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Research paper

Body detachment in response to emotions: Evidence from a rubber hand illusion study in adolescent patients with non-suicidal self-injurious behavior and dissociative symptoms

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ABSTRACT

Previous studies have proposed a connection between dissociation and the sense of body ownership, and initial evidence suggests that emotions could modulate this relationship. Here we aimed to investigate how differently arousing emotions influence the malleability of the bodily self. This study included 50 adolescent psychiatric patients with non-suicidal self-injurious behavior (NSSI)—who were divided into low-dissociation and high-dissociation groups—along with 25 healthy controls. Participants completed six trials of the rubber hand illusion while listening to neutral, sad, or fearful vocalizations. Heart rate, skin conductance level, and non-specific skin conductance responses were concomitantly measured. After each trial, participants completed the rubber hand illusion questionnaire as a subjective illusion measure, and acute dissociation, mood, and proprioceptive drift were assessed. Overall, the NSSI high-dissociation group reported the highest subjective illusion under all conditions. Additionally, fearful vocalizations resulted in a stronger subjective illusion than the neutral condition in the NSSI low-dissociation group, but not in the NSSI high-dissociation and healthy control groups. The NSSI low-dissociation group showed a higher proprioceptive drift than the NSSI high-dissociation group. Moreover, acute dissociation was positively related to subjective illusion, but not related to proprioceptive drift. In conclusion, body detachment in response to emotions may be responsible for the malleability of the sense of body ownership. This finding highlights the need for clinical interventions to stabilize self-experiences during emotional situations, especially in patients with dissociative symptoms.

1. Introduction

Dissociation represents a disruption of the integration of psychological aspects—e.g., memory, identity, consciousness, and motor control (Spiegel et al., 2011)—which can develop through events like trauma or neglect, especially during childhood and adolescence (Putnam, 1997; Brunner et al., 2000). Dissociation is observed in various mental disorders, including borderline personality disorder (BPD), post-traumatic stress disorder (PTSD), and in affective disorders (Lyssenko et al., 2018). Dissociative symptoms are related to the degree of psychopathological severity, non-responsiveness to psychotherapy, and maladaptive neuropsychological functioning (Rufer et al., 2006; Haaland and Landrø, 2009), and are strongly linked to suicidality and non-suicidal self-injurious behavior (NSSI) (Calati et al., 2017). In particular, it has been suggested that NSSI serves an anti-dissociation purpose, as it may help disrupting states of numbness and pain-insensitivity (Klonsky, 2007). Therefore, it comes as no surprise that dissociation is one of the main predictors of NSSI and it even serves as a mediator of the frequently observed relationship between NSSI and childhood neglect and abuse (Zoroglu et al., 2003; Zetterqvist et al., 2014).

Dissociation often involves alienation from oneself (depersonalization experiences) or from the environment (derealization experiences). Symptoms can include emotional numbing, reduced awareness of body sensations, analgesia and feelings of disembodiment (Nijenhuis, 2001;

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Glossary

NSSI	Non–Suicidal Self–Injurious Behavior
BPD	Borderline Personality Disorder
PTSD	Post–Traumatic Stress Disorder
RHI	Rubber Hand Illusion
RH	Rubber Hand
HD	High Dissociation
LD	Low Dissociation
HC	Healthy Control
A–DES	Adolescent Dissociative Experiences Scale
MINI–KID	Mini–International Neuropsychiatric Interviews for Children and Adolescents
SCID–5–PD	Structured Clinical Interview for DSM–V Personality Disorders
CDS	Cambridge Depersonalisation Scale
BDI–II	Beck Depression Inventory II
BAI	Beck Anxiety Inventory
SITBI-G	Self-Injurious Thoughts and Behaviors Interview
HDT	Heartbeat Detection Task
ECG	Electrocardiogram
IAc	Interoceptive Accuracy
IS	Interoceptive Sensibility
IAw	Interoceptive Awareness
RHIQ	Rubber Hand Illusion Questionnaire
SAM	Self–Assessment Manikin
DSS4	Dissociation–Tension Scale 4
HR	Heart Rate
NSCR	Non–Specific Skin Conductance Responses
SCL	Skin Conductance Level
BF	Bayes Factor
Sync.	Synchronous
Async.	Asynchronous
BMI	Body Mass Index
HEP	Heartbeat Evoked Potential

Medford, 2012; Spitzer et al., 2006). Such changes in self-experience can be understood by studying sense of ownership, characterized as the feeling that body parts, emotions, thoughts, or actions belong to oneself (Gallagher, 2000). A widely used approach to assess body ownership is the *rubber hand illusion* (RHI) paradigm (Botvinick and Cohen, 1998), in which tactile stimulation of a participant's hidden real hand and a visible rubber hand (RH) can create an illusion of ownership over the RH (Botvinick and Cohen, 1998). The RHI can be measured using questionnaires, or by assessment of the drift of proprioceptive estimation towards the RH (Botvinick and Cohen, 1998; Longo et al., 2008). Many studies have explored the mechanisms underlying the sense of ownership in the RHI. Early theories proposed that it was driven purely by bottom-up multisensory integration of interoceptive, exteroceptive, and proprioceptive information (Botvinick and Cohen, 1998; Braun et al., 2018). In recent years, however, theories emphasizing top-down influences have gained prominence. For example, Seth et al. (2012) suggested that the brain generates predictions about the position and state of the body. When bottom-up signals do not match these predictions, a prediction error occurs. In the context of the RHI, if visual and tactile stimulation correlate, the prediction error in the proprioceptive domain is corrected through a model update, integrating the rubber hand into the body representation (Seth, 2013).

