Sense of Ownership

The Link to Emotion, Dissociation, and Mindfulness

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Content

Summary

Our sense of ownership reflects the feeling that our body, thoughts, and emotions belong to us (Gallagher, 2000). It can be assessed using the rubber hand illusion (RHI), a task where the actual hand (hidden from the participant) and a rubber hand (visible to the participant) are stroked simultaneously by the experimenter to evoke an illusion of ownership over the fake body part (Botvinick & Cohen, 1998). The RHI has been found to be stronger in arousing emotional situations (Engelen et al., 2017), in individuals with low interoceptive abilities (Tsakiris et al., 2011), and in psychiatric patients with high levels of dissociative symptoms (Bekrater-Bodmann et al., 2016). Based on these findings, the question of whether and how these three aspects are connected was asked. We proposed that certain styles of emotion experience, like detachment (as seen in dissociation) and the level of awareness (Lambie & Marcel, 2002), determine the malleability of the sense of ownership. Besides, we seeked to explore whether the malleability of the sense of ownership depends on the level of arousal of an emotion. Finally, this work aimed to investigate the stabilising effects of a brief body-focused mindfulness intervention, as meditation is associated with an improvement in interoceptive skills (Bornemann & Singer, 2017; Fischer et al., 2017; Mirams et al., 2013) and correlative studies have already shown initial evidence of a stabilisation of the sense of self in individuals with meditation or Tai Chi experience (Kerr et al., 2016; Xu et al., 2018).

To answer these questions, study one examined the influence of different emotional picture conditions on the RHI, measured using the Rubber Hand Illusion Questionnaire (RHIQ) and the drift in the proprioceptive estimation from baseline to post-illusion induction in 122 healthy students. For this purpose, sad, low-arousing images were presented supraliminally in one group and subliminally in a second group, while a third group saw only neutral images prior to the RHI. Analyses showed that only a difference between the supraliminal and the subliminal sadness groups emerged, and no difference to the neutral group. This difference was stronger in participants with higher dissociative traits. In general, higher dissociation was associated with a higher score in the RHIQ.

To better delineate the effects of differently arousing emotions and to confirm the dissociation effects in a clinical sample, study two aimed to investigate the effects of fearful, sad, and neutral vocalisations presented in a counterbalanced order throughout the RHI in adolescent patients with non-suicidal self-injurious behaviour and high (*n* = 25) or low dissociative symptoms (*n* = 25), compared to healthy control participants (*n* = 25). Subjective and physiological arousal, acute dissociation, subjective ownership experiences (RHIQ), and the proprioceptive drift were assessed. Besides, at the beginning of the experiment, interoceptive abilities (interoceptive accuracy = performance accuracy; interoceptive sensibility = confidence in performance; interoceptive awareness = correspondence between accuracy and confidence) were measured using a Heartbeat Detection Task (Garfinkel et al., 2015; Schandry, 1981). No effect of sad vocalisations was detected, and only an effect of fearful vocalisations emerged compared to the neutral condition in the low dissociation group. Besides, the high dissociation group showed the largest RHIQ scores in all conditions compared to the low dissociation and the control group. Consistently, acute dissociation was positively related to the RHIQ but not to the drift. Also, no relation was found between the RHIQ and arousal but a negative relation between the drift and heart rate.

Finally, in study three the effects of a short 20-minute body-focused meditation compared to an equally long audiobook control intervention was investigated in 111 healthy participants. At baseline and after the intervention, a Heartbeat Detection Task, the RHI (synchronous and asynchronous trials), and mood were assessed. Analysis revealed that an effect on the RHIQ and the drift only emerged in participants with high levels of interoceptive awareness. No effects on mood and interoceptive abilities were found. Correlational analyses revealed a negative relation of the RHIQ with trait mindfulness and interoceptive accuracy but no relation to trait dissociation.

The results of studies one and two show that emotion experience plays a large role in the sense of ownership, indicating a close interplay between the emotional system and processes linked to the sense of self. Particularly, dissociation is associated with an unstable sense of self, and it can be destabilised even more in emotional situations. Hence, an already unstable sense of self may be especially vulnerable to exteroceptive manipulations in highly arousing or stressful situations. The link to dissociation and emotions further indicates that a high malleability of the sense of self is connected to immature defence strategies (Peng et al., 2023). In contrast, the proprioceptive drift, which showed a negative relation to arousal, may be a correlate of more efficient defence strategies, emphasising the claim that both measures relate to distinct mechanisms. These findings contribute to a better understanding of the underlying processes of psychopathology, particularly in non-suicidal self-injury, and pave the way for finding suitable therapeutic approaches.

Building upon these findings, the results of study three imply that interventions that aim to stabilise the sense of self should entail exercises that target meta-cognitive abilities. The ability to deliberately allocate attention to the interoceptive and exteroceptive domains may be decisive in determining one's proneness to exteroceptive manipulations. This highlights the need to investigate different domains of interoception in relation to the sense of ownership.

1 Preface

The feeling of being yourself is an essential part of consciousness, as it serves as a reference for all experiences we encounter in everyday life (Damasio, 2003). Damasio (2003) states that without the ability to be consciously aware of one's own self, one would also not be able to adopt a subjective perspective and consequently would not be able to feel emotions. Being aware that "I am being the one undergoing an experience" (Gallagher, 2000, p.15) determines how we experience the world and enables us to empathise, sympathise, and interact with others (Lambie & Marcel, 2002). Only if we know how it is to feel emotions or pain we can understand this experience in others (Lambie & Marcel, 2002). Therefore, awareness of the self is an essential basis for our daily experience, emotions, and coexistence with others.

Self-awareness is not always pleasant. Sometimes, when the impressions of the environment or our own emotions become overwhelming, we take refuge in other worlds, such as books, movies, art, music, or even daydreaming, to escape our own self with its problems and temporarily take on a new identity (Herbert, 2013; Lyssenko et al., 2018). By getting absorbed in stories or fantasies, we lose self-reference and, as a result, reduce self-consciousness (Butler, 2006). This can go as far as no longer recognising yourself in the mirror, being unable to recall autobiographic memories, feeling detached from your own body, or feeling as if the world is unreal (Lyssenko et al., 2018). This is what is known as dissociation. In the case of absorption in fiction or film, we speak of non-pathological detachment from the self, while phenomena like depersonalisation, derealisation, or amnesia can be referred to as pathological dissociation (Butler, 2006).

Non-pathological dissociation offers us relief and escape from stressors. In the flood of information, media, and communication, it can be good to take a break for a while. But where is the limit of what is healthy? How much mindless social media scrolling, podcast listening, or TV-zapping is good for us? How much active attention should we pay our thoughts on the other hand?

Simply noticing what is happening around us without distracting ourselves or immediately judging every experience. In other words, should we go through life more mindfully (Kabat-Zinn, 2013)?

Based on these questions, this thesis aims to gain a deeper understanding of the self in emotional situations, better comprehend how dissociation can dissolve the self, and investigate whether mindfulness can then again restore the self, as it may help to cope with daily stressors and emotions (Hölzel et al., 2011).

2 Theoretical Background and State of Research

First, the concept of the sense of self, specifically the sense of ownership and its operationalisation through the rubber hand illusion, is explained. Underlying theories and possible methods of measuring the illusion are clarified. Subsequently, factors that have been shown to modulate the sense of ownership are identified. Specifically, this chapter will focus on the role of interoceptive abilities, emotions, and dissociation and how these concepts relate to each other. As an outlook, mindfulness meditation is discussed as a potential intervention for restoring interoceptive abilities and for stabilising sense of ownership.

2.1 Sense of Ownership in the Context of the Sense of Self

Following the philosophical conceptualisation of Gallagher (2000), the sense of self is comprised of the *minimal* self and the *narrative* self. The former refers to an immediate self-experience. It consists of the *sense of ownership*, which can be described as the feeling that actions, thoughts, emotions, or body parts are mine, and of the *sense of agency*, reflecting the feeling of being responsible for an action (Braun et al., 2018; Gallagher, 2000). In contrast, the narrative self describes a timely extended self-image and, therefore, a more complex abstraction of the self, which requires language and autobiographical information from episodic memory to generate the sense of a continuous self (Gallagher, 2000). Disruptions of the minimal self have been observed in disorders such as schizophrenia, depression, obsessive-compulsive disorders, and throughout dissociative states, e.g. in the form of thought insertion, misattribution of action or detachment from the body or the environment (Braun et al., 2018; Gallagher, 2000).

2.2 The Rubber Hand Illusion as a Measurement Tool

Studies on the sense of ownership have mainly focused on the sense of body or limb ownership (Braun et al., 2018). The rubber hand illusion (RHI) paradigm is a well-known tool for investigating the malleability of the sense of ownership (Botvinick & Cohen, 1998; Braun et al., 2018). In this task, a rubber hand is visibly positioned in front of the participant while their real hand is hidden. Rubber hand and real hand are stroked with a brush in synchrony or asynchrony. Synchronous stimulation can then lead to a feeling of ownership over the rubber hand (Botvinick & Cohen, 1998; Ehrsson et al., 2005). The asynchronous condition usually serves as a control condition to ensure that the reported embodiment cannot be explained by expectation effects or affirmative tendencies (Riemer et al., 2019). Other possible control conditions entail the use of non-corporeal objects (Riemer et al., 2019; Tsakiris & Haggard, 2005), anatomically implausible limb posture (Riemer et al., 2019; Tsakiris & Haggard, 2005), visual exposure only (Riemer et al., 2019; Rohde et al., 2011), or even conditions without using an object or artificial limb at all (Riemer et al., 2019). Apart from tasks including an artificial hand, other studies investigating limb ownership have also implemented similar setups that involve, e.g. a mirror reflection of the own contralateral hand (Giummarra et al., 2010; Riemer et al., 2019), a video recording of the own hand (Kammers, Longo, et al., 2009; Riemer et al., 2019; Tsakiris et al., 2006), a virtual hand on a computer (Eck et al., 2022) or in virtual reality (Ijsselsteijn et al., 2006; Kocur et al., 2022). Ownership feelings can also be investigated by inducing passive stimulation only or by including movement conditions, which also allows for investigating the sense of agency (Kalckert & Ehrsson, 2012; Tsakiris et al., 2006).

2.2.1 Underlying Mechanisms

Various theories have been put forward on how the RHI works, which differ primarily in the role ascribed to bottom-up and top-down processes (Braun et al., 2018). One bottom-up-based approach suggests that the feeling of ownership can arise in response to an interaction of visual, tactile, and proprioceptive information (Botvinick & Cohen, 1998). The proposed multisensory integration mechanism underlying the RHI is based on the dominant role of vision (Rock & Victor, 1964) when integrating information from different domains: Since visual information is usually weighted higher than information from other senses, a correlation of visuo-tactile information can lead to a remapping of proprioception, causing a drift in the proprioceptive estimation in the direction of the rubber hand (Makin et al., 2008; Suzuki et al., 2013; Tsakiris, 2010; Tsakiris &

Haggard, 2005). Accordingly, bottom-up integration of visual and tactile information can lead to adaptations of the internal body representation and, therefore, cause a feeling of ownership over the rubber hand (Tsakiris & Haggard, 2005). In line with this theory, research on neuronal activity during the RHI shows enhanced activation in areas such as the ventral premotor cortex, the intraparietal area, the right posterior insula, the cerebellum, and the frontal operculum—areas which are involved in multisensory integration (Ehrsson et al., 2004; Tsakiris et al., 2007).

Taken to an extreme, a merely bottom-up-based theory would also suggest that any object can be perceived as part of the body, even a table, for example (Armel & Ramachandran, 2003). However, the findings that non-corporeal objects can become part of the body representation were not supported by other studies that used objects such as a wooden stick (Tsakiris, 2010; Tsakiris & Haggard, 2005). Besides, the integration of visual and tactile information in the ventral premotor cortex, parietal areas, as well as in the putamen and the superior colliculus, has been found to depend on the proximity of the stimulus and therefore to proprioception (Maravita et al., 2003). Consequently, a correlation between visual and tactile information can lead to the emergence of an ownership feeling in response to the RHI, but only if the rubber hand is in an anatomically plausible position and if the visual form is congruent with the own body part (Makin et al., 2008; Tsakiris, 2010; Tsakiris & Haggard, 2005). Based on this finding, Tsakiris (2010) argues that a solely bottom-up mechanism is unlikely to be the underlying cause of the illusion. Accordingly, Tsakiris (2010) suggests a neurocognitive model of body ownership that is comprised of several comparisons between top-down representations and bottom-up signals: First, the model proposes that the object is tested in terms of incorporability (is it shaped like a human body part and are body surface and location of the body part plausible?). In the next step, the anatomical posture is compared with the felt body posture, and finally, the felt and seen touch is matched (Tsakiris, 2010). Hence, this theory argues that internal body representations play at least a partial role, meaning that top-down processes would be involved in the sense of ownership (Braun et al., 2018).

A later approach suggests a predictive coding perspective on the RHI paradigm (Seth et al., 2012). It proposes that our brain makes top-down predictions about the state of our body, and those predictions are matched to the bottom-up signals coming from the body's afferent sensors (Seth, 2013). If the predictions don't match the body signals, a prediction error results (Seth et al., 2012). These prediction errors can be minimised either by updating the predictive model in the brain or by modifying behaviour or precision-weighting of information so the sensory state is again in line with the prediction (Seth, 2013).

According to this theory, the RHI can be explained in the following way: if there is a high correlation between the visual and tactile information, the prediction error in the dimension proprioception leads to an adaption of the internal prediction model (in terms of a modification of the expected proprioceptive position and incorporation of the rubber hand into the body), so the illusion takes place (Seth, 2013).

2.2.2 Measurement of the Rubber Hand Illusion

To measure whether the illusion induction was successful, previous studies usually employed a questionnaire and experimentally measured the proprioceptive drift of the estimated index finger position of the hidden hand (Botvinick & Cohen, 1998; Longo et al., 2008; Tsakiris & Haggard, 2005). Some studies additionally record physiological responses to quantify the effects of the RHI (Riemer et al., 2019). This includes, for example, the measurement of skin temperature, which has been shown to drop in the hidden real hand during the RHI (Moseley et al., 2008), or the measurement of skin conductance responses after injuring or threatening the rubber hand (Armel & Ramachandran, 2003; Ehrsson et al., 2007). The different measurement methods are explained below:

2.2.2.1 The Subjective Feeling of Ownership. Various questionnaires have been applied in the past to assess the subjective feeling of ownership over the rubber hand (Botvinick & Cohen, 1998; Ehrsson et al., 2005; Haans et al., 2012; Kammers, de Vignemont, et al., 2009; Longo et al., 2008). Usually, items are rated on a seven-point Likert scale, ranging from -3 (or – – –) to +3 (or +++). The original questionnaire by Botvinick and Cohen (1998) consists of nine items, whereby particularly the first three items, measuring actual ownership sensations and proprioceptive distortions, are deemed suitable for measuring illusion strength. Items four to nine, which assess, e.g. movements or visual changes in the rubber hand, are usually used as control items (Botvinick & Cohen, 1998; Riemer et al., 2019; Rohde et al., 2011; van Stralen et al., 2014). Later, Longo et al. (2008) used a psychometric approach to develop a questionnaire for measuring the RHI. Initially, they used 27 items belonging to the four components *embodiment of the rubber hand*, *loss of the own hand*, *movement,* and *affect,* as identified by principal component analysis. The ten items that measured the embodiment of the rubber hand were also identified to belong to three subcomponents: *ownership*, *location*, and *agency* (Longo et al., 2008). Often, a subset of these items is used, assessing only ownership and location (Filippetti & Tsakiris, 2017; Tsakiris et al., 2011). Some studies also used the dis-ownership (loss of the own hand) items (Kállai et al., 2015; Longo et al., 2008).

2.2.2.2 The Proprioceptive Drift. In the literature, different methods of assessing proprioceptive drift have been applied. Riemer et al. (2019) distinguished the main techniques by their responses: Perceptual responses require a verbal or computerised indication of the real hand position. For example, the proprioceptive drift can be assessed by covering the real and the rubber hand and attaching a tape measure to the top of the cover, asking the participant to indicate the number below which he or she believes his or her own index finger lies (Crucianelli et al., 2013; Tsakiris et al., 2011). Similarly, a sliding marker can be used, where participants are asked to indicate when the slider reaches the position of their hand, or static markers, where participants shall indicate whether each marker is left or right to the actual position (Kammers, de Vignemont, et al., 2009; Riemer et al., 2019; Rohde et al., 2011). In contrast, motor responses require the participant to make, e.g. a pointing, sliding, or grasping movement toward the estimated position of the real hand (Engelen et al., 2017; Riemer et al., 2019). Regardless of the specific procedure, the proprioceptive estimation is usually taken twice, once before and after the illusion induction. In a successful illusion induction, the proprioceptive estimation is expected to drift closer to the rubber hand (Horváth et al., 2020). However, the use of the proprioceptive drift has also been criticised in the literature, as it has been shown that the drift even occurs in control conditions, such as the asynchronous or vision-only conditions, whereas no subjective embodiment could be found in the illusion questionnaire in these conditions (Rohde et al., 2011). The authors, therefore, suggested distinct multisensory integration mechanisms in both measures. On the one hand, they proposed that visuo-tactile integration may be involved in subjective embodiment, as suggested by Makin et al. (2008) and Tsakiris and Haggard (2005). On the other hand, since they found a similar proprioceptive drift in the synchronous and the vision-only condition (without any stroking), they concluded that tactile mechanisms may not be relevant for the proprioceptive drift, which would speak for a mere visuo-proprioceptive integration mechanism in the proprioceptive drift (Rohde et al., 2011).

2.3 Factors Affecting the Rubber Hand Illusion

The intensity of the illusion depends on various state and trait factors. E.g. details of the setup can modulate the RHI, such as the laterality of the rubber hand (Bertamini & O'Sullivan, 2014; Ocklenburg et al., 2011), the distance between the real hand and the rubber hand (Lloyd, 2007), the visual similarity to the real hand (Bertamini & O'Sullivan, 2014; Filippetti & Crucianelli, 2019), and the stimulation duration (Riemer et al., 2019). RHI studies have successfully been conducted in different age groups, such as young, middle-aged, and elderly adults (Ferracci & Brancucci, 2019; Marotta et al., 2018), children (Cowie et al., 2016; Filippetti & Crucianelli, 2019; Nava et al., 2017), and adolescents (Georgiou et al., 2016). The intensity of the subjective illusion, measured using a questionnaire, appears to be somewhat stable across children and adolescents from different age groups, whereas conflicting results have been reported regarding age effects on the proprioceptive drift (Cowie et al., 2016; Georgiou et al., 2016; Lee et al., 2021; Nava et al., 2017). Besides, a stronger subjective illusion was found in younger (20–22) and older (60–72) compared to middle-aged adults (44–45), but no effect on the proprioceptive drift was observed (Marotta et al., 2018). Similarly, in 16 to 20-year-olds, a higher proportion of RHI responders and a shorter illusion onset time were found compared to older subgroups regarding the RHIQ

(Ferracci & Brancucci, 2019). Marotta et al. (2018) explained these age differences by the fact that participants at very young or old ages experience greater changes in physical appearance compared to middle-aged adults and, therefore, require a more plastic bodily self-representation.

Besides, the illusion intensity has been found to differ from individual to individual, for example depending on certain personality traits. Subjects with a higher schizotypal or paranoid personality trait (Asai et al., 2011; Kállai et al., 2015), higher sensory suggestibility (Marotta et al., 2016), as well as increased interpersonal sensitivity and empathy (Asai et al., 2011; Kállai et al., 2015), showed a stronger subjective ownership experience, while the proprioceptive drift was related to novelty seeking behaviour and harm avoidance (Asai et al., 2011; Kállai et al., 2015). Elevated scores in the RHIQ were also related to pathology, e.g. eating disorders (Eshkevari et al., 2012), borderline personality disorder (BPD; Bekrater-Bodmann et al., 2016), posttraumatic stress disorder (PTSD; Hirschmann & Lev Ari, 2016; Rabellino et al., 2018), and schizophrenia (Thakkar et al., 2011). This dissertation focuses on exploring how dissociative tendencies are related to the RHI and how they modulate effects of emotions on the RHI in healthy and patient samples. Besides, it will be analysed which role interoception plays in this context and if there are potential interventions that can restore ownership experiences in emotional situations.

2.3.1 Interoceptive Abilities

Interoception has been defined as "[…] the top-down and bottom-up processes by which an organism senses, interprets, and integrates signals from within itself and below the skin, across conscious and nonconscious levels" (Desmedt, Luminet, Maurage, & Corneille, 2023, p. 12), while exteroception encompasses the perception of the environment through senses like touch, smell, vision, and hearing, and proprioception entails information about the position and movements from the body (Critchley & Garfinkel, 2017; Seth et al., 2012). Interoceptive and exteroceptive information processing has been found to be related to distinct neural networks but also to share brain activity, as information from both domains can be integrated in the insular cortex (Farb et al., 2013a; Simmons et al., 2013). Together with proprioception, these domains were found to play a role in multiple psychological processes, such as emotions, motor preparation, and the feeling of body ownership (Brown et al., 2011; Maravita et al., 2003; Simmons et al., 2013). First indications of the importance of interoception for body ownership come from Moseley et al. (2008) and Kammers et al. (2011), who showed that a successful illusion induction led to a lower temperature in the participant's real hand and that experimentally induced cooling of the real hand led to a stronger RHI (Seth, 2013).

Suzuki et al. (2013) modulated the classic RHI paradigm by introducing two further conditions. The "cardiac still" condition consisted of cardio-visual feedback of the participant's heartbeat by showing a pulsing light on the rubber hand. In the "cardiac move" condition, the cardio-visual feedback was also applied, and participants were instructed to move their hand freely. Both conditions were repeated with synchronous (light pulses in synchrony with the heartbeat) and asynchronous (light pulses in asynchrony with the heartbeat) stimulation. In the third, "tactile" condition, the participant's hand and the rubber hand were stroked in synchrony or asynchrony with a brush as in the regular paradigm without cardio-visual feedback. In the cardiac still and the tactile conditions, significant differences between synchronous and asynchronous cardio-visual or tactile-visual feedback were found. The authors conclude that the integration of interoceptive and exteroceptive information can modulate the body ownership experience (Suzuki et al., 2013).

Other studies used the Heartbeat Detection Task (HDT) by Schandry (1981) to assess interoceptive abilities. In this task, participants are instructed to count their heartbeat without measuring their pulse physically within different time intervals while the actual heartbeat is recorded (Garfinkel et al., 2015; Schandry, 1981). Garfinkel et al. (2015) distinguish three dimensions of interoception that can be measured using this task. First, interoceptive accuracy (IAc) can be assessed by determining the performance accuracy during the task. Second, interoceptive sensibility (IS) can be measured, e.g. by using self-report questionnaires such as the Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012) or by asking the participants how confident they are regarding their counting following each trial (Garfinkel et al., 2015). Third, interoceptive awareness (IAw) can be determined by calculating the correlation between IAc and IS, reflecting a meta-awareness of one's interoceptive skills (Garfinkel et al., 2015).

Studies on the relation of IAc and the RHI showed that IAc was negatively correlated with the intensity of the illusion (Filippetti & Tsakiris, 2017; Tsakiris et al., 2011). As an explanation for this effect, the predictive coding framework suggests that the RHI can arise due to an update of the internal model in response to tactile and visual correlations (Filippetti & Tsakiris, 2017; Seth, 2013; Seth et al., 2012). This mechanism can differ depending on the individual: distinct precision-weighting of interoceptive, exteroceptive, and proprioceptive information has been proposed to modulate the RHI. In participants with lower interoceptive abilities, exteroceptive information is weighted more strongly, so correlated visual and tactile information dominates the experience. Conversely, participants with strong interoceptive abilities may rely less on exteroceptive signals, leading to a heightened awareness of sensory mismatches (Filippetti & Tsakiris, 2017; Seth, 2013; Seth et al., 2012). Apart from the predictive coding theory, another explanatory approach proposes that participants with lower IAc may direct less attention to internal body signals and may, therefore, have higher attentional resources that can be allocated to multisensory integration (Tsakiris et al., 2011).

The relation to the more meta-cognitive component of interoception, IAw, has not been studied in relation to the RHI very much yet. One study investigated the malleability of bodily self-location in a task where participants saw synchronous or asynchronous stimulation in a first-person or third-person perspective of themselves via a head-mounted display. The authors demonstrated that the extent to which participants reported an out-of-body experience was mediated by IAw, suggesting that IAw may protect the individual from manipulations of bodily self-location (Bekrater-Bodmann et al., 2020). However, not all studies were able to find relations between IAc or IAw and the RHI (Critchley et al., 2021; Crucianelli et al., 2018; Horváth et al., 2020). This may be due to differences in the sensitivity to different interoceptive modalities (Crucianelli et al., 2018), which may not necessarily be correlated (Crucianelli et al., 2022). Despite these measurement challenges, interoception may still play a role in ownership processes.

2.3.2 Emotions

Interoception is known to be the basis for emotions (Craig, 2002) since the early works of James (1884, p. 190), who proposed that "we feel sorry because we cry, angry because we strike, afraid because we tremble, and not that we cry, strike, or tremble, because we are sorry, angry, or fearful". This theory was the foundation for a large research movement, though it was criticised and revised many times (Lambie & Marcel, 2002). A more recent approach came from two psychologists named Stanley Schachter and Jerome Singer, who proposed that emotions arise from two factors—physiological arousal and cognition (Schachter & Singer, 1962). Later, the role of cognition was respecified by appraisal theorists: Lazarus (1991) proposed that emotional responses arise due to the appraisal of emotional significance to a stimulus or an event (Lazarus, 1991; Phillips et al., 2003). In line with his theory, recent brain imaging studies suggest two neural systems for emotional processes: a ventral and a dorsal system (Phillips et al., 2003). The ventral part, which comprises the prefrontal cortex, the insula, the amygdala, the ventral striatum, and the ventral anterior cingulate cortex (ACC), is responsible for the generation of affective states, the appraisal of emotional significance, automatic regulation, and autonomic responses (Phillips et al., 2003). The dorsal system, which includes the prefrontal cortex, the hippocampus, and the dorsal ACC, is involved in the integration of cognitive processes, like executive functions, attention, and planning, with emotional information and is involved in emotion regulation (Phillips et al., 2003). Emotional awareness was also found to share functional connectivity patterns in the insula with mechanisms involved in interoception (Seth et al., 2012; Simmons et al., 2013), emphasising the role of interoception as a "limbic sensory substrate" of emotions (Craig, 2002, p. 662).

Accordingly, it is hardly surprising that interoceptive abilities are also related to the extent of emotional reactions. For instance., higher IAc was related to higher arousal ratings of unpleasant pictures (Pollatos, Traut-Mattausch, et al., 2007) and to more intense affective responses to movie clips (Wiens et al., 2000). Therefore, the findings described in the previous chapter, showing that interoception may be involved in multisensory integration (Tsakiris et al., 2011), give reason to consider whether the RHI intensity also changes in emotional contexts. The following section looks at the possible effects of emotions on the sense of ownership, with reference to specific emotional valence and arousal.

2.3.2.1 Affective vs Non-Affective Stroking. Following these considerations, it seems advisable to consider the role of affective touch in RHI paradigms, which has been argued to be an "[…] interoceptive modality of affective and social significance" (Crucianelli et al., 2018, p. 190). In contrast to fast touch, slow, affective brush stroking activates a specific unmyelinated cell type, the so-called C-tactile nerve cells, which are located in areas with hairy skin, e.g. the forearm (Gordon et al., 2013; Löken et al., 2009). This specific kind of touch leads to pleasant feelings (Crucianelli et al., 2018) and is associated with activation in the insular cortex (Olausson et al., 2002), a region that has frequently been associated with interoceptive and emotional processing (Craig, 2002; Karnath & Baier, 2010). In this way, pleasant touch can have comforting effects by reducing social pain and the feeling of social exclusion (von Mohr et al., 2017). Affective touch has also been shown to relate to ownership processes (Crucianelli et al., 2013; Lloyd et al., 2013; van Stralen et al., 2014). Slow stroking (3 cm/s), that is perceived as more pleasant, triggers a stronger rubber hand illusion than fast (30 cm/s), unpleasant stimulation (Crucianelli et al., 2013; Lloyd et al., 2013; van Stralen et al., 2014). Studies demonstrating a link between slow stroking and the sense of ownership provide first evidence for an involvement of the emotional system in the sense of ownership. Riemer et al. (2019) suggest including different types of stroking in studies investigating the link between the RHI and emotions, as the affective impact of different stroking styles can interact with study conditions.

2.3.2.2 Effects of Threat, Anger, and Happiness on the RHI. Further evidence for the role of the emotional system in self-attribution and ownership processes comes from studies investigating the role of threat for the RHI. Threatening a rubber hand, e.g. by bending a finger backwards or harming the rubber hand with a syringe, leads to larger skin conductance responses in synchronous compared to asynchronous trials (Armel & Ramachandran, 2003; Ocklenburg et al., 2011). Besides, stabbing movements with a syringe also evoked similar brain activation patterns in areas associated with interoception (insula and anterior cingulate cortex) when the rubber hand is threatened as compared to threatening the real hand of a participant, and this neuronal response in the left insular cortex and the anterior cingulate cortex relates to the subjective embodiment feeling (Ehrsson et al., 2007). The authors suggest that the activity in brain areas associated with emotional and interoceptive processes indicates that interoception is required for the vividness and richness of the illusion. Besides, in an experiment where electric shocks were applied to participants' inner forearm, threat ratings, startle blink amplitude, and skin conductance responses were correlated with the subjective RHI strength but not the proprioceptive drift (Riemer et al., 2015). The authors concluded that threat responses reflect an activation of the defence system and that this activation depends on the intensity of the illusion.

However, not only threat and pain but also emotions like anger and happiness have been found to relate to the RHI: In the study of Engelen et al. (2017), participants listened to either angry, happy, non-vocal sounds, or no sounds during the RHI and they demonstrated that the emotional conditions led to greater proprioceptive drift compared to both control conditions. In their second experiment, they confirmed these results by showing that angry vocalisations also led to a higher drift than neutral vocalisations (Engelen et al., 2017).

As an explanation, Engelen et al. (2017) refer to the body-guard hypothesis of de Vignemont (2017) and proposed, as did Riemer et al. (2015), that ownership processes might be involved in self-defence and body protection. This hypothesis states that the sense of body ownership is based on the spatial limits of the body, which are shaped by the protective body schema, and it serves as a defence mechanism for all embodied limbs (de Vignemont, 2017). This space has been described in the literature as the peripersonal space, and it refers to the area around our body (Rizzolatti et al., 1997), in which objects are within reach and can be manipulated (N. P.

Holmes & Spence, 2004). A dual process model of the peripersonal space distinguishes between the goal-directed working space, which is associated with voluntary movements, and the protective space, which rather encompasses more automatic defensive behaviour, as well as improved detection and localisation of objects near the peripersonal space (de Vignemont & Iannetti, 2015). Fear has been found to modulate the peripersonal space in terms of an increased protective space and a reduced working space (de Vignemont & Iannetti, 2015). Engelen et al. (2017) argued that the affective stimuli in their study may have led to an expansion of the protective space, and, as a result, the rubber hand was integrated into the body schema to enable efficient defensive responses.

The circumplex model of affect by Russell (1980) proposes that emotions can be categorised along the two coordinate axes of pleasure–displeasure and sleepiness–arousal. Following this model, it becomes apparent that so far, only emotions categorised as highly arousing have been used in RHI studies, while the influence of low-arousing emotions, such as sadness (Russell, 1980), remains largely unexplored. Only the abovementioned effect of affective, pleasant stroking indicates that possibly also pleasant low-arousing emotions lead to ownership changes. We therefore ask whether unpleasant low-arousing emotions such as sadness have a comparable influence on the illusion and whether other factors, like differences in emotion experience, impact the malleability of the sense of ownership.

2.3.2.3 Emotion Experience. Responses to emotions and experiences of emotions depend on the individual and the specific situation (Frijda, 2005). A conceptual framework of emotion experience by Lambie and Marcel (2002), distinguishes between three aspects of attention and two levels of consciousness which shape emotion experience.

The three components of attention following Lambie and Marcel (2002) can be divided into attention direction, focus, and mode. First, attention can be directed either at the world (e.g. haptic experience of touch) or toward the self (e.g. tactile bodily sensations). Second, the attentional focus may either be on action planning (action possibilities) or emotional evaluation (attribution). Third, analytic (by decontextualising experiences), synthetic (categorising the emotion), immersed (lacking a distinction between how things "seem" and how things "are"), or detached (reduced engagement and distant perceptual experience of the self) modes of attention are possible (Frijda, 2005; Lambie & Marcel, 2002). Self-focused emotion experience, which directs attention, e.g. to bodily sensations, also involves the processing of proprioceptive information and ownership experiences (Lambie & Marcel, 2002). Accordingly, considering the different attentional modes, immersion may lead to intensified ownership sensations regarding own body parts, while detachment may reduce them (Lambie & Marcel, 2002). In line with this, Frijda (2005) suggested that detachment in combination with self-focus can cause symptoms of depersonalisation, while detached world-focused attention can lead to experiences of derealisation.

