The multidimensional self and its interplay with emotion processing across the life span

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Abstract

Until today, experts from different disciplines have been struggling to find an answer into the long standing enigma of body and mind, as an effort of incorporating new scientific knowledge into classical philosophical approaches. In specific, there are two distinct aspects that enable the access to our internal and external bodily self: interoception and exteroception. Researchers argue that these two aspects are strongly related, as they interact with each other and shape a holistic perception of human consciousness; hence they form the multimodal self. On one hand, interoception describes how brain receives and integrates endogenous bodily signals, in order to create body’s phenomenological experience and has been found to be pivotal for emotion processing, decision making, understanding psychopathology etc. Various measures are proposed for determining different aspects of interoceptive signaling, leading the way towards new interdisciplinary and innovative research. On the other hand, exteroception is a term strongly related to the concept of embodiment and body ownership; processes or phenomena which contribute into shaping self-awareness, as they emphasize the interaction between sensory motor experience and external perception of the world and can influence emotion awareness, empathy, as well as overall psychological wellbeing. Bearing these in mind, the scope of the present dissertation is the profound understanding of the exact mechanisms underlying interoceptive and exteroceptive signaling through the life span, as well as how these express themselves in clinical conditions. For exploring possible inter-individual differences and mediating/moderating factors, subjective and objective data regarding emotion processing style, emotion recognition, alexithymia but also physical activity and BMI were collected for various populations (primary school children, adolescents and women currently suffering from bulimia nervosa). In specific, electrocardiography and electroencephalography were implemented for quantifying interoceptive accuracy (IAC) and for recording neural electrical activity in emotion face processing. Furthermore, with the help of wearable devices (Actiheart® and Polar watch ®) it was possible to track physical activity and accordingly cardiac circle in daily life. Besides these, the rubber hand illusion experiment was conducted to investigate exteroceptive/propridoceptive processes and subsequently embodiment. Our findings revealed, firstly, a strong interaction between interoceptive signaling and self-regulation of physical activity or fatigue in primary school children, where one’s own limits regarding exhaustion are becoming more defined. Secondly, the importance of physical fitness from early childhood, which can enable the conscious perception and interpretation of internal bodily signals was
highlighted. Likewise, facets of interoception were found asymmetrical in patients with bulimia nervosa, indicating normal perception of cardiac activity, but a decreased tendency in being internally focused. Lastly, among adolescents, the regulation of frustration and distress caused by recognizing negative emotions in others, was found to be closely related to interoceptive signaling, whilst alexithymic traits were connected to lower levels of embodiment/exteroception. In conclusion, all these findings help us understand better the importance of the interoceptive and exteroceptive self, which together sculpt the multimodal self. The discussion of these findings focuses on their contribution for shaping cognition and affect and thus describe how they amalgamate in order to shape self-awareness through the lifespan. In view of that, integrating this important knowledge in prevention programs in schools, as well as in new intervention methods in inpatient and outpatient settings, can be described as highly valuable. Overall there is great need for further research regarding these aspects, as the road ahead of the multimodal self remains long but challenging.
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>CNS</td>
<td>Central Nervous System</td>
</tr>
<tr>
<td>ACC</td>
<td>Anterior Cingulate Cortex</td>
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<td>IAC</td>
<td>Interoceptive Accuracy</td>
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<td>IS</td>
<td>Interoceptive Sensibility</td>
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<td>IA</td>
<td>Interoceptive Awareness</td>
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<td>AN</td>
<td>Anorexia nervosa</td>
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<td>BN</td>
<td>Bulimia Nervosa</td>
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<td>RHI</td>
<td>Rubber Hand Illusion</td>
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<td>PC</td>
<td>Predictive Coding</td>
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<td>BMI</td>
<td>Body Mass Index</td>
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<td>PA</td>
<td>Physical Activity</td>
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<td>EEG</td>
<td>Electroencephalography</td>
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<td>ECG</td>
<td>Electrocardiography</td>
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<td>ERP</td>
<td>Event Related Potential</td>
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<td>HRR</td>
<td>Heart Rate Reserve</td>
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<td>MBSR</td>
<td>Mindfulness-Based Stress Reduction</td>
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<td>IE</td>
<td>Interoceptive Exposure</td>
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<tr>
<td>SE</td>
<td>Somatic Experiencing</td>
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<tr>
<td>CBT</td>
<td>Cognitive Behavioral Therapy</td>
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<tr>
<td>HEP</td>
<td>Heartbeat-Evoked Potential</td>
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<td>MDD</td>
<td>Major Depressive Disorder</td>
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Prolog

From antiquity until today, strong emphasis has been placed to “know thyself” (from the ancient Greek: γνῶθι σεαυτόν) as an ultimate goal in life, which is connected to wisdom and can lead to prosperity (Bolis & Schilbach, 2018). The problem which arises in this case is that the definition of the self, still remains vague, as the self can be perceived in different ways (Bolis & Schilbach, 2018). Therefore, terms like self-confidence, self-image, self-conception etc. can be vague. Are we aware of who we are? And if yes what defines us?

Consciousness plays undoubtedly a pivotal role for understanding the self. Consciousness can be described as the state of awareness, which persistently changes our internal experience and defines who we are (Weil & Rees, 2010). Scientists argue that the dialectical but also multimodal attunement between internalization and externalization, which unfolds mostly in social interactions, is what characterizes the “dynamic self” (Bolis & Schilbach, 2018, Figure 1), whose fundamentals lay on the body (Tsakiris, 2017). Accordingly, cognition and emotions are rooted in the interaction between body and its environment, thus embodied cognition and affect (Tsakirirs, 2017).

Figure 1: ‘I Interact Therefore I Am’: The Self as a Historical Product of Dialectical Attunement by Bolis & Schilbach (2018), June 13 2019, retrieved from https://link.springer.com/article/10.1007/s11245-018-9574-0; Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/); no changes were made.
Bearing these in mind, this dissertation focuses on the understanding of the multidimensional self and its interplay with emotion processing across the life span from an experimental and scientific point of view, in an effort of identifying a significant part of human consciousness based on the interaction between body and mind, in order to come a step closer towards the definition of self-awareness and, hence, of “know thyself”. To that end, the American psychologist and philosopher William James once said (1950, pp.341) “... the body, and the central adjustments, which accompany the act of thinking, in the head. These are the real nucleus of our personal identity, and it is their actual existence, realized as a solid, present fact, which makes us say ‘as sure as I exist’...”.
Part I Synopsis

1. Introduction: a philosophical glance into the body-mind enigma.

Philosophers have contemplated the meaning and the interconnectivity of mind and body as fundamental elements characterizing human existence. Figure 2 demonstrates the timeline of work and life of these philosophers. Until today scientists from different disciplines argue that mind and body should be connected, whilst technology advances have paved the way towards new methodologies, enabling us to take a closer look into the brain and into the human body. Nowadays, a considerable amount of money is being invested in prevention, intervention, and towards a healthier lifestyle, by promoting physical health as a precondition for happiness and for mental health. However, before exploring the body-mind enigma from an experimental point of view, a philosophical approach concerning this dilemma through centuries will be briefly introduced.

The ancient saying "Healthy mind in a healthy body" (Greek: νοῦς ὑγιής ἐν σώματι ὑγιεῖ; Latin: mens sana in corpore sano) reflects its contemporary meaning, emphasizing in this way that an individual cannot have a healthy mind while having an unhealthy body and vice versa. Aristotle in his work De Anima (c. 350 BC), posits that the soul is the form of the body and the essence of any living thing (Vesey, 1964). For example, an eye by itself is lifeless, as it cannot see; if it has life it would need a body, in order to be capable of seeing. Similarly, our soul is part of our body and has life in it (Vesey, 1964). Therefore, a body without a soul or a soul without a body does not exist (Vesey, 1964). Moreover, Hipocrates in his work On the Sacred Disease (400 BC) postulated that the brain is the source of pleasure, grief, pain, anxiety etc. (Critchley & Garfinkel, 2015), but Aristotle (On the Parts of Animals, 350 BC), on the contrary, said that “the brain is not responsible for any of the sensations…the correct view is that the seat and source of sensation is the region of the heart…the motions of pleasure and pain, and generally all sensation plainly have their source in the heart…” (Critchley & Garfinkel, 2015, pp. 2). According to this, since antiquity, the essence of mind and body has been emphasized, by taking into consideration the brain and the heart.

Centuries later, Renè Descartes (1560-1650) argued that the mind is completely different from the body, as mind is a thinking thing and body a non-thinking thing, which regulates bodily functions such as heart and liver, thus introducing the mind-body dualism (Vesey, 1964). On the other hand, Charles Darwin (1809-82) studied the commonalities in
humans and animals in terms of physiological and behavioral way of expressing emotions, bringing back to life theories connecting emotional feelings and bodily states (Darwin, 1872; Critchley & Garfinkel, 2015). Darwins’ naturalistic impulses were integrated in the scientific work of the American psychologist and philosopher William James (1842-1910; Barresi & Martin, 2014) and the Danish physician Carl Lange (1834-1900), developing a theory also known as James-Lange theory of emotion, positing that emotions emerge from bodily responses, and more specifically, from physiological arousal.

Moreover, a more recent and influential theory known as the Somatic Marker Hypothesis, proposed by the neuroscientist Antonio Damasio (1994), indicates that somatic markers are visceral responses/bodily changes to a stimulus, that are conveyed to the brain and are interpreted as a certain emotions and, over time, can be “marked” by the individual as positive or negative, based on past outcomes (Bechara, 2011). This process is of high importance, as these somatic markers and their evoked emotions, which derive from prior experience, can facilitate advantageous decision making, as “affective” past can be used to anticipate future decisions (Bechara, 2011). Accordingly, relevant unconscious somatic responses are the result of behaviors.

Having taken a look into the past, one can wonder whether this body-mind enigma has now been solved. Surely, all the above demonstrates a long standing debate, in which the majority of hypotheses concerning the somatic and affective interaction are still unidentified. Science has shown until now that human beings are distinct because of their body’s complexity, as well as because of their logic. But what makes us humans conscious and aware about the state that we are in? How do we perceive our emotions? Is there a bodily self? The theoretical introduction related to the above mentioned topics will be presented in the next section of this work, setting the basis further on for a more detailed scientific exploration of the multimodal self and its interplay to emotion processing.
1.2 The interoceptive model of the bodily self.

1.2.1 Understanding Interoception

Having analyzed the historical and philosophical background of body and mind, understanding the construct of interoception is crucial, as interoceptive processing is an important component of this dissertation. Specifically, in the work “The integrative Action of the Nervous System” from 1906, Sir Charles Scott Sherrington (as cited in Ceunen, Vlaeyen, & Van Diest, 2016) referred to bodily signals, which arise from within the body and therefore they have an endogenous origin (interoceptive) and bodily signals that arise from outside of the body and therefore have an exogenous origin (exteroceptive). More specifically, interoceptive signals provide information about the body’s physiological state, such as dyspnea, thirst, coolness, warmth, tachycardia, stomach irritation etc., based on sensations that arise from the following four internal bodily domains: the urogenital, the cardiovascular, the gastrointestinal and the respiratory system (Farb et al., 2015; Tsakiris, 2017). For instance, under anxious circumstances we can feel our heart pumping or the “butterflies in our stomach” and hence this ability of consciously perceiving internal signals, that provide us with a feedback of body’s internal
landscape, can be conceptionalized as interoception (Maister, Tang, & Tsakiris, 2017). Extending this theory, interoception could also be perceived as an umbrella word for body’s phenomenal experience and its internal landscape mapping and describes how the brain receives and integrates these endogenous bodily signals in order to maintain the body’s homeostasis in a shifting environment (Cannon, 1929; Ceunen et al., 2016; Tsakiris, 2017).

Accordingly, although homeostasis is already known to us, it is worth emphasizing how important it is for all living organisms. The best paradigm of understanding homeostasis in our biological system is the control of our body temperature around 37 °C (The editors of Encyclopaedia Britannica, 2018), which indicates a normal and healthy condition. But what does this literally mean? The word homeostasis derives etymologically from the ancient Greek words “όμοιος” (homoios) and “στάσις” (stasis), that means “standing still” or in other words “staying the same” (Freberg, 2010; “Homeostasis”, 2018), something that was also described as “milieu intérieur” from the physiologists and philosophers Cannon and Bernard, suggesting a harmonious condition in bodily system functioning (Cooper, 2008) and a “coordinated physiological process which contributes in retaining most of the steady states in the organism” (Cannon 1929 as cited by Goldstein and McEwen 2002, p. 55).

Taking this into consideration, the awareness of our body is strongly connected to the awareness of ourselves, in order to shape self-consciousness (Tsakiris, 2014). The sense of ourselves as a constant in a changing environment is thought to be a result of the brain’s recurring representation of the interoceptive state of the body (Ainley & Tsakiris, 2013). To understand the exact meaning of this, it is crucial to take a closer look into how the central nervous system (CNS) functions (Ceunen et al., 2016). The CNS includes our spinal cord and our brain and one of its main mechanisms is to create a representation of our internal landscape by collecting available information concerning the internal bodily status and integrating this representation in the part of our brain called the insular cortex, which is responsible for shaping consciousness, emotion awareness as well as regulating homeostasis (Freberg, 2010; Ceunen et al., 2016; Craig, 2008). Therefore, Ceunen and colleagues (2016) argue that interoception should be perceived as CNS-perception of the bodily state. However, our subjective experience could be seen as the main source of interoception and thus our brain, rather than the CNS (Ceunen et al., 2016).

But how are interoceptive signals transmitted to the brain? Interoceptive signals, such as pain, hunger, thirst, body temperature etc., are conveyed along thin fibers via autonomic nerves and ganglia (collection of nerve cell bodies) from our vital organs and end up in the
brain through the spinal cord and a cranial nerve, which collects information from the liver, heart and digestive tract and is known as vagus nerve (Critchley & Harrison, 2013; Freberg, 2010; Garfinkel, Critchley & Pollatos, 2016). Moreover, this interoceptive information concerning the internal bodily state is thought to be converged in the insula and the anterior cingulate cortex (ACC; Craig, 2002; Murphy, Brewer, Catmur, & Bird, 2017), a brain region in the cingulate cortex which plays an important role in empathy, decision making, error detection etc. (Freberg, 2010). Neurotransmitter concentrations in the insula and the ACC have been found to be associated with interoception and subjective well-being (Ernst et al., 2014; Farb et al., 2015; Wiebking et al., 2014). Results of neuro-imaging studies indicate that the right anterior insula cortex is fundamental in the processing of interoceptive signals and could potentially compose the substrate for consciousness, as was suggested in previous studies with primates (Craig, 2002; Craig, 2003; Dobbin, 2015; Garfinkel et al., 2016).