The RHI paradigm has been successfully applied in children and adolescents (Botvinick and Cohen, 1998; Georgiou et al., 2016; Lee et al., 2021) and in adult patients with dissociative symptoms (Bekrater-Bodmann et al., 2016). Stronger RHI intensity has been observed in patient groups with greater levels of dissociative symptoms, compared to healthy controls and patients with lower levels of dissociative symptoms (Bekrater-Bodmann et al., 2016; Hirschmann and Lev Ari, 2016; Rabellino et al., 2018). Moreover, acute dissociative experiences have been positively correlated with RHI strength (Bekrater-Bodmann et al., 2016). This finding might explain the phenomenon of depersonalization in terms of a disturbed ability to differentiate between self and the environment, allowing higher malleability of one's sense of body ownership (Bekrater-Bodmann et al., 2016).

However, some studies failed to show a difference in the RHI strength between BPD or NSSI patients compared to healthy controls (Möller et al., 2020; Fust et al., 2024). In these studies, no distinction was made between high and low dissociation levels and no measures of acute dissociation were used. In light of the ongoing discussions regarding the introduction of a dissociative subtype of NSSI (Ford and Gómez, 2015; Calati et al., 2017), this distinction seems to be important. Bearing in mind that NSSI is a common symptom of PTSD (Ford and Gómez, 2015), the results of Rabellino et al. (2018) may offer an explanation for the observed discrepancy: The authors demonstrated that only PTSD patients with high dissociation exhibited a higher malleability of the sense of ownership than the control group, whereas patients without the dissociative subtype showed a stabilization compared to healthy participants. Consequently, the present study aimed to gain a deeper understanding of the body ownership malleability in NSSI patients with different levels of dissociation.

Furthermore, we aim to investigate whether the relationship between dissociation and the sense of body ownership in an adolescent patient sample with NSSI is comparable to findings from studies on adults, as, to our knowledge, no studies have yet examined this relationship in this age group.

In addition, another study showed that induction of sadness before illusion stimulation led to a stronger subjective illusion in healthy participants with higher dissociative tendencies, compared to participants with a lower manifestation (Schroter et al., 2021). This suggests that emotions may modulate the relation between dissociative experiences and body ownership. Moreover, a study of pain perception demonstrated that reduced arousal following a pain stimulus is associated with an increased sense of ownership of a virtual body (Romano et al., 2014). This indicates the malleability of body ownership, with greater RHI intensity representing a coping mechanism for emotional arousal and pain (Romano et al., 2014; Bekrater-Bodmann et al., 2016). Herein, detached emotion experience may correspond with blunted arousal (Lambie and Marcel, 2002).

Neuroimaging studies support the notion of an arousal shutdown response. Highly dissociative states are related to increased brain activity in regions associated with arousal modulation and emotion regulation, reflecting emotional overregulation by limbic hyperinhibition (Putnam, 1997; Lanius et al., 2010). This may result in blunted physiological and subjective arousal in response to emotional stimuli or trauma scripts (Griffin et al., 1997; Sierra et al., 2002; Danböck et al., 2024). Accordingly, we suggest that arousal shutdown is accompanied by experiences of body detachment, which may be reflected by increased body ownership malleability. Interoceptive abilities, which play essential roles in emotion experience (Garfinkel et al., 2015) and specifically in arousal (Pollatos et al., 2005), are negatively related to RHI (Tsakiris et al., 2011) and to dissociation (Pick et al., 2020). This suggests that interoceptive abilities may be a linking factor.

In summary, individuals with high dissociation levels often exhibit intensified malleability of their sense of body ownership, specifically in response to emotions, suggesting that these changes may originate from detached emotion experience (Schroter et al., 2021). In this study, we aimed to examine the role of arousal in this relation between emotion

and RHI, and to investigate potential moderating effects of interoceptive abilities and arousal blunting. To this end, we evaluated changes in RHI during differently arousing emotion conditions (neutral, sadness, and fear) in young patients with NSSI and high dissociation (HD) or low dissociation (LD) levels, compared with healthy control participants (HC).

We expected patients in the HD group to show lower interoceptive abilities, to be more susceptible to the RHI, and to experience less physical/subjective arousal in response to emotional vocalizations, compared to the HC and LD groups. Moreover, we anticipated that the RHI would be more pronounced when facing a more arousing (threat) emotion, compared to a less arousing (sadness) emotion, and to be lowest in the neutral condition. This difference was expected to be greater in the HD group than in the LD and HC groups. Finally, we hypothesized that the between-group differences in RHI strength under the fear condition would be moderated by interoceptive abilities and subjective/physiological arousal.

2. Methods

2.1. Participants

Based on our power analysis (see Supplementary Material Section S5), 50 adolescent patients from the Department of Child and Adolescent Psychiatry and Psychotherapy at the University of Regensburg, and 25 healthy control participants were recruited. All participants were between 12 and 21 years old (see Table 1). Most patients were sampled through a research project on NSSI, as this patient group is particularly associated with dissociative symptoms (Calati et al., 2017). As assessed in the recruitment process, all patients reported at least five events of self-injurious behavior during the last year, according to the *DSM-V* diagnostic criteria for NSSI disorder. Exclusion criteria were acute suicidality or psychosis, and pre-existing cardiac or neurological diseases. Patients were allocated to the HD or LD group, using the median of 3.35 on the German version (Brunner et al., 2008) of the Adolescent Dissociative Experiences Scale (A-DES; Armstrong et al., 1997) (Table 1). The HC group comprised 25 healthy participants with an A-DES score below 2.5, no psychiatric or neurological disorders, and who were not currently undergoing any psychiatric or psychotherapeutic treatment. Prior to study inclusion, written informed consent was obtained from participants and their legal representatives. Participants received 25€ vouchers as compensation for their participation.