Furthermore, two levels of emotion consciousness have been described: While first-order emotion experience entails a rather unconscious, phenomenological experience of emotions, second-order emotion experience involves conscious emotion perception, which enables evaluation and action planning. This second stage of emotion experience does not always occur. E.g., it is only weakly developed in participants with alexithymia (Lambie & Marcel, 2002; Lane et al., 2000), which is reflected by difficulties with describing and identifying feelings, distinguishing feelings from bodily sensations, externally directed cognitive style, and reduced fantasy relating to affect (Bagby et al., 2009; Lane et al., 2000). Similarly, second-order emotion experience is reduced if stimuli are presented subliminally (e.g. using short presentation times), which may prevent analytical engagement and the ability to describe the emotional state (Lambie & Marcel, 2002) but may still lead to action impulses (Winkielman et al., 2005). Besides, even in terms of first-order emotion experience, the attentional focus can be distinguished in self- and world focus, although, in this state of consciousness, the experience of the self and the world mainly revolves around spatial aspects of the self and objects in the environment (Lambie & Marcel, 2002). Evidence from fMRI studies confirms that subliminal stimuli tend to evoke more activity in the right hemisphere, which is associated with the initial processing of emotions, while supraliminal emotion induction involves more activation in the left hemisphere, which is generally assumed to be more involved in language and higher order emotion processing (Meneguzzo et al., 2014; Shobe, 2014). Moreover, activation in the insular cortex and the anterior cingulate cortex has also been found in subliminal emotion conditions, indicating that processes like interoception (Craig, 2002) may be involved not only in supraliminal but also in subliminal processing (Meneguzzo et al., 2014). This could indicate that ownership processes, which were also found to be connected to interoceptive abilities (Tsakiris et al., 2011), may be involved in the preconscious stage of emotion experience. Consistently, activation in the left anterior insula and the left anterior cingulate cortex have been found to be associated with ownership feelings for a rubber hand under threat (Ehrsson et al., 2007). Hence, the sense of ownership may, at least to some extent, be involved in first-order emotion experience as well, and subliminal stimuli may, therefore, also affect the rubber hand illusion, although possibly not as much as second-order emotion experience.

In summary, these findings indicate that different levels of consciousness in emotion experience and different degrees of detachment, and thus dissociation, may play a role in the relationship between emotions and the sense of ownership.

2.3.3 Dissociation

Although much research has been done on the concept of dissociation in recent years, Şar and Ross (2023) identified some areas of research that should be explored further. These include investigating the relationship between dissociation and maladaptive emotion experiences, such as alexithymia, to better understand the underlying mechanisms of depersonalisation, studying the relation between acute dissociation and trait variables, examining the effects of short-term interventions, and the connection to suicidality and self-harm, as well as the investigation of dissociative experiences in children and adolescents. In line with these suggestions, Lambie and Marcel's (2002) theory of emotion experience proposes that dissociative symptoms can arise due to detached emotion experience. Accordingly, it would seem sensible to take a closer look at the concept of dissociation and to work out the role of the sense of ownership for dissociative experiences, emotions, and interoception, especially in the target group of children and adolescents with self-harming behaviour.

2.3.3.1 Conceptualisations of Dissociation. Dissociation has been defined in the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-V*) as "[…] a disruption of and/or discontinuity in the normal, subjective integration of one or more aspects of psychological functioning, including—but not limited to—memory, identity, consciousness, perception, and motor control" (Spiegel et al., 2011, p. 19). The *DSM-V* comprises several distinct dissociative disorders, such as dissociative identity disorder, dissociative amnesia, depersonalisation/derealisation disorder, other specified dissociative disorders, unspecified dissociative disorders, and a dissociative subtype of PTSD (American Psychiatric Association, 2013; Loewenstein, 2018). Dissociative symptoms, however, can be present in a large range of mental disorders (Lyssenko et al., 2018), and may be assigned to one of two forms of dissociation: detachment and compartmentalisation (E. A. Holmes et al., 2005; Spitzer et al., 2006). Based on this conceptualisation, we find similarities to the construct of the minimal self (see Section 2.1, Gallagher, 2000), which is a first indication that disturbances in the minimal self may underlie dissociative experiences: Symptoms typical for detachment include depersonalisation (feeling alienated or detached from oneself), and derealisation (experiencing the world as unreal), which share in common the detached experience of everyday aspects, that may result in emotional numbing (E. A. Holmes et al., 2005; Spiegel et al., 2011; Spitzer et al., 2006).

Compartmentalisation, however, is described as the failure to volitionary control actions or processes like memory retrieval, resulting in symptoms such as dissociative amnesia (Spitzer et al., 2006). Other neurological symptoms, which are typically classified under conversion disorders (e.g. conversion paralysis, sensory loss, etc.), may also fit into this category (E. A. Holmes et al., 2005). However, while the *DSM-V* strictly distinguishes between dissociative and conversion disorders and assigns the latter to somatoform disorders, the *International Classification of Diseases* (*ICD-10*) presents both as one category and, therefore, suggests that not only psychological functions but also sensory and motor systems may be involved in dissociation (E. A. Holmes et al., 2005; Spiegel et al., 2011; Spitzer et al., 2006; World Health Organisation, 2016).

In addition to these classifications, it has been proposed that dissociation can be adaptive or maladaptive—in other words—non-pathological or pathological (Spiegel et al., 2011). In the past, researchers have discussed two different models of dissociation and pathology: A dimensional model, which assumes that dissociative symptoms range across a continuum from non-pathological to pathological levels (Armstrong et al., 1997) and a typological model (Spitzer et al., 2006). The typological model proposes a strict classification into non-pathological and pathological, to which different dissociative experiences can be assigned. Pathological dissociation, which comprises symptoms like amnesia, depersonalisation, derealisation, and identity alteration, reflects a typological variable, whereas non-pathological experiences, such as absorption and imaginative involvement, rather reflect dimensional constructs (Waller et al., 1996).

2.3.3.2 Dissociation in Children and Adolescents. Pathological dissociation was found to be of high prevalence in children and adolescents: Among a French sample of 93 psychiatric inpatient adolescents between 12 and 20 years, 33% to 43% showed pathological dissociative symptoms (Goffinet & Beine, 2018). In the development of dissociative symptoms, childhood trauma and neglect play a significant role in adolescents (Brunner et al., 2000; Goffinet & Beine, 2018; Sanders & Giolas, 1991) and are also predictive of dissociative symptoms in adulthood (Terock et al., 2016; Vonderlin et al., 2018). One explanation for the increased vulnerability during adolescence is provided by the *Discrete Behavioural States* model, which assumes that control over the modulation and meta-cognitive integration of different behavioural states develops during childhood and adolescence (Putnam, 1997). Behavioural states are described as increasingly complex experiences, e.g. beginning with infant sleeping and eating behaviours and progressing to more complex experiences gained over the course of development. Skills such as emotion regulation, attention span, and self-control aid the integration of behavioural states, whereas trauma can cause a developmental disruption, leading to dissociation, resulting in, e,g, reduced access to memory, skills, and the sense of self (Putnam, 1997). Accordingly, an early diagnosis and treatment of dissociative symptoms appears to be essential, considering that dissociative symptoms during childhood and adolescence are related to lower psychosocial adjustment (e.g. financial independence, leisure activities) during adulthood (Jans et al., 2008) and dissociation was also found to be related to symptom severity, comorbidity, non-responsiveness to psychotherapy, and maladaptive neuropsychological functioning (Bozkurt et al., 2015; Haaland & Landrø, 2009; Kleindienst et al., 2011; Lyssenko et al., 2018; Rufer et al., 2006).

2.3.3.3 Dissociation and Non-Suicidal Self-Injury (NSSI). One can hardly overlook the connection to non-suicidal self-injury (NSSI), when discussing the phenomenon of dissociation in adolescents (Calati et al., 2017). In the most recent version of the *DSM-V*, NSSI disorder has been included as a new diagnosis (Zetterqvist, 2015). Diagnostic criteria include A) Five or more events of NSSI during the last year, B) Expectations that NSSI can solve interpersonal problems or provides relief from difficult thoughts or emotions, C) The presence of at least one criterion (1: Interpersonal problems or negative thoughts/emotions prior to NSSI, 2: Difficulties in dealing with NSSI preoccupation, 3: High frequency of NSSI-related thoughts), D) No social sanctions or restrictions of NSSI, e) NSSI causes significant distress or interferes with daily functioning, F) Does not occur due to psychosis, substance use or cannot be explained better by another psychological or medical condition (American Psychiatric Association, 2013; Gratz et al., 2015).

Although there is a correlation between the concepts of NSSI and suicidal behaviour (Nock et al., 2006), and NSSI has even been found to be a risk factor for suicidal behaviour (Groschwitz et al., 2015), distinguishing between different kinds of deliberate self-harm is of great relevance: Suicidal as compared to non-suicidal deliberate self-harm has been found to be more likely in patients with PTSD and major depressive disorder, and suicidal ideation was lower in an NSSI group compared to a group of patients with past suicide attempts (C. M. Jacobson et al., 2008; Zetterqvist, 2015). What both types of deliberate self-harm have in common is the close connection to dissociative symptoms (Calati et al., 2017). A large study with 816 adolescents showed that dissociation was a significant predictor of NSSI and that it mediated the relationship between childhood abuse and NSSI (Zetterqvist et al., 2014). In a similarly large sample of high school students, dissociation was even identified as the strongest predictor of suicide attempts and NSSI even before childhood neglect and abuse (Zoroglu et al., 2003). A possible reason for this strong association could be the functions of NSSI. Next to social factors (such as the reinforcement of peer bonding), intrapersonal factors include the reduction of negative affect, an increase in body awareness, and the disruption of dissociative experiences (Klonsky, 2007; Koenig et al., 2017). Accordingly, self-injury can help NSSI patients, who were also found to be less sensitive to pain (Koenig et al., 2017), to break through the state of numbness and regain some sensation (Klonsky, 2007). The emotion-regulating function of NSSI could also explain why NSSI is a risk factor for BPD and often precedes BPD (Reichl & Kaess, 2021), a disorder which is highly associated with dissociative experiences (Stiglmayr et al., 2008). Since the prevalence of NSSI peaks in adolescents and decreases in adults (C. M. Jacobson & Gould, 2007), a profound understanding of the underlying mechanisms of dissociation is of great importance for the adolescent age group.

2.3.3.4 Dissociation, Interoceptive Abilities, and the Rubber Hand Illusion. It has been proposed that inadequate body representations, as well as emotional numbing and dissociative states, may stem from deficits in the processing and integration of visceral body signals (Sedeño et al., 2014), causing a the downregulation of interoceptive signals (Saini et al., 2022). In line with this assumption, Sedeño et al. (2014) found a lower IAc in the HDT and lower brain connectivity during an interoceptive task, which entailed focussing on heartbeats and respiration, in a patient with depersonalisation disorder compared to five healthy control participants (Sedeño et al., 2014). This impairment in Iac has been replicated in a larger sample, including 18 patients with dissociative disorders and 18 healthy control participants (Schäflein et al., 2018). Similar results were shown in a study with patients with functional neuronal disorder, showing a decrease in Iac following a dissociation induction procedure (Pick et al., 2020). Moreover, a negative correlation between dissociative symptoms and Iac was found in this study (Pick et al., 2020). Accordingly, in light of the findings on interoceptive abilities and ownership experiences (Tsakiris et al., 2011), it is hardly surprising that studies have also shown a link between the sense of ownership and dissociation.

It has been proposed that the experience of dissociation, specifically depersonalisation, may be explained by an impairment in patients' ability to differentiate between themselves and their environment, reflected by a stronger malleability of the sense of ownership (Bekrater-Bodmann et al., 2016). Evidence for this assumption comes from studies demonstrating that patients with high levels of dissociation show a stronger RHI than patients with low levels of dissociation (Bekrater-Bodmann et al., 2016; Hirschmann & Lev Ari, 2016; Rabellino et al., 2018). For instance, a ketamine infusion, which is known to induce short-term dissociative effects (Ballard & Zarate, 2020), led to a stronger subjective illusion compared to a placebo (Morgan et al., 2011). Besides, in this study, dissociative and psychiatric symptoms were significantly positively related to the RHIQ (Morgan et al., 2011). The study by Morgan et al. (2011) was conducted with healthy participants. However, other studies have been conducted on patient groups with a range of different diagnoses. For example, it was shown that subjects with BPD showed a stronger illusion than healthy control subjects (Bekrater-Bodmann et al., 2016). Both state and trait dissociation were associated with a stronger subjectively reported illusion, although not with a stronger proprioceptive drift (Bekrater-Bodmann et al., 2016). Ownership of their own limbs, on the other hand, was reduced in patients with BPD (Löffler et al., 2020). Similar findings were observed when comparing subjects with the dissociative subtype of PTSD and healthy subjects/patients with schizophrenia (Hirschmann & Lev Ari, 2016) or patients with the non-dissociative subtype of PTSD (Rabellino et al., 2018). While patients with dissociative symptoms displayed high variances in the subjective illusion and the proprioceptive drift, patients with the non-dissociative subtype of PTSD appeared to experience a reduced proprioceptive drift and subjective illusion (Rabellino et al., 2018). The authors propose two coping styles that may be used by patients with dissociative compared to non-dissociative PTSD. First, subjects with strong RHI experiences reported body detachment symptoms and freezing responses, which may result in a smaller protective peripersonal space with weak boundaries, while participants with lower RHI experiences may apply the second strategy, which involves the suppression of afferent signals resulting in a more rigid body representation with a wider protective peripersonal space and sharper boundaries (Rabellino et al., 2018; Rabellino et al., 2020). Accordingly, the authors argue that the RHI may be determined by defence strategies (Rabellino et al., 2018), as did other authors investigating the RHI before (Engelen et al., 2017; Riemer et al., 2015). Their findings may also explain why two studies which compared patients with NSSI or BDP to healthy controls found no difference between groups (Fust et al., 2024; Möller et al., 2020). Distinguishing between dissociative and non-dissociative subtypes may be of high relevance to capturing the use of different defence strategies (Calati et al., 2017; Ford & Gómez, 2015; Peng et al., 2023; Rabellino et al., 2018).

2.3.3.5 Dissociative Experiences in the Context of Bodily Defence. The *defence cascade model* (Kozlowska et al., 2015; Schauer & Elbert, 2010) proposes that defensive responses change along with increasing dissociative symptoms (Lanius et al., 2018). Schauer and Elbert (2010) distinguish six stages of defence: *Freeze*, *Flight*, *Fight*, *Fright*, *Flag*, and *Faint*. They propose that in low levels of dissociation, threat first leads to a short freezing orienting response, allowing initial processing of the threatening stimulus (Lanius et al., 2018), accompanied by physiological and motoric deactivation and focused attention (Schauer & Elbert, 2010). In moderate states of dissociation, catecholamines are released, resulting in the activation of the sympathetic nervous system (e.g. resulting in an increase in heart rate and blood pressure), preparing the individuum for a fight or flight response (Lanius et al., 2018; Schauer & Elbert, 2010). In high levels of dissociation, where the defence probability appears to be low, the integration of sensory stimuli and the responses to the external stressor are reduced (Lanius et al., 2018). This stage is accompanied by an emotional shutdown, a drop in arousal, reduced speech perception and production, and motor paralysis (Lanius et al., 2018; Schauer & Elbert, 2010). Accordingly, an inverted U-shaped relationship between dissociation and psychophysiological arousal emerges (Danböck et al., 2024).

This may explain why results on the relation of dissociation and arousal are sometimes contradictory (Boulet et al., 2022). While the majority of studies on dissociation show a blunting of arousal in response to a stressor, accompanied by increased brain activity in regions associated with arousal modulation and emotion regulation (Lanius et al., 2010), there are also studies that suggest the opposite effect (Nixon et al., 2005). It is, therefore, important to consider the level of dissociation and the time course following a stressor. Consistently, an EEG study demonstrated that dissociative PTSD patients showed an increased preconscious, early neuronal response to emotional faces, while the later conscious response was reduced (Klimova et al., 2013). Moreover, in a study with emotional pictures, there was no difference in valence ratings but a significantly lower arousal rating, and a reduced and later skin conductance responses in patients with depersonalisation disorder (Sierra et al., 2002). These findings regarding arousal blunting in response to emotional stimuli support the notion of emotional overmodulation through limbic hyperinhibition in high levels of dissociation (Lanius et al., 2018; Lanius et al., 2010). Some research also suggests that arousal blunting may bridge the gap between unstable ownership and dissociation: Romano et al. (2014) demonstrated that reduced arousal responses following pain stimulation were related to the degree of the ownership illusion, indicating that ownership malleability may be associated with an arousal shutdown, resulting in analgesia. Similar results were shown by Dewe et al. (2018), who found that a lower skin conductance responses amplitude in response to a threat stimulus applied to the own hand or the hand of another person was related to higher depersonalisation and derealisation experiences.

With these findings in mind, the question arises whether there are therapeutic approaches to overcome emotional overmodulation and restore the sense of ownership. One possibility may be mindfulness interventions.

2.4 Mindfulness Meditation as Potential Tool for Restoring the Sense of Ownership

A popular definition of mindfulness is the conceptualisation by Kabat-Zinn, who defines mindfulness as an intentional, non-judgmental way of focusing attention on the present moment (Kabat-Zinn, 2013). A central component of most mindfulness-based interventions is meditation (Baer, 2003). During meditation, attention can be focused either on inner processes such as thoughts, bodily sensations, and emotions or on the surroundings, without judging or evaluating the experience (Baer, 2003). Meditation practices that are frequently used are breathing meditation, body scan, loving-kindness meditation, and observing-thought meditation (Kok & Singer, 2017). While breathing meditation is used to practice awareness of the breath (e.g. in the belly or the nose) and to learn how to redirect attention from wandering thoughts to the present moment, the body scan involves systematically directing attention to different parts of the body (e.g. starting from the toes), usually while lying on the back (Kabat-Zinn, 2013). Loving-kindness meditation is about formulating and repeating phrases that contain kind wishes (e.g. happiness, wellbeing or peacefulness) for oneself or others (Salzberg & Kabat-Zinn, 2004), and finally, observing-thought meditation is used to learn how to monitor the thinking process by observing the stream of thoughts that enter our mind without dwelling on single thoughts or judging them (Kabat-Zinn, 2013).

According to Dahl et al. (2015), meditation practices can be categorised into different mediation “families”, namely the attentional, the constructive, and the deconstructive family. Meditation practices that belong to the attentional family specifically focus on processes of attention regulation and awareness of thoughts, feelings, and other perceptions (Dahl et al., 2015). Two central categories of attentional meditation can be distinguished: First, during a focused-attention meditation, the aim is to narrow attention to a specific object or sensation, e.g. on breathing. Second, open monitoring interventions involve an expansion of the attentional space on all inner and outer experiences, which can lead to the development of meta-awareness (Dahl et al., 2015; Lutz et al., 2008). Constructive meditation techniques entail the alteration of sensory perceptions and changes in the subjective perspective, as well as the integration of values and ethical perspectives, and the promotion of kindness and compassion towards others (Dahl et al., 2015). The third family of meditation forms, called the deconstructive family, revolves around the exploration of consciousness, physical experiences, and the nature of thoughts and emotions. The experience of subjectivity plays an important role here, especially in the differentiation of the self as actor or observer (Dahl et al., 2015).

2.4.1 Mindfulness in Dissociation Therapy

Mindfulness is an essential component of the third wave of cognitive behavioural therapy and is implemented in various therapy approaches, such as acceptance commitment therapy (ACT; Hayes et al., 2006), dialectic behavioural therapy (DBT; Linehan & Wilks, 2015), and mindfulness-based cognitive therapy (MBCT; Segal et al., 2018; Hayes & Hofmann, 2017). Although these approaches are very popular in clinical practice and also play a large role in the treatment of dissociative symptoms, little research has been conducted on the effectiveness of mindfulness-based therapies on dissociative symptoms (Forner, 2019). Zerubavel and Messman-Moore (2015) summarised different approaches regarding the relationship between dissociation and mindfulness: One conceptualisation suggests that the two concepts lie at opposite ends of a continuum that contrasts a high level of awareness with a lack of awareness. A second conceptualisation assumes a less dualistic model, proposing that dissociation is characterised by a lack of mindfulness, but mindfulness and dissociation still reflect distinct psychological constructs which are linked by contrasting manifestations of awareness, presence, and connectedness (Zerubavel & Messman-Moore, 2015). In line with this, research has found a negative correlation between mindfulness and dissociative symptoms (Bolduc et al., 2018). Mindfulness also represents a core *skill* in DBT (Linehan & Wilks, 2015), and it can serve as a grounding tool to prevent or disrupt dissociative states by directing attention to sensory or external inputs (Zerubavel & Messman-Moore, 2015). Consistently, Bohus et al. (2020) have shown that DBT with trauma-focused cognitive-behavioural interventions over 45 sessions led to reductions of dissociative symptoms in PTSD patients in comparison to cognitive processing therapy.

2.4.2 Mindfulness and Interoceptive Abilities

The term *mindfulness intervention* covers a broad spectrum of possible interventions in the field of mindfulness that can influence various areas of human experience and behaviour, such as cognitive abilities, emotion regulation, and self-management (Baer, 2003; Chambers et al., 2009; Lippelt et al., 2014). In the past, mostly holistic intervention approaches have been studied forfeiting the possibility of isolating the effects of individual mindfulness components. For this reason, Kok and Singer (2017) committed themselves to investigating the effects of four different meditation techniques (breathing meditation, body scan, loving-kindness meditation, observing-thought meditation), assigned to three different modules (presence, affect, perspective), in isolation. In their *ReSource* project, they divided a research sample into three training cohorts that completed the 13-week modules in different order and investigated the effects of the three modules on (meta-) cognitive, affective, and interoceptive outcomes. Among other effects, they found that the body scan led to the greatest improvements in interoceptive abilities (IS & IAc), that loving-kindness meditation most effectively increased positive thoughts and others-focused thoughts, and that observing-thought meditation most improved meta-cognitive awareness (Bornemann & Singer, 2017; Kok & Singer, 2017). The authors anticipated the improvement of interoceptive skills in the presence module, as this module contained the greatest body focus and was, therefore, also intended to train body awareness (Bornemann & Singer, 2017). Consistent with their findings, an eight-week body scan intervention has proven effective in increasing IAc and IS compared to a passive control group (Fischer et al., 2017). Some studies employing shorter interventions also showed effects on interoceptive abilities. For example, in a study of Mirams et al. (2013), practising the body scan daily for one week improved the ability to detect slight vibrations at the fingertip. Other studies have also shown positive correlations between IS (MAIA or confidence judgement) and dispositional mindfulness (Bornemann et al., 2015; Hanley et al., 2017; Mehling et al., 2012;

Parkin et al., 2014) and changes in interoception-related brain areas (increased activity in the insular cortex, and decreased activity in the dorsomedial prefrontal cortex) following an MBSR training (Farb et al., 2013b).

However, the results regarding the relationship between mindfulness and interoception are inconsistent. In the work of Fischer et al. (2017), for example, a first study compared the effect of an eight-week body scan to that of an audio-book group. Although there was a descriptive trend, there was no significant difference in the improvement over time between groups (Fischer et al., 2017). Similarly, a week-long body scan intervention showed no effects on interoceptive measures (IAc, IS, or IAw) compared to a sound scan or a passive control condition (Parkin et al., 2014). Parkin et al. (2014) also conducted a study with an eight-week MBSR intervention and only found an effect on confidence. A meta-analysis from 2019 synthesised the results of various studies on the relationship between mindfulness and interoception (Treves et al., 2019). Thereby, proximal (e.g. heartbeat detection, tactile detection, respiratory tracking) and distal (e.g. tactile sensitivity, proprioception, skin conductance arousal) measures of body awareness have been distinguished. Across 17 studies, only a small effect of mindfulness on body awareness was found independent of proximal or distal measurement type (Treves et al., 2019).

So far, not many studies have investigated the immediate effects of meditation on interoceptive abilities. One study compared the effects of a 10-minute body scan meditation delivered via audio recording to the effects of a natural history reading and found no improvements in IAc or IS (Aaron et al., 2020). However, this study's sample size was determined by an expected medium effect size for their primary aim, the relation of alexithymia and IAc. Therefore, it may be underpowered to detect small effects of the meditation intervention. In addition, 10 minutes may be too short to have a meaningful effect on interoceptive abilities. Nevertheless, it remains interesting to investigate the short-term effects of meditation interventions in greater detail to establish whether meditation can be helpful in acute, e.g. emotional, situations.

2.4.3 Mindfulness and the Rubber Hand Illusion

As discussed, dissociation can range from non-pathological to pathological dimensions (Armstrong et al., 1997; Spiegel et al., 2011; Spitzer et al., 2006). In line with this, positive effects of a seven-week mindfulness-oriented meditation have also been found on IS and dissociative experiences in healthy individuals (D'Antoni et al., 2022). Since close relations of ownership disruptions and dissociation, as well as ownership and interoception, have been found (Bekrater-Bodmann et al., 2016; Filippetti & Tsakiris, 2017; Hirschmann & Lev Ari, 2016; Rabellino et al., 2018; Tsakiris et al., 2011), we are interested in whether mindfulness also impacts the sense of ownership in healthy participants with varying degrees of non-pathological dissociative experiences and whether interoception moderates this relation.

To the best of our knowledge, only a few correlational and quasi-experimental studies have investigated the relationship between mindfulness and the sense of ownership so far. These included a study comparing 15 experienced meditators (more than five years of experience) with 15 non-meditators (Cebolla et al., 2016). Results showed a marginal difference in proprioceptive drift with lower values in the meditation group. In addition, non-meditators had a stronger sense of agency experience during the RHI task. However, the sense of ownership did not differ between groups (Cebolla et al., 2016). In a similarly large sample of meditators (> three months experience) and non-meditators, IS was assessed with the MAIA in addition to the RHI. The results here showed that meditators experienced the RHI less intensively but showed no differences regarding the proprioceptive drift (Xu et al., 2018). Furthermore, an association was found between body dis-ownership experiences (loss of feelings in the own hand; Kállai et al., 2015; Longo et al., 2008) and the MAIA scale *trusting one's body* in non-meditators, and with the MAIA scale *not distracting* in meditators (Xu et al., 2018). Furthermore, practice hours in Tai Chi practitioners were negatively related to the illusion in terms of tactile perception but not regarding proprioception and ownership (Kerr et al., 2016). Only one experimental study has investigated the effects of a meditation intervention so far: Guthrie et al. (2022) conducted two experimental sessions with 14 days in between. Each session consisted of a short 20-minute body scan or control condition (TED Talk on a health- and wellbeing-related topic), followed by the RHI task. Between sessions, participants practised the body scan or listened to TED talks on different topics for 14 days. Data analyses showed a stronger RHI in the body scan group at the first session but a lower RHI after the training period compared to the control group (Guthrie et al., 2022). However, as the sample size was rather small (N = 30) and there was no baseline RHI assessment before the first body scan, these opposing effects may be due to baseline group differences. Nonetheless, further experimental studies are needed to delineate the effect more clearly.

3 Summary of the State of Research

The sense of ownership refers to the feeling that body parts, thoughts, and emotions belong to the self. The malleability of the sense of ownership can be assessed using the rubber hand illusion (RHI), which is usually measured by using a questionnaire and assessing the proprioceptive drift. There are various theories on the origins of the RHI. One suggests that when visual and tactile information correlate, a prediction error results in the proprioceptive domain. This is resolved by an internal model update, leading to illusory ownership over the rubber hand. People with little interoceptive information weigh this visual-tactile information more heavily, which favours the model update and, therefore, leads to a stronger RHI.

Fitting with the large role of interoception, past research has shown that emotions may modulate the way we perceive our body and, therefore, our sense of body ownership. So far, this has mainly involved highly arousing emotions, supporting the claim that changes in the sense of ownership are linked to the body's defence system and the protective space around our body, which cause our sense of ownership to become more malleable, resulting in a stronger RHI. Beyond this theory, however, it was shown that affective comforting touch also intensifies the RHI. It may, therefore, be that it is not only highly arousing emotions that cause this effect, but emotions in general. The malleability of the sense of ownership in response to emotions could instead depend on the way in which we experience our emotions. One central aspect of emotion experience is the attentional mode, which can be immersed or detached. Detached emotion experience can lead to symptoms of dissociation, which have also been found to relate to ownership instability. Besides, different levels of consciousness can shape emotion experience. While subliminal emotions only lead to first-order emotion experience but still activate the interoceptive system to some extent, supraliminal emotions fully enter the conscious second level of emotion experience.

Accordingly, the main aim of the **first** study was to investigate whether the observed changes in the RHI are also elicited by a low-arousing emotion, such as sadness and whether affective touch interferes with this effect. Furthermore, the moderating effects of different styles of emotion experience, specifically dissociative tendencies, and different levels of consciousness, were analysed.

As this was examined in a sample of healthy adults, the **second** study examined the effect of low- and high-arousing emotions on the RHI in adolescent patients with NSSI and high levels of dissociation compared to NSSI patients with low levels of dissociation and healthy control subjects. This target group was selected because the vulnerability for the development of dissociative symptoms is particularly high in childhood and adolescence, and dissociative symptoms predict psychosocial variables as well as therapy responsiveness in adulthood. NSSI, in particular, is a very common phenomenon in this target group and is strongly related to dissociation. In this study, interoceptive abilities, acute dissociation, as well as subjective and physiological arousal, were studied to examine the role of interoception and the defence system in this context.

We were also interested in whether there are possible interventions to restore the sense of self. Mindfulness is in many ways opposed to dissociation and is frequently used as a grounding tool in dissociative states. Moreover, some studies indicate a positive relation between mindfulness and interoceptive abilities and a negative relation between mindfulness and the sense of ownership. For this reason, in the **third** study the effects of a short body-focused meditation on the RHI and interoceptive abilities were investigated and it was analysed whether the effects were more pronounced in participants with stronger dissociative tendencies.

For the sake of consistency of content, the studies are presented in a non-chronological way, as the third study was, in fact, conducted before the second study.

4 First Study: Effects of Sadness Induction and Dissociative Symptoms[1]

4.1 Goals and Hypotheses

The main aim of this study was to examine the effects of a low-arousing emotion (in this case sadness) vs a neutral control condition on the intensity of the rubber hand illusion, while considering factors related to emotion experience, such as dissociative symptoms and the level of awareness of the emotion induction (Lambie & Marcel, 2002). For this purpose, three experimental groups were implemented: one group saw supraliminally presented sad pictures, another group saw subliminally shown sad pictures, masked by neutral pictures, and a third group saw only neutral supraliminally presented pictures. Additionally, slow and fast stroking conditions were added and combined with either synchronous or asynchronous stroking, as it is suggested to include control conditions such as asynchronous touch to control for expectancy effects (Riemer et al., 2019).

The following hypotheses were examined:

1. A stronger subjective illusion and proprioceptive drift are expected following the sadness induction compared to the neutral condition (Engelen et al., 2017).
2. Participants scoring high on a dissociative symptom questionnaire may experience a stronger illusion compared to participants with a lower symptom score (Bekrater-Bodmann et al., 2016). It will also be investigated whether the emotion induction interacts with dissociative symptoms (Bekrater-Bodmann et al., 2016; E. A. Holmes et al., 2005; Klimova et al., 2013; Lambie & Marcel, 2002).
3. Supraliminal emotion induction is expected to have the strongest effect on the illusion, followed by subliminal induction, while the lowest illusion intensity is expected in the neutral condition (Lambie & Marcel, 2002; Winkielman et al., 2005).

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[1] The results presented in this chapter were published in advance in: Schroter, F.A., Günther, B.A.., & Jansen, P. (2021). The effects of subliminal or supraliminal sadness induction on the sense of body ownership and the role of dissociative symptoms. *Scientific Reports*, 11, Article 22274. https://doi.org/10.1007/s12144-021-01785-6

4. Slow and synchronous touch is assumed to lead to stronger illusion effects than their counter-conditions, fast and asynchronous stroking (Crucianelli et al., 2013; Lloyd et al., 2013; van Stralen et al., 2014). At the same time, interactions of stroking speed with the emotion induction condition are expected, as slow stroking might interfere with the sadness induction (Riemer et al., 2019; von Mohr et al., 2017).

4.2 Method

4.2.1 Participants

The required sample size was estimated using the program G*power (Faul et al., 2007). In their second experiment, Engelen et al. (2017) found differences between an emotional sound, a no sound and a neutral sound condition with a medium effect size. Based on their results, we performed a power analysis for repeated measures analysis. Since a higher power was found for mixed models, the determined sample size should be sufficient (Hilbert et al., 2019). Together with a power of 0.9 and an alpha value of .05, a sample size of 132 was estimated to detect the group effect. Following this estimation, 132 participants from the University of Regensburg (mainly students from applied movement science) were recruited. Ten participants had to be excluded because of outlier scores of more than 3 *SD* above/below the mean of the respective experimental group in the RHI questionnaire or in the proprioceptive drift (Marotta et al., 2016), or because they wore non-removable bracelets, or had injuries on the relevant left arm. Of ten excluded participants, four had +/– 3 *SD* outliers, five subjects wore non-removable jewellery, and two had injuries (for one person two criteria applied). Consequently, the remaining sample size was $N = 122$. Overall, the sample population consisted of 86 females (age: $M = 21.24$, $SD = 1.87$) and 36 males (age: $M = 22.83$, $SD = 2.94$), ranging in age from 18 to 32 years.