Even though the amount of knowledge regarding the anatomical foundations of interoception increases, there are still interoceptive mechanisms that remain unidentified, as researchers are still trying to figure out how interoception can be quantified. Most studies on interoception focus on the cardiovascular system due to the informationally rich coupling between the brain and the heart (Tsakiris, 2017). Additionally, heart beating can be considered as an index of autonomic arousal, is distinct and frequent and can be easily measured (Critchley & Garfinkel, 2017; Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015; Schandry, 1981). Taking this into account, our heart beats and pumps blood through our blood vessels, providing in this way oxygen and nutrients to the body (Freberg, 2010). Simultaneously, heart and brain are also connected via the vagus nerve, allowing bidirectional information exchange and playing a vital role in autonomic functions, such as the regulation of the heart rate and the rate of breathing (Berntson, Quigley, Norman & Lozano, 2016; Berthoud & Neuhuber, 2000; Tsakiris, 2017).

Furthermore, a three dimensional model concerning the different facets of interoception has been proposed, as there is empirical evidence that different interoceptive axes can be assessed (Garfinkel et al, 2015; Table 1). Consequently, the accuracy in detecting or tracking internal bodily sensations is known as interoceptive accuracy (IAC; Garfinkel et al., 2015) and can be assessed by the Mental Tracking Task, suggested by Schandry (1981), in which participants are asked to estimate their heartbeat in given time intervals without checking their pulse. This number is compared further to their actual/recorded heartbeats, occurring in a total score of values between 0 and 1, where 1 indicates absolute accuracy in this task (Herbert,
Muth, Pollatos, & Herbert, 2012). The mathematical transformation is used to calculate the total score (Schandry, 1981):

\[
\frac{1}{4} \sum [1 - (|\text{recorded heartbeats} - \text{counted heartbeats}| / \text{recorded heartbeats})]
\]

Results of this task suggest the existence of inter-individual differences, distinguishing between people with higher and lower IAC (Herbert et al., 2012). Moreover, the subjective characterological and questionnaire-assessed trait which describes the self-perceived dispositional tendency to be internally-focused, is called interoceptive sensibility (Garfinkel et al., 2015). Lastly, interoceptive awareness refers to the relationship between objective performance and awareness of performance and reflects the amount of an individual’s certainty when estimating his/her level of interoceptive behavioral accuracy (Garfinkel et al., 2015).

Table 1: Interoceptive dimensions and methodological differences derived from Garfinkel et al. (2015).

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Definition</th>
<th>Type of Assessment</th>
<th>Methodology</th>
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<tr>
<td>Interoceptive Accuracy (IAC)</td>
<td>Objective accuracy in detecting internal bodily signals</td>
<td>Objective Tests</td>
<td>Behavioral performance accuracy during heartbeat detection/mental tracking task</td>
</tr>
<tr>
<td>Interoceptive Sensibility (IS)</td>
<td>Subjective tendency to be internally-focused and interoceptively cognisant</td>
<td>Subjective self-report</td>
<td>Questionnaires: Porges Body Perception Questionnaire, Multidimensional Assessment of Interoceptive Awareness etc.</td>
</tr>
<tr>
<td>Interoceptive Awareness (IA)</td>
<td>Metacognitive Awareness of interoceptive accuracy</td>
<td>Relationship between objective performance and awareness of performance</td>
<td>Non-standardized questionnaire</td>
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Likewise, the use of electroencephalography (EEG) can enable us to evaluate neural automatic processes of cardiac information, which are dependent upon the attention involved in tasks that measure IAC, such as the Mental Tracking Task (Garfinkel et al., 2016). This is
known as the “Heartbeat-Evoked Potential” (HEP), which describes an index of the brain’s
cortical reflection of cardiac interoceptive signals (Garfinkel et al., 2016). In a former study by
Schandry and Weitkunat (1990), participants that demonstrated an enhanced IAC, after taking
part in a short training session of accurately detecting their own heartbeats, showed also a
significant change in their HEP; therefore, suggesting that the HEP could be a useful indicator
of interoceptive processing (Fukushima, Terasawa, & Umeda, 2011).

In conclusion, although there is extensive research concerning cardiac awareness, we
know little about interoceptive signals arising from different sensory axes, such as from the
gastrointestinal system (Herbert et al., 2012). Gastric sensitivity can be assessed by the
standardized “water load test”, in which participants are asked to drink room-temperature water
from a “bottomless” bottle, without being aware of the actual amount of their water intake, and
they are instructed to stop drinking to the point where they perceive first signs of fullness
(Herbert et al., 2012). Herbert and colleagues (2012) demonstrated in a previous study that
higher sensitivity to gastric functions was related to greater cardiac awareness, as individuals
high in IAC consumed less water, because they perceived fullness faster than individuals low
in IAC. This data is in accordance with previous studies suggesting that heart and stomach share
common brain architecture, namely intersecting cortical representations within the insula
(Avery et al., 2015; Harrison, Gray, Gianaros, & Critchley, 2010; Garfinkel et al., 2016).
Contrasting this, respiratory and cardiac IAC were found not to be interrelated, although a
positive association was found between respiratory and cardiac IA, suggesting that the amount
of insight into one’s interoceptive performance was stable across both modalities, but not the
amount of accuracy (Garfinkel et al., 2016). Hence, the above mentioned findings emphasize
the diverse dimensions of interoception across different modalities that could have an impact
on the conscious experience of the inner bodily landscape.

1.2.2 Interoception and emotion processing
In the previous section, emphasis was placed on the theoretical introduction of interoception,
as well as on the methodological assessment tools that exist. Keeping in mind not only the
philosophical, but also the scientific dilemma regarding body and mind interactions, this part
of the introduction focuses on emotions, as the dynamic integration of body and mind can
influence also the way we perceive and process our emotions (Herbert & Pollatos, 2012; Zaki,
Davis, & Ochsner, 2012). Looking back, William James (1884, p.190) remarked that “we feel
sorry, because we cry; angry because we strike; afraid because we tremble”, postulating that
emotions are defined as the perception of bodily reactions (Craig, 2009; Herbert & Pollatos, 2012). In addition, the core element of our emotions is the neural representation of the body’s physiological condition, or else the “somatic markers” as previously described by Antonio Damasio (1994; Bechara, 2011) that trigger feeling states and in their turn shape cognition and behavior (Herbert & Pollatos, 2012).

Extending this, the feedback of physiological reactions caused by emotions is integrated in interoceptive signals that are crucial for maintaining homeostatic and allostatic control and therefore emphasizing the interoceptive cornerstone of emotional feelings (Critchley & Garfinkel, 2017). For example, encountering a snake is connected to a fearful emotional reaction and, as a result, bodily reactions caused by fear emerge (palpitation, sweating, accelerated breath etc.), which lead to a “fight or flight” reaction. Furthermore, prior research has demonstrated that individuals high in IAC tend to experience their emotions more intensely, than individuals low in IAC. One possible explanation might be the fact that activity in the anterior insula evinces the functional overlap between emotion processing and interoception, which suggests a strong coupling between emotional experience and bodily representations and thus a neurological “intersecting zone” in the anterior insula between body and mind (Zaki, Davis, & Ochsner, 2012). In this case, it becomes more plausible why IAC plays such a pivotal role in emotion processing (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Herbert, Herbert, & Pollatos, 2011; Herbert & Pollatos, 2012; Herbert, Pollatos, & Schandry, 2007; Pollatos, Kirsch, & Schandry, 2005).

Further evidence, concerning how the bidirectional connection between the heart and the brain affects emotion awareness, arises from the cardiovascular system, which can provide us with important information on how emotion processing interacts with cardiac interoceptive signaling (Critchley & Garfinkel, 2017). The arterial baroreceptors are sensors in the blood vessels, which are important for the beat-to-beat regulation of blood pressure, which communicates with the brain, in order to maintain proper levels of blood pressure (Berntson et al., 2016; Heesch, 1999). In other words, arterial baroreceptors are responsible for controlling the timing and strength of each heartbeat through the baroreflex (reflex mechanism, which regulates blood pressure) and furthermore in situations where emotional stress is high, the baroreflex is suppressed and stimulates increased heart rate and blood pressure, which indicates cardiovascular arousal and thus informs the brain about this emotional and bodily condition (Critchley & Garfinkel, 2017).
Having described the interoceptive processes involved in emotional experience, a more specific dimension, which has been found to be related to interoception, is alexithymia (Murphy et al., 2017). Alexithymia, literally meaning “no words for emotions”, was first introduced by the psychiatrist Peter Sifneos (1973) and refers to a sub-clinical condition, characterized by the inability of identifying, describing/expressing one’s own feelings and feelings of others (Herbert & Pollatos, 2012) and a general poor emotional awareness (Herbert, Herbert & Pollatos, 2011; Lane, 2000). Alexithymia was found to be related to a wide range of psychiatric disorders, such as depression (Foran & O’Leary, 2013; Panayiotou et al., 2015; Taylor & Bagby, 2004), anxiety disorders (Turk, Heimberg, Luterek, Menin & Fresco, 2005) and eating disorders (Bertoz, Perdereau, Godart, Corcos & Haviland, 2007; de Zwaan, Biener, Bach, Wiesnagrotzki & Stacher, 1996; Corcos et al., 2000; Pollatos et al., 2008; Taylor, Bagby & Parker, 1991). Herbert and colleagues (2011) demonstrated that IAC was negatively correlated with alexithymia, which suggests a close link between poor perception of internal bodily signals and a deficit emotional awareness style (high alexithymic traits). In a same manner, the way individuals empathize was found to be connected to higher levels of IAC (Grynberg & Pollatos, 2015), which reveals a better ability of individuals high in IAC to be more compassionate.

Indeed, in this part of the introduction, the interconnectivity between interoceptive signaling and emotion processing has been shown, setting the stage for a more thorough introduction concerning the developmental aspect of these processes, as well as the methodological issues raised.

1.2.3 Interoception through the developmental spectrum.

The developmental trajectory of interoceptive processes is still unknown, as there are vast gaps concerning our understanding of how interoception develops and alters across the lifespan (Murphy et al., 2017). In all developmental stages, interoceptive challenges are faced, which can be determinant for vulnerability towards psychiatric conditions, such as anxiety and depression (Harschaw, 2015). Therefore, a closer look into interoception from a lifespan view is of high importance. Following findings on early infancy, childhood and adolescence will be introduced. Accordingly, figure 3 demonstrates various methodologies applied for the exploration of interoceptive processes through the developmental spectrum.
Early infancy (0-1 year)

Despite the fact that interoceptive processes in infancy might play an important role in facilitating homeostasis, by abetting e.g. self-regulatory behaviors, like milk-intake (Harshaw, 2008; Maister et al., 2017), research in this field of interest is sparse. After conducting the “Infant Heartbeat Task” (iBEATS), an innovative non-verbal task in which a synchronized-to-the-heart-beat animated character was shown to 5-month old infants during continuous eye-tracking, Maister and colleagues (2017) demonstrated that infants could differentiate synchronous versus asynchronous cardiac rhythms. This could indicate that infants can, not only be sensitive to interoceptive sensations, but also integrate interoceptive information with external stimuli as a possible effort to develop awareness towards their own body boundaries. This finding is of high importance, as it could help us understand how infants experience themselves and the world, something crucial for forming an embodied self-awareness (Maister et al., 2017). As this is the first study for measuring interoception in infants, methodological issues arise in this venture, therefore further research in this field is needed.

Middle Childhood (6-11 years)

Studies on interoception among children suggest that IAC is determinable even from a young age (Murphy et al., 2017), but there is lack of research regarding children aged 2-5 years. On the contrary, children aged between 6-11 years were found to substantially differ in their IAC levels, which demonstrates that IAC is objectively determinable and diverse even from this young age (Koch & Pollatos, 2014). In the above mentioned study (Koch & Pollatos, 2014), the Mental Tracking Task (Schandry, 1981) was adapted for children, by shortening the original time intervals, as one important methodological problem that could emerge when assessing IAC in younger children is the fact that children can miscount during this task and this can lead to higher errors rates (Eley, Gregory, Clark, & Ehlers, 2007; Koch & Pollatos, 2014). It is worth noticing that the methodological difficulties regarding the assessment of IAC among younger children can explain why there is a lack of studies in this field (Murphy et al., 2017).

Adolescence (12-16 years)

Although adolescence is a period where immense psychological and biological changes take place, changes which influence cognition, emotions, self-awareness and the establishment of identity (Blakemore & Choudhury, 2006; Murphy et al., 2017; Rutter & Rutter, 1993), we know only a fraction about the development of interoception in youth. Mata and colleagues (2015)
demonstrated that obesity in adolescence was linked to reduced IAC, as adolescents were more focused on external cues rather than on their internal bodily signals; this supports the idea that interventions targeting the enhancement of perception and appraisal of bodily signals related to satiety and hunger, could be of high importance (Mata, Verdejo-Roman, Soriano-Mas, & Verdejo-Garcia, 2015). Additionally, De Witte and colleagues (2016) included in their sample, youngsters aged 9 to 16 years and discovered that higher IAC was associated to low maladaptive emotion regulation strategies, such as giving up, aggression, rumination etc.

So far, we know that infants can differentiate synchronous versus asynchronous cardiac beating (Maister et al., 2017), as well as that children and adolescents show interinindividual differences in their interoceptive processing, when taking into consideration other variables, such as obesity and emotion regulation (De Witte et al., 2016; Koch & Pollatos, 2014; Mata et al., 2015). All in all, although the above mentioned studies assess different aspects of interoceptive processing in infants, children and adolescents, there is, in fact, a lack of studies concerning the understanding of how interoception evolves in a typical population and how this influences through a developmental perspective an onset of a possible psychopathology (Murphy et al., 2017).