The present study was approved by the ethical committee of the University of Regensburg (protocol number: 21–2746–101) and was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments (World Medical Association, 2013).

2.2. Measures

2.2.1. Psychiatric instruments

The Mini-International Neuropsychiatric Interview for Children and Adolescents (MINI-KID; Sheehan et al., 2010) for DSM-IV and ICD-10 was used to screen for psychiatric disorders. As a supplement, we applied the Structured Clinical Interview for DSM-V Personality Disorders (SCID-5-PD; Beesdo-Baum et al., 2019) subsection for BPD. Psychiatric assessments were conducted by well-trained clinical psychologists.

Subsequently, the participants completed diagnostic questionnaires on a computer. The A-DES (Brunner et al., 2008) and Cambridge Depersonalisation Scale (CDS; Sierra and Berrios, 2000; Michal et al., 2004) were used to assess dissociative symptoms and the frequency and duration of depersonalization experiences during the last six months. Depressive symptoms (Beck Depression Inventory; BDI-II; Beck et al., 1996; Hautzinger et al., 2009) and anxiety symptoms (Beck Anxiety Inventory; BAI; Beck et al., 1988; Margraf and Ehlers, 2007) were also measured. Besides, patients who also participated in the larger research project also completed an interview on self-injurious thoughts and behaviors (Self-Injurious Thoughts and Behaviors Interview; SITBI-G, Nock et al., 2007; Fischer et al., 2014). Characteristics and differences between the LD and HD groups are reported in the Supplementary Material Table S1.

2.2.2. Heartbeat Detection Task (HDT)

Participants initially performed a computerized HDT to assess interoceptive abilities (Schandry, 1981). After a 15-s practice trial, six main trials (25, 30, 35, 40, 45, and 50 s) were conducted in randomized order, requiring participants to count their heartbeats without physically measuring their pulse and without guessing (Schandry, 1981; Tsakiris et al., 2011; Garfinkel et al., 2015; Desmedt et al., 2020). Participants' heart rate count and the objective heartbeat (determined by ECG) were used to calculate interoceptive accuracy (IAc). To determine interoceptive sensibility (IS), participants were asked how confident they were about their judgment (0–100 %) (Garfinkel et al., 2015). Finally, Pearson correlation between IAc and IS was calculated to determine interoceptive awareness (IAw) (Garfinkel et al., 2015) (see Supplementary Material Section S1).

2.2.3. Rubber Hand Illusion (RHI) Induction

For each emotion condition, participants completed one synchronous and one asynchronous trial, yielding a total of six 90-s trials (Engelen et al., 2017). A box set-up was used, in which the real hand was hidden while the RH was visible, according to Tsakiris et al. (Tsakiris et al., 2011). The experimenter stroked both hands through holes in the back of the box (see Supplementary Material Section S2). Using two identical paint brushes, stroking was applied to the index finger either synchronously, or asynchronously with an approximately 1-s delay, with each stroke lasting 1–1.5 s (Filippetti and Tsakiris, 2017). Both trials were performed because the mere illusion effect can be determined based on the difference between synchronous and asynchronous trials (Filippetti and Tsakiris, 2017; Riemer et al., 2019).

2.2.4. Emotion conditions

Throughout each RHI induction, participants wore headphones through which they heard vocal stimuli from the Montreal Affective Voices Database (Belin et al., 2008) (see Supplementary Material Section S3 for details). Engelen et al. (2017) previously reported that affective stimuli from this database led to a stronger RHI, and the fear stimuli were found to evoke a physiological arousal response, which was attenuated in patients with PTSD (Rubin and Telch, 2021).

2.2.5. Proprioceptive drift

Before and after each RHI trial, participants were asked to verbally report the position where they felt their left index finger on a tape measure with random offset (Tsakiris et al., 2011), placed on a wooden lid hiding the RH. Proprioceptive drift was determined by subtracting the post-induction from the pre-induction estimate.

2.2.6. Rubber Hand Illusion Questionnaire (RHIQ)

After obtaining the proprioceptive estimation, participants completed a questionnaire created by Longo et al. (2008) regarding the perceived intensity of the RHI, which has been used among adults and adolescents (Tsakiris et al., 2011; Georgiou et al., 2016). The questionnaire comprises five ownership and three location items, rated on a seven-point Likert scale, from −3 = strongly disagreed, to 3 = strongly agreed (Longo et al., 2008).

2.2.7. Self-Assessment Manikin (SAM)

To assess how the emotion conditions affected participants' mood, we used the SAM (Bradley and Lang, 1994), a non-verbal questionnaire, in which current valence and arousal are ranked on a nine-point Likert scale (1 = unhappy/unaroused; 9 = happy/aroused), corresponding to five figures printed above the scale.

2.2.8. Dissociation-Tension Scale 4 (DSS4)

The DSS4 (Stiglmayr et al., 2009) was developed as a short assessment for acute dissociation, including measures of depersonalization, derealization, analgesia, and somatoform dissociation. Items are rated on a 10-point Likert scale, from 0 = not at all to 9 = very strong.

2.3. Procedure

The study was completed in one (including a break) or two days, and comprised psychiatric diagnostics (~1.5 h), and the experimental part (~1 h). The experimental part began with the HDT. Subsequently,

Table 1
Demographic and clinical characteristics.