Written informed consent was obtained from all participants in advance. Following study completion, participants were briefed on the study background. The present study was performed in accordance with the Declaration of Helsinki and its later amendments (World Medical

Association, 2013) and was approved by the ethics committee of the University of Regensburg (protocol number: 18–1204–101).

4.2.2 Material

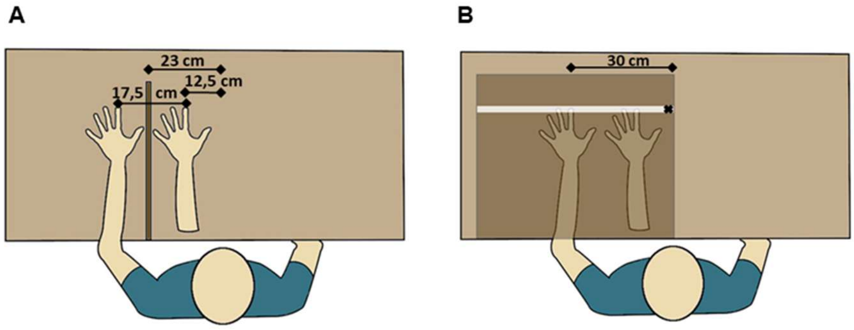
4.2.2.1 Sadness Induction. At the beginning of each trial, participants watched a series of pictures on a computer screen. The stimuli sets consisted of either 24 sad or 24 neutral pictures retrieved from the International Affective Picture System (IAPS; Lang et al., 2008). Both sets were composed of pictures from multiple categories, e.g. people of all ages and ethnicities, nature or indoor settings, buildings and landscapes or social contexts (Gläscher & Adolphs, 2003) and were selected based on their ratings on a nine-point Self-Assessment Manikin scale (sad: mean valence = 2.74, mean arousal = 4.74; neutral: mean valence = 5.06, mean arousal = 3.29; Lang et al., 2008). The subjects were randomly assigned to three conditions: One group saw pictures from the emotionally sad picture set for a duration of 2000 ms per stimulus, so a supraliminal perception of the picture was possible. The second group saw the same sad stimuli, presented subliminally for 30 ms each, masked by a 2000 ms presented neutral picture. Finally, the third group only watched neutral pictures, each shown for 2000 ms (Gläscher & Adolphs, 2003). During each trial, the pictures were presented twice in a random order, so a total of 48 stimuli were shown before each RHI stimulation condition. Between the stimuli, a 500 ms fixation point was shown. Every eight stimuli there was a short 6000 ms break. Beforehand, participants were asked to sit in front of the computer and fixate their eyes on the screen. They were instructed to look at the pictures for as long as they were presented and to return their gaze to the fixation point whenever it was shown.

4.2.2.2 Self-Assessment Manikin (SAM). To measure the effect of the sadness induction, we recorded the mood of the participants in the beginning and after all four picture trials. For this purpose, we used a paper–pencil version of the SAM scale, which assesses valence, arousal and dominance in a non-verbal way. For each dimension, participants were asked to rate their emotional state on a nine-point Likert scale (1 indicates being *unhappy/unaroused/controlled*; 9 indicates being *happy/aroused/controlling*), which corresponded to five figures and the spaces between the figures (Bradley & Lang, 1994). Participants were instructed to choose which one of the figures most closely described their emotional state. If they could not decide between two figures, they could also tick the number in between them. In the past, the SAM scale has frequently been applied in connection with the IAPS. In this combination, it was highly correlated with other tests and physiological measures, like skin conductance response, cardiac acceleration, viewing time, interest ratings and muscle activity (Bradley & Lang, 1994; Lang et al., 1993).

4.2.2.3 Rubber Hand Illusion Stimulation. Throughout the stimulation, participants placed their real left arm on a table behind a wooden screen (40 cm x 1.50 cm x 55 cm), so it was hidden from view (Figure 1A). The screen was installed 23 cm to the left of the body centre of the participants, which corresponds to the average shoulder length of males and females in Germany (males: 48 cm, females: 43.5 cm, both: 45.75 cm—shoulder distance from body centre: 22.87 cm; Lange & Windel, 1981). On the right side of the screen, a rubber arm (Killerink, Liverpool, UK) was positioned visibly, with a distance of 17.5 cm between both index fingers (Lloyd, 2007; Ocklenburg et al., 2011; Tsakiris & Haggard, 2005). During the entire experiment, participants wore a black hairdresser's gown to cover up the visible parts of the own left arm and the stump of the rubber arm. At the beginning of each trial, participants were instructed to simply look at the rubber arm for 15 s (Crucianelli et al., 2013). Subsequently, the stimulation was performed with two identical, synthetic, 30 mm rouge brushes. The experimenter stood at the opposite side of the table and stroked the real and the rubber hand either in synchrony or asynchrony, combined with slow stroking (approx. 3 cm/s) in one half of the trials and fast stroking (approx. 30 cm/s) in the other half of the trials (van Stralen et al., 2014). The stimulation lasted 60 seconds and was applied to the forearm, as it has been done in previous studies, e.g. Crucianelli et al. (2013). Speed was controlled visually using a timer and marked sections on the table, which allowed for slight variations in stroking speed. Participants were instructed to look at the rubber arm during the trials.

Figure 1

Illustration of the Experimental Setup of Study One



Note. A) RHI stimulation setup. B) Proprioception measure, applied using a wooden box with a tape measure.

4.2.2.4 Proprioceptive Drift. To measure the change in the proprioceptive estimation from pre- to post-stimulation, a wooden box (49.50 cm x 74.50 cm x 10.50 cm) was placed over the real- and the rubber arms with the lower right corner of the box positioned at the body centre (Figure 1B). A white tape on the top edge of the box indicated the distance from the body to the tip of the index finger. Participants were asked to place their right index finger above the marked X on the tape and to slide their finger along it with closed eyes until they reached the position below which they believed their left index finger to be (Engelen et al., 2017). Subsequently, the distance between the actual real finger position and the estimated position was calculated.

4.2.2.5 Rubber Hand Illusion Questionnaire (RHIQ). Following the post-stimulation proprioception measure, a questionnaire was given to the participants. It included a German translation of the RHIQ (Appendix A Table A1; Botvinick & Cohen, 1998). The RHIQ consists of nine items and is measured on a seven-point Likert scale, ranging from *strongly disagree* (1 = – – –) to *strongly agree* (7 = + + +). In the past, the first three items of the RHIQ were found to be particularly suitable in measuring the strength of the illusion, while items 4–9 were used as control items (Botvinick & Cohen, 1998; Rohde et al., 2011; van Stralen et al., 2014). Internal consistencies for the illusion (α = 0.80–0.88) and the control items (α = 0.70–0.75) were reasonable. Therefore, a composite score of the illusion items (1–3) was used for the analysis.

4.2.2.6 Comfort Rating. In order to assess whether the stroking was perceived as comforting, we created an item ("I felt comforted by the touch") with a six-point Likert scale ranging from 1 = *totally disagree* to 6 = *totally agree*.

4.2.2.7 FDS Questionnaire. The FDS (Fragebogen zu dissoziativen Symptomen) is a German adaption of the American Dissociative Experience Scale (DES; Bernstein & Putnam, 1986; Freyberger et al., 1999). It was conceptualised as a screening instrument with 44 items and an 11-point Likert scale, ranging from 0% = *never* to 100% = *always* in steps of 10%. It indicates the severity of four different dissociative symptoms (amnesia, absorption, derealisation and conversion). The internal consistency (α = .92–.95), and the test-retest reliability (r = .79–.96) of the FDS were fairly high in the literature (Freyberger et al., 1999). In the present study, we also found an internal consistency of α = .93.

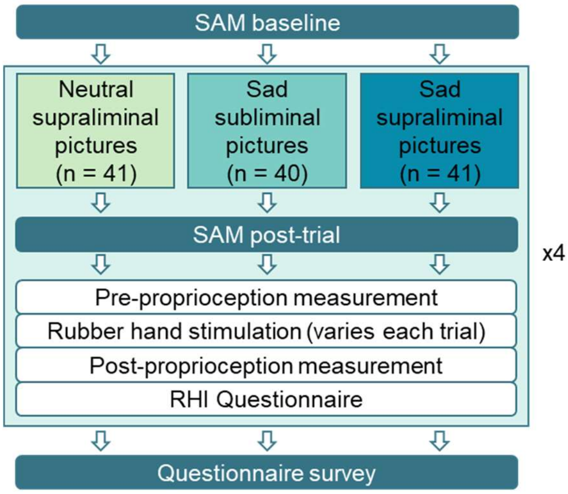
4.2.3 Procedure

Before the start of the experiment, we conducted a baseline assessment of the SAM scale to determine the participants' initial level of valence, arousal, and dominance. We then conducted four experimental trials. Every trial began with a picture series: Participants either viewed neutral pictures (control group), supraliminally presented sad pictures (supraliminal group), or subliminally presented sad pictures (subliminal group). Afterwards, the SAM scale was completed again to assess the affective reactions to the pictures (Figure 2).

The second part of each trial consisted of the RHI stimulation. We conducted four trials to measure the reactions to different stimulation conditions. For this purpose, we combined either synchronous or asynchronous with slow or fast stroking, resulting in four conditions: Synchronous & slow stroking, asynchronous & slow stroking, synchronous & fast stroking and asynchronous & fast stroking. The order of the conditions was counterbalanced among groups so that 25% of each experimental group received the same order of trials. Before and after the stimulation, the proprioceptive estimation was recorded. In addition, the RHIQ and the comfort rating were completed following the post-proprioception measurement. After the experimental part of the study, participants completed computerised questionnaires on dissociative symptoms (FDS) and their demographical background.

Figure 2

Experimental Procedure of Study One



Note. The tasks displayed in the light blue box were repeated four times, each time with a different stroking condition (e.g. asynchronous & slow touch). RHI = Rubber Hand Illusion; SAM = Self-Assessment Manikin.

4.2.4 Statistical Analysis

Statistical analyses were conducted using R (version 4.0.3; R Core Team, 2020). First, it was checked whether our three groups led to the presumed mood effects. Consequently, cumulative link mixed models from the package *ordinal* (Christensen, 2018) with equidistant thresholds were calculated for the SAM dimensions valence, arousal, and dominance with trial (simple contrast coded with reference to the baseline) as within-subject factor, and the experimental group (Helmert contrast coded: control vs intervention (subliminal & supraliminal) and subliminal vs supraliminal) as between-subject factor. Subsequently, another cumulative link mixed model with equidistant thresholds and the predictors synchrony (synchronous vs asynchronous), speed (slow vs fast) and group (Helmert contrast coded as described above) was calculated to analyse whether participants judged the comforting effect of the stimulation differently depending on stroking style and group affiliation.

The next analysis was performed to check for differences in the illusion between the subliminal, the supraliminal, and the neutral group, and to examine if the different stroking styles had the presumed effects. For the two measures of the illusion, linear mixed models (package *lme4*, Bates et al., 2015) with maximum likelihood estimation and the wrapper *optimix* were calculated (Jost & Jansen, 2020; Nash, 2014). Normality, linearity, and homoscedasticity were checked visually, and no deviations were revealed. As predictors, synchrony (synchronous vs asynchronous), speed (slow vs fast), group (Helmert contrast coded as described above) and dissociative symptoms were entered into the model for the RHIQ. For the proprioceptive drift, the predictor time (pre- vs post-stimulation) was also added. Model selection for both the cumulative link mixed models and the linear mixed models was performed according to Barr et al. (2013) and Matuschek et al. (2017): Initially, the maximal model was formed for each dependent variable, which included a random intercept and random slopes for all fixed effects (Barr et al., 2013). Then, non-significant variance components were removed in a stepwise manner, and the fit of the new model was compared to the previous model using likelihood ratio test. In case of a loss in goodness of fit with $p < .200$ (Matuschek et al., 2017), model reduction was stopped unless the model continued to show convergence issues. Subsequently, non-significant fixed effects were excluded from the model based on the likelihood ratio test. In case of a significant deterioration in model fit ($p < .05$), the model complexity reduction was stopped, and the resulting final model was reported. For ordinal dependent variables, Wald confidence intervals were calculated (Christensen, 2022), whereas bootstrapping with 1000 simulations was performed for numerical dependent variables (Jost & Jansen, 2020; Pek & Flora, 2018).

Finally, to examine if the control items (items 4–9) of the RHIQ differed significantly between groups, an ANOVA was performed. In addition, to check whether the control items differed significantly from the illusion items (items 1–3) of the RHIQ, a dependent t-test was calculated between the mean of the control items and the mean of the illusion items.

4.3 Results

4.3.1 Effects on Valence, Arousal, and Dominance

Valence, arousal, and dominance ratings were assessed with the SAM (Bradley & Lang, 1994) and analysed using cumulative link mixed models. The predictors group and trial were entered into the model. For all three variables, non-significant random slopes and fixed effects were dropped, resulting in random intercept models. There was a significant reduction of valence in trials 1–4, a reduction of arousal in trials 2–4 and a reduction of dominance in trials 1–4 compared to the baseline measurement (Table 1, Figure 3). A main effect of group was found for the valence dimension, in terms of a lower valence in the supraliminal compared to the subliminal group. For valence, there was also a significant interaction between trial and control vs intervention group. By looking at Tukey corrected post-hoc comparisons, it becomes clear that this interaction is due to significant valence reductions in the supraliminal group compared to the control group (B/T1: $b = 1.59$, $z = 3.92$, $p = .008$; B/T2: $b = 1.63$, $z = 4.01$, $p = .006$; B/T3: $b = 1.36$, $z = 3.37$, $p = .054$; B/T4: $b = 1.55$, $z = 3.83$, $p = .011$), while no differences were found between control and subliminal group (B/T1: $b = 0.01$, $z = 0.04$, $p = 1.00$; B/T2: $b = -0.07$, $z = -0.16$, $p = 1.00$; B/T3: $b = 0.25$, $z = 0.62$, $p = 1.00$; B/T4: $b = 0.37$, $z = 0.91$, $p = .999$). Moreover, an interaction between trial and subliminal vs supraliminal group was found, showing a drop in valence in the supraliminal group compared to the subliminal group (Table 1, Figure 3A). Besides, an interaction between trial and subliminal vs supraliminal group was found for the variable arousal, showing a stronger decrease in arousal in the subliminal group compared to the supraliminal group (Figure 3B).

Table 1

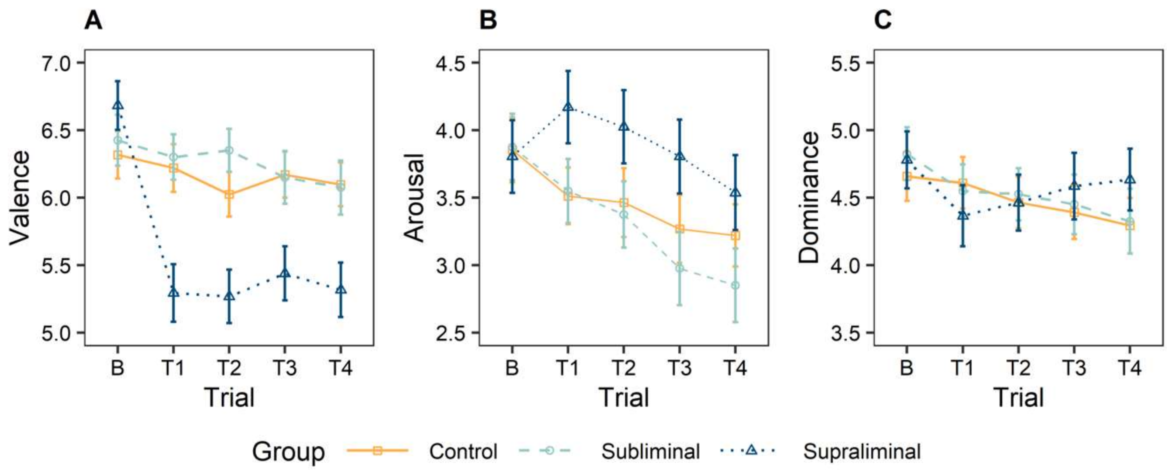
Final Cumulative Link Mixed Models for the Dependent Variables Valence, Arousal, and Dominance

	Valence					Arousal					Dominance				
	b	*se*	*z*	*p*	*95% CIs*	*b*	*se*	*z*	*p*	*95% CIs*	*b*	*se*	*z*	*p*	*95% CIs*
Fixed effects															
Trial															
B/T1	-0.84	0.14	-5.80	**< .001**	-1.12, -0.55	-0.14	0.14	-1.03	.302	-0.42, 0.13	-0.44	0.15	-3.04	**.002**	-0.72, -0.16
B/T2	-0.92	0.14	-6.35	**< .001**	-1.20, -0.64	-0.32	0.14	-2.25	**.024**	-0.59, -0.04	-0.48	0.15	-3.32	**< .001**	-0.77, -0.20
B/T3	-0.86	0.14	-5.97	**< .001**	-1.14, -0.58	-0.72	0.14	-5.00	**< .001**	-1.00, -0.44	-0.50	0.15	-3.42	**< .001**	-0.78, -0.21
B/T4	-1.00	0.15	-6.87	**< .001**	-1.28, -0.71	-0.93	0.15	-6.39	**< .001**	-1.21, -0.64	-0.60	0.15	-4.13	**< .001**	-0.89, -0.32
Group															
C./Int.	-0.12	0.10	-1.23	.219	-0.31, 0.07	0.06	0.13	0.46	.643	-0.20, 0.32					
Sbl./Spr.	-0.52	0.17	-3.03	**.002**	-0.85, -0.18	0.38	0.23	1.63	.104	-0.08, 0.84					
Trial x group															
B/T1 x C./Int.	-0.34	0.10	-3.40	**< .001**	-0.54, -0.14	0.17	0.10	1.68	.093	-0.03, 0.36					
B/T2 x C./Int.	-0.23	0.10	-2.34	**.019**	-0.43, -0.04	0.12	0.10	1.18	.239	-0.08, 0.31					
B/T3 x C./Int.	-0.32	0.10	-3.19	**.001**	-0.51, -0.12	0.06	0.10	0.56	.574	-0.14, 0.25					
B/T4 x C./Int.	-0.33	0.10	-3.33	**< .001**	-0.53, -0.14	-0.02	0.10	-0.16	.870	-0.21, 0.18					
B/T1 x Sbl./Spr.	-0.98	0.18	-5.55	**< .001**	-1.33, -0.63	0.47	0.17	2.75	**.006**	0.14, 0.81					
B/T2 x Sbl./Spr.	-1.04	0.18	-5.85	**< .001**	-1.38, -0.69	0.49	0.17	2.86	**.004**	0.16, 0.83					
B/T3 x Sbl./Spr.	-0.75	0.17	-4.27	**< .001**	-1.09, -0.40	0.65	0.18	3.74	**< .001**	0.31, 1.00					
B/T4 x Sbl./Spr.	-0.78	0.17	-4.48	**< .001**	-1.13, -0.44	0.55	0.18	3.14	**.002**	0.21, 0.89					
Threshold estimates															
Threshold	-5.43	0.25	-21.89		-5.92, -4.94	-2.64	0.22	-12.20		-3.07, -2.22	-5.30	0.28	-18.79		-5.85, -4.75
Spacing	1.55	0.06	26.34		1.43, 1.66	1.33	0.05	26.19		1.23, 1.43	1.75	0.07	25.72		1.62, 1.89
Random effects															
τ_{00} Participant	2.09					4.12					4.26				

Note. B = baseline; T1 = trial 1; T2 = trial 2; T3 = trial 3; T4 = trial 4; C. = neutral control group; Int. = intervention groups; Sbl. = subliminal sadness group; Spr. = supraliminal sadness group.

Figure 3

Self-Assessment Manikin Ratings Depending on Time and Group Affiliation



Note. A) Valence ratings. B) Arousal ratings. C) Dominance ratings. Error bars correspond to the standard error of the mean. B = baseline; T1 = trial 1; T2 = trial 2; T3 = trial 3; T4 = trial 4.

4.3.2 Comforting Effects

Cumulative link mixed models with the predictors synchrony, speed, and group were computed to assess whether the perceived comfort of touch depended on the stimulation condition and the group. After reducing the variance components, the intercept-only model was found to have the best fit. Both within-subject main effects, speed and synchrony, turned out to be significant (Table 2). Slow stroking (*Mdn* = 3.00) had a stronger comforting effect than fast stroking (*Mdn* = 2.50), and synchronous stroking (*Mdn* = 3.00) had a stronger effect than asynchronous stroking (*Mdn* = 2.50). A significant interaction between speed and synchrony was found, as well (Table 2 & 3). The main effect of group was not significant, and all further interaction effects were dropped in the model complexity reduction.

Table 2

Final Cumulative Link Mixed Model for the Dependent Variable Comfort Rating

	Comfort rating				
	b	*se*	*z*	*p*	*95% CIs*
Fixed effects					
Speed	-0.67	0.15	-4.45	**< .001**	-0.97, -0.38
Synchrony	-0.69	0.15	-4.59	**< .001**	-0.99, -0.40
Group					
C./Int.	0.23	0.12	1.83	.067	-0.02, 0.47
Sbl./Spr.	0.38	0.22	1.75	.081	-0.05, 0.80
Speed x synchrony	0.46	0.21	2.17	**.030**	0.04, 0.87
Threshold estimates					
Threshold	-2.41	0.23	-10.39		-2.86, -1.95
Spacing	1.55	0.08	20.59		1.40, 1.70
Random effects					
$\tau_{00\ \text{Participant}}$	3.36				

Note. C. = neutral control group; Int. = intervention groups; Sbl. = subliminal sadness group; Spr. = supraliminal sadness group.

4.3.3 Effects on Proprioception

Linear mixed models with the predictors time, synchrony, speed, group, and dissociative symptoms were calculated for the dependent variable proprioception. Non-significant random slopes and fixed effects were dropped, resulting in an intercept-only model, which included only the main effect of time, showing a significant proprioceptive drift from pre- to post-stroking (Table 3 & 4, Figure 4). No further main effects or interactions were significant, although descriptive data suggest greater drifts for slow and synchronous trials (Table 3). However, these differences did not significantly predict the outcome variable, possibly due to small effect sizes and a lack of power. 66.19% of the variance in proprioception was accounted for by the differences between the participants.

Table 3

Means (Standard Deviations)/Frequencies (Relative %)/Medians of Demographic Data and Outcome Variables

	Neutral control group	Subliminal sadness group	Supraliminal sadness group
Gender			
Female	*n* = 27 (65.85%)	*n* = 29 (72.50%)	*n* = 27 30 (73.17%)
Male	*n* = 14 (34,15%)	*n* = 11 (27.50%)	*n* = 27 11 (26,83%)
Age	*M* = 1.49 (2.17)	*M* =21.68 (2.55)	*M* = 21.98 (2.33)
RHIQ (mean of items 1–3)			
Synchronous & slow	*M* =4.14 (1.70)	*M* =4.03 (1.63)	*M* =4.31 (1.57)
Asynchronous & slow	*M* =2.70 (1.58)	*M* =2.81 (1.46)	*M* =2.91 (1.61)
Synchronous & fast	*M* =4.50 (1.72)	*M* =4.26 (1.56)	*M* =4.42 (1.73)
Asynchronous & fast	*M* =2.82 (1.45)	*M* =3.05 (1.42)	*M* =2.95 (1.51)
Proprioceptive drift			
Synchronous & slow	*M* =1.22 (2.41)	*M* =1.18 (3.04)	*M* =0.90 (2.10)
Asynchronous & slow	*M* =0.89 (2.36)	*M* =0.80 (3.41)	*M* =1.01 (1.87)
Synchronous & fast	*M* =1.40 (2.48)	*M* =0.74 (2.81)	*M* =0.63 (2.94)
Asynchronous & fast	*M* =0.66 (2.19)	*M* =0.28 (2.35)	*M* =0.01 (2.42)
Comfort rating			
Synchronous & slow	*Mdn* = 3.00	*Mdn* = 3.00	*Mdn* = 4.00
Asynchronous & slow	*Mdn* = 2.00	*Mdn* = 3.00	*Mdn* = 3.00
Synchronous & fast	*Mdn* = 2.00	*Mdn* = 3.00	*Mdn* = 3.00
Asynchronous & fast	*Mdn* = 2.00	*Mdn* = 2.00	*Mdn* = 3.00

Note. RHIQ = Rubber Hand Illusion Questionnaire.

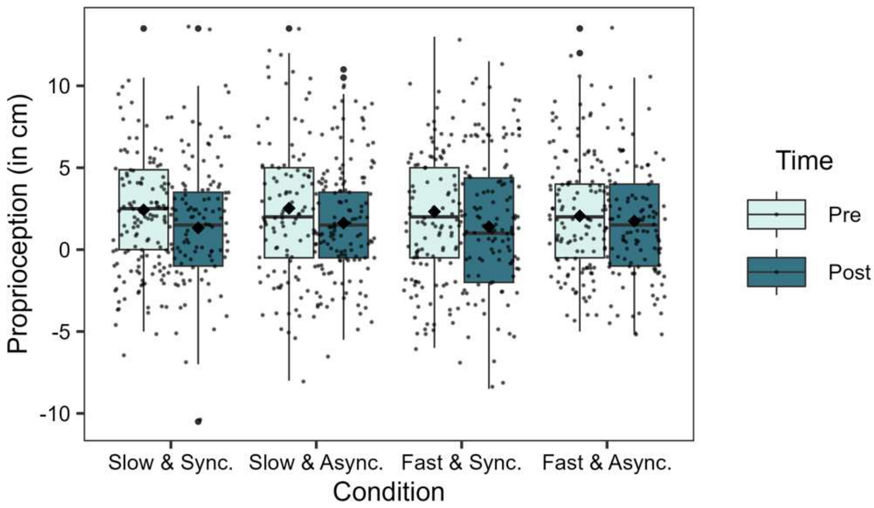
Table 4

Final Linear Mixed Model for the Dependent Variable Proprioception

	Proprioception					
	b	*se*	*df*	*t*	*p*	*95% CIs*
Fixed effects						
Intercept	2.33	0.29	137.02	7.97	**< .001**	1.78, 2.92
Time	-0.81	0.14	854.00	-5.82	**< .001**	-1.07, -0.55
Random effects						
σ^2	4.73					
$\tau_{00\ \text{Participants}}$	9.26					
ICC	0.66					
Marginal R^2/Conditional R^2	0.01/0.67					

Figure 4

Visualisation of the Change in Proprioception from Pre- to Post-Stimulation in Each Condition



Note. Sync. = synchronous; Async. = asynchronous. The rubber hand is positioned at -17.5 cm, accordingly, negative values indicate an estimated position between rubber hand and real hand. The means are indicated by the diamond-shaped dots. The horizontal line represents the median.

4.3.4 Effects on the Rubber Hand Illusion Questionnaire

Linear mixed models with the predictors synchrony, speed, group, and dissociative symptoms were performed for the dependent variable RHIQ. Non-significant random slopes and fixed effects were dropped, resulting in an intercept-only model. The final model showed a significant difference in the RHIQ for the within-subject factors speed and synchrony. Fast and synchronous stroking led to higher scores in the RHIQ compared with slow and asynchronous stroking (Table 3 & 5, Figure 5A). There was no interaction between speed and synchrony. Accordingly, fast stroking seemed to elicit a stronger subjective illusion in both synchronous and asynchronous trials (Figure 5A). A significant main effect of dissociative symptoms and a significant difference between groups was shown as well, but only between the subliminal (M = 3.54, SD = 1.30) and the supraliminal (M = 3.65, SD = 1.32) group (Table 3 & 5, Figure 5B & C).

Besides, the two-way interaction of the subliminal vs supraliminal group with dissociative symptoms and the three-way interaction between the subliminal vs supraliminal group, synchrony, and dissociative symptoms was significant (Table 5). Figure 6 demonstrates that compared to the subliminal group, people in the supraliminal group with a higher symptom burden experienced a stronger illusion than people with fewer symptoms. The comparison of Figure 6A and B shows that the difference between the slopes of the supraliminal and subliminal groups is steeper in synchronous trials. 52.46% of the variance in the RHIQ was accounted for by the differences between the participants.

Table 5

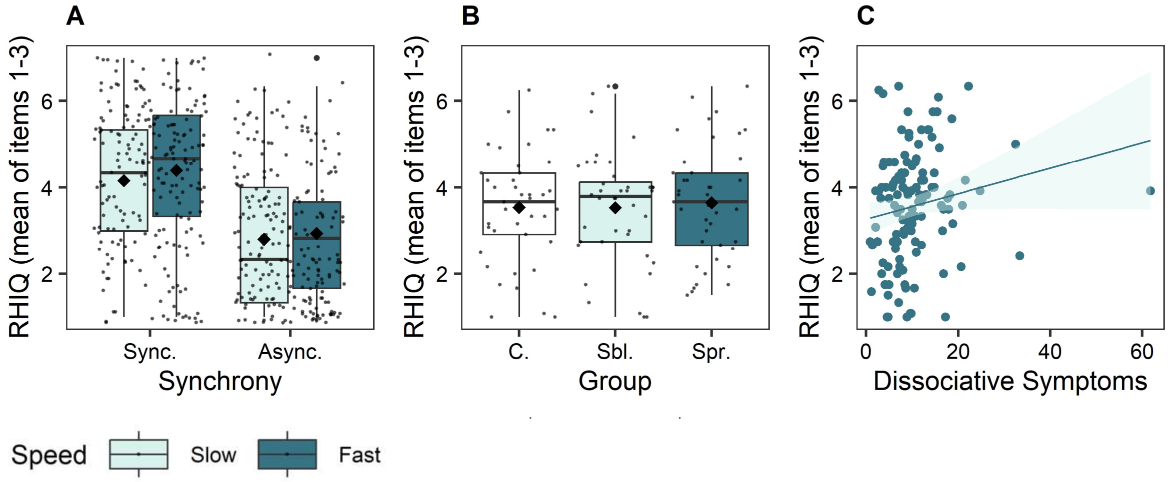
Final Linear Mixed Model for the Dependent Variable Rubber Hand Illusion Questionnaire (RHIQ)

	RHIQ					
	b	*se*	*df*	*t*	*p*	*95% CI*
Fixed effects						
Intercept	3.43	0.23	182.15	14.60	**< .001**	2.98, 3.88
Speed	0.18	0.09	366.00	1.99	**.048**	-0.002, 0.36
Synchrony	-1.16	0.18	366.00	-6.37	**< .001**	-1.50, -0.80
Group						
C./Int.	-0.11	0.17	169.30	-0.64	.521	-0.44, 0.23
Sbl./Spr.	-0.87	0.27	169.30	-3.24	**.001**	-1.34, -0.30
FDS	0.08	0.02	169.30	3.89	**< .001**	0.03, 0.11
Synchrony x group						
Synchrony x C./Int.	0.02	0.13	366.00	0.17	.867	-0.25, 0.28
Synchrony x Sbl./Spr.	0.31	0.21	366.00	1.44	.149	-0.10, 0.72
Synchrony x FDS	-0.02	0.02	366.00	-1.61	.108	-0.06, 0.007
Group x FDS						
C./Int. x FDS	0.01	0.01	169.30	0.67	.506	-0.02, 0.04
Sbl./Spr. x FDS	0.10	0.02	169.30	4.38	**< .001**	0.05, 0.14
Synchrony x group x FDS						
Synchrony x C./Int. x FDS	0.004	0.01	366.00	0.43	.671	-0.02, 0.03
Synchrony x Sbl./Spr. x FDS	-0.04	0.02	366.00	-2.33	**.021**	-0.08, -0.01
Random effects						
σ^2	1.05					
$\tau_{00\ \text{Participants}}$	1.16					
ICC	0.52					
Marginal R^2/Conditional R^2	0.25/0.64					

Note. C. = neutral control group, Int. = intervention groups, Sbl. = subliminal sadness group, Spr. = supraliminal sadness group.

