



UNIVERSITÀ
DI PAVIA

UNIVERSITÀ DEGLI STUDI DI PAVIA

DIPARTIMENTO DI SCIENZE DEL SISTEMA NERVOSO E DEL COMPORTAMENTO

CORSO DI LAUREA MAGISTRALE IN PSYCHOLOGY, NEUROSCIENCE AND HUMAN SCIENCES

**Hippocampal Contextualization of Interoception:
Toward a Contextual Account of Bodily Experience**

RELATORE

Prof. Gerardo Salvato

Tesi di Laurea/Laurea Magistrale di

Ece Gökçe

Matricola n. 54962

Anno accademico 2025/2026

Abstract

Interoception refers to the processing and representation of internal bodily signals, including cardiac, respiratory, visceral, and autonomic states. Contemporary models increasingly conceptualize interoception within predictive processing frameworks, according to which bodily sensations are continuously interpreted through hierarchical generative models that aim to minimize prediction error. Within these frameworks, the subjective meaning and affective salience of bodily sensations are determined not solely by sensory input itself, but also by prior expectations, contextual information, and emotional relevance.

The present thesis proposes the **Hippocampal Contextualization of Interoception Model (HCIM)**, a theoretical framework suggesting that hippocampal-dependent contextual processing may contribute to the interpretation of bodily sensations by integrating interoceptive information with environmental context and previous experience. The model does not propose that the hippocampus generates or directly detects primary interoceptive signals. Rather, it hypothesizes that hippocampal contextual representations may contribute to determining the meaning assigned to bodily sensations under different environmental and emotional conditions. This framework is particularly relevant to trauma-related psychopathology, including post-traumatic stress disorder (PTSD) and complex post-traumatic stress disorder (CPTSD), in which disturbances in contextual processing and bodily awareness may coexist. The HCIM proposes two potential pathways through which disrupted contextualization may contribute to altered interoceptive experience. In hypervigilant presentations, bodily sensations associated with previous threat may retain threat-related meaning despite changes in the current environment. In dissociative presentations, bodily signals may instead become insufficiently integrated with representations of the present self and environmental context.

By integrating findings from interoception research, hippocampal neuroscience, predictive processing, and trauma literature, the HCIM provides a testable theoretical account of how

bodily sensations may acquire context-dependent meaning. The model generates predictions for future behavioral, clinical, and neuroimaging research examining whether hippocampal-dependent contextual processing contributes to flexible interpretation of bodily states across changing environmental conditions. Accordingly, the HCIM is presented as a theoretical framework to be empirically tested rather than as an established neurobiological mechanism.

TABLE OF CONTENTS

Abstract	2
1. Introduction	7
1.1 Rationale and Hypothesis	10
2. From Bodily Signals to Bodily Experience	12
2.1 What Is Interoception?	12
2.2 Dimensions of Interoception	12
2.3 Predictive Processing and Bodily Perception	13
2.4 Why Bodily Sensations Require Interpretation	14
3. Context Gives Meaning to Bodily Signals	15
3.1 Contextual Processing	15
3.2 Memory and Interpretation	16
3.3 Environmental Information	16
3.4 Autobiographical Meaning	17
4. The Hippocampus as a System for Contextual Meaning	17
4.1 Contextual Memory	18
4.2 Spatial Context	19
4.3 Autobiographical Context	19
4.4 Safe Versus Threatening Contexts	20
4.5 Could the Hippocampus Contribute to Bodily Meaning?	20

5. When the Context Becomes Distorted: Trauma and Bodily Experience	21
5.1 Trauma and Contextual Memory	21
5.2 PTSD and CPTSD	22
5.3 Hypervigilance	22
5.4 Dissociation	23
5.5 Altered Bodily Awareness	23
6. A Contextual Account of Altered Interoception	24
6.1 Why Bodily Sensations Become Threatening	25
6.2 Why Bodily Sensations Become Disconnected	26
6.3 Hypervigilance and Dissociation as Divergent Outcomes of Contextual Disruption	27
7. The Hippocampal Contextualization of Interoception Model (HCIM)	27
7.1 Model Overview	28
7.2 Hypervigilant Pathway	30
7.3 Dissociative Pathway	30
7.4 Predictions and Future Directions	31
8. Clinical Implications	33
8.1 Recontextualizing Bodily Sensations	33
8.2 Integrating Internal and External Information	34
8.3 Hypervigilance and Interoceptive Threat	35
8.4 Dissociation and Bodily Reconnection	35

8.5 Implications for Treatment Research	36
9. Limitations	37
10. Conclusion	40
References	44

1. Introduction

Interoception refers to the processing and representation of internal bodily signals, including cardiac activity, respiration, visceral sensations, hunger, thirst, and autonomic states. These signals contribute to the maintenance of homeostasis while simultaneously providing the physiological basis for emotional experience, self-awareness, and adaptive behavior (Craig, 2002, 2009; Khalsa et al., 2018). Although interoception has traditionally been associated with the insular cortex and other viscerosensory regions, accumulating evidence suggests that bodily awareness emerges from interactions among multiple neural systems involved in sensation, memory, emotional regulation, and contextual processing (Barrett & Simmons, 2015; Chen et al., 2021; Khalsa et al., 2018). Consequently, interoception should not be considered an isolated sensory function but rather a multidimensional process that depends on the integration of bodily information with cognitive and environmental representations. One mechanism contributing to this integration involves the continuous interaction between bottom-up sensory input and top-down contextual influences (Barrett & Simmons, 2015; Seth, 2013). Bottom-up processing refers to the transmission of afferent sensory information originating from the body, whereas top-down processing involves the modulation of bodily perception by prior experiences, memories, expectations, and contextual knowledge. Anatomical and theoretical accounts describe interoception as involving reciprocal interactions among ascending visceral pathways and distributed cortical and subcortical systems. These systems contribute to sensory representation, prediction, affective evaluation, and autonomic regulation, rather than forming strictly separate bottom-up and top-down networks (Barrett & Simmons, 2015; Critchley & Harrison, 2013; Khalsa et al., 2018). Rather than functioning independently, these systems continuously interact to generate coherent representations of bodily states. Among these neural structures, the hippocampus occupies a particularly important position because of its well-established role in contextual memory, spatial representation, autobiographical memory, and

the integration of experiences across time. While the hippocampus has not traditionally been regarded as a primary interoceptive structure, emerging evidence suggests that hippocampal and medial temporal lobe processes contribute to interoceptive awareness and to the integration of current bodily states with previously acquired information (Berriman et al., 2016; Dudley & Stevenson, 2016). Given the established role of the hippocampus in integrating contextual information across spatial, temporal, and mnemonic dimensions (Eichenbaum, 2017a), these findings raise the possibility that hippocampal-dependent contextual processing may contribute to how bodily sensations are interpreted in relation to previous experiences and current environmental conditions.

Disruptions in the integration of bodily sensations with contextual and emotional information may contribute to disturbances in bodily awareness observed across several psychiatric disorders (Khalsa et al., 2018). In trauma-related psychopathology, PTSD has been associated with alterations in interoceptive awareness and in the perception and interpretation of bodily signals, including increased body vigilance and threat-related interpretations of physiological sensations (Leech et al., 2024). In addition, these disorders are characterized by heightened autonomic arousal, emotional dysregulation, hypervigilance, and disturbances in bodily self-perception (American Psychiatric Association, 2022; Lanius et al., 2010).

In these conditions, ordinary physiological sensations such as increased heart rate, muscle tension, or respiratory changes may become persistently associated with traumatic memories and emotional distress. Dysfunction within hippocampal networks has consistently been associated with impaired contextual memory, reduced extinction learning, and difficulties distinguishing safe from threatening environments (Liberzon & Abelson, 2016; Maren et al.,

2013). Given evidence linking medial temporal and hippocampal-dependent processes with interoceptive performance, impaired contextual-memory processes may plausibly influence how physiological signals are interpreted in relation to present context (Berriman et al., 2016; Dudley & Stevenson, 2016). Consequently, neutral bodily sensations may continue to evoke threat-related interpretations, contributing to persistent disturbances in interoceptive awareness.

An expanding literature has examined the relationship between interoception and psychopathology; however, comparatively less attention has been given to the specific contribution of hippocampal contextual processing to altered interoceptive awareness. Neuroimaging studies have consistently demonstrated structural and functional alterations of the hippocampus in PTSD, including reduced hippocampal volume and altered connectivity (Bremner et al., 1995; Liberzon & Abelson, 2016). Structural neuroimaging evidence further supports hippocampal involvement in PTSD, with large-scale multisite analyses demonstrating smaller hippocampal volume in individuals with current PTSD than in trauma-exposed controls (Logue et al., 2018). Existing models predominantly emphasize insular processing, autonomic regulation, or emotional appraisal, whereas the potential role of hippocampal mechanisms in integrating bodily sensations with contextual and autobiographical information remains less clearly articulated (Barrett & Simmons, 2015; Chen et al., 2021; Khalsa et al., 2018).