		HD	LD	HC	Group
		N (%)	*N* (%)	*N* (%)	Differences
Gender	Male	2 (8 %)	5 (20 %)	0 (0 %)	$BF^1_{10} = 0.08$
	Female	21 (84 %)	19 (76 %)	25 (100 %)	
	Non-binary	2 (8 %)	1 (4 %)	0 (0 %)	
Sex	Male	0 (0 %)	5 (20 %)	0 (0 %)	$BF^1_{10} = 1.40$
	Female	25 (100 %)	20 (80 %)	25 (100 %)	
Handedness	Right	20 (80 %)	23 (92 %)	23 (92 %)	$BF^1_{10} = 0.01$
	Left	5 (20 %)	1 (4 %)	2 (8 %)	
	Both	0 (0 %)	1 (4 %)	0 (0 %)	
School	Gymnasium	10 (40 %)	13 (52 %)	20 (80 %)	$BF^1_{10} = 0.13$
	Mittelschule	1 (4 %)	4 (16 %)	1 (4 %)	
	Montessori	0 (0 %)	0 (0 %)	1 (4 %)	
	Realschule	11 (44 %)	7 (28 %)	3 (12 %)	
	Other	3 (12 %)	1 (4 %)	0 (0 %)	
Medication	Yes	14 (56 %)	14 (56 %)		$BF^1_{L\neq H} = 0.37$
	SSRI	9 (36 %)	11 (44 %)		$BF^1_{L\neq H} = 0.39$
	Tricyclic	0 (0 %)	1 (4 %)		$BF^1_{L\neq H} = 0.15$
	NaSSA	0 (0 %)	2 (8 %)		$BF^1_{L\neq H} = 0.31$
	Atypical neuroleptics	4 (16 %)	1 (4 %)		$BF^1_{L\neq H} = 0.51$
ICD-10 Psychiatric Diagnoses	F1	4 (16 %)	2 (8 %)		$BF^1_{L\neq H} = 0.32$
	F3	19 (76 %)	14 (56 %)		$BF^1_{L\neq H} = 0.94$
	F4	23 (92 %)	21 (84 %)		$BF^1_{L\neq H} = 0.32$
	F5	13 (52 %)	7 (28 %)		$BF^1_{L\neq H} = 1.42$
	F9	8 (32 %)	2 (8 %)		$BF^1_{L\neq H} = 2.39$
SCID-5-PD	BPD Diagnose	15 (60 %)	4 (16 %)		$BF^1_{L\neq H} = \mathbf{55.48}$

		M (*SD*)	*M* (*SD*)	*M* (*SD*)	
Age		15.16 (1.95)	16.44 (2.27)	15.84 (2.61)	$BF^2_{10} = 0.51$
BMI		22.18 (6.02)	22.37 (3.76)	19.54 (2.72)	$BF^2_{10} = 1.31$
A-DES		5.51 (1.26)	1.87 (0.98)	0.34 (0.26)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} > \mathbf{100}$
BDI-II		38.04 (10.16)	24.32 (13.29)	2.08 (2.72)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} = \mathbf{35.37}$
BAI		31.64 (11.82)	20.52 (13.14)	4.32 (4.41)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} = \mathbf{4.40}$
CDS	Frequency	49.20 (20.75)	20.88 (15.32)	1.84 (2.43)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} > \mathbf{100}$
	Duration	74.96 (36.33)	32.88 (20.52)	2.56 (3.25)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} > \mathbf{100}$
SCID-5-PD	Sum-score	21.20 (3.30)	15.64 (4.40)	9.36 (0.57)	$BF^2_{10} > \mathbf{100}$ $BF^3_{C\neq L} > \mathbf{100}$ $BF^3_{L\neq H} > \mathbf{100}$
Interoceptive Abilities	Iac	0.55 (0.21)	0.50 (0.21)	0.62 (0.17)	$BF^2_{10} = 0.72$
	IS	44.73 (20.21)	38.25 (23.31)	50.84 (20.73)	$BF^2_{10} = 0.57$
	Iaw	0.56 (0.40)	0.20 (0.54)	0.48 (0.36)	$BF^2_{10} = \mathbf{3.32}$ $BF^3_{C\neq L} = 0.53$ $BF^3_{L\neq H} = 1.53$

Note. BF = Bayes Factor for evidence of a difference between HC (healthy control) and LD (low-dissociation) groups ($BF_{C\neq L}$), and between LD and HD (high-dissociation) ($BF_{L\neq H}$) against the H0. BF^1 = contingency table; BF^2 = ANOVA; BF^3 = two-sided *t*-test with corrected Bayes factors. Bayes factor values in bold indicate meaningful evidence for group differences.
Schools: Hauptschule = secondary general school; Realschule = intermediate secondary school; Mittelschule = combination of "Hauptschule" and "Realschule"; Gymnasium = provides university entrance qualification; Montessori = alternative educational method for children of all ages focusing on children's natural interests.
ICD-10 diagnoses: F1 = mental and behavioral disorders due to psychoactive substance use; F3 mood [affective] disorders; F4 = neurotic, stress-related, and somatoform disorders; F5 = behavioral syndromes associated with physiological disturbances and physical factors; F9 = behavioral and emotional disorders with onset usually occurring in childhood and adolescence.
Further abbreviations: BMI = body mass index; A-DES = Adolescent Dissociative Experiences Scale; BDI-II=Becks Depression Inventory II; BAI=Becks Anxiety Inventory; CDS=Cambridge Depersonalisation Scale; SCID-5-PD=Structured Clinical Interview for DSM-V - Personality Disorders. IAc = interoceptive accuracy; IS = interoceptive sensibility; IAw = interoceptive awareness.

participants were instructed to sit down and place their left hand in the RHI box to complete the habituation phase, during which they were asked to close their eyes and relax for 3 min. Thereafter, they completed the SAM and DSS4 baseline measurement, followed by the RHI (see Supplementary Material Fig. S1).

