

Mickleborough, M.J.S., Daniels, J.K., Coupland, N.J., Kao, R., Williamson, P.C., Lanius, U.F., Hegadoren, K., Schore, A., Densmore, M., Stevens, T., Lanius, R.A., 2011. Effects of trauma-related cues on pain processing in posttraumatic stress disorder: an fMRI investigation. Journal of Psychiatry and Neuroscience 36, 6–14.

Nijenhuis, E.R., Spinhoven, P., Van Dyck, R., Van der Hart, O., Vanderlinden, J., 1996. The development and psychometric characteristics of the Somatoform Dissociation Questionnaire (SDQ-20). Journal of Nervous and Mental Disease 184, 688–694.

Nijenhuis, E.R.S., Den Boer, J.A., 2009. Psychobiology of traumatisation and trauma-related structural dissociation of the personality. In: Dell, P.F., O'Neil, J.A. (Eds.), Dissociation and the Dissociative Disorders: DSM-V and Beyond. Routledge, New York, pp. 337–367.

Nijenhuis, E.R.S., van der Hart, O., 2011. Dissociation in trauma: a new definition and comparison with previous formulations. Journal of Trauma and Dissociation 12, 416–445.

Nijenhuis, E.R.S., Van der Hart, O., Kruger, K., 2002. The psychometric characteristics of the traumatic experiences checklist (TEC): first findings among psychiatric outpatients. Clinical Psychology and Psychotherapy 9, 200–210.

Paris, J., 2012. The rise and fall of dissociative identity disorder. Journal of Nervous and Mental Disease 200, 1076–1079.

Putnam, F.W., 1997. Dissociation in Children and Adolescents: A Developmental Perspective. Guilford Press, New York.

Quirarte, G.L., de la Teja, I.S.L., Casillas, M., Serafín, N., Prado-Alcalá, R.A., Roozendaal, B., 2009. Corticosterone infused into the dorsal striatum selectively enhances memory consolidation of cued water-maze training. Learning and Memory 16, 586–589.

Reinders, A.A.T.S., den Boer, J.A., Büchel, C., 2005. The robustness of perception. European Journal of Neuroscience 22, 524–530.

Reinders, A.A.T.S., Nijenhuis, E.R.S., Paans, A.M.J., Korf, J., Willemsen, A.T.M., den Boer, J.A., 2003. One brain, two selves. NeuroImage 20, 2119–2125.

Reinders, A.A.T.S., Nijenhuis, E.R.S., Quak, J., Korf, J., Haaksma, J., Paans, A.M.J., Willemsen, A.T.M., den Boer, J.A., 2006. Psychobiological characteristics of dissociative identity disorder: a symptom provocation study. Biological Psychiatry 60, 730–740.

Reinders, A.A.T.S., Willemsen, A.T.M., Georgiadis, J.R., Hovius, M., Paans, A.M.J., den Boer, J.A., 2002. Interscan displacement-induced variance in PET activation data is excluded by a scan-specific attenuation correction. NeuroImage 17, 1844–1853.

Reinders, A.A.T.S., Willemsen, A.T.M., Vos, H.P.J., den Boer, J.A., Nijenhuis, E.R.S., 2012. Fact or factitious? A psychobiological study of authentic and simulated dissociative identity states. PLoS One 7, e39279.

Sánchez-Resendis, O., Medina, A.C., Serafín, N., Prado-Alcalá, R.A., Roozendaal, B., Quirarte, G.L., 2012. Glucocorticoid-cholinergic interactions in the dorsal striatum in memory consolidation of inhibitory avoidance training. Frontiers in Behavioural Neuroscience 6, 33.

Sar, V., Unal, S.N., Ozturk, E., 2007. Frontal and occipital perfusion changes in dissociative identity disorder. Psychiatry Research 156, 217–223.

Savoy, R.L., Frederick, B.B., Keuroghlian, A.S., Wolk, P.C., 2012. Voluntary switching between identities in dissociative identity disorder: a functional MRI case study. Cognitive Neuroscience 3, 112–119.