The thesis further explores how disruptions in these processes may contribute to altered interoceptive awareness observed in PTSD and CPTSD. By integrating findings from interoception research, hippocampal neuroscience, and trauma literature, this theoretical perspective aims to provide a coherent framework for understanding the relationship between bodily awareness, contextual processing, and psychopathology. Collectively, current evidence suggests that interoception cannot be understood solely as the perception of internal bodily

signals but should instead be viewed as a process emerging from interactions among bodily sensation, contextual memory, and environmental information (Barrett & Simmons, 2015; Chen et al., 2021; Craig, 2009; Khalsa et al., 2018). While substantial progress has been made in identifying the neural correlates of interoception, the potential contribution of hippocampal contextual processing to altered bodily awareness remains comparatively underexplored. This observation provides the foundation for the present review, which aims to examine whether hippocampal-dependent contextual integration may contribute to alterations in interoceptive awareness observed in trauma-related psychopathology.

1.1 Rationale and Hypothesis

Despite substantial advances in interoception research, the contribution of hippocampal contextual processing to interoceptive awareness remains insufficiently integrated within existing theoretical models. Contemporary literature has extensively described the role of the insular cortex in representing internal bodily signals and has established the hippocampus as a key structure for contextual memory, spatial navigation, and autobiographical processing (Craig, 2009; Eichenbaum, 2017a, 2017b; Khalsa et al., 2018; Squire & Zola-Morgan, 2011). However, relatively few studies have examined how hippocampal-dependent contextual mechanisms may influence the interpretation and regulation of bodily sensations, particularly under conditions of emotional distress. This gap is especially relevant in trauma-related disorders. Individuals with PTSD and CPTSD frequently experience altered interoceptive awareness, including heightened physiological arousal, bodily hypervigilance, dissociative symptoms, and disturbances in bodily self-perception (Khalsa et al., 2018; Lanius et al., 2010; Leech et al., 2024). Alterations in bodily experience have been reported in PTSD. Whether comparable processes characterize CPTSD requires further investigation.

While previous research has investigated these processes separately, a comprehensive framework integrating hippocampal contextual processing with altered interoceptive awareness has yet to be clearly articulated. The rationale for the present thesis is therefore to synthesize findings from the literature on interoception, hippocampal function, and trauma-related psychopathology and to examine their potential interaction. Rather than suggesting that the hippocampus constitutes the primary neural substrate of interoception, this thesis proposes that hippocampal-dependent contextual processing may contribute to the interpretation of bodily sensations by integrating interoceptive information with autobiographical memory and environmental context. Such contextual integration may be disrupted following traumatic experiences, contributing to altered bodily awareness and maladaptive emotional responses. The primary hypothesis is that hippocampal-dependent contextual processing contributes to the organization and interpretation of interoceptive information and that disruptions in this process may underlie altered interoceptive awareness in trauma-related psychopathology. Accordingly, the Hippocampal Contextualization of Interoception Model (HCIM) is presented as a theoretically grounded, hypothesis-generating framework for future neuroimaging and clinical research. Its central premise is that bodily sensations are not experienced independently of context; rather, they acquire meaning through their continuous integration with environmental information and hippocampal-dependent contextual memory. To examine this hypothesis, the following literature review first defines the principal components of interoception before evaluating evidence concerning hippocampal function, contextual memory, trauma-related alterations in bodily awareness, and interactions between interoceptive and exteroceptive systems. Together, these literatures provide the theoretical basis for the HCIM.

Internal bodily signals do not inherently possess meaning. Their subjective significance emerges through the interaction between physiological states, prior experiences, and

environmental context. Understanding how bodily sensations acquire meaning, and how this process may become disrupted following trauma, represents the central aim of the present thesis.

2. From Bodily Signals to Bodily Experience

2.1 What Is Interoception?

Interoception refers to the processing and representation of internal bodily signals arising from the cardiovascular, respiratory, gastrointestinal, endocrine, and autonomic systems. These signals provide continuous information about the physiological state of the body and contribute to homeostatic regulation, emotional experience, decision-making, and the sense of self (Carvalho & Damasio, 2021; Craig, 2002, 2009). Rather than representing a single process, interoception encompasses multiple dimensions of bodily perception that differ in their neural mechanisms and behavioral manifestations.

2.2 Dimensions of Interoception

Contemporary literature distinguishes three complementary dimensions of interoceptive processing: interoceptive accuracy, interoceptive sensibility, and interoceptive awareness (Garfinkel et al., 2015). These dimensions describe different aspects of how internal bodily signals are perceived, evaluated, and reported, allowing interoceptive processing to be examined through distinct but related components.

Interoceptive accuracy refers to objective performance on behavioral tasks measuring the detection of physiological signals, such as heartbeat counting or heartbeat discrimination paradigms. Interoceptive sensibility, in contrast, reflects an individual's subjective beliefs and self-reported sensitivity to bodily states. Interoceptive awareness concerns the correspondence

between objective interoceptive performance and an individual's subjective confidence in that performance.

Although these constructs are closely related, they are not interchangeable. An individual may report heightened sensitivity to bodily sensations while demonstrating relatively poor objective interoceptive accuracy. Conversely, accurate detection of bodily signals does not necessarily imply greater subjective sensitivity or awareness. This distinction has important implications for psychiatric disorders characterized by altered bodily perception, where subjective bodily experiences may differ from objectively measurable physiological processes.

2.3 Predictive Processing and Bodily Perception

Predictive processing frameworks conceptualize perception as an active inferential process in which the brain continuously generates predictions about sensory input and updates these predictions according to incoming information and resulting prediction errors (Clark, 2013; Friston, 2010). Perceptual experience therefore reflects an interaction between bottom-up sensory signals and top-down expectations derived from prior experience and contextual information. The relative influence of these sources is determined by precision weighting, whereby greater weight is assigned to information estimated to be more reliable or relevant (Feldman & Friston, 2010). Applied to interoception, this framework suggests that bodily sensations are not passively registered but interpreted through predictions concerning the causes and significance of internal physiological states (Barrett & Simmons, 2015; Seth et al., 2012). Consequently, similar physiological signals, such as increased heart rate, may acquire different subjective meanings depending on prior experience, affective state, and the context in which they occur.

Predictive interoception is also closely related to allostatic regulation, as the brain anticipates physiological needs and adjusts bodily states accordingly rather than responding exclusively to changes after they occur (Barrett & Simmons, 2015; Kleckner et al., 2017). This perspective is particularly relevant to trauma-related psychopathology, in which previously learned threat associations may influence the interpretation of bodily arousal even when the current environment is safe (Liberzon & Abelson, 2016). Because the hippocampus contributes to contextual memory and the discrimination of threat and safety, hippocampal-dependent contextual processing may provide one mechanism through which previous experience and current environmental information influence the interpretation of interoceptive signals (Eichenbaum, 2017a; Maren et al., 2013). Predictive processing therefore provides a theoretical basis for examining how bodily sensations acquire context-dependent meaning and how this process may become altered following trauma.

2.4 Why Bodily Sensations Require Interpretation

Internal bodily signals provide information about physiological changes but do not necessarily determine their subjective psychological meaning. Similar physiological responses can occur across different emotional and behavioral states; for example, increased heart rate may accompany physical exertion, anxiety, excitement, or fear. Consequently, bodily sensations acquire meaning through their integration with affective, cognitive, and situational information (Craig, 2009; Critchley & Harrison, 2013; Khalsa et al., 2018). Importantly, subjective bodily perception does not always accurately correspond to underlying physiological states. Interoceptive accuracy, subjective beliefs about interoceptive ability, and awareness of actual interoceptive performance are partially dissociable dimensions, meaning that an individual may feel highly sensitive to bodily changes without necessarily perceiving them accurately (Garfinkel et al., 2015). Because bodily signals can also be ambiguous or noisy, attention, emotion, learned associations, and beliefs about their causes may influence their interpretation

(Khalsa et al., 2018; Paulus & Stein, 2010). This distinction is particularly relevant in psychopathology, where heightened attention to bodily sensations may not reflect greater perceptual accuracy but may instead contribute to maladaptive or threat-related interpretations. Thus, bodily awareness depends not only on detecting physiological changes but also on interpreting what those changes signify within a given emotional and environmental context. Accordingly, a heartbeat is not inherently threatening, pleasant, or meaningful.