The pre-proprioception measurement was taken at the beginning of each RHI trial, followed by a 1-min resting baseline (Gross and Levenson, 1997). Next, the 90-s RHI trial was performed, in a counterbalanced order regarding emotion and stroking conditions. After each trial, the post-proprioception measurement was conducted, and participants completed the RHIQ, SAM, and DSS4. To ensure full disembodiment of the RH (Eck et al., 2022), a 2-min break was implemented between trials, during which participants removed their left hand from the setup to fill out the questionnaires.

Heart rate (HR) and electrodermal activity (NSCR = non-specific skin conductance responses & SCL = skin conductance level) were measured throughout the habituation period, during resting baselines, and all RHI trials (see Supplementary Material Section S4).

2.4. Statistical analysis

Analyses were performed using R4.2.2 (R Core Team, 2020). Outliers and incomplete questionnaires were excluded (see Supplementary Material Section S6). Group differences were calculated for demographic, diagnostic, and interoceptive variables using Bayesian ANOVAs or contingency tables and post-hoc *t*-tests with adjusted prior odds (*BayesFactor* package) (Westfall, 1997; Morey et al., 2022). Bayes Factors (BFs) were interpreted according to the classification scheme of Jeffreys (see Supplementary Material Section S7), as reported by Wagenmakers et al. (2011). BFs between 1/3 and 3 indicated that the data did not provide meaningful evidence for either model (Dienes, 2021). We also analyzed whether potential confounding variables, such as age, symptom severity (BDI-II, BAI, SCID-5-PD, NSSI lifetime frequency and thought intensity), and interoceptive abilities, were correlated with the mean RHIQ/proprioceptive drift difference scores (sync. − async.).

Next, Bayesian Multilevel Models were computed (*brms* package), as they allow quicker convergence than frequentist approaches and the appliance of a wide range of distribution assumptions and link-functions (Bürkner, 2017). Models were calculated for RHIQ, proprioceptive drift, SAM-arousal, HR, SCL, and NSCR. All models included the fixed effects *group*, *emotion condition*, and *stroking synchrony*, and their interactions. In post-hoc comparisons of interactions, the sync. − async. difference score was used as the dependent variable. The Supplementary Material Section S7 document presents details on model selection and contrast coding.

Exploratorily, we examined potential prediction effects of acute dissociation (DSS4) and arousal (SAM arousal, HR, SCL, and NSCR) on the RHI measures, using *brms*. For the RHI measures, moderation models were calculated, including the covariates of arousal and interoceptive abilities that were significantly related to the outcome.

3. Results

3.1. Group differences

The three groups did not substantially differ in gender, biological sex, school, occupation, age, or BMI (Table 1). Additionally, no substantial differences in interoceptive abilities were found after adjusting prior log odds in post-hoc comparisons. Contingency tables comparing the LD and HD groups further indicated no substantial differences regarding medication and most MINI diagnoses, with the exception of a higher frequency of BPD diagnosis in the HD group (Table 1).

Decisive evidence of group differences was found for all diagnostic questionnaires (Table 1). Post-hoc comparisons between the HC and LD groups revealed higher questionnaire scores in the LD group. Compared to the LD group, the HD group showed a higher symptom burden for dissociative, depersonalization, borderline, depressive, and anxiety symptoms (Table 1).

Additionally, differences between LD and HD groups regarding NSSI characteristics were calculated and can be found in Supplementary Material Table S1. Only a few substantial differences were found between the two groups, including a preference for burning as NSSI method, as well as a higher mention of social problems as a cause of NSSI in the HD group. However, due to a smaller sample size in the SITBI-G, results must be interpreted with caution.

3.2. Correlations to psychiatric symptoms and interoceptive abilities

We did not find substantial evidence that the RHIQ and proprioceptive drift difference scores (sync. − async.) were correlated with age; symptoms of depression, anxiety, and BPD; lifetime frequency of NSSI events and intensity of NSSI related thoughts, or interoceptive abilities ($BF_{10} < 0.93$; Supplementary Material Table S2). Thus, these variables were not included as moderators in further analyses.

3.3. Rubber hand illusion questionnaire

Bayesian cumulative link mixed models were calculated to analyze the main effects and interactions of group, condition, and synchrony (Supplementary Material Tables S3 & S4).

Compared to asynchronous trials, synchronous trials led to higher RHIQ scores, $b = -2.55$, 89 % CI [−3.33, −1.77], $PP_{b<0} = 100$ %. The HD group showed higher subjective illusion scores compared to the HC group, $b = 3.68$, 89 % CI [2.55, 4.81], $PP_{b>0} = 100$ %, and the LD group, $b = 1.88$, 89 % CI [0.74, 3.04], $PP_{b>0} = 98$ %. The illusion rating was higher in the LD group than the HC group, $b = 1.80$, 89 % CI [0.68, 2.91], $PP_{b>0} = 98$ % (Fig. 1; Supplementary Material Table S3).