Figure 5

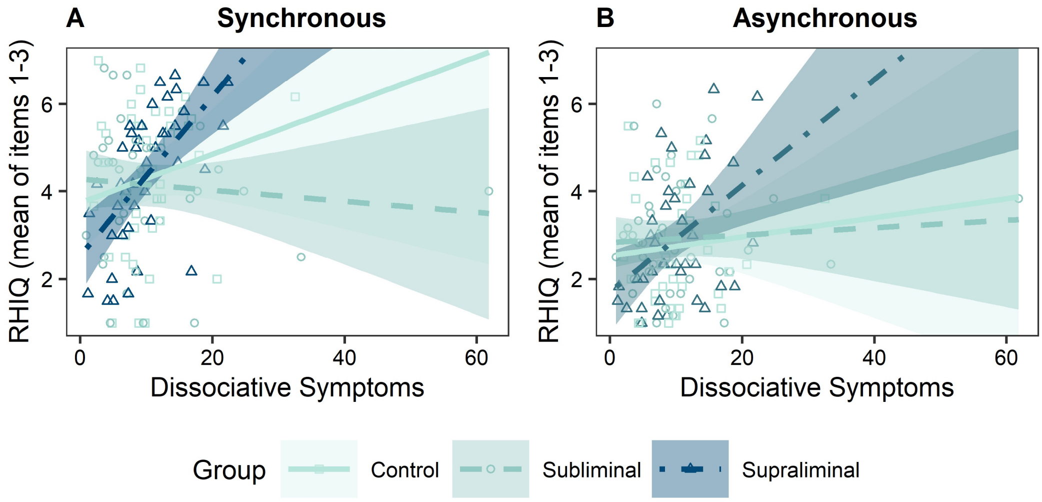
Effects of Synchrony, Group, and Dissociative Symptoms on the Mean Rubber Hand Illusion Questionnaire (RHIQ) Score



Note. A) Differences between stroking conditions in the RHIQ, averaged across all groups. B) Group differences in the RHIQ, averaged across all four trials. C) Regression graph for the main effect of dissociative symptoms on the mean RHIQ scores, averaged across all trials. The means are indicated by the diamond-shaped dots. The horizontal line represents the median. Higher RHIQ values indicate a higher subjective illusion. Sync. = synchronous; Async. = asynchronous. C. = neutral control group; Sbl. = subliminal sadness group; Spr. = supraliminal sadness group.

Figure 6

Regression Graph for the Interaction Effect of Synchrony, Dissociative Symptoms, and Group on the Mean Rubber Hand Illusion Questionnaire (RHIQ) Score



Note. A) Averaged across synchronous trials. B) Averaged across asynchronous trials.

4.3.5 Control Statements

In an ANOVA, no differences between the three experimental groups were found, $F(2, 119) = 0.34$, $p = .714$, $\eta_p^2 = .006$. Besides, a paired t-test was performed to check if there was a difference between the control (mean of items 4–9) and the illusion items (mean of items 1–3) in the RHIQ. Over all trials, the control items ($M = 2.25$, $SD = 0.87$) were found to be rated significantly lower than the illusion items ($M = 3.57$, $SD = 1.29$), $t(121) = 12.57$, $p < .001$, 95% CI [1.11, 1.53].

4.4 Discussion

The present study aimed to investigate the effects of sadness on the RHI, while considering differences associated with emotion experience, such as dissociative symptoms and level of awareness of the emotion induction. In addition, stroking speed and synchrony were varied, as well. First, we found that valence decreased more in the supraliminal group than in both other groups, while arousal was higher at the beginning and decreased over time. Our analysis also showed that regarding the subjective illusion, fast and synchronous stroking elicited higher illusion ratings than their counter-conditions. Moreover, the supraliminal sadness induction was associated with higher scores in the RHIQ compared to the subliminal condition. Contrary to our expectations, there was no difference between the subliminal emotion induction and the control condition. Additionally, a main effect of dissociation and an interaction between emotion induction style and dissociative symptoms was found, showing higher subjective illusion intensities in the supraliminal group compared to the subliminal group when participants had high scores on dissociative symptoms. A three-way interaction of dissociative symptoms, group (subliminal vs supraliminal), and synchrony indicated that this effect was more pronounced in the synchronous conditions compared to the asynchronous conditions. Regarding proprioception, a significant drift from pre- to post-illusion was detected. No group or stroking style difference and no effect of dissociative symptoms was found for the drift.

The finding that supraliminal sadness induction led to a stronger subjective illusion compared to the subliminal group, but no differences were found between both intervention groups and the control group, differs from the findings of previous studies investigating the relationship of emotions and the RHI (Ehrsson et al., 2007; Engelen et al., 2017). The explanation given by Ehrsson et al. (2007) that the embodiment of external body parts under threat might be facilitated to enable more efficient body protection may not fully apply to other types of emotions that are less involved in body protection and are linked with lower levels of arousal (Neuberg et al., 2011; Russell, 1980). Instead, Lambie and Marcel's (2002) theory may provide a possible explanation why there were no significant differences between the control group and the intervention groups, but between subliminal and supraliminal emotion induction. According to Frijda (2005), emotion experience can vary considerably depending on the individual and the situation. We, therefore, propose that the emotion induction itself is not essential; instead, the mechanisms of focal attention involved in second-order emotional awareness, e.g. immersed vs detached attentional mode and self- vs world focus, may be relevant for the link between emotions and the sense of body ownership. For instance, supraliminal fear processing has been found to involve activity in the dorsal prefrontal and sensory brain areas, which play a role in attention direction and top-down processing (Williams et al., 2006). Hence, attentional processes connected with second-order awareness could be crucial for the connection to body ownership. This may explain why no effects were found in the subliminal group, as this condition is considered to involve less second-order awareness (Lambie & Marcel, 2002). As in the study by Winkielman et al. (2005), we did not observe an effect of subliminal induction on valence, supporting the lack of second-order awareness.

The importance of emotion experience becomes even more apparent when it comes to the interaction of group with dissociative symptoms. As mentioned earlier, emotion experience with self- or world focus and a detached attentional mode can lead to experiences of dissociation (Frijda, 2005). People with dissociative symptoms are known to respond to stressful or disturbing stimuli with depersonalisation, derealisation or flattening of the emotion experience (Sedeño et al., 2014; Spitzer et al., 2006). They even experience lower physiological arousal, as measured by skin conductance and heart rate (Griffin et al., 1997). In our study, people with higher dissociative symptoms reported a higher subjective illusion. Our results are consistent with the study by Hirschmann and Lev Ari (2016), where patients suffering from dissociative PTSD experienced a stronger subjective RHI compared to healthy controls and patients with schizophrenia. The interaction between group, dissociative symptoms, and synchrony revealed that the connection between higher symptoms and a higher subjective feeling of embodiment was most prominent in the supraliminal group and in synchronous trials. Consequently, our results could be explained as follows: Presenting emotionally sad pictures in a supraliminal manner (involving second-order awareness) to subjects with higher dissociative symptoms could have led to a disembodiment reaction, resulting in a stronger illusion in the synchronous trials. This effect supports our hypothesis that the relationship of emotions and body ownership depends on features of emotion processing, like emotion experience (Frijda, 2005; Lambie & Marcel, 2002). This may also explain why some studies found large variances in the response to the illusion in samples of patients with dissociative symptoms (Rabellino et al., 2018). Some patients might have experienced the illusion induction as aversive, while others did not. This could have influenced the extent to which patients experienced a detachment from the self. Further research is necessary to investigate this connection with regard to different emotions.

The effects of the supraliminal sadness induction were only found for the subjective feeling of embodiment, not for the proprioceptive drift. This could be due to different multisensory integration mechanisms: According to Rohde et al. (2011), the subjective illusion is based more on a visuo-tactile integration mechanism, whereas the proprioceptive drift results from a visuo-proprioceptive integration mechanism. Consequently, both measures of the RHI are not necessarily influenced equally by emotions. Sadness might have altered the processing of tactile signals, which is mainly relevant for the subjective feeling of ownership but not so much for the proprioceptive drift. The sense of touch involves interoceptive processes that are strongly linked to emotions and feelings of body ownership (Craig, 2002; Tsakiris et al., 2011). For instance, previous research has shown that in a task that required subjects to count their own heartbeats, the presentation of sad faces (low arousal) resulted in a stronger heartbeat evoked potential, which is a marker of interoceptive processes. In contrast, angry faces (high arousal) led to a reduction in heartbeat-evoked potential and visually-evoked potential, whereas positive faces did not elicit any effect (Marshall et al., 2018; Russell, 1980). Therefore, a connection between emotional arousal, interoception and the subjective ownership illusion is possible and should be further investigated in future studies.

Our expectations regarding the effects of the stroking conditions were partially confirmed by our data: Synchronous stimulation elicited a stronger subjective illusion compared to asynchronous stroking, but surprisingly, fast stroking led to a higher subjective illusion compared to slow stroking. Our results also demonstrated that slow and synchronous stroking had comforting effects that may have modified the effect of emotion induction. For instance, it has been shown that conflicting emotional information can lead to difficulties in emotional embodiment (Niedenthal, 2007). Besides, Riemer et al. (2019) argue that slow stroking in interaction with negative emotions might be perceived as less pleasant, which could also affect the illusion strength. However, there was no interaction of group and stroking speed, speaking against this explanation. Another possibility would be that slow vs fast stroking led to differences in arousal, which might explain the contradictory results. These considerations are quite speculative. Therefore, future studies should include a second SAM assessment after the RHI stimulation to confirm the valence and arousal effects of different stroking styles. Besides, fast and synchronous stroking might be harder to discriminate and, therefore, more difficult to predict, which has previously been shown to lead to a stronger RHI (Riemer et al., 2019). In addition, it would be possible that subjects had difficulties discriminating strokes in fast, asynchronous trials so that they may no longer have been perceived as asynchronous. These considerations may also partly explain the lack of differences in the proprioceptive drift between stroking conditions. Although descriptive data show trends in the expected directions (greater drift for slow or synchronous conditions), no significant effect was found. This also supports the findings of Rohde et al. (2011), who found that the proprioceptive drift can also be present in asynchronous or vision-only conditions and has different underlying multisensory integration mechanisms. In addition, Crucianelli et al. (2013) also only found effects of slow vs fast stroking on the subjective illusion, not the proprioceptive drift.

4.4.1 Limitations and Future Research

Limitations of the study include the fact that our study sample was composed of healthy students, so the results on dissociative symptoms only refer to a subclinical population. Therefore, it would be interesting to investigate this connection in a patient sample. Besides, we did not include a questionnaire on state dissociation (Bekrater-Bodmann et al., 2016) and, therefore, cannot evaluate whether the emotion induction resulted in self-reported dissociative symptoms in our experiment and whether these self-reports match the intensity of the RHI. However, it would be an interesting question for future research to investigate the effect of dissociative states on the magnitude of the illusion.

In addition, in previous research, a relationship between subjective illusion and sensory suggestibility has been discovered (Marotta et al., 2016). It would be possible that subjects in the supraliminal sadness group are more prone to social desirability effects. For this purpose, the differences in control items between groups were analysed, and no differences were observed. However, the existence of social desirability effects cannot be completely ruled out, as the use of control items as indicator of expectancy effects has recently been criticised (Lush, 2020). To eliminate this possible explanation, the construction of more valid control items would be necessary.

Further limitations include the lack of control for emotional changes that might be induced by different stroking styles. Future research should measure the change in affect from pre- to post-stroking to control for the impact of the comforting effect. Using physiological measures could also be helpful in this context. Besides, in the present study, the stroking was controlled only manually, which allows only limited control over the speed, the synchronicity, and the reproducibility. Here, a technical device (such as a robot arm; Rohde et al., 2011) should be used in the future, as errors or irregularities in human movements are more likely to occur, especially in asynchronous conditions.

It would also be interesting to directly compare emotions with high levels of arousal (like anger) to less arousing emotions (like sadness) to determine whether the differences between the present study and the study of Engelen et al. (2017) are due to different research designs or to the nature of the emotions.

Regarding practical implications, it could be very informative to examine the effects of body-focused therapies (such as mindfulness-based stress reduction and progressive muscle relaxation) on the sense of body ownership (E. Jacobson, 1987; Kabat-Zinn, 2013), as these approaches have experienced increasing popularity in recent years. Interventions such as mindfulness-based stress reduction aim to promote body awareness, resulting in decreased cognitive rumination about emotions, increased body-related emotion experience and improved emotion regulation (Chambers et al., 2009; Michalak et al., 2012). Thus, examining the link between emotions and the RHI in the context of a mindfulness intervention may provide a deeper understanding of the underlying mechanisms of mindfulness, paving the way for a promising therapy approach for disorders with disembodiment symptoms.

4.4.2 Conclusions

In summary, our results showed that compared to the subliminal group, supraliminal sadness induction led to a stronger feeling of body ownership. Surprisingly, we did not find the same results for the proprioceptive drift. This could be due to a distinction in the underlying multisensory integration mechanisms, which might depend on the type of emotion induced. Besides, slow and fast stroking led to unexpected effects, namely, fast stroking led to a stronger subjective feeling of embodiment, possibly because of the comforting effect of slow stroking, differences in arousal or difficulties in discriminating between strokes. Furthermore, subjects with higher dissociative symptoms reported a stronger subjective illusion, especially after supraliminal sadness induction in the synchronous condition, indicating that disembodiment symptoms could arise in response to a sadness induction.

We conclude that various features of emotional processes are likely to play a role in feelings of body ownership, e.g. individual differences in emotion experience. The extent to which the subjective illusion and the proprioceptive estimation depend on the different forms of valence and arousal remains an open question. A more thorough investigation of this relationship may also provide insight into the underlying mechanisms of interventions based on mindfulness, which are strongly linked to body awareness and may be promising approaches to restore the balance between body and emotion in many disorders.

5 Second Study: Effects of Emotion on Body Detachment in Patients with NSSI[2]

5.1 Goal and Hypotheses

In study one, we found that individuals with high subclinical 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). According to the findings of Romano et al. (2014), who showed a relation between ownership illusion intensity and blunted arousal, detached emotion experience may vary depending on the degree of arousal of an emotion. Therefore, in this study, we aimed to examine the role of arousal in the 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 high dissociation (HD) and low dissociation (LD) levels, compared with healthy controls (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 vocalisations, compared to the HC and LD groups. Moreover, we anticipated that the RHI would be more pronounced when facing a more arousing emotion (threat), compared to a less arousing emotion (sadness), 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 hypothesised that the between-group differences in RHI strength under the fear condition would be moderated by interoceptive abilities and subjective/physiological arousal.

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[2] The results presented in this chapter are submitted for publication: Schroter, F.A., Otto, A, Kandsperger, S., Brunner, R., & Jansen, P. (under review). Body detachment in response to emotions: Evidence from a rubber hand illusion study in adolescent NSSI patients with dissociative symptoms.

5.2 Method

5.2.1 Participants

Prior to data acquisition, a simulation-based power analysis was conducted using the means and standard deviations found in the study of Schroter et al. (2021), and an expected medium effect of the three-way interaction between group (HD, LD, HC), emotion condition (neutral, sadness, fear), and stroking style (synchronous vs asynchronous). To achieve a power of 0.80, a sample size of 75 (25 per group) was determined using the package *superpower* for R (Caldwell & Lakens, 2019; R Core Team, 2020). Simulations were performed only for the fixed effects structure, as including a multilevel structure has proven to yield a higher statistical power than mixed ANOVAs or regression analysis (Hilbert et al., 2019). Based on this power analysis, 50 adolescent patients from the Department of Child and Adolescent Psychiatry and Psychotherapy at the University of Regensburg, and 25 HC participants were recruited. Table 6 presents the participants' demographic and clinical characteristics. All participants were between 12–21 years old. Most patient participants were sampled through a research project on NSSI, as this patient group is particularly associated with dissociative symptoms (Calati et al., 2017). All included patients reported at least five events of self-injurious behaviour during the last year, according to the *DSM-V* diagnostic criteria for NSSI disorder. Exclusion criteria were acute suicidality or acute psychosis, and pre-existing cardiac or neurological diseases. After diagnostic assessment, patients were allocated to the HD or LD group, using the median value of 3.35 on the German version (Brunner et al., 2008) of the Adolescent Dissociative Experiences Scale (A-DES; Armstrong et al., 1997). The HC group comprised 25 healthy participants from the general population who had an A-DES score below 2.5, had no psychiatric or neurological disorders, and were not currently undergoing any psychiatric or psychotherapeutic treatment. During data collection, three participants of the HC group were excluded due to an HDI score above 2.5, and three patients were excluded (one fell asleep during the RHI, one was already 22 years old on the testing day, and one did not meet the NSSI criterion). Excluded participants were immediately replaced in order to attain the required sample size.

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). All participants and their legal representatives gave their written informed consent prior to study participation.

5.2.2 Measures

5.2.2.1 Psychiatric Instruments. The Mini-International Neuropsychiatric Interviews 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; Michal et al., 2004; Sierra & Berrios, 2000) were used to assess dissociative symptoms and the frequency and duration of depersonalisation 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 & Ehlers, 2007) were also measured. Additionally, alexithymia, emotion regulation, and empathy were assessed, and those results will be reported elsewhere.

For analysis, mean values were calculated for the A-DES, while sum scores were calculated for the other questionnaires. The internal consistency of the questionnaires was assessed using McDonald's Omega since it does not require tau equivalency (McNeish, 2018). All total scores of the questionnaires revealed excellent internal consistency (ω = 0.92–0.98).

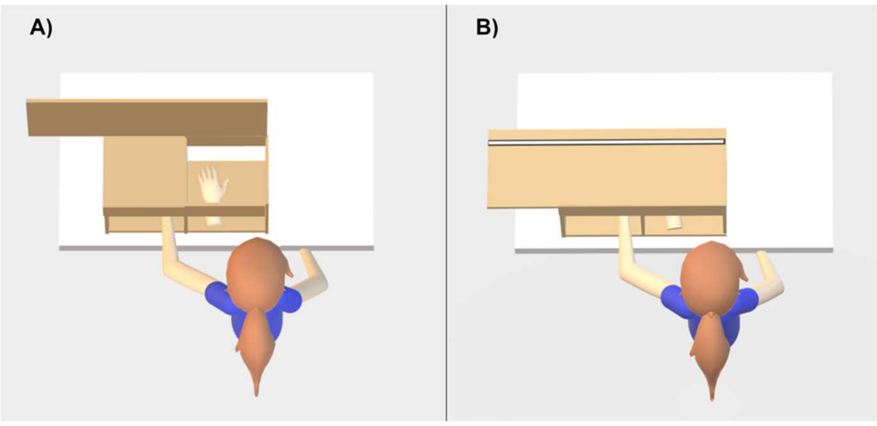
5.2.2.2 Heartbeat Detection Task (HDT). Participants initially performed a computerised HDT to assess interoceptive abilities (Schandry, 1981). After a 15-second practice trial, six main trials (25, 30, 35, 40, 45, and 50 seconds) were conducted in randomised order, requiring participants to count their heartbeats without physically measuring their pulse and without guessing (Garfinkel et al., 2015; Schandry, 1981; Tsakiris et al., 2011). Before the task, an Electrocardiogram (ECG) with two bipolar electrodes and one ground electrode was applied below the collarbones and at the lower left ribcage, following lead-II electrode placement (actiChamp 32 (BIPAUX), Brain Products GmbH, Gilching, Germany). Participants were seated in front of a computer screen and guided through the task by a program. They were instructed to place their hands on their lap and move as little as possible throughout the task. Each trial started with an audio cue, which signalled the participants to count their heartbeats silently until a second audio cue was played (Filippetti & Tsakiris, 2017). Subsequently, they were asked how many heartbeats they counted following the adapted instructions of Desmedt et al. (2020).

Participants' heart rate count and the objective heartbeat (determined by ECG) were used to calculate interoceptive accuracy (IAc): $1/_6 \sum \left[1 - \frac{(|recorded\ heartbeats - perceived\ heartbeat\ \ |)}{recorded\ heartbeat}\right]$ (Schandry, 1981). Participants were asked how confident they were about their judgment, using a visual analogue scale: 0 = *total guess/no heartbeat awareness* to 100 = *complete confidence/full perception of heartbeat* (Garfinkel et al., 2015). The mean of all six confidence judgments was used as an indicator of interoceptive sensibility (IS). Finally, Pearson correlation between IAc and IS was calculated to determine interoceptive awareness (IAw; Garfinkel et al., 2015).

5.2.2.3 Rubber Hand Illusion (RHI) Induction. For each emotion condition, participants completed one synchronous and one asynchronous trial, yielding a total of six 90-second trials (Engelen et al., 2017). Participants sat down in front of the setup, which consisted of a wooden box frame (39.5 cm x 19 cm x 29 cm), similar to the setup used in the study of Tsakiris et al. (2011) with adult participants and the study of Georgiou et al. (2016) with adolescent participants (Figure 7). The box had two chambers open at the back and the front side. The participant's left hand was placed in the left covered chamber, and the rubber hand in the right open chamber, so the rubber hand was visible, while the real hand was not. Besides, participants wore black hairdresser's gowns taped to the front edge of the box, covering their arms. The experimenter stroked both hands through holes in the back of the box. Using two identical paint brushes, stroking was applied from the proximal interphalangeal joint to the fingertip of the index finger. Under synchronous conditions, the experimenter stroked both hands simultaneously, with each stroke lasting 1–1.5 seconds. In asynchronous trials, the rubber hand was stroked after the real hand, with an approximately 1-second delay (Filippetti & Tsakiris, 2017). Both trials were performed because the mere illusion effect can be determined based on the difference between synchronous and asynchronous trials (Filippetti & Tsakiris, 2017; Riemer et al., 2019).

Figure 7

Visualisation of the Rubber Hand Illusion (RHI) Setup of Study Two and Three



Note. A) RHI stimulation setup. B) Proprioceptive measurement setup.

5.2.2.4 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). 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 & Telch, 2021). As a neutral sound clip, we used the same clip used by Engelen et al. (2017). For the sadness and fear conditions, sound clips were created by compiling vocal affective sounds (maximum duration of 2s) from five women and five men into 90-second sound clips, as described by Engelen et al. (2017).

5.2.2.5 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. The rubber hand was hidden by a wooden lid (60 cm x 29 cm), and a tape was placed on the back edge of the lid, using a different offset in each measurement (Tsakiris et al., 2011). Proprioceptive drift was determined by subtracting the post-induction estimate from the pre-induction estimate.

5.2.2.6 Rubber Hand Illusion Questionnaire (RHIQ). After obtaining the proprioceptive estimation, participants completed a translated version (Appendix A Table A2) of the questionnaire created by Longo et al. (2008) regarding the perceived intensity of the RHI, which has been used among adults and adolescents (Georgiou et al., 2016; Tsakiris et al., 2011). The questionnaire comprises five *ownership* items and three *location* items, rated on a seven-point Likert scale, from -3 = *strongly disagreed* to 3 = *strongly agreed* (Longo et al., 2008). Among the six trials, the McDonald's Omega (ω) value for the eight items varied between 0.96–0.97.

5.2.2.7 Self-Assessment Manikin (SAM). To assess how the emotion conditions affected participants' mood, we used the SAM (Bradley & 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 (see Section 4.2.2.2).

5.2.2.8 Dissociation-Tension Scale 4 (DSS4). The DSS4 (Stiglmayr et al., 2009) was developed as a short assessment for acute dissociation, including measures of depersonalisation, derealisation, analgesia, and somatoform dissociation. Items are rated on a 10-point Likert scale, from 0 = *not at all* to 9 = *very strong*. Internal consistency (ω) ranged between 0.93–0.94 for the four items in all six trials.

5.2.2.9 Physiological Assessment. Heart rate (HR) and electrodermal activity were measured throughout the 3-minute habituation period, during resting baselines, and all RHI trials. ECG signal was recorded as described in the HDT (see above), following lead-II electrode placement. Electrodermal activity was measured using two Ag-AgCl electrodes, applied to the thenar and hypothenar eminences of the right hand using an isotonic electrolyte gel and two double-side adhesive rings (Armel & Ramachandran, 2003; Boucsein, 2012). During recording, the right hand was placed on a towel, palm up on the table to minimise interferences. HR and electrodermal activity were recorded with actiChamp 32 (BIPAUX) from Brain Products GmbH (Gilching, Germany) at a sampling rate of 1000 hz. Analysis of the HR was performed with Brainvision Analyser 2.0 and was calculated as beats per minute and averaged over the recording interval. The continuous decomposition algorithm of the software Ledalab was used for the analysis of electrodermal activity (Benedek & Kaernbach, 2010). Two measures of electrodermal activity were obtained. First, non-specific skin conductance responses (NSCR) were calculated as the number of skin conductance peaks over 0.05 μS (Griffin et al., 1997). The log-transformed skin conductance level (SCL) was calculated over each RHI trial and subtracted from the SCL of the last 15 seconds of each resting state baseline (Boucsein, 2012; Gross & Levenson, 1997). Sections including movement artefacts or insufficiently attached electrodes were rejected (electrodermal activity: 1.78%; HR: 0.44%).

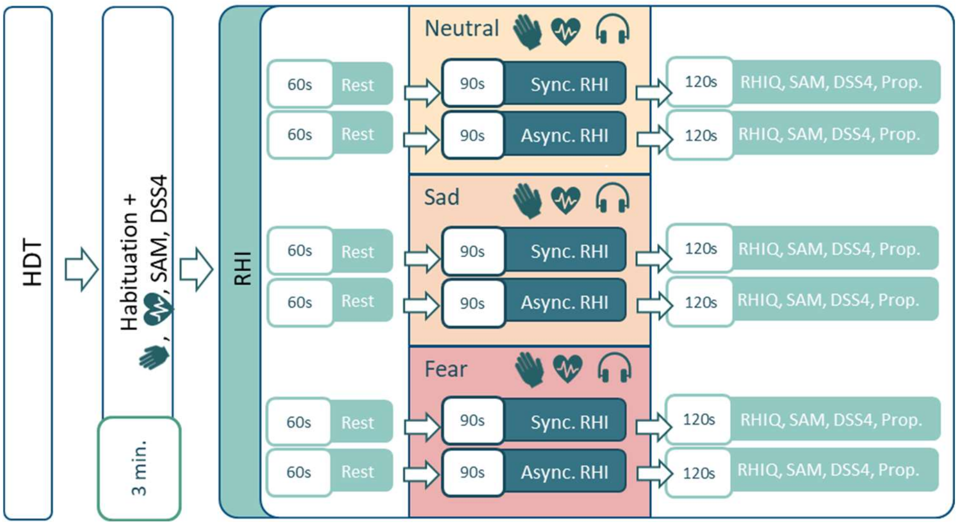
5.2.3 Procedure

The study was completed in one day (including a break) or two days and comprised the psychiatric diagnostics (~1.5 hours) and the experimental part (~1 hour). The experimental part began with the HDT. Subsequently, 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 three minutes while ECG and electrodermal activity were derived. Thereafter, they completed the SAM and DSS4 baseline measurement, followed by the RHI.

The pre-proprioception measurement was taken at the beginning of each RHI trial, followed by a 1-minute resting baseline, during which participants were asked to relax with their eyes closed (Gross & Levenson, 1997). Next, the 90-second RHI trial was performed in a counterbalanced order regarding emotion and stroking conditions. Each emotion condition was repeated twice—once with synchronous and once with asynchronous stimulation. After each trial, the post-proprioception measurement was conducted, and participants again completed the RHIQ, SAM, and DSS4 (Figure 8). To ensure full disembodiment of the rubber hand (Eck et al., 2022), a two-minute break was implemented between trials, during which participants filled out the questionnaires (requiring them to remove their left hand from the RHI setup).

Figure 8

Experimental Procedure of Study Two



Note. HDT = Heartbeat Detection Task; SAM = Self-Assessment-Manikin; DSS4 = Dissociation-Tension Scale 4; Sync. = synchronous; Async. = asynchronous; Prop. = proprioceptive drift. Symbols: Hand symbol = electrodermal activity; heart signal = Electrocardiogram derivation; headphones symbol = presentation of emotional vocalisations.

5.2.4 Statistical Analysis

Outliers and incomplete questionnaires were excluded. Regarding the diagnostic questionnaires, no subscales and overall scores were built in case of missing values (concerns two cases in the BDI-II). During the HDT, one participant indicated no heartbeat awareness. Accordingly, data of the respective participant was excluded. Besides, prior to data analysis, outliers above or below 3 SD were excluded in the RHIQ (0.25%), the proprioceptive drift (1.11%), SAM arousal (0%), SAM valence (0%), DSS4 (2.0%), HR (0.22%), NSCR (0.67%) and SCL (2%).

Analyses were performed using R version R4.2.2 (R Core Team, 2020). Group differences were calculated for demographic, diagnostic, and interoceptive variables using Bayesian ANOVAs or contingency tables (*BayesFactor* package; Morey et al., 2022). Bayes Factors (BFs) were interpreted according to the classification scheme of Jeffreys (BF_{10} evidence for H1: 1–3=*anecdotal*, > 3= *substantial*, > 10 = *strong*, > 30 = *very strong*, > 100 = *decisive*; BF_{10} evidence for H0: 1/3–1 = *anecdotal*, < 1/3 = *substantial*,…), 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). Subsequently, post-hoc t-tests were calculated, and prior odds were adjusted by fixing the probability of the H0 to 0.5 (Westfall, 1997) to control for multiple comparisons. We also analysed whether potential confounding variables, such as age, symptom severity (BDI-II, BAI, and SCID-5-PD), and interoceptive abilities, were correlated with the mean RHIQ and proprioceptive drift difference scores (sync.–async.) across all conditions.

Next, Bayesian multilevel models were computed using the R package *brms*, 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 the dependent variables RHIQ, proprioceptive drift, SAM arousal, HR, SCL, and NSCR. All models included the fixed effects *group*, *emotion condition*, and *stroking synchrony*, as well as their interactions based on the hypotheses. In post-hoc comparisons of interactions, the synchronous−asynchronous difference score was used as the dependent variable. Treatment coding was used for the categorical predictors condition (reference = neutral) and group (reference = HC group). Synchrony was dummy-coded (0 = synchronous, 1 = asynchronous). Continuous predictors were centered and z-standardized. Participant ID was used as random effect, including the random slopes condition, synchrony, and condition*synchrony. For the questionnaire RHIQ, item number was effect coded and also added as random effect (Bürkner & Vuorre, 2019). Non- or weakly informative priors were used due to their minor impact on the resulting parameters (Bürkner, 2018; Danböck et al., 2023). Models with various plausible distribution families were tested against each other. Subsequently, random effects were reduced stepwisely. Pareto-k's, posterior prediction checks, and leave-one-out cross-validation ($\widehat{elpd}_{loo}$difference of > 2 *SE*) methods were applied to find the most suitable distribution and random effects structure (Gabry et al., 2019; Matuschek et al., 2017; Vehtari et al., 2017). Post-hoc comparisons were performed using the *hypothesis()* function. Relevant predictors which had estimates ≠ 0 with an 89% probability given the observed data were reported with the parameter estimate, 89% credibility interval, and the posterior probability ($PP_{b>0}/PP_{b<0}$; Danböck et al., 2023; Danböck et al., 2024). We chose 89% CIs as they were more stable than 95% CIs and required a lower effective sample size (ESS; Kruschke, 2014; Makowski et al., 2019). Graphs display the conditional effects of the predictors. All models converged with Rhat < 1.01 and bulk/tail ESS > 400 (Vehtari et al., 2021).

Exploratorily, we examined potential prediction effects of acute dissociation (DSS4) on arousal, and of arousal/acute dissociation on the RHI measures (RHIQ and proprioceptive drift) using *brms*. As we expected a U-shaped relationship between DSS4 and arousal, we tested whether the relation of acute dissociation to the arousal variables was linear or polynomial. For the RHI measures, moderation models were calculated, including the covariates of arousal and interoceptive abilities that were significantly related to the outcome.

5.3 Results

5.3.1 Group Differences

The three groups did not substantially differ in gender, biological sex, school, occupation, age, or BMI (Table 6). 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 6).

Decisive evidence of group differences was found for all diagnostic questionnaires (Table 6). 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, depersonalisation, borderline, depressive, and anxiety symptoms (Table 6).

Table 6

Demographic and Clinical Characteristics

		HD	LD	HC	Group differences
		N (%)	*N* (%)	*N* (%)	
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%)		$BF^1_{L!=H}$ = 0.37
	SSRI	9 (36%)	11 (44%)		$BF^1_{L!=H}$ = 0.39
	Tricyclic	0 (0%)	1 (4%)		$BF^1_{L!=H}$ = 0.15
	NaSSA	0 (0%)	2 (8%)		$BF^1_{L!=H}$ = 0.31
	Atypical neuroleptics	4 (16%)	1 (4%)		$BF^1_{L!=H}$ = 0.51
ICD-10 Psychiatric Diagnoses	F1	4 (16%)	2 (8%)		$BF^1_{L!=H}$ = 0.32
	F3	19 (76%)	14 (56%)		$BF^1_{L!=H}$ = 0.94
	F4	23 (92%)	21 (84%)		$BF^1_{L!=H}$ = 0.32
	F5	13 (52%)	7 (28%)		$BF^1_{L!=H}$ = 1.42
	F9	8 (32%)	2 (8%)		$BF^1_{L!=H}$ = 2.39
SCID-5-PD	BDP diagnose	15 (60%)	4 (16%)		$BF^1_{L!=H}$ = **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} > **100**
					$BF^3_{C≠L}$ > **100**
					$BF^3_{L≠H}$ > **100**
BDI-II		38.04 (10.16)	24.32 (13.29)	2.08 (2.72)	BF^2_{10} > **100**
					$BF^3_{C≠L}$ > **100**
					$BF^3_{L≠H}$ = **35.37**
BAI		31.64 (11.82)	20.52 (13.14)	4.32 (4.41)	BF^2_{10} > **100**
					$BF^3_{C≠L}$ > **100**
					$BF^3_{L≠H}$ = **4.40**
CDS	Frequency	49.20 (20.75)	20.88 (15.32)	1.84 (2.43)	BF^2_{10} > **100**
					$BF^3_{C≠L}$ > **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 ($BF_{C!=L}$), and between LD and HD (high dissociation) groups ($BF_{L!=H}$) against the H0. BF^1 = contingency table; BF^2 = ANOVA; BF^3 = two-sided t-test with corrected Bayes factors. 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 behavioural disorders due to psychoactive substance use; F3 = mood/affective disorders; F4 = neurotic, stress-related, and somatoform disorders; F5 = behavioural syndromes associated with physiological disturbances and physical factors; F9 = behavioural and emotional disorders with onset usually occurring in childhood and adolescence. 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.