3. Context Gives Meaning to Bodily Signals

Interoceptive signals provide information about changes occurring within the body, but their subjective significance depends partly on the context in which they are experienced. Similar physiological states can accompany substantially different experiences; increased heart rate, for example, may be interpreted as fear in a threatening situation, excitement during a positive event, or a normal consequence of physical activity. Bodily perception therefore involves more than detecting physiological changes: internal signals are integrated with information concerning the current situation, previous experiences, and emotional state to generate meaningful bodily experiences (Barrett & Simmons, 2015; Critchley & Harrison, 2013; Seth, 2013). Context can consequently influence not only how a bodily sensation is interpreted but also the emotional significance attributed to it.

3.1 Contextual Processing

Contextual processing refers to the use of surrounding information to interpret the significance of a particular stimulus or internal state. Because physiological signals are often compatible with multiple possible causes, contextual information can help disambiguate their meaning. The interpretation of bodily arousal therefore depends partly on information about where, when, and under what circumstances the sensation occurs. This principle is consistent with predictive accounts of perception, in which sensory information is interpreted in relation to

expectations and situational information rather than independently of them (Clark, 2013; Seth, 2013). Context therefore provides a framework within which bodily sensations can be evaluated as expected, relevant, safe, or potentially threatening.

3.2 Memory and Interpretation

The interpretation of bodily sensations is also influenced by previous experience. Current physiological states can be evaluated in relation to learned associations and previously encountered situations, allowing similar bodily signals to acquire different meanings across individuals and circumstances. Through learning, bodily changes may become associated with particular events or emotional outcomes, and these associations can subsequently influence how similar sensations are interpreted (Barrett & Simmons, 2015; Paulus & Stein, 2010). A bodily sensation that has repeatedly occurred in threatening circumstances, for example, may later be interpreted differently from the same physiological sensation associated with exercise or positive excitement. Memory therefore provides previously acquired information against which current bodily states can be evaluated and contributes to the emotional meaning assigned to them.

3.3 Environmental Information

Interoceptive experience occurs in continuous interaction with information originating outside the body. Exteroceptive cues, including visual, auditory, social, and spatial information, convey information about the current environment and can influence the interpretation of simultaneous internal sensations. The brain must therefore integrate information about the internal state of the body with information about external circumstances to support adaptive perception and behavior (Allen et al., 2022; Khalsa et al., 2018). For example, increased cardiac activity accompanied by environmental evidence of danger may acquire a different significance from

the same cardiac change occurring in a safe environment. Environmental information can therefore constrain the possible interpretations of ambiguous bodily signals and contribute to determining their immediate behavioral and emotional relevance.

3.4 Autobiographical Meaning

Bodily sensations can also acquire meaning through their relationship with an individual's personal history. Experiences are not interpreted solely according to the immediate environment but also in relation to previously learned associations and personally significant events. Autobiographical information can therefore influence why a particular bodily sensation carries emotional significance for one individual but not another. Consistent with embodied accounts of emotion, bodily states and personally meaningful experiences can become closely associated, allowing subsequent bodily sensations to evoke or reactivate aspects of previously acquired emotional meaning (Critchley & Harrison, 2013; Damasio, 1999). Accordingly, the subjective meaning of an interoceptive signal reflects not only what is occurring within the body at the present moment but also how that bodily state relates to an individual's previous experiences. This interaction between present bodily information, environmental context, and personal history allows physiological sensations to become meaningful components of subjective emotional experience.

4. The Hippocampus as a System for Contextual Meaning

The hippocampus is primarily associated with episodic and relational memory and with the representation of spatial and temporal context (Eichenbaum, 2017a, 2017b). Rather than storing experiences as isolated elements, hippocampal-dependent processes support the organization of information according to relationships among events, places, and temporal

circumstances. These functions allow current experiences to be interpreted in relation to previously acquired contextual information. Although the hippocampus is not considered a primary interoceptive region, evidence from neuropsychological and behavioral studies suggests that hippocampal and medial temporal lobe processes may also contribute to interoceptive awareness, particularly when bodily information must be integrated with previous states or experiences (Berriman et al., 2016; Dudley & Stevenson, 2016).

4.1 Contextual Memory

A central function of the hippocampus is the formation and retrieval of contextual and relational memories. Hippocampal representations allow individual elements of an experience to be organized according to where and when they occurred and how they relate to one another, providing a contextual framework for subsequent interpretation (Eichenbaum, 2017a; Maren et al., 2013). This function may also be relevant when current bodily states must be interpreted in relation to previous experiences. Berriman et al. (2016) reported impaired performance on cardiac and gastric interoceptive tasks in patients with medial temporal lobe damage. However, impairment was observed irrespective of the tasks' memory requirements. These findings suggest a contribution of medial temporal structures to interoceptive performance but do not establish that this contribution depends specifically on explicit memory demands. Similarly, Dudley and Stevenson (2016) reported associations between Logical Memory retention and measures derived from water loading and the Multidimensional Assessment of Interoceptive Awareness questionnaire in healthy young adults. These behavioral associations provide indirect evidence of a relationship between hippocampal-dependent memory processes and selected aspects of interoception. Together, these studies suggest an association between memory-related processes and aspects of interoceptive performance, while leaving the underlying mechanism unresolved.

4.2 Spatial Context

The hippocampus plays a well-established role in representing spatial relationships and supporting navigation through cognitive maps of the environment (Eichenbaum, 2017a, 2017b). Importantly, hippocampal spatial representations provide more than information about physical location; they organize relationships between an individual and the surrounding environment, allowing experiences to be situated within a particular spatial context. This capacity may be relevant to bodily perception because physiological sensations occur within environments that provide information about their possible significance. The same bodily state may therefore be experienced under substantially different spatial circumstances. By representing the relationship between an experience and the environment in which it occurs, hippocampal spatial processing provides a potential contextual framework within which current bodily information can be evaluated.

4.3 Autobiographical Context

The hippocampus also contributes to episodic and autobiographical memory, particularly the reconstruction of personally experienced events within their spatial and temporal contexts (Maguire, 2001; Svoboda et al., 2006). Autobiographical memories combine information about events, places, people, emotions, and the self into representations of personally meaningful experiences. Consequently, present experiences can be interpreted in relation to an individual's personal history rather than only according to immediate sensory information. Because bodily states form part of many emotionally significant experiences, retrieving autobiographical information may provide a personal context for interpreting similar sensations in the present. In this way, the relevance of hippocampal-dependent memory to bodily awareness may extend

beyond remembering physiological states themselves to situating present bodily experiences within a broader personal history.

4.4 Safe Versus Threatening Contexts

The ability to distinguish between safe and threatening contexts provides a particularly important example of hippocampal contextual processing. Fear responses are adaptive when they occur in environments associated with genuine danger, but they must also be inhibited when circumstances indicate safety. The hippocampus contributes to contextual fear learning and to the use of environmental information to determine when previously learned threat associations are relevant (Maren et al., 2013). This process is especially important in PTSD, where impaired contextual processing has been proposed to contribute to the generalization of threat responses beyond the circumstances in which the original threat occurred (Liberzon & Abelson, 2016). As a result, responses previously appropriate in a threatening environment may persist or re-emerge in objectively safe circumstances. Hippocampal contextual processing therefore provides an important mechanism for distinguishing whether a current experience occurs within a context of safety or threat.

4.5 Could the Hippocampus Contribute to Bodily Meaning?

Taken together, these findings raise the possibility that hippocampal contextual functions may contribute to bodily meaning without requiring the hippocampus to directly detect or represent interoceptive signals. Evidence linking medial temporal and hippocampal-dependent processes to interoceptive performance indicates that bodily awareness can involve memory-related mechanisms in addition to classical interoceptive regions (Berriman et al., 2016; Dudley & Stevenson, 2016). At the same time, extensive evidence demonstrates hippocampal involvement in organizing spatial, temporal, autobiographical, and threat-related context (Eichenbaum, 2017a, 2017b; Maren et al., 2013). Together, these two lines of evidence support the hypothesis that hippocampal-dependent contextual information may influence how current

bodily sensations are interpreted in relation to previous experience and present circumstances. However, direct evidence demonstrating this specific mechanism remains limited. The proposed relationship should therefore be considered a theoretical hypothesis emerging from the convergence of interoceptive and hippocampal research rather than an established function of the hippocampus.

5. When the Context Becomes Distorted: Trauma and Bodily Experience

Traumatic experiences can alter the relationship between bodily arousal, emotional meaning, and contextual information. During threat, physiological responses such as increased heart rate, changes in respiration, muscle tension, and autonomic arousal are adaptive components of the defensive response. Following trauma, however, bodily states associated with previous threat may continue to acquire threat-related significance even when the immediate environment is safe (Liberzon & Abelson, 2016; Nicholson et al., 2016). From this perspective, trauma-related psychopathology may involve not only altered physiological arousal but also difficulties interpreting bodily sensations according to the current context. Altered interoceptive processing may therefore contribute to the persistence of trauma-related symptoms when internal bodily cues are experienced as signals of danger, distress, or disconnection from the self (Khalsa et al., 2018; Leech et al., 2024).