We identified an interaction effect of condition, group, and synchrony, HC/LD: $b = -1.19$, 89 % CI [−2.00, −0.36], $PP_{b<0} = 96$ %; LD/HD: $b = -1.58$, 89 % CI [−2.40, −0.76], $PP_{b<0} = 99$ %. Post-hoc comparisons showed that, only in the LD group, the difference between synchronous and asynchronous trials was significantly higher in the fear than in the neutral condition, $b = -1.20$, 89 % CI [−1.71, −0.68], $PP_{b<0} = 100$ (Fig. 1). This effect was not found in the other two groups.

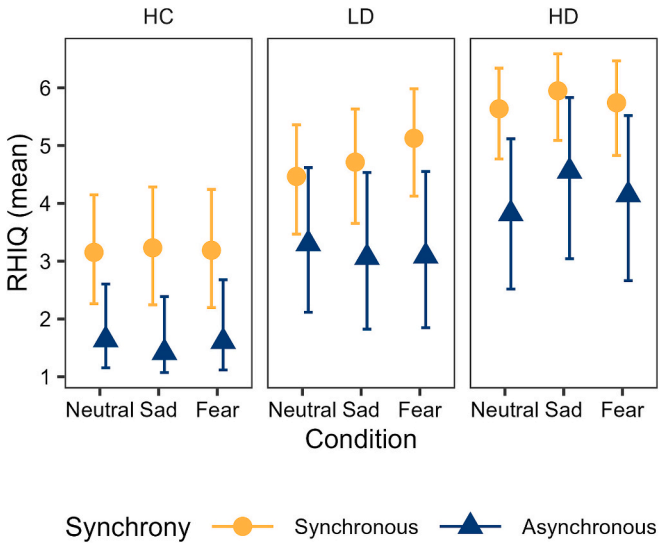

Fig. 1. Conditional effects plot of the 3-way interaction of group, condition, and synchrony on the Rubber Hand Illusion Questionnaire (RHIQ mean). HC = healthy control group; LD = low-dissociation group; HD = high-dissociation group.

3.4. Proprioceptive drift

For drift in the proprioceptive measurement, model comparisons yielded a model with Student's t-distribution (Supplementary Material Tables S3 & S5). Proprioceptive drift was significantly lower in the asynchronous than the synchronous trials, $b = -1.95$, 89 % CI [−3.01, −0.90], $PP_{b<0} = 99$ %, and higher drift was found in the LD compared to the HD group, $b = 1.79$, 89 % CI [0.43, 3.18], $PP_{b>0} = 95$ %. We did not detect a three-way interaction between synchrony, group, and condition.

3.5. Arousal

To analyze the effects of emotional vocalizations on arousal in the different groups, we used a cumulative link model for subjective arousal (Supplementary Material Table S6), and models with Student's t-distribution for NSCR, SCL, and HR (Supplementary Material Tables S7–S9). We did not find interaction effects on either of the arousal variables. The main effect of group showed a higher subjective illusion in the HD and LD groups compared to the HC group, and a higher HR in the HD compared to the LD group. The main effect of condition showed that fear led to more NSCRs, compared to the neutral and sadness conditions, while SCL was higher in the neutral compared to the sadness condition (see Supplementary Material Section S8).

3.6. Relations of acute dissociation, arousal, and the illusion measures

Brms analyses showed that the RHIQ was positively predicted by acute dissociation and proprioceptive drift (Fig. 2a & b), but not by arousal (Table 2). Exploratorily, we calculated the effect of the single DSS4 items on RHIQ, revealing that depersonalization was most strongly related to RHIQ ($b = 0.42$), followed by somatic dissociation ($b = 0.25$), and was not significantly related to derealization and analgesia.

HR negatively predicted proprioceptive drift (Fig. 2c), while acute dissociation was not related (Table 2). We further analyzed the moderation effects of arousal and interoceptive abilities on the fear effect between groups. However, no effects were observed (see Supplementary Material Section S9).

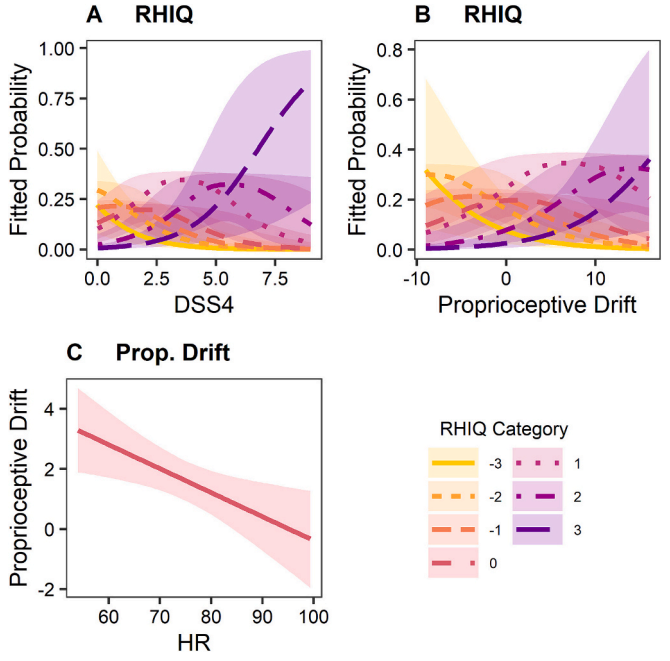

Fig. 2. Relation between arousal, the illusion measures, and acute dissociation. Fitted probability density of each Rubber Hand Illusion Questionnaire (RHIQ) category. a) Dissociation-Tension Scale 4 (DSS4). b) Proprioceptive drift. c) Fitted linear prediction effect of heart rate (HR) on the proprioceptive drift (Prop. Drift).

Table 2
Prediction effects of arousal and acute dissociation on rubber hand illusion.