5.3.2 Correlations to Psychiatric Symptoms and Interoceptive Abilities

We did not find substantial evidence that the RHIQ and proprioceptive drift difference scores were correlated with age; symptoms of depression, anxiety, and BPD; or interoceptive abilities ($BF_{10} < 0.93$; Table 7). Thus, these variables were not included as moderators in further analyses.

Table 7

Correlations of the Rubber Hand Illusion (Sync.–Async.) Difference Scores to Age, Depressive-, Anxiety-, and Borderline Personality Disorder Symptoms, and Interoceptive Abilities

	RHIQ (sync.–async.)		Proprioceptive drift (sync.–async.)	
	r	BF_{10}	r_{Median}	BF_{10}
age	-0.17	0.81	0.02	0.27
BDI-II	0.04	0.28	-0.11	0.42
BAI	-0.01	0.26	-0.17	0.90
SCID-5-PD	-0.01	0.27	-0.15	0.68
IAc	-0.003	0.27	-0.05	0.30
IS	0.01	0.27	0.003	0.27
IAw	-0.17	0.93	-0.04	0.29

Note. RHIQ = Rubber Hand Illusion Questionnaire; sync. = synchronous; async. = asynchronous; BDI-II = Becks Depression Inventory II; BAI = Becks Anxiety Inventory; SCID-5-PD = Structured Clinical Interview for *DSM-V* Personality Disorders; IAc = interoceptive accuracy; IS = interoceptive sensibility; IAw = interoceptive awareness.

5.3.3 Effects on the Rubber Hand Illusion Questionnaire

Bayesian cumulative link mixed models were calculated to analyse the main effects and interactions of group, condition, and synchrony (Table 8 & Appendix B Table B1).

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% (Figure 9 & Appendix B Table B1).

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%). Posthoc 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 (Figure 9). This effect was not found in the other two groups.

Table 8

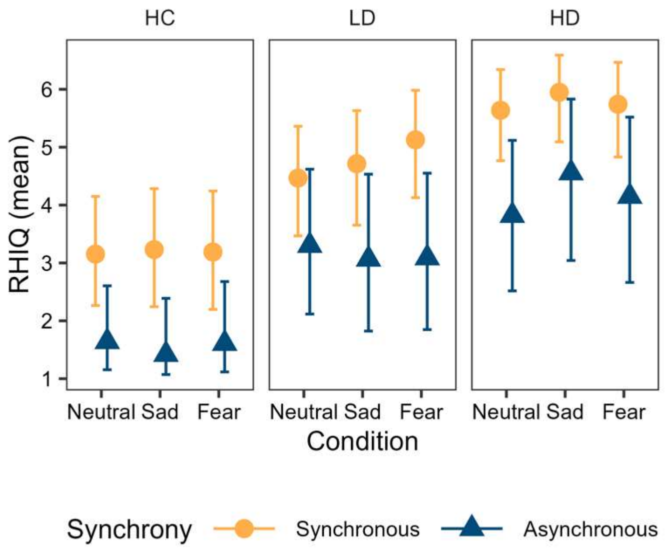
Mean (SD) per Condition, Group, and Stroking Style for the Rubber Hand Illusion Measures, Physiological and Subjective Arousal

	HD			LD			HC		
	Neutral	Sad	Fear	Neutral	Sad	Fear	Neutral	Sad	Fear
RHIQ									
Sync.	5.41 (1.68)	5.52 (1.76)	5.34 (1.67)	4.22 (2.15)	4.34 (2.16)	4.72 (2.12)	3.40 (1.98)	3.53 (2.08)	3.44 (2.03)
Async.	3.70 (2.18)	4.13 (2.15)	3.88 (1.99)	3.43 (1.98)	3.29 (2.12)	3.23 (2.09)	2.20 (1.56)	1.84 (1.12)	2.18 (1.68)
Prop. Drift									
Sync.	1.77 (2.99)	3.10 (4.11)	1.87 (4.45)	3.68 (4.94)	3.48 (3.91)	2.91 (5.13)	2.25 (2.77)	1.43 (2.89)	1.50 (1.95)
Async.	0.91 (3.77)	2.41 (6.16)	0.55 (2.86)	1.73 (3.89)	1.55 (4.57)	0.76 (2.77)	0.38 (3.06)	0.42 (1.86)	-0.52 (2.83)
Arousal									
Sync.	4.96 (2.20)	4.92 (2.27)	5.16 (2.01)	4.68 (2.39)	4.88 (2.13)	4.96 (2.37)	3.64 (1.66)	3.76 (1.20)	3.80 (1.35)
Async.	5.04 (2.07)	4.68 (2.06)	4.87 (2.07)	4.39 (1.99)	4.56 (2.29)	4.88 (2.32)	3.60 (1.66)	3.68 (1.38)	3.68 (1.70)
NSCR									
Sync.	7.96 (9.07)	7.74 (8.20)	7.64 (6.91)	7.71 (8.51)	8.84 (8.43)	8.96 (9.01)	6.88 (8.11)	5.38 (6.92)	9.04 (9.59)
Async.	7.24 (6.60)	7.08 (7.18)	8.55 (8.00)	7.71 (8.76)	9.17 (8.53)	9.60 (10.77)	6.04 (6.39)	5.17 (5.85)	8.68 (10.90)
SCL									
Sync.	2.35 (0.10)	2.31 (0.04)	2.33 (0.08)	2.33 (0.07)	2.33 (0.08)	2.32 (0.06)	2.35 (0.09)	2.32 (0.06)	2.36 (0.10)
Async.	2.33 (0.06)	2.35 (0.09)	2.32 (0.07)	2.32 (0.08)	2.34 (0.11)	2.31 (0.04)	2.33 (0.10)	2.32 (0.08)	2.34 (0.11)
HR									
Sync.	77.97 (11.11)	77.60 (11.26)	77.41 (10.52)	72.48 (8.00)	72.35 (7.97)	71.33 (8.00)	72.91 (12.75)	73.09 (11.85)	71.95 (11.54)
Async.	78.28 (11.43)	77.44 (11.57)	79.33 (10.36)	72.72 (7.55)	71.97 (7.88)	72.00 (8.03)	72.80 (12.66)	73.23 (11.71)	72.21 (11.42)

Note. RHIQ = Rubber Hand Illusion Questionnaire; Prop. Drift = proprioceptive drift; Sync. = synchronous; Async. = asynchronous; NSCR = non-specific skin conductance responses; SCL = skin conductance level; HR = heart rate.

Figure 9

Conditional Effects Plot of the Three-Way Interaction Effect of Group, Condition, and Synchrony on the Rubber Hand Illusion Questionnaire Mean Score (RHIQ mean)



Note. HC = healthy control group; LD = low dissociation group; HD = high dissociation group.

5.3.4 Effects on the Proprioceptive Drift

For drift in the proprioceptive measurement, model comparisons yielded a model with Student's t-distribution (Table 8 & Appendix B Table B2). Proprioceptive drift was significantly higher in the synchronous than the asynchronous 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.

5.3.5 Effects on Arousal

To analyse the effects of emotional vocalisations on arousal in the different groups, we used a cumulative link mixed model for subjective arousal (Appendix B Table B3) and models with Student's t-distribution for NSCR, SCL, and HR (Appendix B Tables B4–B6). We did not find interaction effects on either of the arousal variables. The main effect of group showed that both the HD, *b* = 2.94, 89% CI [1.21, 4.68], $PP_{b>0}$ = 98%, and the LD group, *b* = 2.24, 89% CI [0.59, 3.89], $PP_{b>0}$ = 95%, reported an overall higher subjective arousal than the HC group, and a higher HR was found in the HD compared to the LD group, *b* = -5.57, 89% CI [-9.20, -1.96], $PP_{b<0}$ = 97%. Besides, a condition effect on NSCR showed that fear elicited more NSCR than the neutral *b* = 2.08, 89% CI [0.76, 3.42], $PP_{b>0}$ = 97%, and the sadness condition, *b* = 2.60, 89% CI [1.28, 3.95], $PP_{b>0}$ = 99%. Further, a higher SCL was found in the neutral compared to the sadness condition, *b* = -0.03, 89% CI [-0.05, -0.01], $PP_{b<0}$ = 97%.

5.3.6 Relations of Acute Dissociation, Arousal, and the Illusion Measures

Brms analyses showed that the RHIQ was positively predicted by acute dissociation and proprioceptive drift (Figure 10A & B), but not by arousal (Table 9). Exploratorily, we calculated the effect of the single DSS4 items on RHIQ, revealing that depersonalisation was most strongly related to RHIQ (*b* = 0.42), followed by somatic dissociation (*b* = 0.25), and was not significantly related to derealisation and analgesia.

HR negatively predicted proprioceptive drift (Figure 10C), while acute dissociation was not related (Table 9). Analyses to determine whether acute dissociation predicts arousal revealed no predictive effect for SCL and HR; however, a quadratic relationship was observed with NSCR and subjective arousal (Table 10 & Figure 10D & E).

Table 9

Prediction Effects of Arousal and Acute Dissociation on the Rubber Hand Illusion Measures

	RHIQ		Proprioceptive drift	
	b	*89% CIs*	*b*	*89% CIs*
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.

Table 10

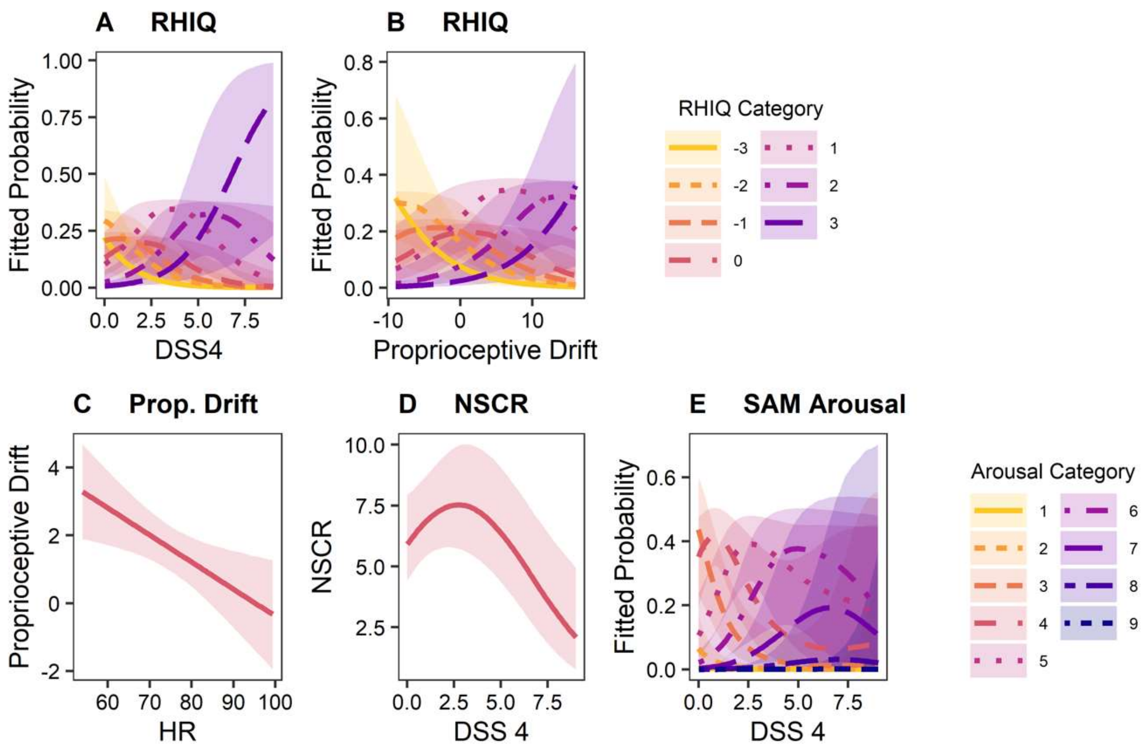
Prediction Effects of Acute Dissociation on Arousal

	Arousal		SCL		NSCR		HR	
	b	*89% CIs*	*b*	*89% CIs*	B	*89% CIs*	*b*	*89% CIs*
DSS4	(1) **1.26** (2) -0.09	0.68, 1.87 -0.19, 0.01	-0.002	-0.004, 0.001	(1) **0.18** (2) **-0.03**	0.04, 0.31 -0.05, -0.01	0.07	-0.16, 0.30

Note. BF_{10} represents two-sided evidence ratios for the H1 (r≠0). (1) and (2) refer to the first- and second-order quadratic terms. DSS4 = Dissociation-Tension Scale 4; SCL = skin conductance level; NSCR = non-specific skin conductance responses; HR = heart rate.

Figure 10

Relation Between Arousal, the Illusion Measures, and Acute Dissociation



Note. A) Fitted probability density of each Rubber Hand Illusion Questionnaire (RHIQ) category for the Dissociation-Tension Scale (DSS4) score. B) Fitted probability density of each RHIQ category for the proprioceptive drift. C) Fitted linear prediction effect of heart rate (HR) on the proprioceptive drift. D) Fitted polynomial prediction effect of the DSS4 on non-specific skin conductance responses (NSCR). E) Fitted probability density of each Self-Assessment Manikin (SAM) arousal category for the DSS4 score.

5.3.7 Moderation Effects of Arousal

We further analysed the moderation effects of arousal and interoceptive abilities. As none of the arousal variables or interoceptive variables were related to the RHIQ and solely HR was related to the proprioceptive drift, it was examined whether HR moderates the effects of the fear condition between groups using the difference score of synchronous and asynchronous trials. The three-way interaction of group and condition with HR on the proprioceptive drift was significant (Appendix B Table B7). However, when comparing the slopes of HR in the fear condition between groups in post-hoc tests, no group differences remained.

5.4 Discussion

The main aim of the present study was to examine whether dissociation experiences 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 vocalisations on the RHI in adolescent psychiatric 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 group than in the HD group. The groups did not substantially differ in interoceptive abilities, and we found no arousal blunting in response to emotional vocalisations in the HD group.

Interestingly, we observed a stronger illusion in response to fearful vocalisations compared to neutral vocalisations, but only in the LD group. The emotional vocalisations did not have the expected effect on proprioceptive drift, and we found no moderation effect 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 to any arousal variable. However, proprioceptive drift was negatively related to HR, indicating that drift may diminish with higher arousal. Finally, we found quadratic relationships of acute dissociation with subjective arousal and NSCR, marked by an initial arousal increase with rising dissociation, and a shutdown in highly dissociative states.

In line with some previous studies (Bekrater-Bodmann et al., 2016; Hirschmann & 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 the study of Fust et al. (2024), where no difference was found between the NSSI and the control group, this indicates that past findings can indeed be extended to adolescents with NSSI and high levels of dissociation (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 the potential to be an indirect measure of acute dissociative experiences in response to emotional situations. Specifically, acute depersonalisation was most strongly related to the illusion questionnaire in our sample, supporting the previous proposal that the RHI may be a sign of depersonalisation experience (Bekrater-Bodmann et al., 2016).

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 elevated levels of subclinical dissociation (Schroter et al., 2021). Detached emotion experience may be the cause of the intensified illusion in both experiments (Lambie & 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 & Iannetti, 2015). This may indicate that proprioception plays a role in sympathetic nervous system activity related to bodily defence rather than in dissociation. 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 between HR and proprioceptive drift. Accordingly, we propose that patients with NSSI may have a generally more plastic protective peripersonal space, which becomes sharper with increasing arousal and defence necessity.

Overall, while the 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 activation level and may be reduced during defence and increased during shutdown. 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 (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 & Ferri, 2018), thereby protecting against exteroceptive manipulations of body experience (Bekrater-Bodmann et al., 2020) and preventing exaggerated activation of defence mechanisms. It would be intriguing to monitor heartbeat-evoked potentials 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).

5.4.1 Limitations and Future Research

We examined a well-characterised 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. Moreover, even though the experimental manipulation showed an effect on physiological arousal, it was not strong enough to trigger a defence system shutdown in the HD group. Hence, the emotion conditions in our study might be insufficient to induce a shutdown state in all participants. Future studies could explore alternative emotion induction procedures, such as a trauma script, for a more comprehensive investigation (Danböck et al., 2024).

Contrary to our expectations, we observed only a main effect of group on the RHIQ, without interaction with synchrony. However, in previous studies (Bekrater-Bodmann et al., 2016; Hirschmann & 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 derealisation 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 analyse 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 BDP symptoms.

5.4.2 Conclusion

In summary, the present findings indicate that dissociative experiences were closely related to malleability of the sense of ownership. Particularly, depersonalisation appears related to ownership changes, indicating a self-detached mode of emotion experience. In participants with moderate dissociation, fear may thereby promote a more plastic sense of self. Moreover, proprioceptive drift may rely on different processes than the subjective illusion rating, such as the defence system, leading to sharpening of the body boundaries in response to arousal. Since the direction of causality remains questionable, future studies should evaluate possible interventions aiming to stabilise ownership experiences and examine whether this results in improvement of dissociative symptoms and a lower likelihood of defence system shutdown under stressful conditions.

6 Third Study: Meditation Effects on Body Ownership and Interoceptive Abilities[3]

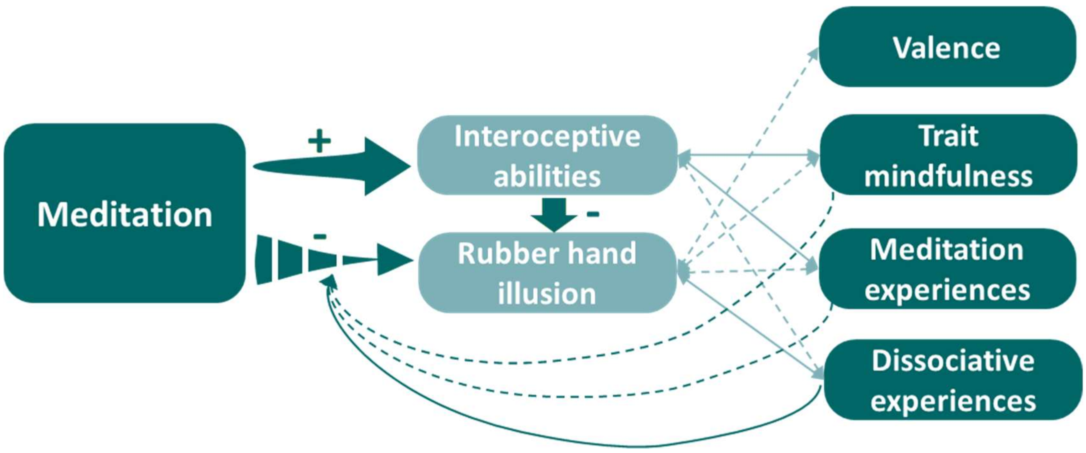
6.1 Goal and Hypotheses

Study three aimed to evaluate the immediate effects of a short mindfulness meditation on the sense of ownership in healthy participants. Furthermore, the effects on interoceptive abilities, such as IAc, IS (confidence in ratings), and IAw, are investigated. Based on previous findings, lower scores in the RHIQ in synchronous compared to asynchronous trials and a higher IAc and IS are expected following a body-focused meditation as compared to an audiobook reading (Figure 11; Fischer et al., 2017; Mirams et al., 2013). Besides, we assume that the changes in the RHI following the intervention are mediated by changes in interoceptive abilities. As a manipulation check, valence and arousal changes will be analysed. Meditation experience, dispositional mindfulness, and dissociative experiences will also be measured since a lower subjective illusion is expected for participants with higher dispositional mindfulness and meditation experience (Cebolla et al., 2016; Xu et al., 2018), higher IAc and IAw (Bekrater-Bodmann et al., 2020; Tsakiris et al., 2011), lower dissociative experiences (Bekrater-Bodmann et al., 2016), and less negative valence (Schroter et al., 2021). Regarding interoceptive abilities, we assume a positive relation between IS and dispositional mindfulness (Bornemann et al., 2015; Mehling et al., 2012), and a negative relation between IS/IAc and dissociative experiences (Pick et al., 2020). Besides, it will be investigated exploratorily if participants with more dissociative tendencies, lower meditation experience, and lower trait mindfulness show a higher change in the outcome variables (Figure 11).

[3] The results presented in this chapter were published in advance in: Schroter, F. A., Siebertz, M., & Jansen, P. (2023). The impact of a short body-focused meditation on body ownership and interoceptive abilities. *Mindfulness*, *14*(1), 159–173. https://doi.org/10.1007/s12671-022-02039-7

Figure 11

Expected Effects and Correlations



Note. Solid lines represent expected positive relations or increasing effects, dashed lines represent expected negative relations or decreasing effects.

6.2 Method

6.2.1 Participants

For our main research question concerning the effect of a short meditation intervention on the subjective RHI, no previous studies with a pre-post design are available as a basis for the sample-size calculation of a three-way interaction (time x group x stroking style). Therefore, means were estimated based on the results of Tsakiris et al. (2011) and an expected medium effect of the intervention. A total of 116 participants were tested, which, according to a power analysis using the *superpower* package for R (Caldwell & Lakens, 2019), is sufficient to achieve a power of 80%. Four participants had to be excluded during data collection due to technical difficulties in the HDT, and one additional participant was excluded due to insufficient commitment to the intervention (< 30%). The sample was comprised of undergraduate students in the Applied Movement Science program from the University of Regensburg. In total, 66 females and 45 males within an age range between 18 and 29 (M = 22.29, SD = 2.02) participated in this study and were randomly assigned to either the meditation group or the control group. The characteristics of each experimental group are shown in Table 11. Groups were not significantly different regarding the variables age, gender, trait mindfulness, dissociative experiences, or meditation practice/experience (Table 11).

This study was approved by the ethical committee of the University of Regensburg (protocol number: 20–1651–101) and was, therefore, in accordance with the 1964 Declaration of Helsinki and later amendments (World Medical Association, 2013).

Table 11

Demographic Differences Between Control and Meditation Group

Characteristic	Control group	Meditation group	Test	*p*
Age	*M* = 22.21 (1.88)	*M* = 22.37 (2.18)	1538.5 [a]	.998
Gender			0.02 [b]	.880
Female	*n* = 33 (57.89%)	*n* = 33 (61.11%)		
Male	*n* = 24 (42.11%)	*n* = 21 (38.89%)		
FDS mean	*M* = 9.97 (6.50)	*M* = 10.39 (6.96)	1520.5 [a]	.913
FFMQ mean	*M* = 3.42 (0.45)	*M* = 3.31 (0.41)	1.26 [c]	.209
Meditation practice (min/week)	*M* = 6.27 (12.19)	*M* = 4.88 (11.92)	1681.5 [a]	.341
Meditation experience (years)	*M* = 1.79 (1.51)	*M* = 1.59 (1.47)	1622.5 [a]	.497

Note. [a] Mann-Whitney-U test, [b] Chi-squared test; [c] T-test. FDS = Dissociative Symptoms Questionnaire; FFMQ = Five Facet Mindfulness Questionnaire.

6.2.2 Measures

6.2.2.1 Five Facet Mindfulness Questionnaire (FFMQ). The FFMQ (Baer et al., 2008; Michalak et al., 2016) is composed of 39 items, which can be assigned to five different facets: *observing*, *non-judging*, *non-reactivity*, *acting with awareness,* and *describing*. The items can be rated on a five-point Likert scale from 1 = *never/rarely applies* to 5 = *applies always/very often*. Adequate validity measures and internal consistencies for the subscales were found in the German version, with internal consistency ranging between $\alpha = .74$ and $\alpha = .90$ (Michalak et al., 2016). In the present study, the R-package *psych* (Version 2.9.1, Revelle, 2021) was used to calculate Cronbach's alpha and McDonald's total omega. Reliability for the total score was $\omega = .92/a = .90$, the subscales ranged between $\omega = .86$ and $\omega = .94/a = .79$ and $a = .93$.

6.2.2.2 Questionnaire on Dissociative Symptoms (FDS). The FDS (Freyberger et al., 1999) was used to screen for dissociative symptoms (for a detailed description, see Section 4.2.2.7). In the present sample, omega for the total score was ω = .93, alpha was *a* = .91, the subscales ranged between ω = .77 and ω = .87/*a* = .64 and *a* = .82.

6.2.2.3 Demographic Questionnaire. At the beginning of the experiment, participants were asked to complete questions on their demographical background. The items included questions on participants' age, gender, previous RHI experience, handedness, job/studies, psychological or neurological diseases, and previous meditation and yoga practice/experiences.

6.2.2.4 Rubber Hand Illusion Induction. Two RHI trials (synchronous and asynchronous) were conducted. The same box setup was used as in study two (for a detailed description of the setup and the procedure, see Section 5.2.2.3 and Figure 7A). The distance between the index finger of the real and the rubber hand (Killerink, Liverpool, UK) was 17.5 cm (Tsakiris & Haggard, 2005). Stroking was applied as in study two, from the proximal interphalangeal joint to the fingertip (see Section 5.2.2.3), with random delay intervals since it was found to evoke a stronger illusion effect than fixed intervals (Riemer et al., 2019). The stimulation lasted 120 s and was applied either in synchrony or in a 1 s asynchrony. The order of the trials (synchronous vs asynchronous) was randomised across participants. Following each RHI trial, the RHIQ was completed. Before and after the RHI, a proprioceptive measurement was also taken.

6.2.2.5 Proprioceptive Drift. Before and after each RHI stimulation trial, a proprioceptive measurement was conducted using the same procedure as in study two (for a detailed description see Section 5.2.2.5 and Figure 7). The proprioceptive drift was calculated as follows: Pre-proprioception–post-proprioception. Since only weak relations to the proprioceptive drift were found in the past, the drift will be analysed exploratorily.

6.2.2.6 Rubber Hand Illusion Questionnaire (RHIQ). To assess the subjectively perceived strength of the rubber hand illusion, eight items of the questionnaire from Longo et al. (2008) were used as in the study of Tsakiris et al. (2011) and as in study two (for detailed description, see Section 5.2.2.6). Reliabilities were calculated for the mean score, separately for each group, timepoint and synchrony condition, revealing omegas between $\omega = .93$ and $\omega = .97$ and alphas between $\alpha = .88$ and $\alpha = .96$.

6.2.2.7 Heartbeat Detection Task (HDT). Interoceptive accuracy (IAc), confidence (Interoceptive Sensibility = IS) and the correspondence between both (Interoceptive Awareness = IAw) were assessed using the HDT, developed by Schandry (1981) and adapted by Garfinkel et al. (2015). The same procedure was applied as in study two (see Section 5.2.2.2).

6.2.2.8 Intervention. The experimenter left the room for the intervention after explaining the task, so blinding was enabled using a program, which randomly assigned the participants either to the meditation or the control condition.

A short introduction was given at the beginning of both audios, in which participants were asked to sit down on a chair, a yoga mat or a meditation cushion and to find a comfortable position. Subsequently, the meditation group heard a 20-minute meditation, which was guided by a trained MBSR instructor with more than 10 years of experience. The meditation focused on the body as a whole, on body sensations, and on the perception of the hands. As in the study of Aaron et al. (2020), the control group heard a 20-minute reading about natural history ("A Short History of Nearly Everything"; Bryson, 2004). The control group audio was read by the same instructor as the meditation audio.

6.2.2.9 Affect Grid (Russell et al., 1989). Using this single-item scale, mood was assessed on two dimensions: valence and arousal. The two dimensions were rated by ticking a box in a grid with nine columns, ranging from *pleasure* to *displeasure* (valence) and nine rows, ranging from *arousal* to *sleepiness* (arousal). The Affect Grid showed strong evidence for convergent and discriminant validity in the study of Russell et al. (1989).

6.2.2.10 Compliance. The compliance with the interventions was measured with the item "On a scale of 0–100%, how much did you commit to the exercise?“ using a 10-point Likert scale. Besides, participants were asked to summarise the content and their experience with the intervention in one to two sentences.

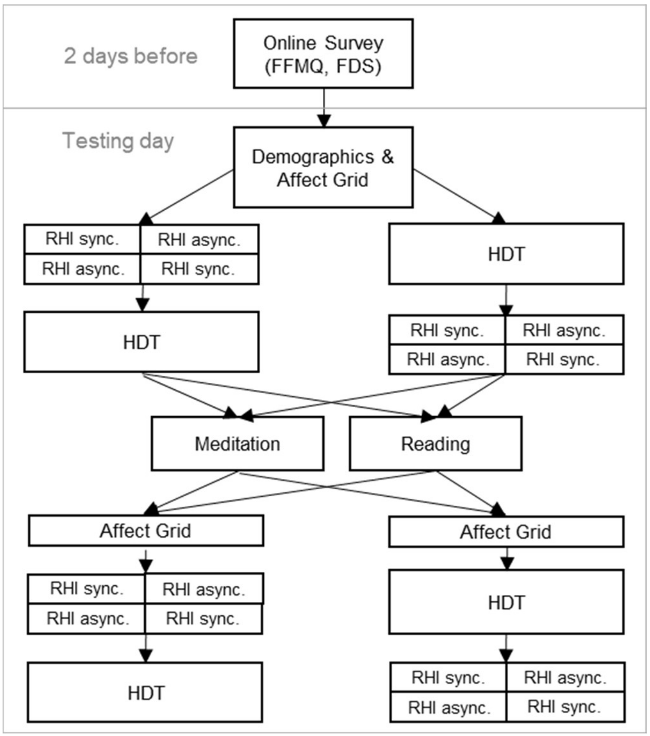
6.2.3 Procedure

To avoid spill-over effects on the experimental tasks, participants were asked to complete the FFMQ and FDS questionnaires two days in advance to their actual testing appointment via an online survey system (*SoSci Survey*, Leiner, 2019).

At the testing date, participants first completed the demographic questions and the affect grid. Subsequently, the baseline measurements of the HDT and the RHI were performed. The order of these tasks was randomised (Figure 12). After this baseline assessment, participants were allocated either to the meditation or to the reading control group. The intervention lasted 20 minutes. Afterwards, affect grid, RHI, and HDT were repeated in the same order as before the intervention and in the end, questions on compliance and experiences with the intervention were asked.

Figure 12

Study Procedure



Note. FFMQ = Five Facet Mindfulness Questionnaire; FDS = Dissociative Symptoms Questionnaire; RHI sync. = synchronous rubber hand illusion trial; RHI async. = asynchronous rubber hand illusion trial; HDT = Heartbeat Detection Task.

6.2.4 Statistical Analysis

In the beginning, we tested if both groups differed regarding their commitment to the intervention using Mann-Whitney-U test.

To analyse the effects of the intervention type on the illusion and on measures of interoception, we conducted separate linear mixed models. For the outcome variables IAc, IS, and IAw, the main effects and interactions of time and group with the variables dissociative experiences, meditation experience, trait mindfulness, and mood (valence, arousal) were analysed. For the subjective illusion, synchrony, IAc, IS, and IAw were also included as fixed factors. For the analysis of the proprioceptive drift, it was preregistered on OSF that proprioception would be used as dependent variable, and the factor pre- vs post-stroking would also be included in the analysis to determine the drift. During analysis, five-way interactions turned out to be significant.

For the sake of greater interpretability, we decided to directly examine the difference between proprioception before and after stroking, hence the proprioceptive drift as a dependent variable. Before subtracting the post-stimulation proprioceptive estimation from the pre-stimulation value, it was analysed using ANOVA whether the stimulation led to the expected drift in the synchronous conditions.

Linear mixed models were performed using *LME4* package for R (Bates et al., 2015; R Core Team, 2020) with the wrapper optimix (Jost & Jansen, 2020; Nash, 2014). As random effect, interindividual differences between participants were included in the models. First, a maximum model was defined, including all random slopes and fixed effects. Subsequently, random slopes were reduced in a stepwise manner following the procedure of Matuschek et al. (2017). Thereby, non-significant variance components were dropped, and after each reduction, the goodness of fit of the new model was compared to that of the previous model. In case of a loss in goodness of fit, indicated by $p < .200$ (Matuschek et al., 2017), complexity reductions were stopped unless convergence issues persisted. Subsequently, non-significant fixed effects were removed from the model, in a stepwise manner as well, using likelihood ratio test and a p-value of $< .05$. In case of significant interactions, the respective main effects and lower-order interactions remained in the model regardless of their significance. Assumptions of normality, linearity, and homoscedasticity were checked visually.

If significant interaction effects were found, Bonferroni-Holm corrected post-hoc linear mixed models were calculated (Holm, 1979). Following the procedure of Tsakiris et al. (2011) and Horváth et al. (2020), difference scores of the RHIQ and the proprioceptive drift were built for this purpose by subtracting asynchronous from synchronous trials, as the illusion can be quantified by the difference of these trials (Riemer et al., 2019; Tsakiris & Haggard, 2005). Subsequently, the effect of the interacting variable on this difference was determined. For three- or four-way interactions, subsets of the data were created either based on different categories (e.g. control vs meditation) or, in the case of continuous variables, based on a median split (e.g. low IAc vs high

IAc) to isolate the effect of a variable under specific conditions. If models failed to converge due to the small data subsets, Bonferroni-Holm corrected linear regression models were used. For significant effects, figures were created based on the difference score. For non-significant post-hoc tests, original values were used and further post-hoc comparisons were computed to localise the source of the interaction.