5.1 Trauma and Contextual Memory

Trauma-related disorders are associated with alterations in contextual learning and memory, particularly in the ability to discriminate between conditions of threat and safety. Normally, contextual information allows defensive responses learned in dangerous situations to remain specific to the circumstances in which threat is expected. In PTSD, impaired contextual processing may contribute to the generalization of fear beyond the original traumatic context, allowing cues associated with past threat to evoke defensive responses in otherwise safe environments (Liberzon & Abelson, 2016; Maren et al., 2013). This process may also be

relevant to bodily experience: physiological arousal associated with a traumatic event may subsequently occur in different contexts, while the emotional meaning previously associated with that bodily state remains active. Consequently, current bodily sensations may be interpreted according to previous threat associations rather than exclusively according to present environmental conditions.

5.2 PTSD and CPTSD

Within ICD-11, PTSD is characterized by re-experiencing the traumatic event in the present, avoidance of trauma-related reminders, and a persistent sense of current threat. CPTSD includes these core features together with disturbances in self-organization involving affect dysregulation, negative self-concept, and difficulties in relationships (Cloitre et al., 2013; World Health Organization, 2022). These clinical features are relevant to bodily experience because trauma-related disorders frequently involve disturbances in autonomic regulation, emotional processing, and awareness of internal states (Lanius et al., 2010; Leech et al., 2024). However, interoceptive alterations should not be regarded as a unitary deficit: individuals may differ in their attention to bodily sensations, subjective sensitivity, interpretation of physiological changes, and objective interoceptive performance. Trauma-related psychopathology may therefore involve altered relationships between bodily signals and their emotional meaning rather than simply reduced or increased interoceptive ability.

5.3 Hypervigilance

Hypervigilance involves heightened monitoring for potentially threatening information and is a prominent feature of trauma-related psychopathology. Although commonly discussed in relation to external threat cues, heightened monitoring may also extend to internal bodily sensations. Increased attention to changes in heart rate, respiration, muscle tension, or other physiological states can make bodily arousal particularly salient, while threat-related expectations may influence how these sensations are interpreted (Leech et al., 2024; Paulus &

Stein, 2010). Importantly, increased attention to bodily signals does not necessarily imply greater interoceptive accuracy. Instead, ambiguous physiological changes may be interpreted as evidence that something is wrong or that danger is imminent. This can create a reinforcing relationship in which perceived bodily threat increases arousal, and increased arousal provides further bodily information that can itself be interpreted as threatening.

5.4 Dissociation

Trauma-related alterations in bodily awareness can also take the opposite form, involving reduced access to or detachment from internal bodily experience. Dissociation is characterized by disruptions in the integration of consciousness, perception, memory, identity, and bodily experience and can include experiences of depersonalization and derealization. A dissociative subtype of PTSD has been associated with distinctive patterns of emotional and neural regulation, including responses characterized by emotional overmodulation rather than the heightened arousal typically associated with re-experiencing states (Lanius et al., 2010). From an interoceptive perspective, dissociation may involve altered attention to, integration of, or subjective connection with bodily signals. Trauma-related bodily disturbances may therefore range from excessive monitoring and amplification of internal sensations to diminished bodily presence or detachment, illustrating that altered interoception does not necessarily manifest in a single direction.

5.5 Altered Bodily Awareness

Taken together, trauma-related disturbances in contextual processing, hypervigilance, and dissociation suggest that altered bodily awareness may involve changes in how internal physiological information is attended to and interpreted rather than abnormalities in bodily signals alone. Evidence examining PTSD and interoception indicates alterations across several

dimensions of interoceptive processing, although findings vary according to the population and measurement method used (Khalsa et al., 2018; Leech et al., 2024). Bodily sensations associated with previous threat may become highly salient or acquire persistent threat-related meaning, whereas other individuals may experience reduced connection with bodily states through dissociative processes. Thus, altered bodily awareness may contribute to the maintenance of trauma-related symptoms when the meaning assigned to current physiological states is insufficiently adjusted according to present contextual information. This perspective provides a basis for examining how interactions among bodily signals, contextual processing, and memory may contribute to persistent trauma-related experience.

6. A Contextual Account of Altered Interoception

Altered interoceptive processing has been reported in trauma-related psychopathology, particularly PTSD, although findings vary according to the dimension of interoception examined and the methods used to assess it (Leech et al., 2024). At the same time, a substantial literature implicates impaired contextual processing in PTSD, including difficulties distinguishing present safety from previously learned threat (Liberzon & Abelson, 2016). These two bodies of evidence provide the empirical basis for considering whether altered interoception after trauma may be related, at least partly, to disturbances in the contextual interpretation of bodily signals.

Physiological sensations do not occur independently of prior experience. Predictive accounts of interoception propose that bodily perception reflects interactions between ascending physiological information and prior expectations or learned information (Barrett & Simmons, 2015; Seth, 2013). Following trauma, bodily states that occurred during genuine threat can therefore acquire learned associations with danger. Evidence from contextual fear research

further demonstrates that the expression of learned threat responses depends on contextual information and that hippocampal-dependent contextual processing contributes to distinguishing threat from safety conditions (Maren et al., 2013).

On this basis, the present thesis proposes that some trauma-related alterations in bodily experience may arise not from abnormal physiological signals themselves, but from differences in how those signals are attended to, integrated with contextual information, and interpreted. The specific claim that hippocampal-dependent contextualization contributes to this process is developed in Chapter 7 as a theoretical hypothesis rather than an established causal mechanism.

6.1 Why Bodily Sensations Become Threatening

During traumatic events, autonomic changes such as increased heart rate, respiratory changes, and muscular tension occur in the presence of genuine danger. Through associative learning, physiological states occurring during such events can become linked to threat-related meaning. Research on fear conditioning and contextual processing indicates that previously learned defensive responses can generalize beyond the circumstances in which they were originally acquired. Contextual information is therefore important for distinguishing conditions of threat from those of safety (Liberzon & Abelson, 2016; Maren et al., 2013).

This literature provides a plausible empirical basis for understanding why physiological sensations resembling those experienced during trauma may subsequently acquire threat significance even in objectively safer circumstances. Paulus and Stein (2010) similarly proposed that maladaptive interpretation of bodily signals contributes to anxiety-related psychopathology. Evidence concerning PTSD and interoception further indicates that alterations in bodily awareness occur across trauma-related presentations, although findings remain heterogeneous rather than indicating a single uniform interoceptive deficit (Leech et

al., 2024). Accordingly, the relevant disturbance may concern the meaning attributed to physiological sensations rather than the presence of physiological arousal alone. The further proposition that impaired contextual updating specifically maintains threat-related interpretations of bodily sensations constitutes a theoretical extension of the existing evidence and is one of the predictions developed within the HCIM.

6.2 Why Bodily Sensations Become Disconnected

Trauma-related alterations in bodily experience are not limited to heightened threat sensitivity. Dissociative states can include depersonalization, derealization, emotional detachment, and diminished subjective connection with bodily experience. Clinical and neurobiological evidence supports the distinction between predominantly hyperaroused PTSD presentations and a dissociative subtype characterized by greater emotional overmodulation (Lanius et al., 2010). Nicholson et al. (2016) reported differences in resting-state functional connectivity between insular subregions and amygdala complexes in PTSD and its dissociative subtype. These findings support the broader conclusion that trauma-related disturbances in bodily experience can involve qualitatively different patterns rather than simply greater or lesser interoceptive ability. From the contextual perspective developed in this thesis, dissociative bodily disconnection is hypothesized to involve reduced integration of current physiological information with representations of the present self, environment, and autobiographical context.

Importantly, available evidence does not establish that disrupted hippocampal contextualization causes dissociation. The HCIM therefore treats this relationship as a testable theoretical possibility derived from the convergence of research on dissociation, contextual processing, and interoception.

6.3 Hypervigilance and Dissociation as Divergent Outcomes of Contextual Disruption

Evidence from PTSD research supports distinctions between hyperaroused and dissociative patterns of responding (Lanius et al., 2010), while research on interoception indicates that different dimensions of bodily perception are dissociable rather than reducible to a single continuum of interoceptive ability (Garfinkel et al., 2015). These findings make it unlikely that trauma-related alterations in bodily experience can be adequately characterized simply as either increased or decreased interoception.