	RHIQ		Proprioceptive Drift	
	b	*89 % CI*	*b*	*89 % CI*
Proprioceptive drift	**0.19**	0.11, 0.27		
DSS4	**0.73**	0.46, 1.00	0.17	−0.07, 0.40
Arousal	−0.07	−0.23, 0.10	0.12	−0.09, 0.34
SCL	−0.13	−1.58, 1.83	0.47	−3.62, 4.67
NSCR	0.03	−0.02, 0.09	0.003	−0.05, 0.05
HR	0.003	−0.04, 0.04	**−0.08**	−0.13, −0.03

Note. BF_{10} represents two-sided evidence ratios for the H1 ($r \neq 0$). RHIQ = Rubber Hand Illusion Questionnaire; DSS4 = Dissociation-Tension Scale 4; SCL = skin conductance level; NSCR = non-specific skin conductance responses; HR = heart rate. Bayes factor values in bold indicate meaningful evidence for group differences.

4. Discussion

The main aim of the present study was to examine whether dissociative symptoms lead to stronger malleability of one's sense of ownership, and whether differently arousing emotions amplify this effect. For this purpose, we investigated the effects of different emotional vocalizations on the RHI in adolescent NSSI patients with high or low dissociative symptoms and healthy controls.

We found a main effect of group on the subjective illusion (RHIQ), with the largest ratings in the HD group, followed by the LD group and the HC group. On the other hand, proprioceptive drift was higher in the LD compared to the HD group. The groups did not substantially differ in interoceptive abilities, and we found no arousal blunting in response to emotional vocalizations in the HD group.

Interestingly, we observed a stronger illusion in response to fearful vocalizations compared to neutral vocalizations, but only in the LD group. The emotional vocalizations did not have the expected effect on proprioceptive drift, and we found no moderation effects for the subjective illusion or proprioceptive drift.

Additional analyses revealed a positive relationship between acute dissociation and subjective illusion, suggesting that dissociative states are associated with stronger malleability of the sense of body ownership. Moreover, RHIQ was positively related to proprioceptive drift, and not related to any arousal variable. However, proprioceptive drift was negatively related to HR, indicating that drift may diminish with higher arousal.

In line with some previous studies (Bekrater-Bodmann et al., 2016; Hirschmann and Lev Ari, 2016; Rabellino et al., 2018), investigation of the relationship between dissociation and sense of ownership in patients with BPD or PTSD revealed a stronger RHI in the HD group, compared with the LD and HC groups. In contrast to Fust et al. (2024) this indicates that past findings can be extended to adolescents with NSSI and high levels of dissociation, suggesting higher body ownership malleability in patients with NSSI and high dissociation, which may relate to identity uncertainties and depersonalization (Bekrater-Bodmann et al., 2016).

The observed positive relationship between acute dissociative symptoms and subjective feelings of ownership also aligns well with these results. The general link between both concepts indicates that the RHI may have potential as an indirect measure of acute dissociative experiences in response to emotional situations. Specifically, acute depersonalization was most strongly related to the illusion questionnaire in our sample, supporting the previous proposal that the RHI may be a sign of depersonalization experience (Bekrater-Bodmann et al., 2016).

Apart from depersonalization, the item for somatoform dissociation was also positively correlated with the RHIQ. Previous studies have already shown that in patients with NSSI, pain perception levels are

associated with dissociation tendencies (Nijenhuis, 2001; Ford and Gómez, 2015). Patients who experienced less pain during self-injury also seemed to exhibit higher levels of dissociation (Russ et al., 1993). Additionally, a study by Romano et al. (2014) demonstrated that successfully embodying an avatar leads to reduced pain responses when pain stimuli are applied to a participant's hand. This suggests that the ability to perceive pain is closely linked to the sense of ownership.

Particularly interesting in this context is further research on distinguishing one's own emotions from those of others. A study by Dewe et al. (2018) found that a threat directed at oneself led to reduced NSCRs in the threat condition among participants with higher levels of depersonalization. Conversely, participants with stronger derealization experiences showed lower NSCRs when another person was threatened (Dewe et al., 2018). These studies provide initial evidence that specific dissociation symptoms may lead to different adaptations of the sense of self in different situations. A systematic investigation of these scenarios (self vs. other), considering various stimuli (negative, positive, or pain/threat stimuli) in relation to the sense of ownership, would therefore be of interest for future research.

Furthermore, our finding that emotional stimuli induce a stronger RHI among moderately dissociating participants aligns with previous findings showing elevated RHI levels in response to sad pictures among individuals with high subclinical dissociation (Schroter et al., 2021). Detached emotion experience may be the cause of the intensified illusion in both experiments (Lambie and Marcel, 2002). The lack of this effect in the HD group might have been due to a ceiling effect, i.e., the illusion induction may have caused substantial distress in individuals with high symptom burden, leading to strong illusion effects under all conditions.