Figure 3: Methodologies of interoceptive processes through the developmental spectrum.
1.2.4 Interoception and Psychopathology

Thus far, although basic knowledge regarding interoceptive signaling was summarized, its determinant role for a plethora of psychiatric disorders should not be neglected (Farb et al., 2015; Tsakiris, 2017). It is worth noticing that even though there is a major interest on the impact of interoception on mental health, it is still unclear whether attenuated interoception could be regarded as the cause or as the aftereffect of developmental psychopathology (Khalsa et al., 2017). Therefore, findings on depression, anxiety and eating disorders will be introduced further on in this section.

On the one hand, prior research has shown that mood and anxiety disorders are related to deficits in interoceptive processing (Khalsa et al., 2017). For instance, impaired interoceptive dysfunction expressed through abnormal somatic signaling has been found in depression (Harshaw, 2015; Garfinkel et al., 2016; Lackner & Fresco, 2016). Taking this into consideration, depression is characterized by a symptomatology closely related to the connection between body and mind, such as: sadness, lack of interest or drive, anhedonia, negative self-referential processing (i.e. rumination) etc. (Harshaw, 2015). Greater anhedonia, rumination and distress were found to be connected to lower levels of IAC in depressive patients (Lackner & Fresco, 2016). Moreover, deficits in the neural processing of IAC in anterior insula regions were found in Major Depressive Disorder (MDD) and more specific a hypo-response effect during an IAC task; something that gradually declined after remission from depression (Wiebking et al., 2015).

On the other hand, heightened IAC in anxiety disorders could be seen as a risk factor, which triggers and perpetuates anxiety. Specifically, patients with anxiety disorder are more vigilant towards somatic sensations and have a tendency to misinterpret bodily signals in a catastrophizing manner (Harbauer-Raum, 1987, Van-der-Does, Antony, Ehlers & Barsky, 2000). Although this sounds clear, it is still under debate whether there is a strong interaction between IAC and anxiety in a clinical sample (Antony et al., 1995; Barsky, Cleary, Sarnie, & Ruskin, 1994; Ehlers, Margraf, Roth, Taylor, & Birbaumer, 1988; Garfinkel et al., 2016; Yoris et al., 2015), or low IAC levels in heightened anxiety (Garfinkel et al., 2016; Vilfredo, Maria, & Raffaele, 1984) and low IAC in normal and functional levels of anxiety (Krautwurst, Gerlach, Gomille, Hiller, & Witthoef, 2014).

In addition, altered interoceptive processing has been found in eating disorders (Khalsa et al., 2017). Findings of a study conducted by Pollatos and colleagues (2008) demonstrated that deficit IAC was present among patients with anorexia nervosa (AN), which suggests a
reduced capacity in differentiating signals of hunger and satiety in AN, as well as difficulties in accurately perceiving own somatic signals. Furthermore, reduced IAC was also found in women recovered from bulimia nervosa (BN) (Klabunde, Acheson, Boutelle, Matthews, & Kaye, 2013), which reveals the difficulty in detecting various bodily cues even after recovery in BN. Taking this into consideration, one could expect that the large shifts in autonomic tone (activity of the autonomous nervous system) that occur in the course of repetitive binging and purging in BN could result in habituation or sensitization toward internal bodily signals (Khalsa & Lapidus, 2016). Klabunde and colleagues (2013) extend this hypothesis by suggesting that interoceptive deficits in BN after recovery could also be perceived as either a biological trait that existed prior to the development of the BN symptomatology, or as a consequence of this eating disorder. Hence, the perception of bodily signals related to hunger and satiety is strongly connected to interoceptive processes and plays a crucial role in the regulation of food intake in different populations (Garfinkel et al., 2016). To sum up, table 2 demonstrates the related symptomatology and interoceptive dysfunction signs of affective, anxiety and eating disorders.

Table 2: Clinical symptoms and signs suggesting interoceptive dysfunction in depression, general anxiety disorder and eating disorders, based on Khalsa et al. (2018).

<table>
<thead>
<tr>
<th>Psychiatric Disorder</th>
<th>Symptoms</th>
<th>Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression</td>
<td>• lethargy&lt;br&gt;• fatigue&lt;br&gt;• anhedonia&lt;br&gt;• increased or decreased appetite&lt;br&gt;• sense of heaviness</td>
<td>• weight gain&lt;br&gt;• weight loss&lt;br&gt;• psychomotor slowing</td>
</tr>
<tr>
<td>Generalized Anxiety Disorder</td>
<td>• muscle tension&lt;br&gt;• palpitations&lt;br&gt;• dyspnea&lt;br&gt;• gastrointestinal complaints&lt;br&gt;• fatigue&lt;br&gt;• restlessness&lt;br&gt;• sleep problems</td>
<td>• trembling&lt;br&gt;• sweating&lt;br&gt;• elevated heart rate and blood pressure&lt;br&gt;• nausea&lt;br&gt;• exaggerated startle</td>
</tr>
<tr>
<td>Eating Disorders</td>
<td>• food anxiety&lt;br&gt;• hunger insensitivity&lt;br&gt;• gastrointestinal complaints</td>
<td>• severe food restriction&lt;br&gt;• severe weight loss&lt;br&gt;• purging&lt;br&gt;• binging&lt;br&gt;• compulsive exercise</td>
</tr>
</tbody>
</table>
1.3 The exteroceptive model of the bodily self

1.3.1 Understanding Exteroception

Thus far, this work has focused on interoceptive processing and its related parameters, such as emotion awareness, psychopathology etc. Scrutinizing the bodily self only through interoceptive signals would have been asymmetrical. Therefore, in the following section, the exteroceptive model of the bodily self as part of the concept of embodiment will be introduced.

Accordingly, being aware that my body belongs to me (embodiment) is profoundly related to self-identity (Bermudez, Marcel, & Eilam, 1995; Tsakiris, Jimenez, & Costantini, 2011) and can be described as body ownership (Tsakiris, 2017). Studies on the field of embodiment have gained considerable influence in different directions, as this construct illustrates the interaction between the organism’s sensory-motor experience and its environment (Fuchs, 2009; Fuchs & Schlimme, 2009; Zahavi, 2009). Furthermore, embodiment has been the focus of theoretical and empirical analyses, in which the interrelation between whole-body functions, brain structures, cognition, consciousness and emotions is underlined (Fuchs & Schlimme, 2009). At this point, exteroceptive stimuli are referred to signals coming from outside the body that contribute into shaping self-awareness and thus body ownership (Tsakiris et al., 2011). But where do these signals come from? Exteroceptive signals arise from vision, touch and sound, but also from vestibular and proprioceptive systems (from the latin propius: own and capio: to grasp; Valenzuela-Moguillansky, Reyes-Reyes, & Gaete, 2017). In particular, proprioception describes the sense of the position one’s own bodily parts and at the same time the amount of effort spent in a movement (Peter, Nagy, & Vardaxis, 2010). As this is necessary for a deeper understanding of exteroception, in this section the experimental procedure for the assessment of the aforementioned variables will be described.

In view of that, in the “Rubber Hand Illusion Experiment” (RHI), distinct components of body ownership are assessed, such as ownership and location of the limb, as well as the sense of control over it (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Tsakiris, 2017) and in this paradigm, illusory effects regarding the body take place (Botvinick & Cohen, 1998; Cascio, Foss-Feig, Burnette, Heacock, & Cosby, 2012). Specifically, participants are asked, during this task, to sit comfortably in front of a table, facing a two-chambered box with two open sides. Meanwhile, a rubber/prosthetic hand is placed on a table in the left chamber, in front of the participants’ vision. Moreover, participants are asked to place their real left hand underneath the table and concentrate solely on the rubber hand. Lastly, the instructor of the experiment
delivers brush strokes in two conditions, one synchronously and one asynchronously. In this way, an effect of body illusion is induced, as the participant starts feeling as if the rubber hand belonged to them. Figure 4 demonstrates the setting of the RHI.

Consequently, after synchronous brush strokes, the perceived location of the participant’s own hand drifts towards the rubber hand, something which is known as proprioceptive drift (Cascio et al., 2012) and is related to the behavioral level of the experiment (Grynberg & Pollatos, 2015). Moreover, at a subjective level, participants report the experienced illusion of the rubber hand and, at a physiological level, the illusion is defined by the skin’s temperature drop of one’s own hand (Grynberg & Pollatos, 2015; Moseley et al., 2008), which reveals changes in the homeostatic control of the real hand (Moseley et al., 2008; Tsakiris, 2017). In addition, prior research suggests that the insula is activated during the experience of body ownership in the RHI (Tsakiris, Hesse, Boy, Haggard, & Fink, 2007). Data concerning patients suffering from somatoparaphrenia, which is described as a neuropsychological syndrome characterized by loss of the feeling over one’s own limb, indicates that the right posterior insula is related to the feeling of body ownership (Tsakiris, 2017). As a result, information from vision and touch amalgamate in the RHI, in order to influence proprioception and body surface representation. Lastly, one can conclude that the RHI

Figure 4: Alexithymia modulates the experience of the rubber hand illusion by Grynberg & Pollatos (2015), June 13 2019, retrieved from https://www.frontiersin.org/articles/10.3389/fnhum.2015.00357/full#h7; Attribution 4.0 International (CC BY 4.0; https://creativecommons.org/licenses/by/4.0/); no changes were made.
occurs from multisensory processing (Botvinick, 2004; Cascio et al., 2012; Tsakiris & Haggard, 2005).

Finally, an interaction between low body ownership and high alexithymic traits was found by Grynberg and Pollatos (2015), suggesting a close link between alexithymia and the integration of exteroceptive stimuli in adults. This finding sets the basis for understanding how emotion processing is related to the exteroceptive bodily self, something that reminds the close interaction between emotion processing and the interoceptive bodily self.

1.3.2 Exteroception across the life span.
Moving to experoception from a developmental perspective, it is worth noticing that infants discover their world and explore themselves through proprioceptive cues, such as moving their limbs, or sucking their fingers (Rochat & Striano, 2000). Research with infants has shown how knowledge concerning symbols, meanings and emotions arises from engaged and embodied action; something that resembles Piaget’s theories about cognitive development (Marshall, 2016). Identifying and differentiating the self from the others is pivotal in developmental theories for imitation, empathy and in general social behaviors (Cascio et al., 2012; Chaminade, Meltzoff, & Decety, 2005). Prior research has demonstrated that infants were able to detect synchronous vs. asynchronous information and differentiate the self from the others (Filippetti, Johnson, Lloyd-Fox, Dragovic, & Farroni, 2013). Cascio et al. (2012) demonstrated that children with autism spectrum disorder aged between 8 and 17 years indicated a slower multidimensional integration of exteroceptive bodily signals in the RHI in comparison to typically developed children, which suggest developmental differences concerning body ownership between autism and typical cognitive development. Nava and colleagues (2017) discovered that the subjective feeling of body ownership was already present in children aged 4 years. Certainly, these first findings reveal the underlying mechanisms regarding the integration of proprioceptive, somatosensory and visual information in children and adolescents.

1.4. Unifying interoceptive and exteroceptive signals: towards the formation of the multimodal self.
Having defined the interoceptive and exteroceptive bodily self, a unified model of the self as multisensorial is being proposed (Petzschner et al., 2017; Tsakiris, 2017). As previously described, signals from our internal bodily environment (interosensations), such as heart rate,
breathing, temperature etc. reach the brain via afferent fibers on the spinal cord and the vagus nerve and converge on the insula cortex, a region described also as interoceptive cortex (Cechetto & Saper, 2004; Evrard, Logothetis, & Craig, 2014; Petzschner et al., 2017). At the same time, external signals which originate from our external environment, are conveyed through vision, touch etc. to the brain’s primary cortical regions (Petzschner et al., 2017). In this stage, interoceptive and exteroceptive information merge together based on prior beliefs regarding one’s own body and together shape a combined and a multisensory perception of the body in the world (Petzschner et al., 2017; Tsakiris, 2017) and hence consciousness. This process of multimodality is depicted in Figure 5.

Undoubtedly, this multimodal integration of interoceptive and exteroceptive stimuli plays a vital role in the regulation of bodily states to maintain homeostasis and allostasis (Petzschner et al., 2017). Furthermore, interoceptive predictive coding (PC), as proposed by

![Figure 5: Computational Psychosomatics and Computational Psychiatry: Toward a Joint Framework for Differential Diagnosis by Petzschner et al. (2017), June 13 2019, retrieved from https://www.sciencedirect.com/science/article/pii/S0006322317315846; Creative Commons Attribution-Non Commercial-No Derivatives License (CC BY NC ND); https://creativecommons.org/licenses/by-nc-nd/4.0/; no changes were made.](image-url)
Seth and colleagues (2012), suggests that subjective feelings states are influenced by predictions regarding the interoceptive state of the organism. In other words, PC is determined by probabilistic predictions about the body’s interoceptive state, by comparing incoming information with preexisting internal models (Tsakiris, 2017). If there is a mismatch between predictions and incoming information, then “prediction errors” (PE) are generated (Garfinkel et al., 2016; Tsakiris, 2017), which trigger adaptation processes aiming at minimizing such errors, e.g. by tuning more attention to internal signals if there is a mismatch between expected and perceived intensity. This can also be applied in the processing of exteroceptive information, as these signals might arise and are compared to interoceptive predictions, in order to attain multimodal integration of the body and as a result to shape the “self” (Garfinkel et al., 2016; Tsakiris, 2017). To this end, this model is crucial for self-awareness, but also lays the foundations for the self-other relations (Tsakiris, 2017).
1.5 Thesis Objective

The scope of the present thesis is the exploration of the multidimensional self in terms of interoceptive and exteroceptive processing through the life span and its interplay with emotion processing. For this reason, primary-school children, adolescents and female patients currently suffering from BN were included in our samples. In all four studies of this dissertation, we took into consideration variables such as emotion processing style and further moderating or mediating parameters. Besides this, challenges were faced in applying various objective and subjective experimental tools. Consequently, on the one hand interoception was measured by the use of electrocardiography in a laboratory setting, but also by the use of wearable devices in a field setting. Moreover, data on physical activity, physical fitness and BMI in children were included in our analyses. Concerning emotion processing, emotion recognition was investigated by the use of electroencephalography in healthy adolescents. Lastly, emphasis was set on eating disorders and more specifically in female patients currently suffering from bulimia nervosa. On the other hand, exteroception was assessed by the RHI in adolescents and data were compared for individuals with high and low alexithymic traits. In the following section, all four studies included in this work are presented in a detailed way. Figure 6 demonstrates a summarized overview of the aim of this dissertation, including the three central domains: physical fitness, psychopathology and emotion processing.