Hypervigilance and dissociation provide an example of this heterogeneity. Hypervigilance involves heightened sensitivity and responsiveness to potential threat, whereas dissociation can involve subjective detachment from bodily and emotional experience. The contextual account developed here proposes that these apparently opposing presentations may nevertheless involve different forms of mismatch between current bodily information and the context within which that information is interpreted. This possibility provides the conceptual basis for the HCIM developed in the following chapter, which examines whether hippocampal-dependent contextual processing could contribute to these heterogeneous patterns of bodily experience.

7. The Hippocampal Contextualization of Interoception Model (HCIM)

Several established but currently separate lines of evidence provide the empirical foundation for the HCIM. First, contemporary models of interoception describe bodily perception as an inferential process in which ascending physiological signals interact with prior expectations and learned information (Barrett & Simmons, 2015; Seth, 2013). Second, multisensory accounts propose that information arising from the body and information arising from the external environment interact during perception (Kirsch & Kunde, 2023). Third, extensive evidence implicates the hippocampus in contextual memory and in the discrimination of

context-dependent meaning, including the regulation of learned threat responses according to current environmental conditions (Eichenbaum, 2017a, 2017b; Maren et al., 2013).

A separate, more limited body of evidence suggests an association between hippocampal-dependent processes and interoceptive performance. Dudley and Stevenson (2016), for example, reported associations between performance on hippocampal-dependent learning and memory measures and selected measures of interoceptive awareness in healthy adults. Berriman et al. (2016) additionally reported impaired cardiac and gastric interoceptive performance in patients with bilateral medial temporal lobe damage primarily involving the hippocampus, although conclusions are limited by the very small lesion sample. Together, these findings provide preliminary evidence linking hippocampal-dependent processes with aspects of interoceptive performance, but they do not establish a causal role for the hippocampus in interoceptive interpretation.

The Hippocampal Contextualization of Interoception Model (HCIM) is proposed to integrate these currently separate lines of evidence. Its central hypothesis is that hippocampal-dependent contextual representations contribute to the interpretation of interoceptive signals by relating current bodily states to information about previous experience and the present environment.

The HCIM does not propose that the hippocampus generates primary interoceptive signals, nor does currently available evidence establish that hippocampal activity directly assigns meaning to physiological sensations. Instead, the model identifies hippocampal contextual processing as a candidate mechanism through which contextual information could influence the interpretation of bodily states. This distinction makes the HCIM a hypothesis-generating framework whose claims require direct empirical testing.

7.1 Model Overview

The HCIM distinguishes three sources of information relevant to bodily interpretation: current physiological state, previously acquired contextual information, and information about the

present environment. Evidence from predictive and multisensory research establishes that bodily perception is influenced by information beyond the physiological signal itself (Barrett & Simmons, 2015; Kirsch & Kunde, 2023; Seth, 2013). The model extends existing predictive and multisensory accounts by specifying contextual memory as a potential source of information through which bodily states can be differentiated across situations.

For example, increased cardiac activity can occur during exercise, emotional excitement, and threat. The physiological change itself therefore does not uniquely specify its psychological significance. Research on hippocampal-dependent contextual memory demonstrates that the hippocampus contributes to representing spatial, temporal, and relational information that allows experiences to be distinguished according to context (Eichenbaum, 2017a; Maren et al., 2013). The HCIM extrapolates from this established function by hypothesizing that similar contextual representations may contribute to distinguishing the meaning of comparable bodily states across different circumstances. The proposed contribution is therefore interpretive rather than primarily interoceptive. The HCIM predicts that hippocampal-dependent contextual processing influences what a physiological state signifies under current conditions, rather than whether that physiological state is detected or generated.

PTSD provides a clinically relevant domain in which this hypothesis can be examined. Evidence supports both abnormalities in contextual processing in PTSD (Liberzon & Abelson, 2016) and alterations in dimensions of interoceptive experience (Leech et al., 2024). What has not yet been demonstrated is that these phenomena are mechanistically linked through hippocampal-dependent contextualization. Establishing that relationship represents a central empirical prediction of the HCIM.

7.2 Hypervigilant Pathway

The hypervigilant pathway is derived from established evidence concerning threat learning, context processing, and trauma-related hyperarousal. Contextual fear research demonstrates that environmental context contributes to determining whether learned defensive responses are expressed (Maren et al., 2013), while PTSD has been associated with impaired contextual discrimination and inappropriate generalization of threat responses to safe conditions (Liberzon & Abelson, 2016).

The HCIM extends these findings to bodily perception. Specifically, it predicts that individuals with predominantly hypervigilant presentations will show greater persistence of threat-related interpretations of bodily arousal when environmental information changes from threat to safety. A physiological state such as increased cardiac activity may therefore retain threat significance despite contextual information indicating that the current situation is safe. This prediction should be distinguished from the established observation that subjective interoceptive experience and objective interoceptive accuracy are not equivalent. Garfinkel et al. (2015) demonstrated that interoceptive accuracy, sensibility, and awareness represent dissociable dimensions. The HCIM therefore does not predict that hypervigilance necessarily reflects superior detection of bodily signals. Instead, it predicts a specific alteration in the contextual interpretation of those signals. Evidence currently supports the individual components of this account—altered contextual processing in PTSD, learned threat generalization, and multidimensional interoceptive processing—but does not yet demonstrate their integration through the mechanism proposed by the HCIM.

7.3 Dissociative Pathway

The dissociative pathway is grounded in evidence that dissociative PTSD differs phenomenologically and neurobiologically from predominantly hyperaroused PTSD presentations. Lanius et al. (2010) described the dissociative subtype as involving emotional

overmodulation, whereas predominantly re-experiencing and hyperaroused presentations are characterized by emotional undermodulation. Subsequent neuroimaging findings have provided further evidence of altered functional organization in PTSD with prominent dissociative symptoms (Nicholson et al., 2016).

Building on these findings, the HCIM hypothesizes that dissociative bodily experiences involve reduced integration of physiological signals with representations of the present self and environment. Under this proposal, physiological signals can remain present while being less coherently incorporated into conscious bodily experience. This interpretation goes beyond the available empirical evidence. Existing studies support altered bodily, emotional, and neural processing in dissociative PTSD, but they do not establish that impaired hippocampal contextualization produces dissociative symptoms. Accordingly, the HCIM treats reduced contextual integration as a candidate explanation to be tested rather than a demonstrated mechanism. The model consequently generates different predictions for hypervigilant and dissociative presentations. Hypervigilance is predicted to involve persistent threat-related contextual meaning despite changing safety information, whereas dissociation is predicted to involve weaker correspondence among physiological state, subjective bodily experience, and present contextual information. These predictions allow the two proposed pathways to be empirically differentiated.

7.4 Predictions and Future Directions

The value of the HCIM depends on whether its proposed relationships can be tested beyond the evidence from which the model was derived. Several predictions follow directly from the framework. First, if contextual information contributes to the interpretation of bodily signals, experimentally manipulating environmental context while holding bodily stimulation as constant as experimentally feasible should systematically influence the subjective meaning attributed to that bodily state. Existing multisensory theory and supporting empirical literature

indicate that bodily and external information can interact during perception (Kirsch & Kunde, 2023). The HCIM makes the more specific prediction that individual differences in this contextual modulation of bodily meaning will be associated with hippocampal function. Second, the model predicts that poorer contextual discrimination in PTSD will be associated with reduced flexibility in the interpretation of bodily arousal across changing threat and safety contexts. Hypervigilant participants should show greater persistence of threat-related interpretations after transition to safety. Dissociative participants, by contrast, are predicted to show weaker correspondence among physiological changes, subjective bodily reports, and contextual information. Third, if hippocampal-dependent contextual processing contributes specifically to these effects, contextual modulation of bodily interpretation should covary with hippocampal activity or functional connectivity between the hippocampus and regions involved in interoceptive and affective processing. This prediction could be examined using experimentally manipulated contexts combined with controlled interoceptive tasks and measures of the hippocampus, insula, amygdala, anterior cingulate cortex, and medial prefrontal cortex.

These predictions distinguish evidence already supporting the conceptual components of the HCIM from evidence still required to support the model itself. At present, research demonstrates that bodily perception is shaped by prior and external information, that the hippocampus contributes to contextual representation, that hippocampal-dependent performance is associated with some measures of interoception, and that both contextual and interoceptive abnormalities occur in PTSD (Dudley & Stevenson, 2016; Kirsch & Kunde, 2023; Leech et al., 2024; Liberzon & Abelson, 2016). What remains to be demonstrated is whether hippocampal-dependent contextual processing directly explains variation in the interpretation of bodily signals. The HCIM therefore builds upon established predictive and multisensory accounts rather than replacing them. Its contribution is the formulation of a

specific, falsifiable relationship between contextual memory and interoceptive meaning. Direct experimental evidence supporting or contradicting these predictions would allow the model to be refined, constrained, or rejected.