In the case of categorical data, such as valence and arousal, cumulative link mixed models from the package *ordinal* by Christensen (2018) were calculated. Equidistant thresholds were used and model building was performed based on the procedure of Matuschek et al. (2017), as well.

In general, outliers above or below 3 SD were excluded from the respective analyses in IAc, IAw, and IS, as well as in the difference variables of the RHIQ and the proprioceptive drift.

6.3 Results

6.3.1 Effects on Mood and Subjective Experiences

Cumulative link mixed models were used for valence and arousal. Model building resulted in one random intercept model each. Both variables were significantly predicted by time but not by group. In the case of valence, a significant increase was observed from baseline ($Mdn = 6$) to post-intervention ($Mdn = 7$), $b = 1.30$, $SE = 0.17$, $z = 7.52$, $p < .001$, 95% CI [0.96, 1.64]. In contrast, a significant decrease from baseline ($Mdn = 6$) to post-intervention ($Mdn = 4$) was found for the variable arousal, $b = -1.50$, $SE = 0.18$, $z = -8.49$, $p < .001$, 95% CI [-1.84, -1.15].

Regarding the commitment to the intervention, participants achieved a mean commitment score of $M = 83.64\%$, with a standard deviation of $SD = 14.82\%$. Commitment was significantly higher in the control group ($Mdn = 90\%$) than in the meditation group ($Mdn = 80\%$), $U = 1836.5$, $p = .046$. In their subjective experience reports, participants of the meditation group often stated a feeling of warmth, tingling or pulsation in the hands, a higher focus on body sensations (e.g. the heartbeat), relaxation effects, but also difficulties with concentration and wandering thoughts.

Participants in the control group often reported that they found the story interesting, but many of them also reported relaxing effects or drowsiness.

6.3.2 Effects on Interoceptive Abilities

6.3.2.1 Interoceptive Accuracy (IAc). The effect of the intervention on IAc was determined using linear mixed models. Model building resulted in a random intercept model, including the fixed factor time, $b = 0.07$, $SE = 0.01$, $t(111) = 6.66$, $p < .001$, 95% CI [0.05, 0.09], showing that IAc increased from baseline ($M = 0.64$, $SD = 0.18$) to post-intervention ($M = 0.71$, $SD = 0.18$). Variance explained by the participants, $\tau_{00} = 0.03$, accounted for 81% of the total variance. The proportion of the variance explained by the fixed factors was $R^2_{marginal} = .04$, the proportion explained by the whole model was $R^2_{conditional} = .82$.

6.3.2.2 Interoceptive Sensibility (IS). The model reduction procedure also resulted in a random intercept model for the variable IS. The fixed factors time, $b = 12.38$, $SE = 3.51$, $t(118.16) = 3.52$, $p = .001$, 95% CI [5.77, 19.47], arousal, $b = 1.27$, $SE = 0.60$, $t(127.34) = 2.13$, $p = .035$, 95% CI [0.06, 2.39], as well as the interaction of time and arousal, $b = -1.99$, $SE = 0.73$, $t(117.82) = -2.74$, $p = .007$, 95% CI [-3.53, -0.63], significantly predicted IS. In addition, trait mindfulness remained in the model, although it only showed a trend towards significance, $b = 7.78$, $SE = 3.93$, $t(110.86) = 1.98$, $p = .050$, 95% CI [-0.06, 15.62]. The positive connection between the main effect time and IS shows that an improvement can be observed over time (baseline: $M = 55.46$, $SD = 18.54$; post-intervention: $M = 58.27$, $SD = 18.99$). A closer inspection of the interaction effect using Bonferroni-Holm corrected post-hoc regressions showed neither an effect of time in participants with low or high arousal (*p*s = 1.00) nor an effect of arousal at pre- or post-intervention (*p*s ≥ .386). Variance explained by the participants, $\tau_{00} = 298.86$, accounted for 89% of the total variance. The proportion of the variance explained by the fixed factors was $R^2_{marginal} = .04$, and the proportion explained by the whole model was $R^2_{conditional} = .90$. To rule out the possibility that HR predicts the IS better than the variable arousal, it was included in an exploratory model. The arousal effect and the interaction with time remained significant, HR had no significant effect.

6.3.2.3 Interoceptive Awareness (IAw). For the dependent variable IAw, convergence issues remained even after reducing the model to random intercepts. Consequently, a backward linear regression was calculated. Overall, the model was not significant, R^2 = .03, $R^2_{adjusted}$ = -.008, F(9, 212) = 0.81, p = .605, and none of the predictors reached significance (Table 12).

Table 12

Final Backward Linear Regression Model for the Dependent Variable Interoceptive Awareness

	Interoceptive Awareness				
	b	*SE*	*t*	*p*	*95% CIs*
Intercept	-0.07	0.43	-0.16	.868	-0.93, 0.79
Time	0.24	0.71	0.33	.740	-1.17,1.64
Group	-0.17	0.41	-0.41	.682	-0.97, 0.64
FFMQ mean	0.15	0.12	1.31	.191	-0.08, 0.38
Valence	-0.03	0.05	-0.58	.566	-0.13, 0.07
Time * group	0.88	0.73	1.19	.234	-0.57, 2.32
Time * FFMQ mean	-0.23	0.16	-1.43	.155	-0.55, 0.09
Group * valence	0.03	0.07	0.47	.639	-0.10, 0.17
Time * valence	0.09	0.09	1.05	.293	-0.08, 0.27
Time * group * valence	-0.16	0.11	-1.42	.156	-0.38, 0.06
R^2	.03				
$R^2_{adjusted}$	-.008				
F(9, 212)	0.81				
P	.605				

Note. FFMQ mean = Five Facet Mindfulness Questionnaire mean score.

6.3.3 Effects on Measures of the Rubber Hand Illusion

Rubber Hand Illusion Questionnaire (RHIQ). Linear mixed models with the predictors time, group, synchrony, dissociative experiences, trait mindfulness, meditation practice, IAc, IS, and IAw, as well as valence and arousal were calculated. Model reduction resulted in a random intercept model. The predictors which remained in the model after model reduction can be found in Table 13. Significant main effects of synchrony, group, and trait mindfulness emerged. Synchronous stimulation (M = 0.96, SD = 1.40) led to a stronger subjective illusion score compared to asynchronous stimulation (M = 0.72, SD = 1.49), and the control group (M = 0.39, SD = 1.61) showed a higher RHIQ score than the meditation group (*M* = -0.16, *SD* = 1.70). Besides, trait mindfulness was negatively associated with the RHIQ score (Table 13). Looking at the two-way interactions, it can also be observed that trait mindfulness interacts with synchrony. In a post-hoc linear mixed model, it was examined if trait mindfulness predicts the difference between synchronous and asynchronous trials, revealing no significant effect ($p = .278$). Further post-hoc linear mixed models regarding the mean RHIQ score showed only a significant effect of the FFMQ on synchronous ($p = .006$), not on asynchronous ($p = .069$) trials (Figure 13A).

A significant interaction with synchrony was also found for the variable IAc (Table 13). As the post-hoc comparison demonstrates, a higher IAc was associated with a smaller difference between synchronous and asynchronous trials ($p = .008$, Figure 13B).

Besides, a three-way interaction of group, time, and IAw and a four-way interaction of synchrony, group, time, and IAw were found (Figure 14A). Post-hoc comparisons for the difference between synchronous and asynchronous trials were performed for the higher-order interaction, separately for each group and time point. Post-hoc tests could not be calculated using *lmer* due to convergence issues in the small data subsets. Instead, linear regression models with Bonferroni-Holm corrected p-values were performed and showed that IAw was associated negatively with the RHIQ difference score in the meditation group post-intervention ($p = .004$). An effect of time only applied to participants with high IAw in the meditation group ($p < .001$), showing a decrease in the illusion from baseline to post-intervention. Group differences were not significant, showing only a trend for participants with high IAw post-intervention ($p = .087$) in terms of a lower illusion in the meditation group compared to the control group (Figure 14A).

No mediation analysis was performed since IAw itself did not change through the intervention.

Table 13

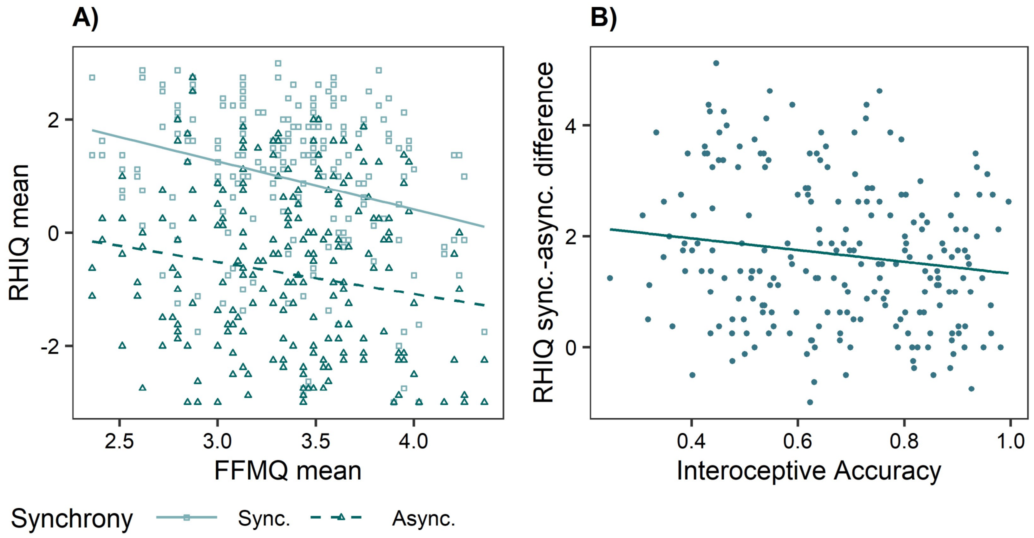
Final Linear Mixed Model for the Dependent Variable Rubber Hand Illusion Questionnaire (RHIQ)

	RHIQ mean					
	Estimate	*SE*	*95% CIs*	*t*	*p*	*df*
Fixed effects						
Intercept	5.17	1.06	3.18, 7.31	4.87	**< .000**	169.81
Synchrony	-4.31	0.77	-5.83, -2.73	-5.59	**< .000**	325.10
Time	-0.21	0.21	-0.60, 0.20	-1.02	.308	352.74
Group	-0.73	0.28	-1.28, -0.19	-2.64	**.009**	240.07
FFMQ mean	-1.02	0.28	-1.58, -0.49	-3.71	**< .000**	141.09
IAc	-0.55	0.55	-1.65, 0.54	-0.99	.321	356.86
IAw	-0.01	0.25	-0.49, 0.51	-0.03	.978	375.98
Synchrony * IAc	1.48	0.46	0.53, 2.39	3.20	**.002**	325.10
Synchrony * IAw	-0.22	0.30	-0.84, 0.39	-0.72	.473	325.10
Synchrony * time	0.11	0.28	-0.44, 0.67	0.41	.685	325.10
Synchrony * group	0.06	0.25	-0.41, 0.62	0.23	.817	325.10
Time * group	0.12	0.27	-0.40, 0.64	0.42	.672	341.51
Synchrony * FFMQ mean	0.48	0.19	0.11, 0.87	2.52	**.012**	325.10
Group * IAw	0.56	0.37	-0.15, 1.25	1.53	.127	377.95
Time * IAw	0.13	0.40	-0.71, 0.92	0.33	.738	361.29
Synchrony * time * group	-0.08	0.37	-0.81, 0.66	-0.23	.820	325.10
Synchrony * group * IAw	-0.33	0.44	-1.17, 0.57	-0.75	.457	325.10
Synchrony * time * IAw	0.01	0.50	-1.04, 1.07	0.02	.986	325.10
Time * group * IAw	-1.31	0.56	-2.36, -0.23	-2.33	**.020**	380.06
Synchrony * time * group * IAw	1.38	0.67	0.00, 2.68	2.06	**.040**	325.10
Random effects						
σ^2	0.68					
$\tau_{00\ \text{Participant}}$	1.13					
ICC	0.62					
$N_{\text{Participant}}$	109					
Observations	436					
Marginal R^2/Conditional R^2	0.35/0.75					

Note. FFMQ = Five Facet Mindfulness Questionnaire; IAc = interoceptive accuracy; IAw = interoceptive awareness.

Figure 13

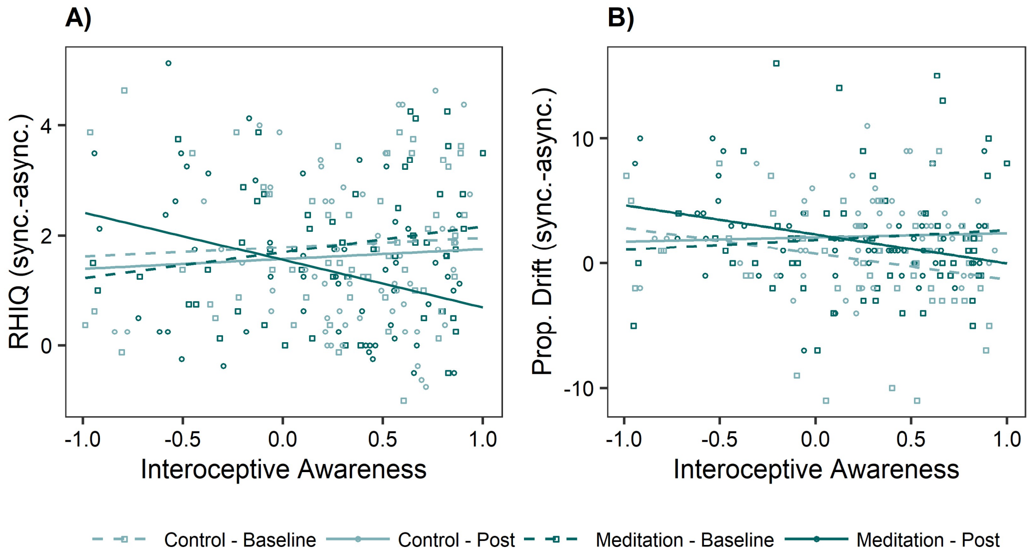
Effects of Trait Mindfulness and Interoceptive Accuracy on the Rubber Hand Illusion Questionnaire (RHIQ)



Note. A) Effect of trait mindfulness (FFMQ mean) and synchrony on the RHIQ mean. B) Effect of interoceptive accuracy on the difference in the RHIQ between synchronous (sync.) and asynchronous (async.) trials. Lines were fitted based on linear mixed model coefficients.

Figure 14

Effect of Time, Group, and IAw on the Rubber Hand Illusion Questionnaire and the Proprioceptive Drift



Note. Effect of time, group and interoceptive awareness on A) the difference in the Rubber Hand Illusion Questionnaire (RHIQ) between synchronous (sync.) and asynchronous (async.) trials, and B) the difference in the proprioceptive drift between sync. and async. trials. The real hand was positioned at 0, the rubber hand at 17.5. Positive values indicate a stronger drift toward the rubber hand in sync. compared to async. trials. Lines were fitted based on linear regression.

6.3.3.1 Proprioceptive Drift. Before the proprioceptive drift was calculated, it was first examined whether there were significant differences in the proprioceptive estimates between pre- and post-stroking. A mixed ANOVA confirmed a significant drift from pre- (M = 0.89, SD = 3.47) to post- (M = 2.99, SD = 5.02) stroking, F (1,213) = 77.60, p = < .001, η^2_p = .267, in the direction of the rubber hand. Besides, the main effect of synchrony, F (1, 213) = 18.68, p < .001, η^2_p = .081, and the interaction of time and synchrony, F (1, 213) = 31.27, p < .001, η^2_p = .128, show that the drift was stronger in synchronous (pre: M = 0.83, SD = 3.43; post: M = 3.73, SD = 5.02), compared to asynchronous trials (pre: M = 0.94, SD = 3.52; post: M = 2.24, SD = 4.92).

As a next step, linear mixed models were calculated. The models were reduced again until an intercept-only model resulted. The remaining fixed factors can be seen in Table 14. It was found that the main effects of IAc and IS significantly predicted the proprioceptive drift independent of synchrony. In this regard, IAc appeared to be positively related to the drift, whereas IS was negatively associated with it (Table 14). Besides, an interaction between IAw and synchrony was detected and a four-way interaction of synchrony, time, group, and IAw was also found for the proprioceptive drift (Figure 14B). Due to convergence problems, linear mixed models could not be calculated as post-hoc tests for this interaction. Instead, regressions with Bonferroni-Holm corrected p-values were used again. IAw was negatively associated with the difference score of the proprioceptive drift in the meditation group post-intervention (p < .001). The effect of group was only significant in the high IAw group before the intervention, with the control group showing a smaller difference in the drift (p = .028). Besides, a time difference (p < .001) indicated an increase in the difference score from baseline to post-intervention for participants with a high IAw in the control group (Figure 14B).

Table 14

Final Linear Mixed Model for the Dependent Variable Proprioceptive Drift

	Proprioceptive drift					
	Estimate	*SE*	*95% CIs*	*t*	*p*	*df*
Fixed effects						
Intercept	2.79	1.21	0.33, 5.08	2.31	**.022**	222.67
Synchrony	-0.77	0.60	-1.94, 0.33	-1.29	.200	318.82
Time	0.56	0.66	-0.80, 1.90	0.85	.396	349.84
Group	-0.02	0.82	-1.69, 1.56	-0.03	.977	290.03
IAc	3.05	1.51	0.22, 6.21	2.02	**.044**	204.64
IS	-0.03	0.02	-0.06, 0.00	-2.21	**.029**	156.70
IAw	0.13	0.83	-1.59, 1.77	0.16	.871	387.27
Synchrony * IAw	2.07	1.02	0.15, 4.17	2.04	**.042**	318.82
Synchrony * time	-1.31	0.89	-3.12, 0.43	-1.47	.143	318.82
Synchrony * group	-1.09	0.85	-2.74, 0.62	-1.28	.200	318.82
Time * group	-1.11	0.89	-2.92, 0.69	-1.25	.214	339.49
Group * IAw	0.75	1.21	-1.54, 3.15	0.62	.538	388.86
Time * IAw	-0.35	1.28	-2.83, 2.20	-0.27	.785	370.97
Synchrony * time * group	0.86	1.22	-1.37, 3.15	0.70	.483	318.82
Synchrony * group * IAw	-2.87	1.47	-5.88, -0.14	-1.95	.052	318.82
Synchrony* time * IAw	-2.41	1.61	-5.48, 0.81	-1.50	.135	318.82
Time * group * IAw	-2.24	1.80	-5.89, 1.39	-1.24	.216	392.54
Synchrony * time * group * IAw	5.55	2.19	1.20, 9.58	2.54	**.012**	318.82
Random effects						
σ^2	7.67					
$\tau_{00\ \text{Participant}}$	7.45					
ICC	0.50					
$N_{\text{Participant}}$	107					
Observations	428					
Marginal R^2/Conditional R^2	0.11/0.55					

Note. IAc = interoceptive accuracy; IAw = interoceptive awareness.; IS = interoceptive sensibility.

6.4 Discussion

The aim of the present study was to evaluate the effects of a short mindfulness meditation on the sense of body ownership under the consideration of interoceptive abilities, dissociative experiences, mood, trait mindfulness, and meditation experience. For this purpose, the effects of the interventions on mood, interoceptive abilities, and the rubber hand illusion were analysed.

We found a general increase in valence and a reduction in arousal, although this was only expected in the meditation group, not the control group (Zeidan et al., 2010), and therefore could also reflect habituation to the experimental environment.

Regarding interoceptive abilities, the expected effect of the intervention was not found. Instead, a time effect on IAc and IS indicates a general improvement from baseline to post-intervention, which might be a training effect. This result is in line with the findings of Aaron et al. (2020), who conducted even shorter meditation vs natural history interventions and found an improvement in IAc and IS independent from group. Parkin et al. (2014), who conducted two studies with one week of body-focused meditation vs control interventions, did not even find a time effect. The authors suggest that cardiac perception might be a stable trait. Therefore, repeating the HDT on the same day may reflect training effects that are less persistent. Brief mindfulness interventions do not appear to substantially enhance these short-term improvements. Instead, changing interoceptive abilities may require long-term interventions, as in the study of Fischer et al. (2017), who conducted an eight-week body scan intervention and showed an improvement in IAc and IS.

In our study, IS was further predicted by the level of arousal and an interaction of time and arousal, whereby the second relation was no longer evident in the post-hoc analyses. Although this was not part of the hypotheses, relations of interoception and arousal have also been found in previous literature, e.g. higher subjective arousal was associated with a higher IAc (Pollatos, Herbert, et al., 2007). To our knowledge, the relation between IS, measured by confidence, and arousal is new: Participants who experience higher levels of subjective arousal may overestimate their ability to perceive their own heartbeat.

In contrast to our expectations, no relation of IS or IAc to dissociative experiences (Pick et al., 2020) was found, but a trend towards a positive relation of IS with trait mindfulness. This is in line with the study of Parkin et al. (2014) who found effects of an eight-week body scan intervention on IS and a relation of confidence and trait mindfulness.

No significant predictors were found for IAw, and it did not even improve over time. Thus, IAw seems to be unaffected by immediate meditation practice and by repetitions of the same task within a short period of time. This is in line with the literature, which only reported a relation between trait mindfulness and IAw so far: Parkin et al. (2014) showed that IAw was not affected by one or eight-week mindfulness interventions, but it was positively related to the FFMQ facets describing, acting with awareness, non-judging, and the total score, while observing was connected to a lower IAw. Accordingly, this variable appears to be rather related to more complex mindfulness skills than to mere body awareness. A short body-focused meditation training might not be enough to enhance IAw. Instead, whole mindfulness interventions, like MBSR or MBCT, including not only body-focused meditation but also exercises focusing on thoughts, emotions, and compassion (Baer, 2003; Kok & Singer, 2017) might be necessary. According to Hölzel et al. (2011), mindfulness interventions entail the promotion of attention and emotion regulation, body awareness and change in the perspective of the self, e.g. through developing meta-awareness. For example, the intervention program of Kok and Singer (2017) showed that observing-thoughts meditation can lead to an increase in meta-cognitive awareness of thoughts. Especially the interaction of meta-cognitive abilities with attention on the body might be relevant for IAw and should, therefore, be targeted by mindfulness interventions aiming to improve interoceptive skills (Khalsa et al., 2018). It is often criticised that the underlying mechanisms of mindfulness are not sufficiently identified (van Dam et al., 2018). However, this interplay of body- and meta-awareness indicates that individual components cannot always be clearly separated from each other but rather unfold their effect through their interaction. This should be given attention in future research.

Regarding the rubber hand illusion, we did find the expected effects of synchrony on both measures. Furthermore, a main effect of group on the RHIQ was found, indicating baseline differences between both groups, with the meditation group showing a lower illusion score regardless of the time of measurement. The effects of the intervention may be weakened by these pre-existing differences. Besides, dispositional mindfulness was negatively related to the subjective illusion in synchronous trials, as in the study of Xu et al. (2018). Meditation experience did not relate to the illusion, although this might be because of a rather low mean meditation practice in the present study, while the study of Xu et al. (2018) explicitly compared novices with experienced meditators. Similarly, no effect of dissociation was found, which could also be due to the fact that mainly subclinical scores were found in the healthy student sample in this study. In contrast, other studies like the one of Bekrater-Bodmann et al. (2016) investigated patients with BPD compared to healthy participants. An effect of mood could also not be determined (Schroter et al., 2021), possibly because other related variables like interoception explain more variance in our models. IAc was negatively related to the difference between synchronous and asynchronous trials, which is in line with the literature (Tsakiris et al., 2011). The proprioceptive drift did not show this effect. Instead, a positive relation to IAc and a negative relation to IS were shown, independent of synchrony. Since synchrony is missing in this connection, expectation effects or affirmative tendencies cannot be ruled out (Riemer et al., 2019). It may be speculated that a general bias toward the body centre among good heartbeat perceivers and a greater confidence in the stability of the body representation in participants with a high IS may explain these results.

Regarding IAw, the abovementioned relevance of improving meta-awareness alongside body-focused meditations becomes even more evident regarding the main findings of this paper: Neither the subjective illusion nor the proprioceptive drift showed a mere significant interaction of synchrony, time and group. Instead, for both the proprioceptive drift and the subjective illusion, a four-way interaction of synchrony, time, group, and IAw showed that a brief meditation had no direct effect on the sense of ownership. Instead, this effect depended on the level of IAw. Only subjects with higher IAw showed a stabilisation of the body representation after the meditation, as indicated by a lower subjective rubber hand illusion or proprioceptive drift. The post-hoc comparison of baseline and post-intervention RHIQ scores was significant for participants with high IAw in the meditation group. The difference between groups at post-intervention only showed a trend in the RHIQ, which might be due to the baseline differences between groups. For the proprioceptive drift, some unexpected effects were found: post-hoc tests showed that in subjects with high IAw, the control group had a smaller difference in drift between synchronous and asynchronous trials at baseline, but this difference converged to the level of the meditation group's baseline measurement at the second measurement. Although these baseline group differences only affected subjects with high IAw, they still limit the generalizability of the results.

Overall, the four-way interactions suggest that IAw plays a large role in the effectiveness of brief mindfulness meditations. Contrary to our expectation, IAw was not a mediator in this relationship, as it was not influenced by the intervention itself. Instead, our results may suggest that meta-awareness is a necessary skill to effectively enhance body awareness, which cannot be changed by short interventions. This stresses the importance of including exercises which promote one's ability to monitor mental processes, to identify and to detach from one's thoughts and the static sense of self (Hölzel et al., 2011; Kok & Singer, 2017). A study by Farb et al. (2007) investigated differences between novices and mindfulness-experienced participants regarding self-referential processing. When instructed to engage in present moment experience of the self, e.g. by concentrating on their own thoughts, emotions, and body sensations, mindfulness-experienced individuals showed higher activation in brain regions associated with a more objective analysis of interoceptive and exteroceptive sensory events, compared to novices. This more objective focus on the self might not indicate a detachment from the self as in depersonalisation (Farb et al., 2007) or a generally more plastic self (Hölzel et al., 2011), but rather an enhanced control over the weighting of interoceptive and exteroceptive information. Meta-awareness combined with attention on the body may protect the individual from outer manipulations of the sense of self by providing the individual with the ability to balance exteroceptive and interoceptive sensations. Bekrater-Bodmann et al. (2020) manipulated bodily self-location by presenting via head-mounted display either a third- or first-person perspective of oneself sitting in a chair and being touched in synchrony or asynchrony by a brush. The results of this study demonstrated that participants with a higher IAw had a lower malleability of self-location by exteroceptive input. These findings are in line with our results and emphasise the necessity to include interventions targeting IAw alongside exercises targeting body awareness to restore the balance of interoceptive and exteroceptive influences. Effectively enhancing IAw may provide a protective effect against external manipulations of the sense of self, possibly by improving the control over the weighting of interoceptive and exteroceptive information. This might be especially helpful in patient populations, e.g. in participants with strong dissociative symptoms (Bekrater-Bodmann et al., 2020; Pick et al., 2020; Schäflein et al., 2018; Sedeño et al., 2014). Overall, our results emphasise the need to expand the intervention with exercises that improve meta-awareness.

6.4.1 Limitations and Future Research

As stated above, the shortness of the intervention is the main limitation of this study. Brief interventions don't seem to impact interoceptive abilities and only have a limited influence on the sense of body ownership, which depends on trait IAw. It would therefore be interesting to investigate the effects of long-term interventions on the RHI. Besides, including exercises that promote meta-awareness would be a promising future research issue.

In addition, a replication of the study with patients suffering from clinically relevant dissociative symptoms could provide further interesting insights into the treatment of unstable self-representation, as we used a healthy sample here, which may not provide enough variance to investigate interactions with dissociative experiences appropriately.

Regarding the effect of arousal on IS, we tried to rule out that this effect was due to cardiac arousal by including the heartrate into the model. However, other measures of physiological arousal, like blood pressure need to be investigated, since systolic blood pressure in particular has been associated with increased IAc in the past (Murphy et al., 2018), possibly because of an improved detectability of the pulse.

Besides, our sample consisted of very young participants. Studies with different age cohorts showed that the RHI is rather high among this group and declines with age (Ferracci & Brancucci, 2019). Accordingly, our results may not be generalisable to older participants.

Finally, this study includes multiple self-report measures, which could cause a method bias, e.g. through certain response styles, item context, proximity, and wording, which may lead to changes in reliability and validity of the scales and may also influence the covariance of latent constructs (Podsakoff et al., 2012).

7 General Discussion

7.1 Summary

The aim of this dissertation was to investigate whether emotions change the malleability of the sense of ownership, measured using the RHI task, and whether an increase in ownership malleability depends on the amount of arousal of an emotion, on interoceptive abilities, and on dissociative symptoms. Following up on this, we posed the question whether mindfulness meditation can restore the stability of the sense of ownership.

To answer these questions, in study one, we attempted to explore whether a sadness induction using affective pictures leads to an increase in the RHI compared to no emotion induction and whether this effect depends on differences in emotion experience, such as dissociative tendencies, and the level of emotion experience that is manipulated, for example, by subliminal or supraliminal emotion induction (Schroter et al., 2021). Study two built on the findings of study one by investigating the effects of differently arousing emotion conditions (fearful, sad, or neutral vocalisations) on the sense of ownership in patients with NSSI and high vs low levels of dissociative symptoms compared to healthy control participants. Further, the moderating effects of interoceptive abilities and subjective or physiological arousal were studied (Schroter et al., under review). To provide an outlook on possible interventions, study three focused on investigating whether a 20-minute, body-focused mindfulness meditation leads to a stabilisation of the sense of ownership in terms of a decrease in RHI compared to an audiobook control group. In addition, it was investigated whether changes in the RHI were mediated by changes in interoceptive abilities and whether the change in the RHI induced by the intervention is more pronounced in participants with higher dissociative tendencies, lower meditation experience, and lower trait mindfulness (Schroter et al., 2023).

Methodologically, synchronous stimulation was compared with asynchronous stimulation in all three studies (Schroter et al., 2021; Schroter et al., under review; Schroter et al., 2023), confirming that synchronous stimulation generally led to a stronger subjective illusion and a stronger proprioceptive drift (apart from study one) compared to asynchronous stimulation. In addition, different stroking speeds (3 cm/s and 30 cm/s) were used in study one, as previous research has shown that slow affective stroking can reinforce the illusion (Crucianelli et al., 2013). In contrast to this finding, fast stroking led to a stronger subjective illusion effect compared with slow stimulation (Schroter et al., 2021).

Regarding the main objective of this dissertation, we found that the effect of emotions on the sense of ownership only applies to the subjective illusion, not to the proprioceptive drift, and is highly dependent on differences in emotion experiences. For example, the level of emotional awareness plays a role, as only supraliminal emotion induction led to a stronger subjective illusion compared to subliminal emotion induction (Schroter et al., 2021). The emotion effect depended even more on dissociative tendencies or symptoms, which may reflect detached emotion experience (Lambie & Marcel, 2002; Schroter et al., 2021; Schroter et al., 2023). In study one, the effect of supraliminal compared to subliminal sadness induction was more pronounced in healthy participants with high subclinical levels of dissociation compared to participants with lower dissociation levels. No difference was found regarding the comparison of neutral and both sadness conditions (Schroter et al., 2021).

Similar findings were obtained in study two (Schroter et al., under review). Again, no main effect of emotion condition was observed. Instead, patients in the LD group, who showed moderate dissociation levels compared to the HD and the HC group, were found to experience a stronger subjective illusion in response to fearful compared to neutral vocalisations. However, this effect could not be found in the HD group, possibly due to a ceiling effect. Data from study two further showed the highest subjective illusion levels across all conditions in the HD group, followed by the LD group and the HC group. In general, acute dissociation, particularly acute depersonalisation (study two), and trait dissociation (study one) were positively related to the subjective illusion but not to the proprioceptive drift. Furthermore, acute dissociation was related to arousal in an inverted U-shaped pattern. Also, there was no relation between the subjective illusion and subjective or physiological arousal but a negative relation between the proprioceptive drift and HR (Schroter et al., under review).

Interoceptive abilities did not modulate the emotion effect (Schroter et al., under review), and IAc was only related to the illusion intensity in study three (Schroter et al., 2023). Moreover, no group-specific changes in interoceptive abilities were caused by the mediation intervention in study three. However, IAw still played a large role in this study, as it was found that the effect of the meditation intervention on the RHI depended on IAw. Only participants with high IAw showed a stabilisation in the sense of ownership following the meditation. This interaction with IAw was found for both the subjective illusion and the proprioceptive drift. To investigate whether the intervention is particularly effective for people with strong dissociative tendencies, the moderating effect of dissociative and mindfulness traits was also examined, but no effect was found. However, a negative relation between trait mindfulness and the subjective illusion was shown (Schroter et al., 2023).