![Figure 6: Overview of the present dissertation. Interoception and Exteroception are here regarded as the continuum of the biphasic sides of the multimodal self through the developmental spectrum under the observation of physical fitness, psychopathology and emotion processing.](Image)
## Part II: Summary of the present studies

<table>
<thead>
<tr>
<th>Study I</th>
<th>Study II</th>
<th>Study III</th>
<th>Study IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Domain: physical fitness)</strong></td>
<td><strong>(Domain: psychopathology)</strong></td>
<td><strong>(Domain emotion processing)</strong></td>
<td><strong>(Domain emotion processing)</strong></td>
</tr>
<tr>
<td><strong>Title</strong></td>
<td>Interaction of physical activity and interoception in children</td>
<td>Normal interoceptive accuracy in women with bulimia nervosa</td>
<td>Describe your feelings: Body Illusion related to Alexithymia in Adolescence</td>
</tr>
<tr>
<td><strong>Authors</strong></td>
<td>Eleana Georgiou, Ellen Matthias, Susanne Kobel, Sarah Kettner, Jens Dreyhaupt, Juergen M. Steinacker, Olga Pollatos</td>
<td>Olga Pollatos, Eleana Georgiou</td>
<td>Elena Georgiou, Sandra Mai, Olga Pollatos</td>
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<tr>
<td><strong>Publication Status</strong></td>
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</tr>
<tr>
<td><strong>Sample size</strong></td>
<td>N=49</td>
<td>N=23</td>
<td>N=54</td>
</tr>
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<td><strong>Methodology</strong></td>
<td>Actiheart® multi-sensor device, Polar watch</td>
<td>Electrocardiography</td>
<td>Rubber Hand Illusion Experiment</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>Daily physical activity, general physical fitness and its interrelation to interoception in primary-school children.</td>
<td>Interoceptive accuracy and awareness in young women with current Bulimia Nervosa and healthy women.</td>
<td>Alexithymia and Body ownership arising from exeroceptive/prioprioceptive signals in healthy adolescents.</td>
</tr>
</tbody>
</table>
2.1 Interaction of Physical Activity and Interoception in children

**Study I: Georgiou, Matthias, Kobel, Kettner, Dreyhaupt, Steinacker & Pollatos (2015)**

Two older studies have shown that a higher state of fitness could be advantageous for interoception (Borg & Linderholm, 1967; Montgomery, Jones, & Hollandsworth, 1984). Moreover, Herbert and colleagues (2007) investigated the self-regulation of physical activity, termed as physical load, in good and poor heartbeat perceivers. Findings of this study suggested that good heartbeat perceivers demonstrated a more enhanced perception of their exhaustion, after they were instructed to run on a bicycle ergometer for 15 min., whilst being free to control their cycling pace. Good heartbeat perceivers indicated lower changes in their heart rate, stroke volume and cardiac output than poor heartbeat perceivers, which revealed a higher ability of self-regulation, by setting their physical endeavor to a lesser extent. Furthermore, overweight and obese individuals were found to be less accurate in perceiving their own internal bodily signals (Herbert & Pollatos, 2014). Findings regarding a direct assessment of physical activity and physical fitness concerning interoceptive processes are sparse. More specific, to our knowledge, no study to date has explored the link between these variables of interests among children. Therefore, in Study I we aimed to investigate the interaction between interoceptive accuracy (IAC), physical activity not only in a performance task, but also in day-to-day activities, and body mass index (BMI) among 49 primary school children. We hypothesized that a healthy and a physical fit bodily state would be connected to higher IAC in primary school children, after taking into considerations previous findings in adults, implying a possible interconnectivity (Borg & Linderholm, 1967; Herbert & Pollatos, 2014; Montgomery et al., 1984).

Our subsamples of 49 and 21 primary school children derived from the “Baden Württemberg Study”; a study conducted by the team of “Join the Healthy Boat-Primary School” in south-western Germany (Dreyhaupt et al., 2012). Physical fitness in a performance task was assessed by the “6-min-run” (Dordel & Koch, 2014), in which children had to run around a volleyball field in, ideally, 6 minutes. Moreover, physical activity in free living conditions was measured for 5 consecutive days (5 x 24h) by the multi-sensor device Actiheart® (CamNtech Ltd., Cambridge, UK) which combines heart rate (inter-beat intervals) and accelerometer (in counts per minute) recordings. Data analysis was based on the metabolic equivalents (METs), a physiological measure that refers to the rate of energy consumption during physical activity.
(Ainsworth et al., 2000), in order to differentiate children with sedentary (<1.5 METs), light (1.5–3.0 METs) and moderate to vigorous (>3.0–6.0 METs) physical activity (Pate, Pratt, & Blair, 1995). Lastly, cardiac activity in a resting state was recorded using the mobile heart frequency monitor RS800CX (Polar Electro Oy, Kempele, Finland) and the children’s version of the mental tracking task (Koch & Pollatos, 2014; Schandry, 1981) was conducted.

Findings of this study revealed the essential role that physical fitness plays when perceiving one’s own internal bodily signals. More specifically, a good fitness state, normal to high BMI, as well as regular light physical activity were connected to higher levels of IAC in primary school children. We assume that these findings could also be relevant to regulatory health-related aspects of IAC, as previously suggested in adults (Herbert et al., 2007b). As this is the first study investigating these variables in childhood, we encourage more thorough research in this field in other developmental stages.

2.2 Normal interoceptive accuracy in women with bulimia nervosa

**Study II: Pollatos & Georgiou (2016)**

Bulimia nervosa is an eating disorder characterized by a fixation towards body weight maintenance, after episodes of bingeing large amounts of food followed by self-induced purging or other compensatory behaviors (American Psychiatric Association, 1994). Although anorexia nervosa is defined by a reduced BMI, patients suffering from bulimia nervosa appear to have normal or even in some cases an elevated weight-status (Pollatos et al., 2008; Pollatos & Georgiou, 2016). Interoceptive accuracy was found to be attenuated in Anorexia Nervosa (Pollatos et al., 2008), as well as in women recovered from bulimia nervosa (Klabunde et al., 2013). Whether this is also the case concerning those who currently have bulimia nervosa is still unknown, as preoccupation with bodily signals related to hunger and satiety is also central in bulimia nervosa (Cooper, Wells, & Todd, 2004). Bearing these in mind, scope of Study II was the exploration of a possible deficit interoceptive processing in women who currently suffer from bulimia nervosa disorder.

Our sample consisted of 23 patients, including purging and non-purging type and of 23 healthy women without any eating or mental disorder. IAC was assessed by the use of electrocardiography during the mental tracking task (Schandry, 1981), whilst interoceptive
sensibility was assessed by the Eating Disorder Inventor-2 (EDI-2; Thiel & Paul, 2006). Lastly, the effects of anxiety, depressivity and alexithymia were also taken into account.

Findings of this study did not reveal any differences regarding IAC in healthy participants and BN patients, something that contradicts previous findings in anorexia nervosa (Pollatos et al., 2008). On the contrary, interoceptive sensibility was found to be impaired in patients recovered from BN (Klabunde et al., 2013). An inverse correlation between IAC and interoceptive sensibility was found only in BN patients, which suggests that these two interoceptive processes do not go hand in hand and implies that a heightened attention to cardiac activity is not necessarily connected to a sustained attention towards satiety and hunger. Additionally, the adaptation of regulatory “skills” of BN patients reflected by the bingeing-purging symptomatology are taken into consideration, in an effort of explaining our findings. In summary, Study II encourages integrating elements connected to interoception in the therapeutic treatment of patients with BN, such as mindfulness techniques or somatic experiencing methods (Payne, Levine, & Crane-Godreau, 2015) to improve the perception of bodily sensations related to hunger and satiety, as attention to cardiac awareness was not found to be impaired.

2.3 Describe your feelings: Body Illusion related to Alexithymia in Adolescence

Study III: Georgiou, Mai & Pollatos (2016)

Forming the bodily self and differentiating the self from the others are essential factors in the formation of complex social behaviors from an early age, such as empathy, social referencing, dealing with ostracism, etc. (Cascio et al., 2012; Gallese, 2003; Pollatos, Matthias, & Keller, 2015). In addition, body ownership (the feeling of body as mine) might be under constant development in adolescence, where major physiological and psychological changes take place (Georgiou, Mai, & Pollatos, 2016). The “rubber hand illusion experiment” (RHE) combines visual, tactile and proprioceptive information in order to assess the concept of body ownership. Although various studies exist in this field among adults (Longo et al., 2008; Tsakiris et al., 2007; Tsakiris, 2010; Tsakiris et al., 2011; Tsakiris & Haggard, 2005), we know a fraction of this concept among adolescents. Extending these, a previous study (Grynberg & Pollatos, 2015) on adults demonstrated an interconnectivity between higher alexithymic traits and higher malleability of body-ownership. To our knowledge, no study to date has explored these two
variables in adolescents. Therefore, the goal of **Study III** was to scrutinize the association between low body ownership (termed as body illusion) and alexithymia (the inability to identify and describe one’s own and other’s feelings; (Herbert et al., 2011; Sifneos, 1973) in adolescents.

Accordingly, 54 healthy adolescents aged 12 to 17 years came to our laboratory. The RHI, which combines behavioral and autonomic data for assessing body illusion, took place. Participants had to fill in the “Toronto Alexithymia Scale” (TAS-20; Herbert et al., 2011; Taylor et al., 1991) in order to quantify alexithymia, which includes the following sub-scales: difficulties in identifying feelings, difficulties in describing feelings and externally oriented thinking. Results of **Study III** demonstrated a close relationship between higher body illusion and difficulties in describing feelings in adolescents, something that highlights the importance of embodiment (integration of exteroceptive and proprioceptive signals) on forming healthy levels of emotion awareness. In other words, adolescents with an attenuated body ownership, demonstrated at the same time more difficulties in describing feelings. Whether a disturbed body ownership triggers alexithymia, or the other way around, still remains unclear.

### 2.4 I see neither your fear nor your sadness-Interoception in Adolescents

**Study IV**: Georgiou, Mai, Fernandez & Pollatos (2018)

Prior research on interoception has indicated a close interrelation between high IAC and greater emotional experience in adults (Terasawa, Moriguchi, Tochizawa, & Umeda, 2014; Wiens, Mezzacappa, & Katkin, 2000). Furthermore, activity in the anterior insula revealed the interconnectivity between bodily and emotion experience (Craig, 2009; Critchley et al., 2004; Harrison et al., 2010; Seth, Suzuki, & Critchley, 2012; Zaki et al., 2012). At the same time, decoding facial expressions plays a salient role in socializing (Suzuki, Poon, Kumari, & Cleare, 2015) and can be regarded as a prerequisite for forming emotional experiences in daily life. Whether interoception can influence emotion processing via reading facial expressions of others is still unresolved. To our knowledge, no study to date has examined this topic, neither in adults nor in children and adolescents. Therefore, the scope of **Study IV** was to understand how adolescents perceive emotions of others by taking as a starting point the perception of their bodily signals.

Participants of **Study IV** were 54 healthy adolescents, aged between 12 to 17 years. In this study, brain activity was recorded by the use of Electroencephalography (EEG), while
participants had to observe pictures with different facial expressions, which depicted the following emotions: neutral, happy, sad, afraid and surprised. At the end of the task, participants had to name each facial emotion separately. Lastly, electrocardiography (ECG) was used in order to quantify IAC by the Mental Tracking Task (Shandry, 1981).

Visual evoked potentials (VEPs) were assessed and EEG data for the following components of the VEPs were examined: the P100, the N170 and the P300 ERP components, which revealed intriguing associations between cognitive and emotion processing during the decoding of fear and sadness. Adolescents high in IAC paid more attention and consequently perceived fearful faces more intensely, as reflected by higher N170. Interestingly, adolescents high in IAC did not accurately recognize fear or sadness, but were able to recognize the negative and unpleasant content of these stimuli. All in all, Study IV places emphasis in the dynamic integration of mind and body to form emotion recognition, by taking into consideration the regulatory nature of IAC, as well as the asymmetry observed concerning emotional valence and arousal.
Part III: Discussion

Overall, this dissertation aims to establish a basis in understanding how cognition and affect interact in order to shape human consciousness and hence the perception of the *multimodal self*, in order to maintain homeostasis across the lifespan. Table 3 demonstrates the thematic overview of the present studies. More specifically, Studies I, II and IV try to elucidate the underlying mechanisms of interoceptive abilities in different populations. Firstly, Study I introduced IAC in primary school children and demonstrated that a physically fit bodily state can be beneficial for IAC, raising questions concerning the general role of physical fitness and weight status in interoceptive signaling. Interestingly, higher levels of IAC were associated to light physical activity, rather than to moderate or vigorous, something that might be related to a more self-controlled physical workload. Bearing these in mind, one can wonder whether physical activity and physical fitness could contribute to enhancing interoceptive processing in childhood and thus maintaining a healthy body and mind interaction through the years.

Moreover, Study II compared the role of various interoceptive axes, such as IAC and interoceptive sensibility in a sample of women currently suffering from bulimia nervosa (BN). Patients with BN indicated normal IAC levels but concurrently reduced levels of interoceptive sensibility, something that contradicts prior research in eating disorders (Klabunde et al., 2013; Pollatos et al., 2008). The association between these two interoceptive facets in the clinical sample were not found to be interwoven, but on the contrary asymmetrical, and therefore this finding distinguishes between hyper-vigilance towards bodily signals related to hunger and satiety and accuracy in detecting cardiac activity. These results raise questions regarding the therapeutic treatment of patients with eating disorders, by introducing a new perspective in the field of interoceptive processing. In Study IV, the relationship between IAC and emotion face recognition in healthy adolescents was explored. Electrophysiological evidence revealed higher sensitivity, but low accuracy towards negative emotions in adolescents high in IAC. Variables like valence and arousal were taken into account in emotion recognition, highlighting the regulatory mechanisms of IAC in adolescence, which might contribute in maintaining homeostasis and is associated to health related parameters. Lastly, Study III focuses on the concept of embodiment and explores the possible connection between body ownership and alexithymia in adolescents. Higher malleability of body ownership was found to be connected...
to more difficulties in describing feelings, suggesting a close interplay between bodily and emotion processes. In this case, a vicious circle can occur, in which affect and integration of exteroceptive/proprrioceptive signals become more entangled.