8. Clinical Implications

The clinical literature provides evidence that interoceptive processes are relevant to post-traumatic stress and that interventions engaging bodily awareness or physiological sensations have shown promise for improving post-traumatic stress outcomes. A recent systematic review identified 19 studies of interoception-based interventions for post-traumatic stress and reported overall improvements in post-traumatic stress symptoms across several intervention approaches, while also highlighting substantial heterogeneity and limited assessment of the interoceptive mechanisms underlying those effects (Putica et al., 2025).

These findings support the clinical relevance of interoceptive processes but do not establish the contextual mechanism proposed by the HCIM. Accordingly, the implications developed below should be understood as hypotheses for treatment research rather than as evidence supporting a new intervention or changes to current clinical practice.

8.1 Recontextualizing Bodily Sensations

Exposure and extinction research provides established evidence that new safety learning does not simply erase previously acquired threat associations and that contextual information contributes to determining whether threat or safety learning is expressed (Maren et al., 2013). Clinical research also provides preliminary evidence that intentionally engaging physiological sensations can be incorporated into interventions for post-traumatic stress. Wald and Taylor (2005) described a case report combining interoceptive exposure with trauma-related exposure for PTSD, and the broader systematic review by Putica et al. (2025) found promising reductions

in post-traumatic stress symptoms across interoceptive intervention approaches, although the evidence base remains heterogeneous.

The HCIM offers one possible interpretation of these findings. If bodily sensations acquired threat-related meaning during trauma, repeated experience of comparable physiological sensations under objectively safer circumstances could provide opportunities for their meaning to become more context-dependent. Importantly, existing intervention studies do not demonstrate that clinical improvement results from hippocampal-dependent recontextualization. The model therefore generates a more specific prediction than the general observation that interoceptive interventions can reduce symptoms: if contextual relearning is relevant, improvement should be associated with an increased ability to assign different meanings to comparable bodily sensations when environmental context changes. Demonstrating this relationship would provide stronger evidence for the mechanism proposed by the HCIM.

8.2 Integrating Internal and External Information

Evidence from multisensory research indicates that perception of bodily and external information is interactive rather than completely independent (Kirsch & Kunde, 2023). This provides an empirical basis for examining interoceptive experience alongside concurrent visual, auditory, spatial, and proprioceptive information.

The HCIM extends this observation to trauma-related psychopathology by hypothesizing that present environmental information may contribute to differentiating current bodily experiences from bodily states associated with previous threat. The model therefore predicts that the clinical processing of bodily sensations may differ depending on whether those sensations are experienced alongside clear contextual information regarding present safety. This remains a research hypothesis. Current evidence does not demonstrate that attending simultaneously to internal and external cues improves PTSD outcomes through hippocampal mechanisms, nor

does it establish that common grounding procedures directly modify hippocampal function. Such claims would require experimental evidence demonstrating changes in contextual discrimination, bodily interpretation, and relevant neural processes.

A more appropriate implication of the HCIM is therefore methodological: future intervention studies could directly compare conditions that engage bodily sensations alone with conditions that systematically manipulate or emphasize concurrent contextual information.

8.3 Hypervigilance and Interoceptive Threat

Empirical research demonstrates that subjective attention to bodily states is not equivalent to objective interoceptive accuracy (Garfinkel et al., 2015). This distinction is particularly relevant to hypervigilant presentations because heightened bodily concern or monitoring should not automatically be interpreted as enhanced physiological perception.

Within the HCIM, the clinically relevant variable is therefore hypothesized to be flexibility of interpretation rather than the overall amount of bodily attention. The model predicts that improvement in hypervigilant symptoms should be associated with an increased ability to modify threat-related interpretations of physiological arousal in response to changes in contextual information. Interoceptive intervention studies provide a means through which this prediction could be examined (Putica et al., 2025). However, existing evidence demonstrating symptom improvement does not establish that altered contextual interpretation mediates those effects. Future studies would need to measure changes in bodily interpretation across threat and safety contexts and test whether such changes statistically or experimentally account for clinical improvement.

8.4 Dissociation and Bodily Reconnection

Clinical and neurobiological evidence indicates that dissociative PTSD can differ from predominantly hyperaroused PTSD presentations (Lanius et al., 2010; Nicholson et al., 2016). This provides a basis for considering whether intervention mechanisms may also differ across

these presentations, but it does not imply that individuals with dissociation should receive fundamentally different treatment. Indeed, meta-analytic evidence indicates that pretreatment dissociation does not reliably predict poorer psychotherapy outcomes in PTSD (Hoeboer et al., 2020). Dissociation should therefore not be interpreted as evidence that trauma-focused psychotherapy is ineffective or inappropriate.

The HCIM instead generates a mechanistic hypothesis concerning bodily integration. It predicts that improvement in dissociative symptoms may be accompanied by stronger correspondence among physiological state, subjective bodily experience, and information about the present self and environment. This prediction differs from simply expecting increased bodily attention or stronger physiological sensation. At present, no evidence demonstrates that such improvement is mediated by hippocampal-dependent contextualization. Testing this proposal would require simultaneous assessment of dissociative symptoms, physiological responses, subjective interoceptive experience, contextual discrimination, and potentially hippocampal function over the course of treatment.

8.5 Implications for Treatment Research

Beyond the experimental predictions outlined in Section 7.4, the HCIM also generates hypotheses that can be examined specifically within treatment research. Its principal clinical contribution is therefore not the proposal of a new intervention but the identification of variables through which existing interventions and their mechanisms could be studied. Existing evidence supports the relevance of interoceptive processes to post-traumatic stress and indicates that interoceptive interventions have been associated with symptom improvement across several treatment approaches in at least some populations and treatment formats (Putica et al., 2025). The unanswered question is whether changes in contextual interpretation of bodily states contribute to these clinical effects.

Future longitudinal studies could assess interoceptive accuracy, interoceptive sensibility, contextual discrimination, PTSD symptoms, and dissociation before and after treatment. Experimental tasks could present comparable physiological states across threat-related and safe contexts to determine whether treatment increases flexibility in bodily interpretation. Mediation analyses could then examine whether changes in contextual flexibility are associated with symptom improvement. Neuroimaging studies could provide a stronger test of the HCIM by determining whether changes in contextual modulation of bodily experience correspond to changes in hippocampal activity or functional interactions between the hippocampus and regions involved in interoceptive and emotional processing. Such evidence would be necessary before attributing clinical improvement specifically to hippocampal-dependent contextualization.

The HCIM therefore generates the testable proposition that recovery from trauma-related disturbances in bodily experience may involve greater flexibility in assigning meaning to physiological states according to current circumstances. Existing evidence supports the individual components from which this hypothesis is derived, but not yet the complete proposed mechanism. Establishing whether hippocampal-dependent contextual processing contributes to this flexibility is therefore a question for future experimental and clinical research rather than an established conclusion.

9. Limitations

Several limitations should be considered when evaluating the Hippocampal Contextualization of Interoception Model (HCIM). Most importantly, the evidence supporting the model is currently convergent rather than directly mechanistic. Research has independently

demonstrated hippocampal involvement in contextual representation and threat discrimination (Eichenbaum, 2017a; Maren et al., 2013), abnormalities in contextual processing in PTSD (Liberzon & Abelson, 2016), and alterations in interoceptive processing in trauma-related psychopathology (Leech et al., 2024). However, these findings do not establish that hippocampal contextual processing directly determines the meaning assigned to interoceptive signals. The relatively small literature directly connecting medial temporal or hippocampal-dependent processes with interoception provides preliminary support for such an interaction (Berriman et al., 2016; Dudley & Stevenson, 2016), but the specific mechanism proposed by the HCIM has not yet been experimentally demonstrated. Moreover, evidence from medial temporal lobe lesions cannot necessarily be attributed specifically to the hippocampus, because lesions may involve additional medial temporal structures and their connections. The model should therefore be regarded as a testable theoretical account rather than an established neurobiological mechanism.

A second limitation concerns the measurement and conceptualization of interoception itself. Interoception encompasses distinguishable dimensions, including objective performance on interoceptive tasks, subjective beliefs about bodily sensitivity, and metacognitive correspondence between subjective confidence and objective performance (Garfinkel et al., 2015). Studies also differ substantially in the physiological systems and tasks used to assess interoception, including cardiac, respiratory, and gastrointestinal measures (Khalsa et al., 2018). Consequently, evidence for “altered interoception” cannot necessarily be generalized across all bodily systems or dimensions of interoceptive processing. This issue is particularly relevant to PTSD, where the existing literature demonstrates considerable heterogeneity rather than a uniform increase or decrease in interoceptive ability (Leech et al., 2024). Future tests of the HCIM should therefore specify which dimension and physiological domain of interoception is being examined rather than treating bodily awareness as a single construct.