7.2 Interoception as a Linking Factor

The results of previous research indicate that interoception could be relevant to the sense of ownership (Filippetti & Tsakiris, 2017; Tsakiris et al., 2011). However, the findings on the relationship between the sense of ownership and interoceptive abilities are ambiguous: In the past, many studies investigating the relationship of cardiac IAc and the RHI reported a negative correlation between both measures (Filippetti & Tsakiris, 2017; Schroter et al., 2023; Tsakiris et al., 2011), but there have also been studies which failed to replicate the relation between IAc and the RHI strength (Crucianelli et al., 2018; Horváth et al., 2020). Similarly, study two showed no correlation between interoceptive measures and the malleability of the sense of ownership (Schroter et al., under review). Furthermore, no differences in interoceptive abilities were found between patients with high or low dissociation and no mediation effect of interoceptive abilities on the relationship between emotion and the RHI was detected (Schroter et al., under review), although connections between interoceptive abilities and dissociation (Pick et al., 2020; Schäflein et al., 2018; Sedeño et al., 2014) and emotion (Craig, 2002; Pollatos, Herbert, et al., 2007; Seth et al., 2012; Simmons et al., 2013) have been suggested in the past. A possible explanation for the inconsistency of these findings may be the role of top-down interoceptive expectations, proposed by Paulus and Stein (2010). The authors state that interoceptive beliefs may be altered in depression or anxiety. For instance, interoceptive signals may be interpreted based on a negative self-view in depression or based on the expectation of threat in anxiety disorders, leading to anticipatory biases that can result in withdrawal or avoidance behaviours. As a result, the perceived interoceptive input may be amplified or attenuated (Paulus & Stein, 2010), which can affect IAc. In line with this assumption, Pollatos, Traut-Mattausch, et al. (2007) showed that the relationship between trait anxiety and emotional arousal in response to unpleasant pictures was mediated by IAc. Hence, if interoceptive signals are interpreted based on self-beliefs and schemata (Paulus & Stein, 2010), the presentation of emotional stimuli may primarily change interoceptive expectations and only indirectly result in modified IAc. Applied to the predictive-coding approach, emotions that go along with the attenuation of internal signals may reduce the precision-weighting of interoceptive information and, in turn, lead to a higher malleability of the sense of self through exteroceptive manipulations (Bekrater-Bodmann et al., 2020; Filippetti & Tsakiris, 2017; Seth, 2013; Seth et al., 2012). Therefore, a single measurement of the HDT before emotion induction would not be sufficient to explain the relation between emotions and the sense of self. Instead, interoceptive abilities should be measured in different emotion conditions to assess changes in interoceptive signal processing in response to emotional stimuli.

Regarding dissociation, we expected deteriorated interoceptive abilities in the HD group of study two, as it has been proposed that in dissociative disorders, particularly in depersonalisation disorder, interoceptive prediction errors are suppressed (Saini et al., 2022). Consequently, an interoceptive silencing of threat information coming from the body would occur, and as a result, the sense of self would depend solely on exteroceptive information (Saini et al., 2022), which may open up possibilities for manipulating the sense of self (Bekrater-Bodmann et al., 2020). Contrary to this assumption, no group differences were detected in study two (Schroter et al., under review). In addition, Michal et al. (2014) reported no relation of IAc to depersonalisation experiences in a patient sample diagnosed with depersonalisation disorder. They further conducted a body perception questionnaire and found that body perception scores correlated with IAc but only among HC participants. They concluded that patients with depersonalisation disorder may have an intact ability to detect bodily signals (IAc) but fail to integrate these interoceptive signals into their sense of self (Michal et al., 2014). Building on the approach of Paulus and Stein (2010) and the conceptualisation by Garfinkel et al. (2015), Michal et al. (2014) state that IAw reflects the interplay between interoceptive top-down beliefs (= IS) and bottom-up interoceptive signals (= IAc; Michal et al., 2014). Based on their finding that body perception and IAc were not correlated in their patient sample, they argue that IAw may be a key factor that shapes the sense of self (Michal et al., 2014). Accordingly, in dissociation, the awareness of sensory mismatches may be down-regulated due to the suppression of interoceptive information under threat, which arises in response to the top-down belief that interoceptive signals are harmful (Paulus & Stein, 2010; Saini et al., 2022). Hence, altered interoceptive beliefs could lead to the avoidance of interoceptive information under threat. However, this assumption needs to be tested in studies that systematically investigate the influence of emotions or threats on interoceptive abilities in samples with dissociative symptoms. Solely analysing baseline differences cannot yield clarity in this context.

The view that the integration (IAw) of top-down beliefs and bottom-up signals is essential is in line with the findings of study three (Schroter et al., 2023). In this study, it was shown that only in participants with high IAw, meditation helped to stabilise the sense of self and reduce the impact of exteroceptive manipulations through the RHI procedure (Schroter et al., 2023). We concluded that this might be due to distinct precision-weighting of interoceptive and exteroceptive information. E.g., participants with strong interoceptive abilities may rely less on exteroceptive information, which could result in a lower RHI due to a stronger awareness of sensory mismatches (Bekrater-Bodmann et al., 2020; Seth, 2013; Seth et al., 2012).

7.3 Emotions and the Sense of Self

Previous research has suggested that threat and other emotions may lead to a stronger RHI compared to a neutral condition independent of dissociative symptoms (Ehrsson et al., 2007; Engelen et al., 2017; Riemer et al., 2015). However, in the experiments conducted in the scope of this dissertation no effects to support this notion were found (Schroter et al., 2021; Schroter et al., under review). Even though we followed the procedure of Engelen et al. (2017) in study two, neither the sadness nor the threat condition were associated with main effects in our data (Schroter et al., under review). Possibly, this discrepancy stems from the use of different emotions. Engelen et al. (2017) used anger and happiness, which may be tied to different attentional processes than sadness and fear. In line with this idea, a study that used heartbeat-evoked potentials to measure the interoceptive attentional focus, using a repetition suppression paradigm, found a significant repetition enhancement of the heartbeat-evoked potentials for repeating sad and painful facial expressions and a significant repetition suppression for repeating angry expressions (Marshall et al., 2018). The authors explain the increase in the heartbeat-evoked potentials as enhanced cardiac processing and cardiac learning in response to painful and sad stimuli, reflecting a greater attentional focus on the interoceptive domain. In contrast, they suggest that in response to repeating angry faces, the attentional focus is directed to the exteroceptive domain in order to prepare for action, for example, defending against an angry opponent (Marshall et al., 2018). Consequently, embodiment mechanisms may differ depending on the attentional focus with respect to the interoceptive–exteroceptive attention continuum and the resulting changes in interoceptive precision-weighting (Seth, 2013; Seth et al., 2012). Related to this, distinct approach or avoidance behaviour connected to emotions like fear and anger (Carver & Harmon-Jones, 2009) may have contributed to the inconsistency of results in this dissertation compared to the results found in the study of Engelen et al. (2017).

Anger has been proposed to lead to higher exteroceptive attention (Marshall et al., 2018) and approach behaviour (Carver & Harmon-Jones, 2009), while fear appears to be associated with withdrawal behaviour (Carver & Harmon-Jones, 2009) and with increased IAc (Pollatos, Traut-Mattausch, et al., 2007). These differences in the interoceptive–exteroceptive focus of attention and the associated behavioural activation could explain why no main effects of emotion were observed in our studies. It is possible that only emotions with a strong exteroceptive focus lead to a decrease in interoceptive precision-weighting (Seth, 2013; Seth et al., 2012) in healthy participants and, as a consequence, to an increase in the malleability of the sense of self. Different mechanisms could apply in patients with dissociation: As they may already avoid interoceptive information (Saini et al., 2022), arousing emotions like fear could amplify this avoidance effect (Paulus & Stein, 2010), further lowering interoceptive precision-weighting.

Besides, in contrast to the study of Engelen et al. (2017), adolescent participants and patients with NSSI participated in our study. Age differences may have modulated emotion effects, as it is known that emotion recognition from movements, face or vocal stimuli improves during childhood and matures only in adolescence (Grosbras et al., 2018; Meinhardt-Injac et al., 2020; Ross et al., 2012). Furthermore, patients in our sample were diagnosed with NSSI, so impaired emotion recognition is likely to be a potential interfering factor, since patients with NSSI have been shown to score high on alexithymia (Raffagnato et al., 2020), which is in turn associated with changes in the RHI (Georgiou et al., 2016; Grynberg & Pollatos, 2015). Accordingly, not all participants in study two may have reached a fully matured state of emotion recognition, which could have interfered with the expected effects. Future studies should systematically investigate the interaction effect of different stages of development with emotions on the sense of ownership.

7.3.1 Emotion Experience

Importantly, our results indicate that the mere presentation of emotional stimuli does not determine changes in body ownership. Instead, our studies suggest that various aspects of emotion experience play a role in this context (Schroter et al., 2021; Schroter et al., under review). Following the framework of emotion experience by Lambie and Marcel (2002), we can conclude that the attentional mode, which comprises immersed vs detached emotion experience, and levels of emotional awareness are at least two factors of emotion experience that may be of high relevance for ownership processes. In line with this, neurophysiological research shows that lesions in somatosensory areas, and in particular the right insular cortex, impair both emotion experience and the sense of self (Craig, 2002; Damasio, 2003). Based on these findings, Ehrsson et al. (2007, p. 9831) proposed that the "[…] feeling of ownership might necessitate the engagement of the emotional systems, or the emotional responses may be a consequence of ownership". Accordingly, the question of causality remains unclear, as emotions may lead to a higher illusion (Engelen et al., 2017), but the illusion intensity also predicts the neuronal anxiety response (Ehrsson et al., 2007). Our results contribute to this discourse in showing that individuals with different dissociative tendencies differ fundamentally in terms of their stability in the sense of self regardless of the emotional situation (Schroter et al., 2021; Schroter et al., under review). Evidence for disturbances in the sense of self in patients with dissociation also comes from a study investigating the ownership feeling of their own body areas (Löffler et al., 2020). The authors found a significantly lower feeling of ownership in patients with BPD, which is often preceded by NSSI (Reichl & Kaess, 2021), and a significant correlation between feeling lower ownership of one's own body parts and dissociative symptoms (Löffler et al., 2020). Taken together, diminished feelings of ownership over own body parts and a higher proneness to the RHI (Bekrater-Bodmann et al., 2016; Hirschmann & Lev Ari, 2016; Löffler et al., 2020; Rabellino et al., 2018) suggest a generally less stable sense of self in patients with dissociation (Bekrater-Bodmann et al., 2016). As mentioned in Section 7.2, this may be due to impaired integration of top-down expectations with bottom-up signals that shape the precision-weighting of interoceptive information (Michal et al., 2014; Paulus & Stein, 2010; Saini et al., 2022; Seth, 2013; Seth et al., 2012).

Moreover, our results show that emotions can further destabilise ownership experiences in people with an already unstable sense of self (Schroter et al., 2021; Schroter et al., under review). In this respect, the question of causality seems to be void, as emotions and the sense of self appear to influence or even amplify each other. Even though this work cannot provide a conclusive answer to questions about the development processes of the sense of self and emotions, the present results reinforce the assumption that the emotional system and the sense of self are closely intertwined (Damasio, 2003).

7.3.2 The Importance of Arousal

In our first study, we aimed to investigate whether also low-arousing emotions like sadness might influence ownership processes. However, seeing as we found no difference between a sadness condition and a neutral condition in this study, we rejected the hypothesis that this would be the case (Schroter et al., 2021). The finding from study two that a higher illusion was only found in the fear compared to the neutral condition in the LD group, and no difference between the neutral and the sadness condition emerged in this study (Schroter et al., under review), adds to the assumption that arousal or threat may indeed be the driving force behind the emotion effects established in previous works (Ehrsson et al., 2007; Engelen et al., 2017; Riemer et al., 2015). This notion is further supported by the observation that fast stimulation during the rubber hand illusion in study one led to a stronger subjective illusion than slow stimulation (Schroter et al., 2021), which contrasts the findings of Crucianelli et al. (2018), Lloyd et al. (2013), and van Stralen et al. (2014) who found a stronger illusion in response to slow affective stroking compared to fast stroking. The top-down expectation of sensory pleasure was cited as a possible explanation for this effect (Crucianelli et al., 2018). The finding that the effect was reversed in study one does not necessarily contradict this explanation. On the contrary, the setting in this study could have changed the top-down expectation through the combination with emotional stimuli (Paulus & Stein, 2010). Arousal from the picture presentation could have been intensified by the fast stimulation and evoked expectations of potential threat, leading to interoceptive avoidance (Paulus & Stein, 2010), while the slow stimulation in this setup was perceived as comforting and could, therefore, have interfered with the experimental conditions.

Overall, it can be summarised that arousal appears to play a role in the relationship between the sense of ownership and emotion experience. This is not surprising, considering existing theories of emotion. For example, Schachter and Singer's (1962) theory, which postulates that emotions arise when physical arousal is perceived, and this arousal is related to its source through cognitive attribution (Lambie & Marcel, 2002). Building upon this theory, Frijda (2005, p. 494) proposed that emotion experience "generally contains conscious reflections of the four major nonconscious components of the process of emotions: affect, appraisal, action readiness, and arousal". Thereby, arousal shapes the intensity of an experienced emotion (Lambie & Marcel, 2002) and is, therefore, of central importance to the process of emotion experience.

7.4 The Role of Dissociation and Bodily Defence

The findings on the relation of arousal and sense of ownership changes show that results are partly contradictory. Some findings indicate a positive relation (Riemer et al., 2015), while others suggest a negative relation (Romano et al., 2014) between both variables. Additionally, sometimes results refer to the proprioceptive drift and other times to the subjective illusion. For instance, while in the studies conducted in the scope of this dissertation, only effects of the emotion condition on the subjective illusion were observed (Schroter et al., 2021; Schroter et al., under review), Engelen et al. (2017) only found effects on the drift.

The reason for these contradictory results may be that the relationship between arousal and ownership variables is not linear and that the RHIQ and the proprioceptive drift measure different aspects of the illusion. With regard to dissociation, the defence cascade model suggests that arousal initially increases at low levels of dissociation and, after a certain threshold is exceeded, an arousal shutdown occurs, which reduces the fight or flight probability together with physical and subjective arousal experience again (Danböck et al., 2024; Kozlowska et al., 2015; Lanius et al., 2018; Schauer & Elbert, 2010). This inversely U-shaped relation between arousal and acute dissociation was found in study two, as well (Schroter et al., under review). Also, a linear relation between acute dissociation and the RHIQ was found, whereas no relation between acute dissociation and the drift was detected, but a linear negative relation of the drift with arousal. Hence, we concluded that the RHIQ might rather be a direct correlate of dissociation than of arousal. Consequently, a non-linear, inversely U-shaped relation of the RHIQ to arousal is possible and should be investigated in future studies. Transferred to the predictive coding approach, we propose that interoceptive precision-weighting (Seth, 2013; Seth et al., 2012) changes along the defence cascade as follows: During the initial freezing or orienting response (Lanius et al., 2018), the attentional focus may be oriented outwards toward the opponent, attenuating the processing of interoceptive signals. Later, when the individual enters the fight or flight stage, defence mechanisms are activated (Lanius et al., 2018; Schauer & Elbert, 2010). To allow for efficient activation of the sympathetic nervous system (Schauer & Elbert, 2010), interoceptive beliefs, such as "I can fight or flee", are effectively integrated with interoceptive signals, for example muscle tension (Michal et al., 2014; Paulus & Stein, 2010). As soon as the interoceptive belief enters a stage where defence probability is rated low (Lanius et al., 2018), interoceptive signals are attenuated due to the expectation of harm (Saini et al., 2022), leading to impaired speech and motor commands (Lanius et al., 2018; Schauer & Elbert, 2010), and open up to exteroceptive manipulations (Bekrater-Bodmann et al., 2020; Saini et al., 2022), such as the RHI.

7.4.1 Dissociation and Defence Mechanisms in Patients with NSSI

In contrast to the RHIQ, the proprioceptive drift, did show a linear relation with arousal, indicating that the drift may be more involved in fight or flight behaviour. As displayed in Section 2.3.2.2, bodily defence involves the extension of the protective peripersonal space of the body, which represents an area allowing for automatic defensive behaviour (de Vignemont & Iannetti, 2015). Also, Rabellino et al. (2020) argued that the size and the flexibility of the peripersonal space depend on the level of dissociation. Based on these findings, the negative relation of HR and the proprioceptive drift, and the higher drift in the LD compared to the HD group, may be explained as followed: Patients with NSSI may have a more flexible peripersonal space which becomes more rigid (resulting in a lower drift) when the defence system (indicated by elevated HR) is successfully activated, whereas in a state of defence system shutdown the flexibility may increase and a larger drift may result. As the HD group displayed a higher mean HR, the lower drift may speak for a successful sharpening of body boundaries in this group (Schroter et al., under review). Consistently, the proprioceptive drift has previously been found to be correlated with changes in the peripersonal space, as shown by shifts toward the fake hand in a landmark task (Milner et al., 1993), where subjects were instructed to decide whether a vertical line was right or left of a screen centre (Smit et al., 2023). Moreover, the proprioceptive drift has been shown to be greater in participants with lower harm avoidance tendencies (Kállai et al., 2015). In line with this, NSSI frequency was negatively correlated with mature defence mechanisms (Peng et al., 2023). Consequently, patients with NSSI appear to have difficulties applying efficient defence mechanisms. They may instead react with dissociation, which can be regarded as an immature defence mechanism (Andrews et al., 1989; Peng et al., 2023), resulting in an unstable sense of self and a higher subjective RHI. If they still manage to activate adaptive defence mechanisms, they may show a reduced proprioceptive drift, possibly reflecting stabilised body boundaries.

Furthermore, it is unclear whether the relationship between dissociation and the sense of self discovered in study two is specific to the adolescent patient group with NSSI. A recent publication also investigated the expression of RHI in patients with NSSI but in adult women (Fust et al., 2024). They found no differences between 41 women with NSSI compared to 40 female healthy control participants and did not replicate the previously discovered relation between dissociative traits and the RHI (e.g. Bekrater-Bodmann et al., 2016). It remains open whether these contradictory findings were due to different procedures, different developmental stages (Ferracci & Brancucci, 2019; Marotta et al., 2018), or the division into high and low dissociation in study two of this dissertation (Schroter et al., under review).

As stated before, NSSI can have different functions: It may, for instance, help alleviate negative feelings or disrupt dissociative states (Klonsky, 2007; Koenig et al., 2017). Furthermore, a meta-analysis (Calati et al., 2017) and a review (Ford & Gómez, 2015) on the relationship between NSSI and dissociation both suggested considering a dissociative subtype in patients with NSSI. Ford and Gómez (2015) justify this claim by citing studies showing that patients with NSSI differ in their perception of pain and their dissociative tendency: For instance, Russ et al. (1993) divided their sample into patients who experience pain during self-injury and those who do not and showed that the second group displayed higher levels of dissociation. Hence, by dissociating, some patients with NSSI may be able to cope with distress and reach a state of analgesia, a symptom that can be categorised as somatoform dissociation, which can arise in response to threat (Ford & Gómez, 2015; Nijenhuis, 2001). This may also be the process underlying the RHI: In the study of Romano et al. (2014), self-identification with an avatar during painful stimulation of the participant's hand with a needle was negatively related to skin conductance responses. Their results indicate that identification with an avatar can trigger analgesia, supporting the claim that the malleability of the sense of self may reflect a dissociative response to pain or threat.

7.4.2 Non-Pathological Aspects of Dissociation and Sense of Ownership Malleability

Dissociation can arise as a result of disruptions in the integration of behavioural states throughout development (Putnam, 1997), which can be caused by trauma or neglect (Brunner et al., 2000; Vonderlin et al., 2018), resulting in high emotional activation, blocking, or punishment of emotion expression or the failure to attain the emotional purpose (Carlson et al., 2009). Thereby, clinicians often argue that dissociation can protect the individual from traumatic stress (Bremner & Brett, 1997) by applying a different information processing style (Barlow & Freyd, 2009). It has been found that words and pictures that relate to a traumatic event were less likely to be remembered, reaction time for threat words was lower, verbal working memory capacity was higher, cognitive inhibition to negative words was reduced, and integration of sensory information into autobiographical memory was reduced in patients with high dissociation levels (Barlow & Freyd, 2009). The *betrayal trauma theory* rationalises this modified information processing by arguing that in children who are abused by their caregivers memories related to the trauma are suppressed so the relationship, on which they are inherently very dependent, can be maintained and survival is ensured (Barlow & Freyd, 2009; Freyd, 1994). Accordingly, some researchers suggest that dissociation can help cope with trauma in the short-term, while in the long-term, it may lead to psychopathology (Bremner & Brett, 1997; Lynn, 2005). Since dissociation is often considered along a continuum between pathological and non-pathological levels (Spiegel et al., 2011), one can argued that dissociation can also have functional aspects. Along the same lines, it can be claimed that an increased malleability of the sense of ownership does not necessarily have to be negative. For example, a stronger RHI has been found to be related to higher self-esteem and empathy (Asai et al., 2011; Romano et al., 2021); specifically in terms of the ability to take a different perspective (Romano et al., 2021). Applying pain stimuli to the rubber hand resulted in higher pain ratings and higher illusion scores in participants with higher empathy (Seiryte & Rusconi, 2015). Moreover, the virtual hand ownership illusion has been found to be connected to creativity: In a study where convergent (problem solving) and divergent (searching for multiple possible solutions) thinking tasks were applied in combination with a virtual hand illusion task, the divergent thinking condition led to a stronger illusion in the synchronous condition, suggesting that flexibility is associated with the malleability of the sense of self (Ma & Hommel, 2020). Creativity is also often placed on the continuum of dissociative experiences (Lynn, 2005). These findings show that a flexible sense of self does not always have to be a disadvantage and is not necessarily associated with pathology. Instead, the malleability of the sense of self may also range along a continuum from non-pathological to pathological. However, it appears challenging to define a cut-off to determine what constitutes pathological malleability. Schauer and Elbert (2010) suggested that preventing a defence system shutdown during exposure therapy would facilitate the therapy process and lead to a reduction of dissociative experiences in daily life. Hence, ownership malleability may be, to some degree, adaptive as long as the defence system is functional. Therefore, investigating changes in ownership along the defence cascade would be very insightful for understanding the underlying processes of dissociation and identifying potential treatment approaches.

7.5 Mindfulness and Other Potential Interventions

Schauer and Elbert (2010) proposed specific therapeutic interventions for patients who experience a defence system shutdown. These include interventions for sensory and motor afferents, emotion- and language-processing, as well as nutritional demands, e.g. by focusing on the present moment, including sensations or muscle activations, and allowing the expression of emotions (Schauer & Elbert, 2010). This approach is reminiscent of the grounding function of mindfulness interventions, on the basis of which the rationale of study three, regarding stabilisation of the sense of self through meditation, was developed (Schroter et al., 2023). Results of this study showed that only participants with a high level of IAw showed a reduction in the RHI following a short meditation intervention. Also, the results of Bekrater-Bodmann et al. (2020) mirror our findings in showing that IAw leads to a lower malleability of bodily self-location in a third-person perspective scenario. Based on their results and interpretations, we concluded that interoceptive meta-awareness may provide a protective effect against external manipulations of the sense of self (Bekrater-Bodmann et al., 2020), potentially through greater control over the weighting of interoceptive and exteroceptive information (Saini et al., 2022; Seth, 2013; Seth et al., 2012). These findings imply that first, short-term interventions may not be very effective in stabilising the sense of self in participants with low levels of IAw, and second, interventions may be necessary to improve IAw and, consequently, the sense of ownership.

However, specific mindfulness interventions for IAw still need to be developed, as past research has mainly focused on studying the effects on IAc and IS (Bornemann & Singer, 2017; Fischer et al., 2017; Mirams et al., 2013; Treves et al., 2019). In a study by Parkin et al. (2014), the effects of a short one-week mindfulness intervention or an eight-week MBSR or MBCT course on IAw were investigated, showing no effect. Garfinkel et al. (2015) refer to IAw as metacognitive awareness over one's own interoceptive abilities, which would suggest that training in metacognitive abilities may be essential for improving IAw. This is in line with Hölzel et al. (2011), who suggest that meta-awareness is necessary to enable a transitory instead of a static sense of self: "[…] the process of a repeatedly arising sense of self becomes observable to the meditator through development of meta-awareness" (Hölzel et al., 2011, p. 547). In this way, interoceptive beliefs may be modified (Paulus & Stein, 2010), and the individual can hereby become an observer of their own sense of self, allowing more control over exteroceptive manipulations of the sense of self (Bekrater-Bodmann et al., 2020; Hölzel et al., 2011). Interventions like metacognitive training (Wells, 2011) or mindfulness meditations (Kabat-Zinn, 2013; Segal et al., 2018), like observing-thought meditation (Kok & Singer, 2017), may be required to improve interoceptive beliefs and, in consequence also interoceptive meta-awareness.

Through mindfulness interventions, patients with dissociative symptoms who are likely to avoid interoceptive sensations (Saini et al., 2022) due to maladaptive interoceptive beliefs (Paulus & Stein, 2010) can learn that signals coming from the body may not necessarily be harmful, but can be observed in a non-judgemental way (Kabat-Zinn, 2013). By reducing the interoceptive avoidance, the integration of interoceptive signals into the sense of self (IAw) can be restored (Michal et al., 2014). Consistently, D'Antoni et al. (2022) showed that interoceptive beliefs (like worrying about body sensations and the avoidance of listening to body signals) could be improved through seven weeks mindfulness training and that increased mindfulness further led to a reduction in dissociative tendencies.

Further indications for the effectiveness of mindfulness interventions on the maintenance of a stable sense of self under emotional conditions come from a study by Farb et al. (2010). The authors conducted a study in which participants watched a sad and neutral film before and after undergoing a mindfulness (MBSR) intervention or a waitlist condition. Neuroimaging results showed that participants in the mindfulness group showed lower activation in regions associated with self-referential processing and a reduced deactivation of the insular region during the film. The authors interpret their findings as improved IAw contributing to more effective emotion regulation strategies (Farb et al., 2010).

In addition to improving interoceptive meta-awareness, it appears necessary to perform meditation or similar exercises to stabilise the sense of ownership (Schroter et al., 2023). But what are the underlying mechanisms of meditation operating here? Since no improvement has been shown in cardiac IAc following the mediation (Schroter et al., 2023), other mechanisms seem to be decisive. Desmedt, Luminet, Maurage, and Corneilles (2023) suggested that other interoceptive domains should also be considered, such as the domain of interoceptive attention. The meditation intervention of study three involved focusing on the body, and in particular on the hands, indicating that attention may be drawn to the interoceptive domain. A study by Farb et al. (2013b) demonstrated that an eight-week MBSR course led to greater functional plasticity in the insular cortex, as well as enhanced connectivity between posterior and anterior parts of the insula and generally higher activation in the anterior insula, which was previously identified as a key neural region for interoceptive processing (Craig, 2002), indicating that mindfulness interventions may increase interoceptive attention (Farb et al., 2013b). They also found a lower breathing frequency and greater respiratory volume in an interoceptive attention task (focus on breathing) compared to an exteroceptive attention task (focus on word stimuli) in the MBSR compared to a waitlist control group (Farb et al., 2013b). These results indicate that mindfulness meditation may not necessarily promote interoceptive performance accuracy but that it could at least direct attention to the interoceptive domain (Farb et al., 2013b). This also fits in with existing conceptualisations of mindfulness and meditation, which identify attention meditation as an important component for training the perception of sensory stimuli (Bornemann & Singer, 2017; Dahl et al., 2015). This raises the question whether IAw, in combination with interoceptive attention, determines stabilisation in the sense of ownership. To get to the bottom of this question, further studies should systematically investigate the role of interoceptive attention in the context of the RHI.

Moreover, patients with interoceptive beliefs like “attending to my body means experiencing pain or harm” may not be able to observe their body signals in a non-judgmental way but instead may experience anxiety or distress when directing attention to interoceptive signals, possibly triggering dissociative reactions. Consequently, it appears essential to change interoceptive beliefs so the individual becomes able to attend to bodily sensations without evaluating them as dangerous and consequently may finally be able to integrate them into the sense of self.

Next to mindfulness interventions, this may be achieved by exposing the individual to interoceptive sensations that usually elicit anxiety through harmless exercises, such as physical activity (Sabourin et al., 2008). As the *transient hypofrontality theory* suggests, physical activity leads to neuronal activation in areas important for motor control, autonomic regulation, and perception of sensory input, and to a decrease of activation in areas related to cognitive and emotional processes, such as the prefrontal cortex (Dietrich, 2006). Besides, physical activity, such as cycling, has been found to lead to increased cerebral blood flow in the left insular cortex (Williamson et al., 1997), supporting the notion that interoceptive attention is increased during physical activity. There are studies on the sense of self that also show correlations with activities that are associated with increased importance of motor- and somatosensory functions in the own hand (Pyasik et al., 2019): For example, experienced badminton players had a lower RHI compared to players with less experience (Sakamoto & Ifuku, 2022). Moreover, expert pianists showed a much smaller subjective illusion and proprioceptive drift compared to non-musicians (Pyasik et al., 2019). The authors explain their findings as reduced visual dominance in favour of tactile and proprioceptive sensory discriminability since pianists were also found to be superior in tactile spatial acuity tasks (Hosoda & Furuya, 2016; Pyasik et al., 2019).

Accordingly, one may speculate that simultaneous training of meta-cognitive skills and interventions that increase the interoceptive focus may induce a change in multisensory integration and thus weaken the influence of visual-exteroceptive information on the sense of self. However, further studies are required to determine how integral the role of interoceptive attention actually is for the sense of ownership and whether physical activity can be as effective as meditation in directing attentional focus to internal bodily processes.

7.6 Limitations

The use of the HDT can be considered one limitation of this dissertation. Several weaknesses of the HDT have been pointed out, and the question of whether the HDT is a sufficient measure for interoceptive abilities has been discussed in the past. Validity concerns have been raised, as participants tend to underestimate their HR during the HDT, correlations between actual and counted HR were found to be rather low, and the IAc appears to decrease in longer time intervals (Corneille et al., 2020). Besides, under the original task instructions, HR counting correlated with time estimation tasks and participants' knowledge about their own HR, indicating that participants may guess based on counting seconds (Desmedt et al., 2020). However, we used the adapted instructions of Desmedt et al. (2020) in our tasks, which emphasise the importance of not guessing and encourage participants to report only the real number of felt heartbeats. Under adapted instructions, no correlation between HR knowledge and time estimation was found in the study of Desmedt et al. (2020). Furthermore, in a study by Crucianelli et al. (2022), the relation of different submodalities of interoception was studied, showing no correlations between cardiac awareness, thermo-sensation, affective touch, and nociception, apart from the cold temperature and pain conditions. Hence, Crucianelli et al. (2022) claim that interoceptive abilities should be assessed by using a battery of tests that cover multiple submodalities of interoception. Further criticism comes from Desmedt, Luminet, Maurage, and Corneille (2023), who argue that a more comprehensive conceptualisation of interoception, which includes the measurement of a variety of interoceptive dimensions, is required. So far, research has mainly focused on studying interoceptive detection abilities and has vastly neglected other interoceptive dimensions, such as interoceptive attention (Desmedt, Luminet, Maurage, & Corneille, 2023). Building on the eight interoceptive features (attention, detection, magnitude, discrimination, accuracy, insight, sensibility, and self-report) proposed by Khalsa et al. (2018) and the three dimensions (IAc, IS, and IAw) suggested by Garfinkel et al. (2015), Desmedt, Luminet, Maurage, and Corneille (2023) present their factor model of interoception, which distinguishes the factors interoceptive attention (attention to internal signals), interoceptive sensing (conscious or unconscious sensing of internal signals), interoceptive interpretation (beliefs and attitudes), and interoceptive memory (sensory or pain related memories). Based on this conceptualisation, the authors call for the development of psychometrical instruments to quantify the individual factors and subfactors (Desmedt, Luminet, Maurage, & Corneille, 2023) and to move on from measuring mainly IAc to assessing multiple dimensions of interoception (Desmedt, Luminet, Walentynowicz, & Corneille, 2023). Transferred to the studies conducted in the scope of this dissertation, validity-, modality-, and factor-related limitations suggest that the role of interoception cannot yet be fully clarified. Based on the results presented here, conclusions can only be drawn about the cardiological interoceptive accuracy, sensibility, and awareness. Beyond that, studying further interoceptive modalities, such as tactile, pain, or temperature discrimination (Crucianelli et al., 2022) in the hand region and the assessment of additional interoceptive factors, such as interoceptive attention (Desmedt, Luminet, Maurage, & Corneille, 2023), may provide a more comprehensive picture.