Table 3: schematic overview of the main thematic field of the present studies.

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<th>Multimodality</th>
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Reflecting back, Sherington (1906) was the first scientist to use the term “interoceptive” stimuli and, until today, interoception has been the focus of interdisciplinary debate (Ceunen et al., 2016). Moreover, exteroception and proprioception subserve the formation of embodiment, which has drawn substantial attention, as embodied interaction is crucial for social cognition and can influence the onset of psychopathology (Fuchs & Schlimme, 2009). Taken together, interoceptive and exteroceptive processes are crucial for the self’s multidimensional representation (Tsakiris, 2017), as well as for the maintenance of a healthy state of mind (Tsakiris & Critchley, 2016). Nevertheless, developmental studies concerning these different aspects were, until now, sparse (Murphy et al., 2017). Nowadays, little is known of how interoception and exteroception evolve and which role emotions play, since the feeling of the self can be regarded as the anatomical foundation of our emotional awareness (Craig, 2008; Herbert & Pollatos, 2012). For all the aforementioned reasons, we chose to elaborate on these topics, in an effort to expand knowledge on this field. Accordingly, a more thorough discussion regarding these topics is outlined in the following chapter:

3.1 Developmental characteristics of interoception and exteroception

Study I revealed that interoception can be objectively determined in primary school children, using the children’s version of the Mental Tracking Task as previously proposed by Koch & Pollatos (2014), in which the given time intervals in this task are shorter (15, 20 and 18 sec.). Children were able to detect their heartbeats and differed considerably in their IAC, without checking their pulse. These results are in accordance with the study of Koch & Pollatos (2014),
who found out that children aged between 6 to 11 were able to detect their heartbeat, as primary school children are in general able of being aware of their bodily functions from this young age (Jaakkola & Slaughter, 2002; Koch & Pollatos, 2014). But why is it important to explore interoception in childhood? Murphy and colleagues (2017) suggested that atypical interoception, which describes unusually high or low IAC, IS and IA (see p. 9, table 1) in the general population, could be perceived as a common factor causing a variety of psychological disorders. Understanding the development of interoceptive processes throughout a life span could contribute to understanding better the etiology and genesis of mental disorders associated to atypical interoception (Murphy et al., 2017). Psychological disorders connected to atypical interoception include mood and anxiety disorders (Paulus & Stein, 2010), as well as eating disorders (Berner et al., 2018; Frank, 2015; Kerr et al., 2016; Khalsa et al., 2015; Khalsa et al., 2017; Pollatos et al., 2008), post-traumatic stress disorder, somatic symptoms disorders (Khalsa & Lapidus, 2016), borderline personality disorder, obsessive compulsive disorder and developmental disorders, such as autism spectrum disorder (Flack, Pané-Farré, Zernikow, Schaan, & Hechler, 2017; Garfinkel et al., 2016; Khalsa et al., 2017). Furthermore, understanding how body perception develops through the ages can help us further explore the developmental phases of self-regulation, self-awareness and socio-emotional abilities (Maister et al., 2017).

One potential problem is that the methodological limitations can hinder the study of interoception from a developmental aspect. Kindergarten children cannot count, in comparison to older children, and therefore the mental tracking task (Schandry, 1981) cannot be implemented in this case. Maister and colleagues (2017) developed the non-verbal Infant Heartbeat Task (iBEAT), in which infants (mean age 5.13 months) viewed a synchronized and an asynchronized, to their heartbeat, moving animated character and were able to integrate external stimuli with interoceptive signals, paving the way towards new methodologies that measure cardiac awareness and that are suitable for younger age groups, but also for non-human animals (Evrard, Logothetis, & Craig, 2014; Maister et al., 2017). Therefore, these methodological issues can be considered as a vast scientific challenge for the future, which could enable us to broaden the opportunity of including manifold samples in the study of interoception.

Study IV demonstrated that assessing IAC is also reliably possible among adolescents, as 14 out of 54 participants were found to be good heartbeat perceivers, which reveals distinct inter-individual differences in the cardiac accuracy in adolescence. It is known that adolescence
is characterized by immense hormonal, physical and neurological changes (Blakemore, Burnett, & Dahl, 2010; Blakemore & Choudhury, 2006; Coleman & Hendry, 1990; Crone, van Duijvenvoorde, & Peper, 2016; Murphy et al., 2017), as well as by psychological changes concerning cognitive flexibility, the sense of identity and self-awareness (Blakemore & Choudhury, 2006; Rutter & Rutter, 1993) and the maturation of self-regulatory behavior (Li, Zucker, Kragel, Covington, & LaBar, 2017), all characteristics that can influence, later on, the proclivity for psychological disorders (Murphy et al., 2017). In line with that, an interesting point raised by Li and colleagues (2017), is that the development of the contextualization of interoceptive processes might peak during adolescence, as adolescents can perceive the effects that social interactions might have on their own visceral changes (e.g. behavior guidance or socializing according to what makes one feel good or happy), but without explicitly being aware of the ongoing interoceptive processes or having executive control over their interosensations. To elaborate, atypical interoception in adolescence could lead to poor contextualization of bodily signals and moreover to clinical conditions (Murphy et al., 2017). On the other hand, Herbert and Pollatos (2012), describe interoception as a trait-like sensitivity in adults. One could wonder whether, firstly, atypical interoception found in adolescents, does constitute a trait which remains stable through the years, or, secondly, this phenomenon is malleable and protean. In other words, if, in 7-years’ time, we were to involve in a future study the same participants included in Study IV, but instead as adults, would we still find the same results as in Study IV? Would individuals demonstrate same levels of high IAC after seven years? To answer these questions, the implementation of a further longitudinal study would be needed.

Thus far, after examining interoceptive signaling, it is worth underlining that in exteroceptive processing, body perception and the sense of self are under constant development from infancy to childhood (Cowie, Makin, & Bremner, 2013). In accordance, Study III presented that the exploration of body ownership/embodiment through multisensory integration arising from vision, touch and proprioception is feasible among adolescents aged 12 to 17 years in a subjective, behavioral and autonomic level. Investigating this is of high importance, as the sense of body ownership can influence the formation of self-identification and self-differentiation (Cascio et al., 2012), that are prominent in developing more complex social behaviors, such as: empathy and imitation (Cascio et al., 2012; Chaminade et al., 2005; Gallese, 2003). This could suggest that pinpointing one’s own bodily and mental state is essential for social relatedness. Indeed, social relatedness and autonomy are crucial elements in the daily life of adolescents, as there is a high need of, firstly, being accepted by their peers and secondly,
being independent in life; factors connected to healthy development and psychological wellbeing (Deci & Ryan, 2008; Leversen, Danielsen, Birkeland, & Samdal, 2012). Taking this into consideration, one can assume that a dysfunctional representation of the bodily self in adolescence, as defined by low body ownership, could be connected to lower social relatedness and autonomy, which can lead to a poor mental health development. As there is a dearth of research in this field, future studies should shed light on this.

In conclusion, the above mentioned studies demonstrated that the measurability of interoceptive and exteroceptive processes in primary school children and adolescents is feasible. At the same time, questions regarding the methodological issues especially in young aged samples were raised. Both interceptive and exteroceptive processes were connected to health-related behaviors and could possibly indicate a risk factor for developing psychopathology, not only at the current developmental stage, but later on in life, as both processes are connected to the sense of identity, self-awareness, self-regulation, self-differentiation, social relatedness and empathy. Collectively, one can wonder what the future of prevention and intervention in clinical and developmental psychology will look like. There is a need for developing prevention programs in kindergarten, elementary and high schools, by integrating the interconnectivity between body and soul in the promotion of psychological and physical wellbeing, as well as a need for the development of new therapeutic approaches by placing the same amount of emphasis on the body, as on the emotions. In the following section of the dissertation, a more thorough discussion on emotion recognition follows.

### 3.2 Domain: physical fitness

In Study I, the role of physical activity and physical fitness were explored, as prior research on adults has demonstrated that a better fitness state could be advantageous for interoception (Borg & Linderholm, 1967; Montgomery et al., 1984). Our findings in primary school children indicated that physical fitness plays a determinant role in IAC, also in cases where BMI is high. Therefore, children in a good physical state perceived their heartbeats more accurately (Fig. 7), underlying the positive outcomes of physical fitness in early and later childhood. Prior research has shown that children’s excess weight can influence negatively the heart’s physiological function, as obese children demonstrate lower heart rate reserve (HRR), an indicator that describes the difference between maximum and resting heart rate (Vaccaro & Huffman, 2016). On the contrary, it has been found that, when children exercise regularly, there is an increase on their HRR (Vaccaro & Huffman, 2016) and a decrease in the resting heart rate,
as the heart tends to become larger due to endurance training and it does not need to beat so fast, in order to produce blood (Dong, Wang, Wang, & Ma, 2015; Fernandes et al., 2013; “Resting Heart Rate, 2012), something that in the long term is crucial for the prevention of cardiovascular diseases in adulthood (Fernandes et al., 2013). Whether changes in the HRR and the size of the heart among physically fit children can influence the way that children perceive their cardiac signals, it still remains an open question.

![Diagram](image)

*Figure 7: primary-school children with normal to high BMI and high physical fitness perceived their cardiac activity more accurately.*

Interestingly, a recent study in professional adult ballet dancers revealed higher IAC levels, in comparison to non-dancers, suggesting that dancing includes physical fitness and a strong focus on attention to bodily signals through movement coordination and flexibility, as well as the use of the body for expressing emotional states, something that, seemingly, plays a crucial role in IAC (Christensen, Gaigg, & Calvo-Merino, 2017). As this is the first study investigating a specific group of individuals, who undergo regularly intensive training, more scientific research is needed in order to find out whether this applies also to other athletes or individuals who are just physically active in their daily life and not professional athletes.
Moreover, in Study I, higher levels of IAC were revealed in children that undertook light physical activity, rather than moderate or vigorous, which uncovers the possible regulatory aspects of interoception. Prior research on adults has demonstrated that individuals high in IAC perceived their exhaustion faster and set their physical endeavor to a lesser extent than individuals low in IAC, after being instructed to run on a bicycle ergometer for 15 minutes (Herbert et al., 2007b). Taking this into consideration, the interpretation of our results concentrate on the fact that children high in IAC, might perceive their cardiovascular strain faster due to their heart’s accelerated beating and increased oxygen demand, whilst undertaking physical activity and, as a result, they are more able in self-regulating their physical activity, in order to avoid fatigue in everyday life and maintain homeostasis. Learning how to perceive fatigue from this young age is crucial, as fatigue can reduce children’s quality of life, is related to health problems and psychiatric conditions (Aromaa, Rautava, Helenius, & Sillanpää, 2003; Luntamo, Sourander, Santalahti, Aromaa, & Helenius, 2012). In this way, interoception not only enables children to listen to their own bodily signals, but it could also be seen as a protective factor against overexertion, by providing continuous feedback of the body, which could accompany children throughout life.

From another point of view, McMorris and colleagues (2018) posit that that the way we perceive fatigue is much more multifactorial than expected, as this derives from interoceptive predictions. Hence interoceptive predictions are central, as these are based on past experiences of analogous physical exercise, on the subjective perception of existing fitness level, the importance of the activity undertaken and beliefs on whether or not current performance is going to be evaluated, like in competition situations (McMorris, Barwood, & Corbett, 2018). Lastly, own long-term goals, personality traits and development can further affect these predictions. Taking into account that the self-regulation of physical activity can be dependent on the above mentioned interoceptive predictions, the concept of predictive coding (PC) can be noted, as previously described in the introduction part, in which prior internal knowledge is compared to incoming information, resulting in prediction errors (Marshall, Gentsch, & Schuetz-Bosbach, 2018). When there is a discrepancy between preexisting internal models and sensory feedback, then prediction errors concerning body’s interoceptive state are developed (Marshall et al., 2018; Tsakiris, 2016). Applying all this knowledge to the regulation of fatigue; it can be that by lowering the above mentioned discrepancy between prior knowledge / experience regarding physical activity and physical fitness and bodily sensory feedback while being physical active, could result in less prediction errors regarding the body’s interoceptive
state and possibly give rise to a more effective self-regulation of physical activity, as the individual would be more aware of the timing of exhaustion (Fig. 8). To achieve this in children, the promotion of experiential knowledge concerning bodily signals in physically active and not physically active situations, as well as the training of mindful based techniques, is needed.

![Diagram of predictive coding](image)

*Figure 8: PC in describing the self-regulation of PA. PC: predictive coding, PA: physical activity, PE: prediction errors.*

Overall, in this section of the discussion, we demonstrated that physically fit children with a normal to high BMI revealed higher levels of IAC. A possible explanation for this can be the changes in the maximum and resting heart rate that children in the long term are more eager to perceive. Furthermore, we showed that children that undertook regularly light physical activity, at the same time also indicated higher levels of IAC, as a possible effort for regulating their fatigue, suggesting a possible association between self-regulation of physical activity and IAC in childhood. Keeping these in mind, interoceptive predictions and other variables such as personality, should be taken into account in future studies.

### 3.3 Domain: emotion processing

Researchers have been struggling with the interconnectivity of bodily experience and emotions for over a century (James, 1884). Keeping this in mind, in Study III, we demonstrated that low levels of embodiment were connected to heightened difficulties in describing feelings
among adolescents and therefore suggesting that the connection between body and emotions might be stronger than we have expected. Accordingly, prior research has shown that alexithymia is related to experiential avoidance, which is described as the effort of avoiding experiencing negative memories or emotions, as well as unpleasant bodily sensations (Panayiotou et al., 2015). In a same manner, it has been found that alexithymic individuals have a general difficulty distinguishing somatic from affective symptoms (Byrne & Ditto, 2005; Panayiotou et al., 2015). But the question still remains, whether this idea is also analogous to interoception.