Moreover, we found that RHIQ was positively related to acute dissociation, but not to arousal. This underscores the hypothesis that the RHIQ could serve as an indirect measure of dissociation rather than being a direct correlate of arousal, as it has been proposed in the past (Riemer et al., 2015). However, distinct processes may be involved regarding proprioceptive drift, which was not found to be related to acute dissociation. Unlike the subjective illusion, proprioceptive drift is correlated with changes in peripersonal space (Smit et al., 2023), defined as the area around the body where objects can be reached and manipulated, which has a protective function for the body (de Vignemont and Iannetti, 2015). Rabellino et al. (2020) suggested that patients with the dissociative subtype of PTSD develop a more flexible but narrower protective space, compared to patients with the non-dissociative PTSD subtype. In our sample we found a lower drift and a higher HR in the HD compared to the LD group, and a negative relation of HR and the proprioceptive drift. Accordingly, based on Rabellino et al. (2020) we propose that patients with high dissociation may have narrower and more plastic boundaries of the protective peripersonal space, which become sharper with increasing arousal and defense necessity. Therefore, our findings also emphasize the importance of distinguishing between the subgroups of high and low levels of dissociation, which was one of the main methodological differences to the study of Fust et al. (2024). Following Rabellino et al. (2018), the level of dissociative tendencies may be decisive regarding a sharpening or blurring of body boundaries and the choice of different defense strategies under threat (Rabellino et al., 2018; Rabellino et al., 2020; Peng et al., 2023). Hence, our results may even support the claim to introduce a dissociative subtype of NSSI (Ford and Gómez, 2015; Calati et al., 2017).

Overall, while plasticity of the sense of ownership seems to increase with the extent of dissociative experiences, the proprioceptive drift (potentially signifying the limits of peripersonal space) seems contingent on the level of activation. Accordingly, Rohde et al. (2011) posited that distinct underlying multisensory integration mechanisms may apply to proprioceptive drift and the RHIQ.

Our results showed no between-group differences in interoceptive abilities and no correlation with proprioceptive drift, in contrast to the findings of Tsakiris et al. (2011). However, we only measured cardiac interoception once before the experiment. Continuous measurement of interoceptive focus during the task, such as by heartbeat-evoked potential (HEP) (Marshall et al., 2018), may provide greater insight into the role of interoceptive–exteroceptive attention allocation and information integration. Improving interoceptive abilities may be particularly helpful in threatening situations, as it can narrow the peripersonal space (Ardizzi and Ferri, 2018), thereby protecting against exteroceptive manipulations of body experience (Bekrater-Bodmann et al., 2020). It would be intriguing to monitor HEP during the RHI under varied emotion conditions, or to adopt a more experimental approach involving the training of interoceptive abilities, e.g., through mindfulness interventions (Fischer et al., 2017).

Finally, a few strengths and limitations must be pointed out: We examined a well-characterized sample, representative of a typical adolescent treatment population in child psychiatric inpatient and outpatient clinics. Although NSSI is highly relevant in this age group, the choice of sampling limits the interpretation of results to this target group. In addition, the RHI has been shown to be closely related to the subjectively reported acute dissociation and may therefore even serve as an indicator of acute dissociation. This introduces new methodological possibilities. Although this type of measurement may seem impractical for clinical practice, the instrument offers a wide range of possibilities for assessing dissociation in research studies. The manipulation of ownership sensations can also be achieved using virtual reality avatars (Kocur et al., 2022) or, even more simply, by displaying body parts on a computer screen (Eck et al., 2022).

An extension of this would also be to explore the effects of emotions on the experience of "disembodiment." For example, Löffler et al. (2020) found that patients with dissociative symptoms generally experienced a lower sense of ownership over their own bodies. Therefore, it would be interesting to investigate in future studies whether disembodiment of one's own body is related to susceptibility to ownership manipulations.

Furthermore, the present study only investigated the effects of negative emotions on the RHI. For a more conclusive comprehension of the underlying mechanisms, further studies should extend the present findings to positive emotions and pain stimuli, as well.

Contrary to our expectations, we observed only a main effect of group on the RHIQ, without interaction with synchrony. Instead, the feeling of the illusion seemed to rise along with the level of dissociation. However, in previous studies (Bekrater-Bodmann et al., 2016; Hirschmann and Lev Ari, 2016; Rabellino et al., 2018), group comparisons were based solely on synchronous trials, aligning with our findings. In the patient groups of our sample, some participants reported feelings of time leaps, illusory sensations, and derealization during asynchronous trials—consistent with previous reports (Rabellino et al., 2018). Accordingly, the asynchronous control condition may not be adequate for this target group.

The sample size was determined using simulation-based power analysis, and included a correspondingly large number of subjects to analyze the main research question. Some secondary analyses revealed inconclusive Bayes Factors that require further investigation.

Beyond that, group comparisons revealed a higher general symptom burden in the HD compared to the LD group. We cannot exclude that the overall symptom severity may have influenced the results. However, no substantial correlations were identified between the difference score of illusion measures and the degrees of depressive, anxiety, and BPD symptoms.

In summary, the present findings indicate that dissociative experiences were closely related to malleability of the sense of body ownership, particularly in fearful situations. Depersonalization appears to be related most strongly with ownership changes, indicating a self-detached mode of emotion experience. Moreover, proprioceptive drift may rely on different processes than the subjective illusion rating, possibly involving a sharpening of the body boundaries in response to arousal. Since the direction of causality remains questionable, future studies should evaluate possible interventions aiming to stabilize ownership experiences, and examine whether this results in

improvement of dissociative symptoms under stressful or emotional situations. This may help reducing NSSI symptoms by providing alternative strategies to disrupt dissociative states.

Preregistration

The study was registered at the German Clinical Trials Register (https://www.bfarm.de, ID: DRKS00029131) on the 13th of June 2022.

CRediT authorship contribution statement

Franziska A. Schroter: Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alexandra Otto:** Writing – review & editing, Project administration, Methodology, Investigation. **Stephanie Kandsperger:** Writing – review & editing, Resources, Project administration. **Romuald Brunner:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition. **Petra Jansen:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2025.03.061.

Data availability

The data set generated and analyzed in this study and the code used for the analysis are available in the OSF repository (https://osf.io/t8jne).

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