A third limitation concerns neural specificity. Interoceptive processing is supported by distributed neural systems that include the insular cortex, anterior cingulate cortex, somatosensory regions, amygdala, thalamic and brainstem structures, and prefrontal regions (Craig, 2009; Critchley & Harrison, 2013; Khalsa et al., 2018). Similarly, contextual processing and threat regulation cannot be attributed exclusively to the hippocampus but depend on interactions among hippocampal, amygdala, and prefrontal systems (Liberzon & Abelson, 2016; Maren et al., 2013). Emphasizing hippocampal contextualization therefore risks oversimplifying a distributed process. The HCIM should instead be understood as identifying a candidate contribution of hippocampal-dependent contextual information within a broader network. Future neuroimaging studies should consequently examine context-dependent changes in hippocampal connectivity with established interoceptive and threat-processing regions rather than hippocampal activity in isolation.

Clinical generalizability represents an additional limitation. PTSD is heterogeneous in symptom expression, trauma exposure, autonomic responses, dissociation, and patterns of bodily awareness, and current evidence does not support a single interoceptive profile across individuals with PTSD (Leech et al., 2024). The evidence base is even more limited for CPTSD. Although CPTSD includes disturbances in affect regulation, self-concept, and interpersonal functioning in addition to core PTSD symptoms, findings obtained in PTSD samples cannot automatically be generalized to CPTSD. The HCIM's proposed hypervigilant and dissociative pathways should therefore be considered dimensional hypotheses rather than fixed clinical subtypes, particularly because hyperarousal and dissociation may coexist or vary within the same individual over time (Lanius et al., 2010).

Finally, the direction of the proposed relationships remains unresolved. Cross-sectional associations among hippocampal abnormalities, contextual-processing difficulties,

interoceptive alterations, and PTSD symptoms cannot determine whether altered contextualization contributes to symptom persistence, develops as a consequence of prolonged trauma-related symptoms, reflects pre-existing vulnerability, or results from reciprocal interactions among these processes. This distinction is particularly important because hippocampal differences observed in PTSD cannot by themselves establish trauma-induced dysfunction or a causal role in altered bodily awareness. Longitudinal and experimental studies manipulating contextual information while measuring bodily perception, physiological responses, and hippocampal activity will therefore be necessary to distinguish these possibilities. Until such evidence is available, the HCIM is best understood as an integrative framework that generates specific hypotheses about the relationship between contextual memory and interoceptive meaning rather than as a comprehensive explanation of trauma-related psychopathology.

10. Conclusion

The present review examined whether hippocampal-dependent contextual processing may contribute to the interpretation of interoceptive signals and whether disruption of this process may help explain alterations in bodily awareness observed in trauma-related psychopathology. The reviewed evidence supports several components of this hypothesis. First, interoceptive experience is not determined exclusively by ascending physiological information; bodily perception is influenced by prior expectations, emotional states, and information about the external environment (Barrett & Simmons, 2015; Khalsa et al., 2018; Seth, 2013). The interaction between bodily and environmental information is further supported by multisensory accounts emphasizing reciprocal influences between interoceptive and exteroceptive

perception (Kirsch & Kunde, 2023). Second, hippocampal-dependent systems organize spatial, temporal, and relational information and contribute to the contextual regulation of learned threat responses (Eichenbaum, 2017a, 2017b; Maren et al., 2013). Third, although direct evidence remains limited, medial temporal lobe and hippocampal-dependent processes have been associated with interoceptive performance, providing an empirical basis for considering memory-related contributions to bodily awareness (Berriman et al., 2016; Dudley & Stevenson, 2016).

These findings become particularly relevant when considered alongside the trauma literature. PTSD is associated with difficulties in contextual processing and in regulating learned threat responses according to present environmental conditions (Liberzon & Abelson, 2016), while interoceptive research demonstrates heterogeneous alterations in bodily awareness in PTSD (Leech et al., 2024). Importantly, these alterations do not reflect a single pattern of increased or decreased interoceptive ability. Trauma-related bodily experience may involve heightened attention to and threat-related interpretation of physiological sensations, but may also involve detachment from bodily and emotional experience in dissociative presentations (Lanius et al., 2010; Leech et al., 2024). Existing evidence therefore identifies abnormalities in both contextual and interoceptive processing in trauma-related psychopathology, but the relationship between these processes remains insufficiently understood.

To address this gap, the present thesis proposes the **Hippocampal Contextualization of Interoception Model (HCIM)**. The central hypothesis of the HCIM is that hippocampal-dependent contextual representations contribute to interoceptive experience by relating current bodily states to previous experience and present environmental conditions. The hippocampus is not proposed as a primary generator or detector of interoceptive signals. Rather, the model hypothesizes that contextual information supported by hippocampal-dependent processes

contributes to constraining the meaning assigned to bodily sensations. Under adaptive conditions, this mechanism would allow similar physiological states to acquire different meanings according to their context. Following trauma, impaired contextualization could instead allow bodily sensations associated with previous threat to retain threat-related meaning in currently safe environments or, in dissociative presentations, contribute to reduced integration of bodily information with representations of the present self and environment.

The principal contribution of the HCIM is therefore the integration of previously separate lines of evidence into a testable account. Existing research establishes that context influences bodily perception, that hippocampal systems contribute to contextual representation, that hippocampal and medial temporal processes can be associated with interoceptive performance, and that both contextual and interoceptive processing are altered in PTSD (Berriman et al., 2016; Dudley & Stevenson, 2016; Leech et al., 2024; Liberzon & Abelson, 2016). However, current evidence does not establish that hippocampal contextual dysfunction causes altered interoception following trauma. This proposed connection represents the central hypothesis generated by the synthesis rather than a conclusion already demonstrated by existing research.

The HCIM consequently generates concrete predictions for future investigation. If hippocampal contextualization contributes to bodily meaning, changing environmental context while maintaining comparable physiological states should modify the subjective interpretation of those states, and the magnitude of this contextual effect should be associated with hippocampal activity or connectivity with interoceptive and threat-processing networks. In trauma-related populations, poorer contextual discrimination should predict reduced flexibility in modifying the meaning of bodily arousal across safe and threatening environments. These predictions could be examined through experimental paradigms combining interoceptive

manipulation with contextual threat and safety cues, alongside physiological measurement, behavioral assessment, and functional neuroimaging.

Overall, the evidence reviewed in this thesis supports a shift from considering interoception solely as the detection of internal physiological states toward examining how bodily signals acquire meaning within context. The **Hippocampal Contextualization of Interoception Model (HCIM)** extends existing predictive and multisensory accounts by proposing hippocampal-dependent contextual processing as one candidate mechanism through which current bodily states may be related to previous experience and present environmental conditions. Its central proposition—that disruption of this contextualization may contribute to altered bodily awareness in trauma-related psychopathology—remains to be directly tested. By translating this proposition into experimentally falsifiable predictions, the HCIM provides a framework through which the relationship among interoception, contextual memory, and trauma can be investigated empirically.

References

- Allen, M., Levy, A., Parr, T., & Friston, K. J. (2022). In the body's eye: The computational anatomy of interoceptive inference. *PLOS Computational Biology*, 18(9), Article e1010490. <https://doi.org/10.1371/journal.pcbi.1010490>
- American Psychiatric Association. (2022). *Diagnostic and statistical manual of mental disorders* (5th ed., text rev.). <https://doi.org/10.1176/appi.books.9780890425787>
- Barrett, L. F., & Simmons, W. K. (2015). Interoceptive predictions in the brain. *Nature Reviews Neuroscience*, 16(7), 419–429. <https://doi.org/10.1038/nrn3950>
- Berriman, J., Stevenson, R. J., Thayer, Z. C., Thompson, E., Mohamed, A., Watson, J. D. G., & Miller, L. A. (2016). Testing the importance of the medial temporal lobes in human interoception: Does it matter if there is a memory component to the task? *Neuropsychologia*, 91, 371–379. <https://doi.org/10.1016/j.neuropsychologia.2016.09.005>
- Bremner, J. D., Randall, P., Scott, T. M., Bronen, R. A., Seibyl, J. P., Southwick, S. M., Delaney, R. C., McCarthy, G., Charney, D. S., & Innis, R. B. (1995). MRI-based measurement of hippocampal volume in patients with combat-related posttraumatic stress disorder. *American Journal of Psychiatry*, 152(7), 973–981. <https://doi.org/10.1176/ajp.152.7.973>
- Carvalho, G. B., & Damasio, A. (2021). Interoception and the origin of feelings: A new synthesis. *BioEssays*, 43(6), Article 2000261. <https://doi.org/10.1002/bies.202000261>