For clarifying this, it is worth mentioning that recent prior research has shown that individuals with accurate body perception, tend to experience their emotions more intensely (Barrett et al., 2004; Critchley, 2004; Herbert et al., 2007a; Terasawa et al., 2014; Wiens et al., 2000; Zaki et al., 2012) and there is strong evidence that interoception and emotional experience share the same functional neural overlap, namely the anterior insula (Zaki et al., 2012). This sets the basis for a deeper understanding on how individuals experience their own emotions, but does not necessarily clarify what happens with recognizing emotions of others. In other words, does this juxtaposition automatically denote that individuals high in IAC would also experience the emotions of others in the same intense or granularity emotions, as they experience their own emotions? If this is the case, will they also be generally better at recognizing emotions? In Study IV, it was demonstrated that adolescents high in IAC were less accurate in recognizing fear and sadness, thus negative emotions, despite experiencing more intensely these emotions, as evidenced by higher N170 ERPs amplitudes. Accordingly, the N170 is an event-related potential (ERP) linked to facial processing (Earls et al., 2016; Mai et al., 2015) and is dependent upon neural system maturation, thus upon age (O’toole, DeCicco, Berthod & Dennis, 2013). Remarkably, these adolescents detected the negative and unpleasant content of these stimuli, as they confused fearful with sad facial expressions. But why was interoception connected, in this case, with more recognition errors in fear and sadness when participants high in IAC paid greater deal of attention to these two emotion categories?

One possible explanation might arise from the emotion regulation strategy of reappraisal, in which the importance of an emotion is being reframed to lower its affective impact (Gross & Thompson, 2007). The down-regulation of negative-affect arousal was found to be connected to IAC in a previous study in adults (Fuestoes, Gramann, Herbert, & Pollatos, 2013), reflected by lower P300 amplitudes. In this way, the more aware a person regarded his or her own interoceptive signaling, the more successfully could this person regulate a possible
negative affect. Taking this into consideration, one could hypothesize that in Study IV, despite being more attentive, adolescents high in IAC made more errors in recognizing fear and sadness as an effort of minimizing feelings of negativity, frustration and distress, that negative emotions often cause (Suzuki et al., 2015). This comes in agreement with further “appraisal theories”, in which explicit cognitions concerning the causes of physiological reaction, which are guided by attention and awareness (Frith & Frith, 2008), can have an impact on our emotional behavior and the formation of our subjective affective state (Gendron & Feldman Barrett, 2009; Seth, 2013).

In the same manner, the close link between signal processing from the heart and emotion face recognition was demonstrated in a study by Garfinkel and Critchley (2016), in which the heartbeat timing effect on emotional processing, and more specifically on fear, was investigated. As a result, it was found that cardiovascular arousal could amplify feelings of fear. In that study, pictures of fear were presented according to the cardiac cycle either at systole (robust contraction-heartbeat) or at diastole (heart muscles are quiescent-between heartbeats). Findings among participants revealed that the experienced intensity, as well as the detection ability of fear was greater in the systolic condition rather than in the diastolic condition (Garfinkel & Critchley, 2016). Furthermore, this was found to be connected to a heightened amygdala activity; a brain region, in which physiological and affective information are found to be integrated, thus contributing to the rapid distinction between flight or fight responses (Garfinkel et al., 2014; Garfinkel & Critchley, 2016). Accordingly, reading fearful face expressions in adults is influenced by the heart, in order to shape perceptual consciousness, influenced by interoceptive signaling (Garfinkel & Critchley, 2016). In light of this, in Study IV adolescents high in IAC could have been more sensitive to threat, but not accurate in decoding fear, in an effort of regulating a possible sympathetic activation, or in other words, a more finely tuned “fight or flight” response, as interoception is related to homeostatic control and allostatic adaptation (Tsakiris & Critchley, 2016).

Having clarified the regulatory mechanisms of IAC, another possible explanation concerning high sensitivity to negative emotions, but low accuracy in the recognition of fear and sadness, could arise from the “circumplex model of affect” proposed by Russel (1980), in which valence (pleasure-displeasure continuum) and arousal (alertness) are the two crucial neurophysiological systems that form emotional experience and contribute in differentiating emotions from a nearby/similar emotion (Posner, Russell, & Peterson, 2005). More specifically, fear involves, on the one hand, negative valence and on the other hand, heightened arousal in
the central nervous system and the subjective experience of fear is often related to the cognitive interpretation of the neurophysiological changes based in these two systems (Russell, 2003). Ultimately, in Study IV adolescents high in IAC could have been more focused on the stimulus averseness, rather than on its arousal dimension (thus lower P300 amplitudes), as sadness and fear are perceived as equally unpleasant emotions, something that might have resulted in more errors in emotion face recognition.

One could hypothesize that the high error rate in emotion face recognition among adolescents high in IAC might reveal disturbed social abilities, as recognizing facial emotion expressions can be considered as a cognitive basis of interpersonal functioning (Berenschot et al., 2014). Findings regarding these are mixed, as an enhanced emotion face accuracy recognition was found among adolescents with personality pathology compared to healthy controls, whereas adolescents with social anxiety were less accurate in identifying angry faces (Jarros et al., 2012). In a recent study, children with social anxiety disorder did not differ in electrocortical and behavioral responses in comparison to healthy controls in emotion face recognition (Keil, Uusberg, Blechert, Tuschen-Caffier, & Schmitz, 2018), hence a close link between accurate face recognition and normal interpersonal functioning could not be confirmed. All these questions are crucial in adolescence, where peer relations play a pivotal role and the vulnerability to negative experiences in interpersonal behaviors is high (Berenschot et al., 2014, Georgiou et al., 2015).

To that end, inter-individual differences in emotional vulnerability and distress as a reaction to negative emotions of others, can be influenced by the body-brain-mind axis, described as interoception. Enhanced interoceptive processing from a young age might constitute a protective factor against the development of psychiatric disorders that can be related to misinterpreted physiological hyper- and hypoarousal, which can underpin negative affective states and in its turn can cause catastrophic interpretations and dysfunctional cognitions (Clark et al., 1997; Garfinkel & Critchley, 2016; Paulus & Stein, 2010; Teachman, Marker, & Clerkin, 2010). After all, the way we experience our physical and social environment might be more interactive than expected (Garfinkel & Critchley, 2016). To summarize, future research should clarify the interaction of emotion recognition and interoceptive processing.
3.4 Domain: psychopathology
Eating disorders, including anorexia nervosa (AN) and bulimia nervosa (BN) are psychiatric illnesses, characterized by a chronic course and increased risk of mortality (Arcelus, Mitchell, Wales, & Nielsen, 2011; Brown et al., 2018). Findings of a previous study with women suffering from AN (Pollatos et al., 2008), revealed difficulties in accurately perceiving bodily signals, as well as in differentiating feelings related to satiety and hunger. One could hypothesize that a similar processing pattern will be also present in BN.

On the one hand, in Study II, women currently suffering from BN demonstrated normal levels of IAC, when compared to healthy women, which reveals the absence of difficulties in accurately detecting cardiac signals and a possible finely tuned adaptation of regulatory strategies, as interoception has been found to be related to better self-regulation (Fuestoes et al., 2013; Herbert et al., 2007b), something that, in this case, could foster the maintenance of bulimic psychopathology. This finding does not come in agreement with prior research, in which women who recovered from BN revealed deficits in IAC, even after recovery (Klabunde et al., 2013). One central symptom in BN is binge eating, which could reveal a finely tuned implicit emotion regulation that describes a process elicited automatically and without conscious effort by a stimulus (Robinson, Safer, Austin, & Etkin, 2015). In line with that, the “affect regulation model” describes binge eating as an effort of providing temporary relief against aversive emotional states via negative reinforcement, such as consumption of large amounts of high caloric food (Polivy & Herman, 1993; Robinson et al., 2015; Telch, Agras, & Linehan, 2001). Accordingly, this pattern enables the distraction from thoughts and emotions and in the process of purging the anxiety normally declines, followed by relief and a general emotional catharsis (Figure 9; Burton, Stice, Bearman, & Rohde, 2007; Cooper et al., 2004; Kaye, Gwirtsman, George, Weiss, & Jimerson, 1986). The fact that in Study II IAC was found to be normal might indicate that BN patients adapt a coping mechanism reflected by this binge eating-purging scheme, as an effort of regulating their thoughts and emotions, something which differs from patients with AN, who use as a coping strategy shutting down any bodily sensations, thus deficit IAC. The answer to whether this coping mechanism in BN would have a long lasting positive effect in maintaining homeostasis, could be in this case a negative one, as this is related mainly to a temporal relief, which reinforces the maintenance of psychopathology. Lastly normal IAC found in Study II could explain why patients with BN try to maintain their body weight, although they show a general body image disturbance (Mai et al., 2015).
On the other hand, in **Study II** interoceptive sensibility measured by the self-report Eating Disorder Inventor-2 (EDI-2; Garner, 1984; Paul & Thiel, 2005) was found to be attenuated compared to the healthy sample, which suggests low propensity of being interoceptively focused and at the same time reveals decreased sensitivity towards bodily processes regarding hunger and satiety. This finding was expected, as BN patients demonstrate a lack of control over eating behaviors (Cooper et al., 2004). Interestingly, an inverse interrelation was found between IAC and interoceptive sensibility, arguing that a deficit attention and evaluation of internal signals of hunger and satiety, could not decrease the accurately detection of cardiac signals. Such findings have been demonstrated in prior research (Garfinkel et al., 2015) among healthy participants, in which IAC and interoceptive sensibility were found to be dissociable (Figure 10). This asymmetrical relationship between these two facets of interoception underline the multidimensionality found in its objective and subjective indices. Inevitably, these findings could have clinical implications, as there is a need for developing new treatments that include interoceptive processes. Learning how to evaluate internal bodily cues related to hunger and satiety, as well as finding counter-strategies, which do not include self-harmful behaviors such as binge eating or purging could play an important

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*Figure 9: “The cognitive model of bulimic pathology” based on Cooper et al. (2004). Vicious circle depicting reinforcement.*
role in the therapeutic intervention of BN. Similarly, mindful techniques or somatic experiencing that use interoception as an essential element in reducing symptoms caused by chronic and traumatic stress (Payne et al., 2015), might be highly effective in the treatment of eating disorders.

![Figure 10: Contrasting findings between objective and subjective indices of interoception in bulimia nervosa.](image)

### 3.5 Improving multidimensional integration/intervention

Thus far, we tried to define and discuss our findings on interoception and exteroception from a developmental, clinical and affective perspective. In specific, **Studies I, II, III and IV** underlined the importance of embodied cognition for physical and mental health through the life span, paving the way for new advances in the development of prevention and intervention. A common point in all four studies was that normal to high IAC and a strong sense of embodiment, as defined by body ownership, could be advantageous for a healthy state of body mind. Certainly, by promoting and increasing mental and physical health in children and adolescents is fundamental for every society, as it can increase levels of happiness and psychological well-being that could last until later adulthood. Subsequently, a plausible question which raises concerns is about the way this could be achieved. Accordingly, is interoception alterable? Should attenuated levels of interoception and embodiment be
considered as a trait and thereby not changeable? In other means, is there scientific evidence that body perception can be trained and as a result can be improved?

Prior research suggests that mindfulness techniques, such as mindfulness-based stress reduction (MBSR) can reduce feelings of stress, associated with chronic psychiatric disorders (Bowen et al., 2006; Haase et al., 2016; Hofmann, Sawyer, Witt, & Oh, 2010) and might be helpful in improving interoception (Farb et al., 2015), as training perceiving internal bodily signals consists a crucial aspect in these interventions. More specifically, mindfulness can be described as the awareness, which arises through non-judgmental focus in a present moment (Haase et al., 2016; Kabat-Zinn, 2006). Findings of a former study among active duty marines (Haase et al., 2016), demonstrated that mindfulness-based techniques had an effective impact on neural modulation, particularly a low right anterior insula activation, after being exposed to an aversive interoceptive respiratory stimulus and contributed to enhanced coping abilities. In a same manner, interoceptive sensibility was increased after a mindful based intervention in depressive patients with chronic pain, underlying its clinical relevance (de Jong et al., 2016). However, previous studies have shown that experienced meditators did not demonstrate higher levels of IAC in comparison to controls (Khalsa et al., 2008; Nielsen & Kaszniak, 2006), as well as brief meditating training did not have an impact on cardiac awareness (Mirams, Poliakoff, Brown, & Lloyd, 2013; Parkin et al., 2014). Contradicting these results, findings of a recent large longitudinal study (N=160) (Bornemann & Singer, 2017) demonstrated that IAC was enhanced after 39 weeks of a mindfulness-intervention in a healthy population, as well as another study group revealed that body scan interventions can enhance interoceptive processes over 8 weeks (Fischer, Messner & Pollatos, 2017). All these diversifying findings reveal a long-lasting debate, in which broadening the emphasis on various bodily systems when exploring the effect of mindfulness techniques on interoception, might be of high importance (Parkin et al., 2014).

In clinical practice, interoceptive exposure (IE) is a core element of cognitive behavioral therapy (CBT), which describes an in vivo exposure related to interoceptive sensations, in which confronting physical sensations related to negative emotional experiences through interoceptive conditioning play a key role (Boettcher, Brake, & Barlow, 2016). Goal of IE is to provoke bodily sensations arising from the cardiovascular, audiovestibular, respiratory and gastrointestinal system (Boettcher et al., 2016), by running on an ergometer to achieve tachycardia, or breathing through a straw to induce shortness of breath and dizziness etc. (Lee et al., 2006). Although there is an abundance of studies investigating whether IE can be effective
in treating psychiatric disorders, there is a dearth of research concerning whether IE can improve IAC and in general embodiment.

Targeting embodiment, virtual reality can be seen as a useful medium in applying bodily illusion, such as body swapping (Serino et al., 2015). In the body swapping illusion, a person observes a virtual body being stroked with its own real body, as a result an experimentally “out-of-body” experience in a conscious way is induced, affecting body-representation (Serino et al., 2015). Although this task has been applied mostly on healthy participants, a future challenge could focus on patients suffering from eating disorders (Serino et al., 2015), or even in other clinical and healthy populations, in order to train embodiment.