A further limitation stems from the use of samples of undergraduate students enrolled in the Applied Movement Science program in studies one and three (Schroter et al., 2021; Schroter et al., 2023). One may speculate that the majority of such samples is physically more active than the average student population. As Section 7.5 shows, exercise is associated with a more stable sense of ownership (Sakamoto & Ifuku, 2022), which may have limited the variance in our samples. Also, both study populations were mostly comprised of participants in their early twenties, which is an age range where an especially pronounced subjective illusion has been shown (Ferracci & Brancucci, 2019; Marotta et al., 2018). Together with study two, which was conducted with adolescent patients and participants (Schroter et al., under review), all three samples were rather young, restricting the findings to similar age groups. In the long run, investigating emotion effects in older populations would enable higher generalisability, as emotion processing varies depending on age (Grosbras et al., 2018; Meinhardt-Injac et al., 2020; Ross et al., 2012).

Furthermore, the studies presented here rely partly on self-report measures, such as the RHIQ, mindfulness measures, and dissociative symptom questionnaires. Self-report measures come along with certain risks of bias, including acquiescence (agreement) or disacquiescence (disagreement) biases, extreme or midpoint response biases, social desirability effects, proximity of items bias, wording (e.g. ambiguity) and context (e.g. item order) effects, biases related to intellectual abilities and motivation, and many others, that may also influence reliability and construct validity and accordingly may change the relation to other variables (Podsakoff et al., 2012).

Another point to consider is the choice of the experimental design. While in the first study, the emotion condition factor was between-subjects, we chose a within-subjects paradigm for the factor emotion condition in study two. This limits the comparability of results, as different designs can yield vastly different results (Charness et al., 2012). While demand effects and confounds (e.g. condition order) play a larger role in within designs, they also come along with large advantages: For example, internal validity is usually better, as they do not depend on randomisation, and statistical power is higher than in between-subjects designs, which often produce noisy results (Charness et al., 2012). However, the largest advantage of between-subjects designs is that no carry-over effects from other experimental conditions can occur (Charness et al., 2012). Hence, both designs provide several advantages and disadvantages. The finding that the results in both studies point in a similar direction may also indicate that the use of different designs may be a strength in terms of the reliability of the results. However, in experiment one, other conditions were varied within-subject, e.g. stroking speed (Schroter et al., 2021). This could have interfered with emotion induction (Riemer et al., 2019), as stroking speed itself has affective components (Crucianelli et al., 2018). Statistically, it is not possible to disentangle these effects, which is why it would be advisable to investigate both effects separately in future designs.

Another limitation concerns the different emotion induction techniques applied in studies one and three. As we used emotional picture presentations prior to the RHI in study one (Schroter et al., 2021) and affective vocalisations presented simultaneously with the RHI in study two (Schroter et al., under review), the comparability of the results of both studies is limited. Besides, the IAPS is a tool designed for emotion induction (Lang et al., 2008), whereas the Montreal Affective Voices Database was originally designed to study auditory emotion categorisation (Belin et al., 2008). However, fearful vocalisations have been shown to induce higher arousal in healthy controls (Rubin & Telch, 2021) compared to patients with PTSD and have led to more NSCR in study two (Schroter et al., under review). Nonetheless, a more fine-grained differentiation of the emotional processes regarding self-related and other-related emotions would provide a better understanding of the involvement of the sense of self in dissociation and the defence system.

7.7 Outlook

With regard to the lack of differentiation between one's own emotions and the emotions of others, it would be useful to examine these in direct comparison in relation to the sense of ownership. E.g. it has been shown that self-threat (simulated blood-giving procedure with a syringe on the own arm) vs other threat (same procedure applied to another person seated beside or opposite to the participant) led to varying NSCR frequency at different levels of depersonalisation or derealisation symptoms (Dewe et al., 2018): The experience of depersonalisation was negatively associated with NSCR during self-threat, whereas the experience of derealisation was negatively associated with NSCR during other-threat (Dewe et al., 2018). As an explanation, the authors propose altered attention processes with regard to interoceptive and exteroceptive attention allocation in combination with suppressed emotion processing (Dewe et al., 2018). Therefore, it appears promising to investigate the effects of techniques that target the biographical relevance of emotional stimuli, such as autobiographic recall (Mills & D'Mello, 2014) or trauma script-imagery (Danböck et al., 2024; Lanius et al., 2007) in comparison to the effects of emotional expressions of others. This distinction is particularly relevant in the clinical context, as the processing of fear stimuli in relation to one's own biography without experiencing defence shutdown is a large challenge in therapy with PTSD patients experiencing dissociative symptoms (Schauer & Elbert, 2010).

In addition, the findings of Dewe et al. (2018) show an arousal shutdown in relation to depersonalisation and derealisation. In light of the findings of study two, where dissociation was positively related to the RHIQ, and arousal was negatively related to the proprioceptive drift (Schroter et al., under review), the question arises how a threat to either the own body or the rubber hand would affect the sense of self and the drift in relation to depersonalisation or derealisation experiences. Further, applying an additional measure for assessing the protective peripersonal space (de Vignemont & Iannetti, 2015; Rabellino et al., 2020), for example, the landmark task (Milner et al., 1993), which was used in the study of Smit et al. (2023), would provide further insight into the activation or shutdown of the defence system accompanying ownership changes.

Moreover, based on the suggestion of Dewe et al. (2018) that interoceptive–exteroceptive attention allocation may determine the self–other distinction in emotional contexts, it appears sensible to include measures of interoceptive and exteroceptive attention (Desmedt, Luminet, Maurage, & Corneille, 2023) to improve our understanding of the relation between emotions and the sense of self. For instance, it has been found that one correlate of interoceptive attention is the neural processing of the heartbeat, which can be assessed by measuring heartbeat-evoked potentials that arise around 200 to 500 ms following an R wave in the EEG (Coll et al., 2021; Pollatos & Schandry, 2004). Petzschner et al. (2019) demonstrated that in a task where participants should either focus on their heartbeat or on a white noise sound, heartbeat-evoked potentials amplitude was significantly higher in the heart condition compared to the sound condition, emphasising the relation of the heartbeat-evoked potentials with the attentional focus. Accordingly, the heartbeat-evoked potentials may be useful as an online indicator of interoceptive vs exteroceptive attention allocation during the RHI procedure. First evidence comes from a study by Park et al. (2016), who found that lower negative heartbeat-evoked potentials in the posterior cingulate cortex correlated with the subjective illusion strength in a virtual full-body illusion, possibly due to a higher attentional resource allocation on exteroceptive visual information, which may lead to a higher exteroceptive precision-weighting (Seth, 2013) and, therefore, updating of the internal self-representation. This finding suggests that investigating factors like interoceptive attention could improve our understanding of the relation between interoception and the sense of body ownership. With regard to the results of this dissertation, the effects of emotions or meditation interventions may be better explained by interoceptive attention or interoceptive abilities in other modalities, raising the need for further research in this area.

Another interesting area of research is the investigation of disembodiment. As Löffler et al. (2020) showed, patients with dissociative symptoms had a lower ownership experience with regard to their own bodies. Therefore, it would be interesting to study this in relation to the embodiment of artificial limbs or a virtual body. In addition, few studies have examined disembodiment of the rubber hand after discontinuation of stimulation as of yet. Pfister et al. (2021) conducted a moving RHI task where participants were asked to tap their finger while watching the same tapping movement on the rubber hand for two minutes. Afterwards, participants were instructed to either continue tapping, stop tapping and only watch the rubber hand, or the rubber hand was hit by a hammer and tapping was stopped. Embodiment was assessed every 30 s throughout both phases. Their data showed that embodiment continued in the first condition, gradually faded out in the watch-only condition, and instant disembodiment occurred in the hammer condition (Pfister et al., 2021). Accordingly, disembodiment is dependent on the continuation of the different sensory stimulations. As patients with dissociative symptoms appear to be more vulnerable to exteroceptive manipulations of the sense of self (Bekrater-Bodmann et al., 2016; Saini et al., 2022), it is questionable whether disembodiment would occur in the same way as with healthy participants or whether it would occur faster (e.g. due to a less stable sense of self) or slower (e.g. due to a lack of control over exteroceptive–interoceptive attention allocation).

Furthermore, in light of the absence of differences between women with NSSI and healthy controls in the study of Fust et al. (2024), our results support the call to introduce a dissociative subtype of NSSI (Ford & Gómez, 2015; see Section 7.4.1). Similarly, a study by Möller et al. (2020) failed to replicate the RHIQ differences between patients with BPD and healthy controls found in the study by Bekrater-Bodmann et al. (2016). One possible explanation for these contrasting findings would be that Fust et al. (2024) and Möller et al. (2020) did not distinguish between patients with a strong tendency to dissociate and patients with a lesser tendency to dissociate. Rabellino et al. (2018) did this with patients with PTSD and showed that those with a tendency to dissociate experienced a stronger RHI, while those without a tendency to dissociate experienced a weaker RHI compared to the healthy control sample. Hence, the level of dissociation seems to be crucial to the malleability of the sense of self. This further implies that different defence mechanisms are employed in dissociative vs non-dissociative subtypes of psychological disoreders (Peng et al., 2023; Rabellino et al., 2020). Discussions regarding a dissociative subtype already existed in the past for PTSD (Wolf et al., 2012), which led to the inclusion of the dissociative subtype in the *DSM-V* (American Psychiatric Association, 2013). Based on the considerations presented in this section, future research on mental disorders should generally pay closer attention to the presence of dissociative symptoms. It may be advisable to differentiate between dissociative and non-dissociative subtypes in other disorders, as well, as it appears helpful to know about the dominating coping and defence strategies in the conceptualisation of treatments (Schauer & Elbert, 2010).

Finally, and taking these considerations a step further, it would be interesting to investigate the effects of already existing therapeutic approaches on the sense of self. As suggested in Section 7.5, a combination of meta-cognitive exercises and exercises that promote interoceptive attention seems advisable. Certain psychotherapeutic approaches such as DBT, ACT, MBSR, and MBCT combine these facets already (Hayes et al., 2006; Kabat-Zinn, 2013; Linehan & Wilks, 2015; Segal et al., 2018), suggesting that future research should investigate the effects of these therapies on the sense of self. This could help us to better understand the underlying mechanisms of existing therapies. Besides, our results are restricted by the fact that the meditation intervention in study three was only applied to healthy participants and was rather short (Schroter et al., 2023). Hence, to transfer the effects to patients with dissociative symptoms, randomised controlled studies with clinical samples are vital.

7.8 Implications and Conclusions

The results of this dissertation imply that the sense of self is closely linked to the emotional system. Individual differences in the experience of emotions play a particularly important role here

(Lambie & Marcel, 2002): The level of emotion experience (subliminal or supraliminal) can determine the effect of emotions, but above all, the level of detachment proved to be a decisive factor (Schroter et al., 2021; Schroter et al., under review). People who are prone to dissociation, especially those who experience depersonalisation, seem to have a more unstable sense of self, which is destabilised even more in emotional situations (Schroter et al., under review). The intensity of an experienced emotion is determined by arousal (Lambie & Marcel, 2002). Therefore, it is not surprising that detachment from the body, reflected by a stronger RHI, occurs especially in response to highly arousing emotions (Schroter et al., under review). Accordingly, the stability of the sense of self is especially endangered in stressful or threatening situations.

Transferred to the original theories explaining the RHI paradigm, the finding that emotion conditions led to a higher malleability of the sense of ownership in participants with higher dissociation levels makes a merely bottom-up-based mechanism (Botvinick & Cohen, 1998) appear unlikely (Braun et al., 2018). Instead, the predictive coding theory offers a more coherent explanatory approach (Seth, 2013; Seth et al., 2012): The emotional conditions in study two and three may have changed the top-down interoceptive expectations (Paulus & Stein, 2010) in participants with interoception-avoiding, dissociative traits (Saini et al., 2022), possibly amplifying the avoidance tendency. Hence, interoceptive precision-weighting is reduced, and participants become more vulnerable to exteroceptive manipulations of the sense of self (Bekrater-Bodmann et al., 2020; Filippetti & Tsakiris, 2017; Seth, 2013; Seth et al., 2012).

Another implication that can be drawn from study two is that the two measures of the RHI, which capture the subjective ownership experience on the one hand and proprioceptive drift on the other, appear to be related to different coping mechanisms for emotions (Schroter et al., under review). While the subjective illusion is strongly linked to the experience of dissociation, the proprioceptive drift shows connections to physiological arousal (Schroter et al., under review) and, thus, possibly to a more mature part of the defence system (Peng et al., 2023; Rabellino et al., 2020). Therfore, it appears to be sensible to assess both aspects of ownership to get a better understanding of the emotion effects on the sense of self. Accordingly, additional measures of defence strategies (Andrews et al., 1989) or accompanying measures of physiological changes (Schauer & Elbert, 2010) and changes in the peripersonal space (Rabellino et al., 2020; Smit et al., 2023) may be insightful in future designs, as well.

Just as dissociation can have non-pathological aspects, so may a higher malleability in the sense of self not necessarily be negative. In fact, it can be related to higher creativity, empathy, and self-esteem (Asai et al., 2011; Ma & Hommel, 2020; Romano et al., 2021). In the short-term, dissociation can protect against stress (Bremner & Brett, 1997; Lynn, 2005), but in the long-term, it can prevent trauma-associated or fear-related issues from being addressed effectively in therapy (Schauer & Elbert, 2010). To prevent these shutdowns, therapeutic approaches that stabilise the sense of self are deemed particularly useful. We extended past findings on mindfulness and the sense of ownership by showing that the stabilisation of the sense of self depends on two factors: Firstly, individuals need good interoceptive meta-awareness, which may be promoted through interventions like meta-cognitive therapy or specific meditation exercises that improve interoceptive beliefs (Kok & Singer, 2017; Paulus & Stein, 2010; Wells, 2011) and secondly, attention to internal bodily processes must be established (Schroter et al., 2023), e.g. through body scan, breathing exercises (Farb et al., 2013b; Schroter et al., 2023), or similar body-focused or physical exercise interventions (Amaya et al., 2021; Fischer et al., 2017; Mölbert et al., 2016). Improving IAw may enable the integration of bottom-up signals and top-down beliefs (Michal et al., 2014) and may consequently lead to a lower dependence on exteroceptive information (Bekrater-Bodmann et al., 2020), resulting in a lower proneness to the RHI.

In the context of these considerations, the large role of interoceptive processes becomes apparent. The investigation of IAw opens up a completely new field of interoception research, which should be explored even more thoroughly in the future by opening up further interoceptive domains, such as interoceptive attention (Desmedt, Luminet, Maurage, & Corneille, 2023).

In conclusion, this dissertation demonstrates that detached emotion experience is a predictor of the stability of the sense of self. Particularly in individuals with dissociative experiences, the sense of self is especially prone to exteroceptive manipulations, and this vulnerability can even be amplified by arousing emotions. These results add to the understanding of the underlying mechanisms of dissociation and of the interplay of the emotional system with the sense of self. They stress the impeding role of dissociation in therapy and provide encouragement for the evaluation of potential interventions. The effects of meditation intervention in interaction with IAw leads to the conclusion that the training of interoceptive meta-awareness may improve control over the weighting of exteroceptive and interoceptive information, and, accordingly, appears to be vital for the stabilisation of ownership processes. This has important implications for the therapy of patients with dissociative symptoms and should, therefore, be considered in clinical practice when developing new treatment approaches.

8 Declarations

8.1 Compliance with Ethical Standards

The presented studies were approved by the ethical committee of the University of Regensburg (study one: 18–1204–101, study two: 21–2746–101, study three: 20–1651–101). All procedures were conducted in accordance with the 1964 Declaration of Helsinki and its later amendments (World Medical Association, 2013). Participants (and their legal representatives) gave their written informed consent for participation and publication of the anonymised results in advance to the experiment.

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8.3 Open Research Practices

Data and code affiliated with this thesis can be accessed at the Open Science Framework (OSF) at https://osf.io/smrb4/ (study one), https://osf.io/t8jne/ (study two), https://osf.io/c4sf8/ (study three). Study one was not preregistered, the second study was registered at the onset of participant enrolment at the German Clinical Trial Register (DRKS: https://drks.de/search/de/trial/DRKS00029131), and the third study was preregistered at OSF (https://osf.io/6dvh5).

8.4 Conflict of Interests

There were no conflicts of interests to disclose for the studies conducted in the scope of this thesis.

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Appendix A

Table A1

RHI Questionnaire Translation Used in Study One

German translation	Original items of Botvinick and Cohen (1998)
1. Es schien so, als würde ich die Berührung des Pinsels dort fühlen wo sich die Gummihand befand.	1. it seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.
1. Es schien so, als ob die Berührung, die ich empfand, durch das Streicheln der Gummihand entstehen würde.	2. It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.
2. Es fühlte sich so an, als ob die Gummihand meine eigene Hand wäre.	3. I felt as if the rubber hand were my hand.
3. Es fühlte sich so an, als ob sich meine eigene Hand nach rechts (in Richtung der Gummihand) bewegen würde.	4. I felt as if my (real) hand were drifting towards the right (towards the rubber hand).
4. Es fühlte sich so an, als ob ich mehr als eine linke Hand/Arm hätte.	5. It seemed as if I might have more than one left hand or arm.
5. Es fühlte sich so an, als ob die Berührung, die ich empfand von einer Stelle zwischen meiner realen Hand und der Gummihand herkam.	6. It seemed as if the touch I was feeling came from somewhere between my own hand and the rubbser hand.
6. Es fühlte sich so an, als ob meine eigene Hand zu Gummi werden würde.	7. It felt as if my (real) hand were turning "rubbery".
7. Es sah so aus (visuell), als ob sich die Gummihand nach links (in Richtung meiner eigenen Hand) bewegen würde.	8. It appeared (visually) as if the rubber hand were drifting towards the left (towards my hand).
8. Die Gummihand begann meiner eigenen Hand ähnlich zu sehen, hinsichtlich ihrer Form, Hautfarbe, Sommersprossen oder anderer Merkmale	9. The rubber hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles or some other visual features.

Table A2

RHI Questionnaire Translation Used in Study Two and Three

German translation	Original items of Longo et al. (2008)
1. Es schien, als ob ich direkt auf meine eigene Hand schauen würde, nicht auf eine Gummihand.	1. During the block it seemed like I was looking directly at my own hand, rather than at a rubber hand.
2. Es schien, als würde die Gummihand meiner echten Hand ähneln.	2. During the block it seemed like the rubber hand began to resemble my real hand.
3. Es schien, als ob die Gummihand zu mir gehören würde.	3. During the block it seemed like the rubber hand belonged to me
4. Es schien, als ob die Gummihand meine eigene Hand wäre.	4. During the block it seemed like the rubber hand was my hand.
5. Es schien, als ob die Gummihand ein Teil meines Körpers wäre.	5. During the block it seemed like the rubber hand was part of my body.
6. Es schien, als ob die Berührung, die ich fühlte, durch den Pinsel verursacht wurde, der die Gummihand berührte.	6. It seemed like the touch i felt was caused by the paintbrush touching the rubber hand.
7. Es schien, als wäre meine Hand an der Stelle, an der sich die Gummihand befand.	7. During the block it seemed like my hand was in the location where the rubber hand was.
8. Es schien, als wäre die Gummihand an der Stelle, an der sich meine Hand befand.	8. During the block it seemed like the rubber hand was in the location where my hand was.

Appendix B

Table B1

Main BRMS Model of Rubber Hand Illusion Questionnaire (RHIQ)

	RHIQ			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept[1]	-2.31	0.69	-3.41	-1.22
Intercept[2]	-0.65	0.69	-1.75	0.43
Intercept[3]	0.51	0.69	-0.58	1.60
Intercept[4]	1.56	0.69	0.47	2.65
Intercept[5]	3.30	0.69	2.20	4.40
Intercept[6]	5.03	0.70	3.92	6.13
Async.	-2.55	0.64	-3.57	-1.54
Condition (sad)	0.10	0.34	-0.45	0.63
Condition (fear)	0.04	0.36	-0.54	0.62
Group (LD)	1.80	0.91	0.35	3.26
Group (HD)	3.68	0.92	2.21	5.17
Async.: condition (sad)	-0.68	0.51	-1.50	0.14
Async.: condition (fear)	-0.13	0.48	-0.89	0.63
Async.: group (LD)	0.95	0.79	-0.31	2.21
Async.: group (HD)	-0.23	0.80	-1.51	1.06
Condition (sad): group (LD)	0.27	0.47	-0.48	1.03
Condition (fear): group (LD)	0.97	0.51	0.15	1.78
Condition (sad): group (HD)	0.49	0.49	-0.27	1.28
Condition (fear): group (HD)	0.15	0.52	-0.66	0.99
Async.: condition (sad): group (LD)	-0.02	0.72	-1.15	1.13
Async.: condition (fear): group (LD)	-1.19	0.67	-2.26	-0.11
Async.: condition (sad): group (HD)	1.12	0.71	-0.03	2.26
Async.: condition (fear): group (HD)	0.39	0.67	-0.67	1.46
Random effects				
Intercept	3.02	0.27	2.61	3.49
Async.	2.46	0.25	2.09	2.88
Condition (sad)	1.24	0.17	0.98	1.52
Condition (fear)	1.42	0.17	1.15	1.71
Async.: condition (sad)	1.86	0.25	1.48	2.27
Async.: condition (fear)	1.62	0.25	1.24	2.03

Note. Model formula: RHIQ ~ 1 + synchrony*condition*group + (1 + synchrony*condition || participant) + (1 + group*synchrony*condition || item). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to the item score threshold (seven-point Likert scale) of the healthy control group in the synchronous neutral condition.

Table B2

Main BRMS Model of Proprioceptive Drift

	Proprioceptive drift			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept	2.24	0.82	0.93	3.56
Async.	-1.95	0.86	-3.33	-0.59
Condition (sad)	-0.74	0.82	-2.07	0.57
Condition (fear)	-0.65	0.82	-1.98	0.64
Group (LD)	1.28	1.17	-0.58	3.15
Group (HD)	-0.51	1.15	-2.32	1.35
Async.: condition (Sad)	0.92	1.15	-0.91	2.75
Async.: condition (Fear)	-0.04	1.17	-1.90	1.86
Async.: group (LD)	-0.06	1.22	-1.98	1.91
Async.: group (HD)	0.97	1.19	-0.92	2.87
Condition (sad): group (LD)	0.71	1.17	-1.16	2.58
Condition (fear): group (LD)	-0.15	1.22	-2.11	1.80
Condition (sad): group (HD)	1.90	1.18	0.01	3.78
Condition (fear): group (HD)	0.87	1.17	-0.98	2.74
Async.: condition (sad): group (LD)	-1.14	1.66	-3.82	1.47
Async.: condition (fear): group (LD)	0.57	1.71	-2.18	3.28
Async.: condition (sad): group (HD)	-0.61	1.67	-3.29	2.07
Async.: condition (fear): group (HD)	-0.14	1.69	-2.84	2.55
Random effects				
Intercept	2.60	0.27	2.19	3.06

Note. Model formula: Proprioceptive drift ~ 1 + synchrony*condition*group + (1 | participant). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to proprioceptive drift of the healthy control group in the synchronous neutral condition.

Table B3

BRMS Model of Subjective Arousal (Self-Assessment Manikin)

	Subjective arousal			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept[1]	-5.70	1.09	-7.46	-4.00
Intercept[2]	-2.72	1.00	-4.36	-1.16
Intercept[3]	0.21	0.97	-1.33	1.77
Intercept[4]	2.31	0.98	0.75	3.88
Intercept[5]	4.31	1.01	2.72	5.93
Intercept[6]	6.39	1.05	4.73	8.08
Intercept[7]	8.70	1.12	6.92	10.51
Intercept[8]	11.21	1.29	9.21	13.30
Async.	-0.14	0.55	-1.02	0.73
Condition (sad)	0.42	0.64	-0.58	1.45
Condition (fear)	0.55	0.70	-0.58	1.64
Group (LD)	2.24	1.37	0.05	4.41
Group (HD)	2.94	1.42	0.68	5.22
Async.: condition (sad)	-0.02	0.77	-1.27	1.20
Async.: condition (fear)	-0.29	0.78	-1.52	0.97
Async.: group (LD)	-0.53	0.78	-1.76	0.71
Async.: group (HD)	0.65	0.81	-0.64	1.95
Condition (sad): group (LD)	0.25	0.90	-1.19	1.69
Condition (fear): group (LD)	0.17	0.99	-1.40	1.75
Condition (sad): group (HD)	-0.30	0.94	-1.79	1.23
Condition (fear): group (HD)	0.40	1.00	-1.21	2.00
Async.: condition (sad): group (LD)	-0.07	1.08	-1.79	1.68
Async.: condition (fear): group (LD)	0.63	1.11	-1.18	2.40
Async.: condition (sad): group (HD)	-0.86	1.12	-2.65	0.94
Async.: condition (fear): group (HD)	-1.01	1.14	-2.81	0.83
Random effects				
Intercept	4.42	0.49	3.69	5.24
Condition (sad)	1.69	0.41	1.04	2.32
Condition (fear)	2.15	0.41	1.51	2.82

Note. Model formula: Arousal ~ 1 + synchrony*condition*group + (1 + condition || participant). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to the SAM score threshold (nine-point Likert scale) of the healthy control group in the synchronous neutral condition.

Table B4

BRMS Model of Non-Specific Skin Conductance Responses (NSCR)

	NSCR			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept	5.89	1.53	3.43	8.34
Async.	0.67	0.81	-0.61	1.99
Condition (sad)	-0.52	0.80	-1.80	0.74
Condition (fear)	2.08	1.08	0.38	3.83
Group (LD)	1.22	2.17	-2.19	4.69
Group (HD)	0.36	2.15	-3.17	3.75
Async.: condition (sad)	-0.20	1.08	-1.91	1.52
Async.: condition (fear)	-0.86	1.15	-2.74	0.96
Async.: group (LD)	-0.66	1.19	-2.60	1.20
Async.: group (HD)	-0.26	1.11	-2.04	1.49
Condition (sad): group (LD)	1.27	1.20	-0.61	3.21
Condition (fear): group (LD)	-0.96	1.53	-3.41	1.49
Condition (sad): group (HD)	1.03	1.13	-0.78	2.83
Condition (fear): group (HD)	-1.31	1.52	-3.74	1.10
Async.: condition (sad): group (LD)	0.10	1.67	-2.54	2.78
Async.: condition (fear): group (LD)	0.49	1.68	-2.20	3.16
Async.: condition (sad): group (HD)	-0.24	1.56	-2.69	2.30
Async.: condition (fear): group (HD)	0.57	1.61	-2.00	3.14
Random effects				
Intercept	7.07	0.65	6.10	8.15
Condition (sad)	0.85	0.61	0.08	1.99
Condition (fear)	3.12	0.62	2.14	4.07

Note. Model formula: NSCR ~ 1 + synchrony*condition*group + (1 + condition || participant). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to the NSCR of the healthy control group in the synchronous neutral condition.

Table B5

BRMS Model of Skin Conductance Level (SCL)

	SCL			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept	2.34	0.02	2.31	2.36
Async.	-0.004	0.01	-0.03	0.02
Condition (sad)	-0.03	0.02	-0.06	-0.005
Condition (fear)	-0.01	0.02	-0.03	0.02
Group (LD)	-0.01	0.02	-0.04	0.02
Group (HD)	-0.01	0.02	-0.04	0.02
Async.: condition (sad)	0.01	0.02	-0.02	0.04
Async.: condition (fear)	0.01	0.02	-0.02	0.04
Async.: group (LD)	0.002	0.02	-0.03	0.03
Async.: group (HD)	0.02	0.02	-0.01	0.05
Condition (sad): group (LD)	0.01	0.02	-0.02	0.05
Condition (fear): group (LD)	-0.001	0.02	-0.04	0.03
Condition (sad): group (HD)	0.02	0.02	-0.02	0.05
Condition (fear): group (HD)	0.01	0.02	-0.02	0.05
Async.: condition (sad): group (LD)	0.02	0.03	-0.03	0.06
Async.: condition (fear): group (LD)	-0.01	0.02	-0.05	0.03
Async.: condition (sad): group (HD)	-0.01	0.03	-0.05	0.03
Async.: condition (fear): group (HD)	-0.03	0.02	-0.07	0.01
Random effects				
Intercept	0.05	0.01	0.03	0.07
Async.	0.02	0.01	0.01	0.04
Condition (sad)	0.05	0.01	0.02	0.06
Condition (fear)	0.05	0.01	0.03	0.06
Async.: condition (sad)	0.03	0.02	0.004	0.07
Async.: condition (fear)	0.01	0.01	0.001	0.03
Cor(Intercept, async.))	0.43	0.27	-0.04	0.81
Cor(Intercept, condition (sad))	-0.86	0.12	-0.96	-0.68
Cor(Async., condition (sad))	-0.34	0.29	-0.76	0.15
Cor(Intercept, condition (fear))	-0.61	0.20	-0.85	-0.24
Cor(Async., condition (fear))	-0.06	0.30	-0.53	0.41
Cor(Condition (sad), condition (fear))	0.46	0.26	-0.02	0.78
Cor(Intercept, async.: condition (sad))	0.13	0.34	-0.45	0.63
Cor(Async., async.: condition (sad))	-0.05	0.34	-0.58	0.53
Cor(Condition (sad), async.: condition (sad))	-0.14	0.33	-0.63	0.43
Cor(Condition (fear), async.: condition (sad))	-0.15	0.32	-0.63	0.42
Cor(Intercept, async.: condition (fear))	0.15	0.38	-0.50	0.72
Cor(Async., async.: condition (fear))	0.02	0.37	-0.58	0.61
Cor(Condition (sad), async.: condition (fear))	-0.15	0.38	-0.72	0.50
Cor(Condition (fear), async.: condition (fear))	-0.14	0.37	-0.70	0.49
Cor(Async.: condition (sad), async.: condition (fear))	0.06	0.37	-0.56	0.64

Note. Model formula: SCL ~ 1 + synchrony*condition*group + (1 + synchrony*condition | participant). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to the SCL of the healthy control group in the synchronous neutral condition.

Table B6

BRMS Model of Heart Rate (HR)

	HR			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept	72.80	2.08	69.56	76.18
Async.	-0.14	0.53	-0.97	0.70
Condition (sad)	0.28	0.61	-0.70	1.27
Condition (fear)	-0.80	0.61	-1.77	0.17
Group (LD)	-0.31	2.96	-5.06	4.36
Group (HD)	5.27	2.95	0.58	9.97
Async.: condition (sad)	0.24	0.63	-0.77	1.25
Async.: condition (fear)	0.34	0.67	-0.73	1.39
Async.: group (LD)	0.19	0.74	-1.01	1.36
Async.: group (HD)	0.47	0.73	-0.68	1.63
Condition (sad): group (LD)	-0.92	0.87	-2.30	0.46
Condition (fear): group (LD)	-0.44	0.85	-1.80	0.91
Condition (sad): group (HD)	-1.15	0.88	-2.55	0.27
Condition (fear): group (HD)	0.04	0.84	-1.30	1.39
Async.: condition (sad): group (LD)	-0.21	0.89	-1.63	1.19
Async.: condition (fear): group (LD)	0.29	0.91	-1.14	1.78
Async.: condition (sad): group (HD)	-0.56	0.89	-2.00	0.87
Async.: condition (fear): group (HD)	0.003	0.92	-1.47	1.47
Random effects				
Intercept	10.45	0.88	9.16	11.95
Async.	1.08	0.33	0.50	1.56
Condition (sad)	2.09	0.32	1.58	2.60
Condition (fear)	1.94	0.32	1.44	2.45

Note. Model formula: HR ~ 1 + synchrony*condition*group + (1 + synchrony*condition | participant). Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to the HR of the healthy control group in the synchronous neutral condition.

Table B7

BRMS Model of Proprioceptive Drift (Sync.–Async. Difference) including Heart Rate (HR)

	Proprioceptive drift (sync.–async.)			
	b	*se*	*l89%*	*u89%*
Fixed effects				
Intercept	2.00	1.03	0.34	3.63
Condition (sad)	-1.03	1.28	-3.08	1.02
Condition (fear)	0.49	1.32	-1.63	2.59
Group (LD)	1.49	1.43	-0.79	3.77
Group (HD)	-1.32	1.39	-3.54	0.88
HR	-1.13	1.10	-2.88	0.63
Condition (sad): group (LD)	-0.42	1.82	-3.33	2.48
Condition (fear): group (LD)	-2.72	1.95	-5.84	0.39
Condition (sad): group (HD)	0.82	1.78	-1.99	3.66
Condition (fear): group (HD)	-0.26	1.86	-3.22	2.72
Condition (sad): HR	0.80	1.34	-1.34	2.93
Condition (fear): HR	1.02	1.36	-1.13	3.19
Group (LD): HR	3.99	1.73	1.20	6.71
Group (HD): HR	1.81	1.36	-0.35	3.97
Condition (sad): group (LD): HR	-4.73	2.18	-8.15	-1.24
Condition (fear): group (LD): HR	-3.91	2.34	-7.65	-0.17
Condition (sad): group (HD): HR	-0.19	1.78	-3.04	2.67
Condition (fear): group (HD): HR	-2.41	1.80	-5.27	0.47
Random effects				
Intercept	1.15	0.60	0.17	2.09

Note. Model formula: Proprioceptive drift (sync.–async.) ~ 1 + condition*group*HR + (1 | participant). Sync. = synchronous; Async. = asynchronous; LD = low dissociation; HD = high dissociation. Intercept refers to proprioceptive drift of the healthy control group in the synchronous neutral condition.