Schlumpf, Y.R., Nijenhuis, E.R.S., Chalavi, S., Weder, E.V., Zimmermann, E., Luechinger, R., La Marca, R., Reinders, A.A.T.S., Jäncke, L., 2013. Dissociative part-dependent biopsychosocial reactions to backward masked angry and neutral faces: an fMRI study of dissociative identity disorder. NeuroImage 3, 54–64.

Schwabe, L., Dalm, S., Schächinger, H., Oitzl, M.S., 2008. Chronic stress modulates the use of spatial and stimulus-response learning strategies in mice and man. Neurobiology of Learning and Memory 90, 495–503.

Simeon, D., Guralnik, O., Hazlett, E.A., Spiegel-Cohen, J., Hollander, E., Buchsbaum, M.S., 2000. Feeling unreal: a PET study of depersonalization disorder. American Journal of Psychiatry 157, 1782–1788.

Spiegel, D., 1984. Multiple personality as a post-traumatic stress disorder. Psychiatric Clinics of North America 7, 101–110.

Spiegel, D., Loewenstein, R.J., Lewis-Fernández, R., Sar, V., Simeon, D., Vermetten, E., Cardeña, E., Dell, P.F., 2011. Dissociative disorders in DSM-5. Depression and Anxiety 28, 824–852.

Stein, D.J., Koenen, K.C., Friedman, M.J., Hill, E., McLaughlin, K.A., Petukhova, M., Ruscio, A.M., Shahly, V., Spiegel, D., Borges, G., Bunting, B., Caldas-de-Almeida, J. M., de Girolamo, G., Demyttenaere, K., Florescu, S., Haro, J.M., Karam, E.G., Kovess-Masfety, V., Lee, S., Matschinger, H., Mladenova, M., Posada-Villa, J., Tachimori, H., Viana, M.C., Kessler, R.C., 2012. Dissociation in posttraumatic stress disorder: evidence from the world mental health surveys. Biological Psychiatry 73, 302–312.

Steinberg, M., 1993. Structured Clinical Interview for DSM-IV Dissociative Disorders (SCID-D). American Psychiatric Press, Washington DC.

Talairach, J., Tournoux, P., 1988. Co-Planar Stereotaxic Atlas of the Human Brain. Thieme Verlag, Stuttgart.

Tsai, G.E., Condie, D., Wu, M.T., Chang, I.W., 1999. Functional magnetic resonance imaging of personality switches in a woman with dissociative identity disorder. Harvard Review of Psychiatry 7, 119–122.

Van der Hart, O., Nijenhuis, E.R.S., Steele, K., 2006. The Haunted Self: Structural Dissociation and the Treatment of Chronic Traumatization, 1st ed. W. W. Norton & Company, New York/London.

Weniger, G., Siemerkus, J., Barke, A., Lange, C., Ruhleder, M., Sachsse, U., Schmidt-Samoa, C., Dechent, P., Irle, E., 2013. Egocentric virtual maze learning in adult survivors of childhood abuse with dissociative disorders: evidence from functional magnetic resonance imaging. Psychiatry Research 212, 116–124.

Wolf, E.J., Lunney, C.A., Miller, M.W., Resick, P.A., Friedman, M.J., Schnurr, P.P., 2012a. The dissociative subtype of PTSD: a replication and extension. Depression and Anxiety 29, 679–688.

Wolf, E.J., Miller, M.W., Reardon, A.F., Ryabchenko, K.A., Castillo, D., Freund, R., 2012b. A latent class analysis of dissociation and posttraumatic stress disorder: evidence for a dissociative subtype. Archives of General Psychiatry 69, 698–705.

Yehene, E., Meiran, N., Soroker, N., 2005. Task alternation cost without task alternation: measuring intentionality. Neuropsychologia 43, 1858–1869.

Yehene, E., Meiran, N., Soroker, N., 2008. Basal ganglia play a unique role in task switching within the frontal-subcortical circuits: evidence from patients with focal lesions. Journal of Cognitive Neuroscience 20, 1079–1093.