Furthermore, somatic experiencing, a form of trauma therapy (SE), focuses mainly on attention towards interoceptive and proprioceptive signals, as well as towards kinesthesis (Payne et al., 2015) and it aims to create new corrective and more functional interoceptive experiences that physically contravene previous frustrating and overwhelming experiences. In other words, in SE the focus is brought to internal sensations that catalyze biological completion of traversing responses occurring from chronic and traumatic stress, in order to form new interoceptive experiences that could lead to a better regulation of excessive autonomic arousal (Payne et al., 2015). Thereby questioning, like “What does it feel like my body wants to do” (Payne et al., 2015, p.15) facilitates drawing attention to interoceptive and proprioceptive information as part of psychotherapeutic treatment.

In conclusion, the answer to the appointed question on whether interoception and the sense of embodiment are alterable, would be that the available scientific evidence is not strong enough to support the idea that we indeed can train the phenomenological experience of our body state based on internal, external or proprioceptive signals. Although there is data pointing out that MBSR could enhance interoceptive signals, scientific findings concerning these are mixed.

### 3.6 Limitations and strengths of the empirical studies

In total, findings of **Study I, II, III and IV** were carried out in samples including primary-school children, adolescents and female patients suffering from BN. In **Study I** we did not include variables like hyperactivity or deficit attention that could have an influence on the mental tracking task. Concerning **Study II**, the clinical sample was heterogeneous, as patients with comorbidities such as anxiety disorder and major depression were included, something that could have an impact on our results and moreover the samples’ size was relatively small.
Furthermore, the clinical sample derived from counseling units and not from in-hospital settings, where there was a lack of control over the psychotherapeutic treatment, as part of these patients underwent CBT or psychoanalysis and another part did not receive any psychotherapy. To that end, future studies should include a larger sample of BN patients, receiving similar psychotherapeutic treatment. Moving to Study III, the fact that we did not include in our analyses variables like personality traits, such as: introversion and extraversion, when assessing alexithymia, could be seen as a shortcoming. Furthermore, we assessed alexithymia by using only self-reports and not objectively determined measures. Due to the small sample size (N=54), statistical analyses including exploratory factor analysis for the exploration of the patterns of correlation between RHI and alexithymia, was not possible. In Study IV, we found that adolescents were able to detect their heartbeat, which indicates that adolescents could focus on their interoceptive signaling in a performance task set in the laboratory. Whether this applies to everyday life and during social interactions, remains unclear. The fact that we did not include measures of emotion regulation and data concerning valence and arousal, could also be seen as a shortcoming. To that end, we encourage conducting further developmental studies in a longitudinal manner, by including larger samples.

However, the empirical studies included in this dissertation also have certain strengths. Firstly, the methods used for assessing our data were diverse, as we did not include only self-reports in our experiments, but also psychophysiological methods. In Study I wearable devices, suitable for our field study in primary schools, measured heart rate, as well as physical activity in everyday life. This allowed us to take a closer glimpse into the cardiac data of children, by collecting data in 15 second epochs and under real-time conditions. Furthermore, in Studies II and IV we assessed IAC by the use of electrocardiography and in Study IV brain activity was recorded by the use of electroencephalography (EEG), in which cognitive and attentional processes were measured along cardiac activity. Lastly, in Study IV the aforementioned rubber hand illusion experiment was conducted to experimentally assess body ownership. Therefore, in all four studies there was a variety of methods involved, something that strengthens our findings. In addition, these empirical studies could also be characterized as innovative, as in this field of studies there is a lack of research, as important questions were scrutinized as relevant for developmental and clinical psychology, as well as neuropsychology, cybernetics etc. Last but not least, the fact that we included samples of children, adolescents and a clinical population of adult females in our studies, can also be perceived as a strength. In summary, the
variety of methods used, the innovation regarding our scientific hypotheses and the diverse
samples can be all seen as sizable strengths of this dissertation.

3.7 Synopsis and future research-The Road Ahead

Undoubtedly, the field of multimodal integration of interoceptive and exteroceptive stimuli for
forming the self and hence consciousness, is vast. Although philosophers have been struggling
throughout the centuries to find an answer to this body-mind enigma, it has been only recently
in 1906 that Sir Charles Scott Sherrington referred to endogenous versus exogenous stimuli.
Since then, and more specifically after 1980, there has been a surge of scientific interest, due to
the fact that interoceptive and exteroceptive processing were found to influence emotion
awareness, consciousness, self-regulation etc. (Khalsa et al., 2018). A key factor in the scientific
research of these aspects has been, until now, the interdisciplinary approach, as well as the
development of new experimental methodologies, such as wearable devices etc.

Thus far, we know that, on the one hand, interoception is vital for maintaining the body’s
homeostasis (Ceunen et al., 2016; Tsakiris, 2017), is strongly connected to the awareness of the
self (Tsakiris, 2014), is related to different aspects of emotion processing (such as intensity and
arousal; Barrett et al., 2004; Critchley, 2004; Pollatos, Gramann, & Schandry, 2006; Wiens,
2005; Zaki et al., 2012), is negative correlated with alexithymia (Herbert et al., 2011), can be
objectively determined in infants (Maister et al., 2017) and is connected to a plethora of
psychiatric disorders (Garfinkel et al., 2016; Harschaw, 2015; Khalsa et al., 2018; Klabunde et
al., 2013; Lackner & Fresco, 2016; Pollatos et al., 2008; Vlifredo, et al., 1984; Wiebking et al.,
2015). On the other hand, exteroception is connected to self-identity (Bermudez et al., 1995;
Tsakiris et al., 2011), to cognition and emotions (Fuchs & Schlimme, 2009), it has been found
to be negative interrelated to alexithymic traits (Grnyberg & Pollatos, 2015) and there are
differences in exteroceptive signaling in children with Autism Spectrum Disorder (Cascio et
al., 2012), as well as in individuals with eating disorders (Eshkevari, Rieger, Longo, Haggard,
& Treasure, 2012). Keeping these in mind, the conception that there might be a multimodal
self, by unifying interoceptive with exteroceptive signals is relatively new (Tsakiris, 2017). One
theory, supporting this unifying concept, has lately emerged, namely the predictive coding (PC;
Friston, 2010; Seth, 2013), which was previously described. The contribution of PC in the
unifying model is that it describes how interoceptive and exteroceptive information integrate to
minimize prediction errors in the process of shaping body-awareness (Tsakiris, 2017). This
could expound how psychiatric symptoms, such as anhedonia, anxiety or panic attacks, hunger insensitivity etc. emerge and remain stable or alter through the years.

Having discussed the available data concerning the bodily self in the past years, it is worth taking a brief look into the most important findings of this dissertation; Figure 11 summarizes these findings. Subsequently, we demonstrated that primary school children and adolescents have the ability to perceive their cardiac activity and they indicate considerable inter-individual differences. Furthermore, differences were also revealed in the way adolescents perceive their bodies based on exteroceptive signals. Moreover, we took a closer look into physical fitness and identified that children with normal to high BMI in very good physical fitness could perceive more accurately their interoceptive signaling, suggesting that physical fitness is crucial from this young age, not only for somatic health, but also for enabling the conscious perception and interpretation of the inner self. In terms of physical activity, children high in IAC displayed a self-regulation of physical activity, indicating a more finely tuned perception of fatigue, something that can be observed also as a protective factor against proclivity for psychological disorders, where one’s own limits concerning exhaustion or burn out are more defined. Additionally, we explored how emotion processing interacts with interoception and exteroception in adolescents and emphasized that adolescents high in IAC not only experience negative emotions of others more intensely, but also focus more on their averseness during their effort of decoding these emotions and are able of regulating a possible frustration or distress caused by these. Besides this, we demonstrated that adolescents low in body ownership had more difficulties in describing feelings, something which is related to alexithymia and can be regarded as a possible risk factor for psychological disorders. Last but not least, after exploring BN, we demonstrated that women currently suffering from BN could perceive their cardiac activity, something that explains how self-harming regulatory strategies, such as purging or laxative abuse are being adapted. On the contrary, BN patients exhibited a subjective decreased tendency in being internally focused, as well as indicated low signals of hunger and satiety.
In conclusion, our findings shed light onto the, until now, unedified mechanisms of how the interoceptive and exteroceptive self, that together sculpt the multimodal self, develop, function and determine cognition and affect, in order to form self-awareness and consciousness. After all, it is our bodies that exist in the current moment, they cannot wander in the past or the future as our thoughts and emotions can, thus it can reflect present time. Taking all these into consideration, we strongly encourage integrating relevant promotion projects in elementary schools and high schools. These projects can entail practices that enable learning to listen to internal bodily signals, such as signals from the heart or breathing in physically active, or inactive, situations, but also learning how to trust these signals and, as a result terminating, this activity “when it does not feel good”, as a measure of maintaining homeostasis. At the same time, we encourage a more individual approach of how each of us perceive these signals, as there are a lot inter-individual differences, such as personality, interoceptive and exteroceptive predictions etc., that can influence the way we see ourselves in the world. By learning from a young age to accept one’s own limits before exhaustion, it might lead to a positive impact on an individual’s quality of life. At the same time, the role of emotions should not be neglected.

Figure 11: Summary of the present findings of this dissertation.
There is a high need to integrate in school, trainings that target emotional activation and emotion regulation, as well as learning how the body reacts in different emotional situations. This could have an impact on adapting effective coping strategies in situations that can be frustrating or distressing, by minimizing internal and external prediction errors and trusting one’s own somatic and emotional markers. From another perspective, we strongly recommend the development of new intervention methods that target confronting somatic sensations in various situations that can be coupled with different emotions. Therefore, future psychotherapeutic approaches should place more emphasis in interventions such as somatic experiencing, interoceptive exposure, MBSR etc., not only in eating disorders, but also in a wide spectrum of psychiatric disorders. It would be valuable to implement these approaches in in-patient and outpatient settings, by integrating all the knowledge concerning the multimodal self in psychoeducation and exposition sessions, but also throughout the therapeutic process. The objective of the treatment should be to get in touch with one’s own multimodal signals, to learn how to separate psychophysiological reactions coupled to emotion activation, or as reactions to positive and negative emotions, to hyper-and hypo arousal, anxious and non-anxious situations etc., confronting pleasant or unpleasant reactions, but also to have the opportunity of training this in everyday life by the use of wearable devices that monitor these signals.

In summary, the road ahead in the research of the multimodal self could be defined by studies, with an interdisciplinary approach, that place emphasis on the further identification of neural systems involved in these multimodal processes that possibly overlap with those in emotion processing, cognition and pain (Khalsa et al., 2018). Likewise, an important component could be to conduct longitudinal studies that accompany infants to later adulthood and take into consideration neurophysiological and pathophysiological parameters affecting mental health, but also personality traits, biological factors, such as genetics and epigenetics, as well as the generation of prediction errors. Furthermore, technological developments such as artificial intelligence, virtual reality, internet of things and also the use of wearable devices that monitor multimodal signals and give real-time feedback, can be integrated in interventions, such as virtual body swapping, interoceptive exposure etc. Surely, the road ahead concerning multimodal integration and emotion processing is long, yet remains promising, as all this research takes the self as a starting point and extends it, in order to understand its complex multimodality and at the same time the enchanting nature of human existence.
Reference List


PART II Original Research Articles

I. Interaction of physical activity and interoception in children


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Interaction of physical activity and interoception in children

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**Background:** Physical activity (PA) is associated with positive health outcomes, whereas physical inactivity is related to an increased risk for various health issues including obesity and cardiovascular diseases. Previous research indicates that interindividual differences in the perception of bodily processes (interoceptive sensitivity, IS) interact with the degree of PA in adults. Whether there is a similar relationship between PA and IS in children has not been investigated yet. Therefore, the aim of this study was to investigate the interaction between IS and PA during physical performance tasks and in everyday situations. **Methods:** IS was assessed using a heartbeat perception task in a sample of 49 children within the health promotion program “Join the Healthy Boat” which is implemented in several primary schools in the southwest of Germany. PA was examined using a physical performance task, assessing the distance covered during a standardized 6-min run. In a subsample of 21 children, everyday PA was measured by a multi-sensor device (Actiheart, CamNtech, Cambridge, UK) during five consecutive days with more than 10 h of daily data collection. **Results:** Children with higher IS performed better in the physical performance task. Additionally, based on energy expenditure defined as metabolic equivalents, IS was positively correlated with the extent of light PA levels in the morning and afternoon. **Conclusion:** Our findings reveal that IS interacts positively with the degree of PA in children supporting the idea that interoception is important for the self-regulation of health-related behavior.

**Keywords:** interoceptive sensitivity, physical performance, metabolic equivalent, childhood/youth, interoception, self-regulation

**Introduction**

The feedback of afferent signals arising from within the body to the brain and their perception is commonly known as interoception (Vaitl, 1996; Cameron, 2001), while the sensitivity in perceiving bodily signals is known as interoceptive sensitivity (IS). Referring back to the emotion theories of James (1884) as well as Schachter and Singer (1962), who postulated that there is no emotional experience without the perception of bodily changes, a substantial body of research demonstrates evidence for the suggested close link between interoception and emotional processes in recent decades (for reviews, see Wiens, 2005; Herbert and Pollatos, 2008). Furthermore, the somatic marker theory of Damasio (1994, 1999) emphasized the relevance of visceral and somatosensory feedback from the body to the brain, mapped in distinct higher brain areas, for the emergence of emotions and the regulation of one's behavior. Thus, Damasio inspired studies that demonstrated the benefit...
of a person's high degree of bodily sensitivity to regulate emotional decision making (e.g., Werner et al., 2009; Dunn et al., 2010, 2012) as well as to process emotions (Wiens et al., 2000; Barrett et al., 2004; Pollatos et al., 2005; Herbert et al., 2007a). Furthermore, the feedback of internal bodily signals is related to the self-regulation of physical activity (PA). The self-perception of bodily signals, like breathing or other internal bodily processes based on cardiovascular activity, might influence the amount of physical effort, when undertaking PA and is known as the self-control of physical load (undertaking PA and is known as the self-control of physical load). Theself-perception of bodily signals, like breathing or other internal bodily processes based on cardiovas-
ular activity, might influence the amount of physical effort, when undertaking PA and is known as the self-control of physical load (Pennebaker and Lightner, 1980; Herbert et al., 2007b).