- Chen, W. G., Schloesser, D., Arensdorf, A. M., Simmons, J. M., Cui, C., Valentino, R., Gnadt, J. W., Nielsen, L., St. Hillaire-Clarke, C., Spruance, V., Horowitz, T. S., Vallejo, Y. F., & Langevin, H. M. (2021). The emerging science of interoception: Sensing, integrating, interpreting, and regulating signals within the self. *Trends in Neurosciences*, 44(1), 3–16. <https://doi.org/10.1016/j.tins.2020.10.007>
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36(3), 181–204. <https://doi.org/10.1017/S0140525X12000477>
- Cloitre, M., Garvert, D. W., Brewin, C. R., Bryant, R. A., & Maercker, A. (2013). Evidence for proposed ICD-11 PTSD and complex PTSD: A latent profile analysis. *European Journal of Psychotraumatology*, 4(1), Article 20706. <https://doi.org/10.3402/ejpt.v4i0.20706>
- Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews Neuroscience*, 3(8), 655–666. <https://doi.org/10.1038/nrn894>
- Craig, A. D. (2009). How do you feel—now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, 10(1), 59–70. <https://doi.org/10.1038/nrn2555>
- Critchley, H. D., & Harrison, N. A. (2013). Visceral influences on brain and behavior. *Neuron*, 77(4), 624–638. <https://doi.org/10.1016/j.neuron.2013.02.008>
- Damasio, A. R. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. Harcourt Brace.

- Dudley, L., & Stevenson, R. J. (2016). Interoceptive awareness and its relationship to hippocampal dependent processes. *Brain and Cognition*, 109, 26–33.
<https://doi.org/10.1016/j.bandc.2016.08.005>
- Eichenbaum, H. (2017a). On the integration of space, time, and memory. *Neuron*, 95(5), 1007–1018. <https://doi.org/10.1016/j.neuron.2017.06.036>
- Eichenbaum, H. (2017b). The role of the hippocampus in navigation is memory. *Journal of Neurophysiology*, 117(4), 1785–1796. <https://doi.org/10.1152/jn.00005.2017>
- Feldman, H., & Friston, K. J. (2010). Attention, uncertainty, and free-energy. *Frontiers in Human Neuroscience*, 4, Article 215. <https://doi.org/10.3389/fnhum.2010.00215>
- Friston, K. (2010). The free-energy principle: A unified brain theory? *Nature Reviews Neuroscience*, 11(2), 127–138. <https://doi.org/10.1038/nrn2787>
- Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. *Biological Psychology*, 104, 65–74. <https://doi.org/10.1016/j.biopsycho.2014.11.004>
- Hoeboer, C. M., De Kleine, R. A., Molendijk, M. L., Schoorl, M., Oprel, D. A. C., Mouthaan, J., Van der Does, W., & Van Minnen, A. (2020). Impact of dissociation on the effectiveness of psychotherapy for post-traumatic stress disorder: Meta-analysis. *BJPsych Open*, 6(3), Article e53. <https://doi.org/10.1192/bjo.2020.30>
- Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., Feusner, J. D., Garfinkel, S. N., Lane, R. D., Mehling, W. E., Meuret, A. E., Nemeroff, C. B., Oppenheimer, S., Petzschnner, F. H., Pollatos, O., Rhudy, J. L.,

- Schramm, L. P., Simmons, W. K., Stein, M. B., . . . Interoception Summit 2016 participants. (2018). Interoception and mental health: A roadmap. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 3(6), 501–513.
- <https://doi.org/10.1016/j.bpsc.2017.12.004>
- Kirsch, W., & Kunde, W. (2023). On the role of interoception in body and object perception: A multisensory-integration account. *Perspectives on Psychological Science*, 18(2), 321–339. <https://doi.org/10.1177/17456916221096138>
- Kleckner, I. R., Zhang, J., Touroutoglou, A., Chanes, L., Xia, C., Simmons, W. K., Quigley, K. S., Dickerson, B. C., & Barrett, L. F. (2017). Evidence for a large-scale brain system supporting allostasis and interoception in humans. *Nature Human Behaviour*, 1(5), Article 0069. <https://doi.org/10.1038/s41562-017-0069>
- Lanius, R. A., Vermetten, E., Loewenstein, R. J., Brand, B., Schmahl, C., Bremner, J. D., & Spiegel, D. (2010). Emotion modulation in PTSD: Clinical and neurobiological evidence for a dissociative subtype. *American Journal of Psychiatry*, 167(6), 640–647. <https://doi.org/10.1176/appi.ajp.2009.09081168>
- Leech, K., Stapleton, P., & Patching, A. (2024). A roadmap to understanding interoceptive awareness and post-traumatic stress disorder: A scoping review. *Frontiers in Psychiatry*, 15, Article 1355442. <https://doi.org/10.3389/fpsy.2024.1355442>
- Liberzon, I., & Abelson, J. L. (2016). Context processing and the neurobiology of post-traumatic stress disorder. *Neuron*, 92(1), 14–30.
- <https://doi.org/10.1016/j.neuron.2016.09.039>
- Logue, M. W., van Rooij, S. J. H., Dennis, E. L., Davis, S. L., Hayes, J. P., Stevens, J. S., Densmore, M., Haswell, C. C., Ipser, J., Koch, S. B. J., Korgaonkar, M., Lebois, L. A.

- M., Peverill, M., Baker, J. T., Boedhoe, P. S. W., Frijling, J. L., Gruber, S. A., Harpaz-Rotem, I., Jahanshad, N., . . . Morey, R. A. (2018). Smaller hippocampal volume in posttraumatic stress disorder: A multisite ENIGMA-PGC study: Subcortical volumetry results from posttraumatic stress disorder consortia. *Biological Psychiatry*, 83(3), 244–253. <https://doi.org/10.1016/j.biopsych.2017.09.006>
- Maguire, E. A. (2001). Neuroimaging studies of autobiographical event memory. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 356(1413), 1441–1451. <https://doi.org/10.1098/rstb.2001.0944>
- Maren, S., Phan, K. L., & Liberzon, I. (2013). The contextual brain: Implications for fear conditioning, extinction and psychopathology. *Nature Reviews Neuroscience*, 14(6), 417–428. <https://doi.org/10.1038/nrn3492>
- Nicholson, A. A., Sapru, I., Densmore, M., Frewen, P. A., Neufeld, R. W. J., Théberge, J., McKinnon, M. C., & Lanius, R. A. (2016). Unique insula subregion resting-state functional connectivity with amygdala complexes in posttraumatic stress disorder and its dissociative subtype. *Psychiatry Research: Neuroimaging*, 250, 61–72. <https://doi.org/10.1016/j.psychresns.2016.02.002>
- Paulus, M. P., & Stein, M. B. (2010). Interoception in anxiety and depression. *Brain Structure and Function*, 214(5–6), 451–463. <https://doi.org/10.1007/s00429-010-0258-9>
- Putica, A., Argus, A., Khanna, R., Nursey, J., & Varker, T. (2025). Interoceptive interventions for posttraumatic stress: A systematic review of treatment and interoception outcomes. *Traumatology*, 31(2), 195–211. <https://doi.org/10.1037/trm0000507>

- Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences*, 17(11), 565–573. <https://doi.org/10.1016/j.tics.2013.09.007>
- Seth, A. K., Suzuki, K., & Critchley, H. D. (2012). An interoceptive predictive coding model of conscious presence. *Frontiers in Psychology*, 2, Article 395. <https://doi.org/10.3389/fpsyg.2011.00395>
- Squire, L. R., & Wixted, J. T. (2011). The cognitive neuroscience of human memory since H.M. *Annual Review of Neuroscience*, 34(1), 259–288. <https://doi.org/10.1146/annurev-neuro-061010-113720>
- Svoboda, E., McKinnon, M. C., & Levine, B. (2006). The functional neuroanatomy of autobiographical memory: A meta-analysis. *Neuropsychologia*, 44(12), [2189–2208](https://doi.org/10.1016/j.neuropsychologia.2006.05.023). <https://doi.org/10.1016/j.neuropsychologia.2006.05.023>
- Wald, J., & Taylor, S. (2005). Interoceptive exposure therapy combined with trauma-related exposure therapy for post-traumatic stress disorder: A case report. *Cognitive Behaviour Therapy*, 34(1), 34–40. <https://doi.org/10.1080/16506070510010648>
- World Health Organization. (2022). *ICD-11 for mortality and morbidity statistics* (11th rev., version 2022-02). <https://icd.who.int/browse/2022-02/mms/en>