Moreover, one study investigated the regulation of PA in relation to interoceptive processes (Herbert et al., 2007b) and highlighted that these two processes might interact positively with each other. In this study, Herbert et al. (2007b) instructed their participants, aged 20–40, to cycle on a bicycle ergometer for a constant period of time (15 min), whilst being free to control their cycling pace. Results showed that good heartbeat perceivers set their physical endeavor to a lesser extent, demonstrating a more enhanced perception of their exhaustion and of their internal bodily states, than poor heartbeat perceivers. Furthermore, good heartbeat perceivers revealed lower changes in their heart rate, stroke volume and cardiac output. This suggested that participants with higher IS where those who at the same time regulated better their physical load in a performance task. Moreover, Herbert et al. (2007b) implemented this study in terms of regulating physical load in a performance task (cycling task). However, it remains a rather open question whether interoceptive processes do also interact with PA in terms of day to day PA (i.e., in terms of PA under free-living conditions). Lastly, in this study there was no evidence found showing that physical fitness does play a role when differentiating the good from the bad heartbeat perceivers.

On the other hand, but in line with this question, two older studies suggested that a higher state of fitness might be advantageous for better IS (Borg and Linderholm, 1967; Montgomery et al., 1984). Montgomery and Jones (1984) also found that the best predictor for IS in men is the body's fat content. In agreement with these results, Herbert and Pollatos (2014) also demonstrated an inverse relationship between the body mass index (BMI) and IS in adults, and that overweight and obese individuals are less accurate in perceiving bodily signals. These studies suggest that interoceptive processes and individual differences in IS are important for physical fitness or weight status in adults and are of high importance to health-related questions. Although being overweight is established in childhood and youth, there is scant research in examining these questions in children.

Most of the aforementioned studies assess and quantitate IS in terms of people's ability to perceive their own heartbeat. Assessment of heartbeat perception in adults has been shown to be sufficiently reliable (Schandry, 1981; Mussgay et al., 1999), to have substantial interindividual differences (Ehlers and Breuer, 1992; Domschke et al., 2010) and to correlate with the ability to detect changes in other autonomic innervated organs (Whitehead and Drescher, 1980; Harver et al., 1993; Herbert et al., 2012). One of the most frequently used methods to measure cardiac sensitivity is the Mental Tracking Method proposed by Schandry (1981; Dunn et al., 2007; Herbert et al., 2007b; Pollatos et al., 2009; Ainley et al., 2012). A recent study by Koch and Pollatos (2014a) adapted this method for children by shortening the intervals used. In spite of the great importance of interoceptive processes for health processes, only a few studies exist that assess IS in children. To our knowledge, there are only four studies that assess heartbeat perception in children, either using the original Schandry paradigm (three trials with the length of 35, 25, and 45 s; see Eley et al., 2004, 2007; Schmitz et al., 2012) or the adapted version (Koch and Pollatos, 2014a,b). The internal consistency of the shorter adapted version was found to be excellent (Cronbach's α = 0.91) in a large sample of about 1350 children aged between 6 and 11 years (Koch and Pollatos, 2014a). Additionally, Koch and Pollatos (2014a) investigated the distribution of cardiac sensitivity in relation to general emotional processing and found correlations to interpersonal emotional intelligence and adaptability. Relevant findings were the associations between interoceptive processes and anxiety symptoms (panic and social anxiety) in small samples of eight to 12-year-old children (Eley et al., 2004, 2007; Schmitz et al., 2012). Furthermore, cardiac sensitivity in children can be seen as a dynamic developmental process, that has weaker but yet similar characteristics and relations to emotional parameters than found in adults (Koch and Pollatos, 2014a).

The scope of the present study was to investigate the interrelation between PA in a performance task and in day to day activities (under free-living conditions) with IS in a main sample of 49 primary school children and moreover in a subsample of 21 in the context of the “Baden Württemberg Study,” which evaluated the effectiveness of the health promotion program “Join the Healthy Boat” in Southwestern Germany. Taking into account the majority of the studies regarding this matter in adults (Borg and Linderholm, 1967; Montgomery et al., 1984; Herbert and Pollatos, 2014) and the lack of studies in this field among children, we hypothesized that a healthy and fit physical state is associated with higher IS in children. This should be reflected in a better performance when participating in a physical task as well as in a higher level of daily PA in children. Furthermore, considering the results of the study from Herbert et al. (2007b), we further hypothesized that children with a higher IS will also demonstrate a finer ability to regulate their PA, in comparison to children with low IS.

**Materials and Methods**

**Participants**

Participants were children of the third wave of a larger on-going intervention study (“Join the Healthy Boat—Primary School”, Schreiber et al., 2014). Our data derived from a subsample of the Baden-Württemberg Study, which evaluated the health promotion program “Join the Healthy Boat—Primary School” in the south-west of Germany. Protocol and study design of the Baden-Württemberg Study have been depicted elsewhere (Dreyhaupt et al., 2012). In total, 1047 children in the age of 9.59 (SD = 0.63) years from third to fourth grade were recruited from primary schools in the federal state of Baden-Württemberg, after legal guardians had provided written informed consent. Approval for the study was obtained from the Ministry of Education as well as from the University's Ethics Committee.
For logistical reasons (scope of measurements of the Baden-Württemberg study and distances between schools) objective PA assessments and IS measurements were only carried out in different schools in the region of Ulm and among fewer children. The sample used in the present analyses consisted of 49 children and the subsample of 21 respectively with complete data on all variables of interest. Children were tested individually with regard to IS in a separate room at school. Additionally, all participants filled out questionnaires regarding their health status, in order to fulfill all criteria for participating in this study. In total, there were 49 healthy participants, 20 girls (40.8%) and 29 boys (52.4%) with a mean age of $M = 9.72$ years ($SD = 0.58$) in the main sample. In the subsample of the study, there were 21 children in total, 10 boys (47.6%) and 11 girls (52.4%) with a mean age of $M = 9.97$ years ($SD = 0.39$).

**Performance Task for Physical Fitness**

For the measurement of children's physical fitness, the 6 min run-performance task was conducted. The Dordel-Koch-Test (Dordel and Koch, 2004; Graf et al., 2004) is conducted in order to measure the developmental state of the participant's basic motoric skills in accordance to intensity, coordination and endurance of the movement. The 6 min run is a subtask of the Dordel-Koch-Test, which assesses a person's aerobic endurance. It could be compared to a screening test, in which cardiopulmonary stamina is being measured. The participants of this task had to run around a volleyball field (round length 54 m) for 6 min. The last round was announced by the instructor of the task, who, afterward, marked the rounds already covered by the children. For the evaluation of this task, the aggregation of the number of completely covered rounds and the distance of the last round were calculated.

The 6-min-run task is a highly standardized assessment tool, which is frequently used not only because it is extremely time-saving, but also relatively simple to conduct and unambiguous. For this reason, it has a high level of objectivity. As far as the norm values are concerned, the reliability and objectivity are $r = 0.91$ for the total sample. Von Haaren et al. (2008) also reported reliability values that swayed between $r = 0.61$ and 0.92. Moreover, they compared the results regarding the $V_{O_{2}}\text{max}$ (among others an essential indicator for the aerobic stamina) between the 6-min-run performance and a treadmill test and they noticed a strong connection between those two performance tasks ($r = 0.69$).

**Measurement of Daily Physical Activity**

Within the context of the Baden-Württemberg study, daily PA was measured in a subsample of 21 primary school children, in order to examine if current PA recommendations of at least 60 min MVPA (moderate to vigorous PA) per day were met, not only during school time, but also during spare time. After the informed consent of the parents, PA was measured via a multi-sensor device (Actiheart®, CamNtech Ltd., Cambridge, UK).

The Actiheart® is a light multi-sensor device that combines recordings of the accelerometer (in counts per minute) and of heart rate (in beats per minute). This multi-sensor device was attached using two standard electrocardiograph electrode pads on the children's chest. The children were instructed to follow their daily routine while wearing the Actiheart® and not to remove the device even during sleep for five consecutive days (á 24 h). Energy expenditure based on metabolic equivalents (METs) was calculated by the Actiheart® software using a branched model approach, previously validated in children (Corder et al., 2007). For this specific recording, a 15-s epochs recording interval was selected. Besides heart rate and accelerometry data, gender, age, body weight, and height were also taken into account in order to assess MET levels. MET was divided into three categories: sedentary (<1.5 METs), light (1.5–3.0 METs), moderate to vigorous (>3.0–6.0 METs) (Pate et al., 1995).

For data assessment, some specific criteria had to be fulfilled in order for the data to be included in the analysis. Only recordings with at least 10 h of daily data collection were included in this sample. Moreover, recordings of 5 days in total were selected, in which at least 1 day was a weekend day and the rest were weekdays, so as to secure a high reliability among children (see also Trost et al., 2000). All recordings between 11 pm and 6 am were removed as this time was considered as normal sleeping time. Additionally, recordings that included more than 45 min of sedentary activity, between 9 pm and 11 pm, were also extracted. Furthermore, recording periods of 100 min or more with zero activity counts were also removed. Hesketh et al. (2014) suggested three possible day-segmentations that might correspond to the daily program of the preschool and school children in the UK. We chose a similar day-segmentation, because of the resemblance to the German primary school system. Therefore, each day was divided in three periods, as follows: morning (6 am–12 pm), afternoon (12–5 pm) and, lastly, evening (5–11 pm).

**Heartbeat Perception Task**

For the heartbeat perception task, cardiac activity was recorded using the mobile heart frequency monitor R800CX (Polar Electro Oy, Kempele, Finland). Polar watches are mobile devices that enable easy, non-invasive recording of inter-beat-intervals and were used to assess IS in other studies with children (Koch and Pollatos, 2014a,b). Validity and reliability compared to alternative ECG measurement devices have been proven in children and adults (Radespiel-Tröger et al., 2003; Kingsley et al., 2005; Gamelin et al., 2008; Nunan et al., 2008). Due to the fact that the study took place in the school setting, the strap with the electrodes was attached to both hands and secured on a table. Signals were sampled at 1000 Hz and analyzed by the corresponding Polar ProTrainer five software (version 5.40.172).

The heartbeat perception task was performed following the Mental Tracking Method, proposed by Schandry (1981) and identical to the children's version implemented by Koch and Pollatos (2014a). After a short practice interval of about 10 s, there were three intervals of 15, 20, and 18 s, separated by two standard resting periods of 20 s. During each interval, participants were precisely instructed to silently count their own heartbeats by concentrating on their heart activity while not being allowed to check their pulse or to attempt any other physical manipulations (e.g., holding their breath) that could facilitate the detection of heartbeats. Participants were seated and were given no information as to the length of the intervals or their performance. The test supervisor signaled the beginning and the end of the counting...
phases by announcing “start” and “stop.” Participants were asked to verbally report the number of counted heartbeats straight after the “stop” signal. IS was determined via the heartbeat perception score, which represents the mean score across the three intervals and which is calculated according to the following transformation:

\[
\frac{1}{3\Sigma}[1 - \left(\frac{\text{[recorded heartbeats]}}{\text{[recorded heartbeats]}}\right)]
\]

Higher scores indicate higher IS, so that the maximum score of 1 indicates absolute accuracy of heartbeat perception.

**Body Mass Index**
Children’s body weight and height were taken according to the International Society for the Advancement of Kinanthropy (ISAK; Stewart et al., 2011), with children wearing only underwear and no shoes. More specifically, body weight was measured to the nearest 0.05 kg, using calibrated electronic scales (Seca 862, weighing and measurement systems, Hamburg, Germany). Using a stadiometer, height was measured to the nearest 0.1 cm (Seca 213, weighing and measurement systems, Hamburg, Germany). BMI was calculated (kg/m²) and converted to BMI percentiles (BMIPCT) based on national reference data for German children (Kromeyer-Hauschild et al., 2001).

**Statistical Analyses**
Continuous variables were summarized as mean and standard deviation; frequencies were used to analyze nominal and ordinal variables. Continuous variables were compared using the two-sample t-test and analysis of variance (ANOVA). Regression analyses as well as Pearson correlations and partial correlations were conducted to investigate the relationship between IS, age and gender, BMI and the activity measures.

As far as physical performance is concerned, one hierarchical regression analysis (linear mixed effects regression model, forward stepping) was carried out with IS, BMI and the interaction term IS × BMI as predictors and performed distance as criterion.

As far as everyday PA is concerned, we calculated correlations between mean activity at different activity levels and while controlling for age and BMI.

All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, version 21). Because of the explorative nature of this study, no adjustment for multiple testing was made (Altman, 1991; Victor et al., 2010). A p value less than 0.05 was considered significant. The results of all statistical tests are interpreted in an exploratory sense.

**Results**

**Sample Descriptives**
Sample characteristics on relevant variables are shown in Table 1.

**Interoceptive Sensitivity as Assessed by Heartbeat Perception**
The mean heartbeat perception score for the main sample was 0.59 (SD = 0.18). Moreover, there was a minimum score of 0.16 and a maximum of 0.91 regarding the heartbeat perception in the overall sample. Taking into account the possible interrelation between gender and heartbeat perception, a two-sample sample t-test was conducted, resulting in boys (M = 0.62, SD = 0.19) and girls (M = 0.55, SD = 0.17) not differing in their IS \(t(46) = 1.2, p = 0.24\). The same finding occurred after comparing gender and heartbeat perception in the subsample \(t(19) = 1.9, p = 0.07\). No significant gender difference was found after considering BMIPCT as a covariate. Accordingly, one way ANOVA was conducted in order to examine heartbeat perception and age, after dividing age in three categories. No differences were found between these variables \(F(2,45) = 0.46, p = 0.63\) in the main sample and in the subsample, respectively \(F(1,19) = 0.07, p = 0.79\).

**Physical Fitness**
In the physical performance task, boys covered a mean distance of 1003.6 meters (SD = 138.5), whereas girls’ mean covered distance was 904.97 meters (SD = 131.77). Moreover, boys and girls showed significantly different physical performances in the 6-min-run \(F(45) = 2.45, p = 0.02, d = 0.73\). The distance covered in 6 min were classified, according to Jouck (2008) in different grades from 1 to 6, taking into account not only the gender but also the age. Mark one refers to an excellent physical performance and mark six to a poor physical performance. As far as minimum and maximum marks of the participants go, there was a deviation ranging from 2 to 6. On the subject of differentiating the physically fit toward physically non-fit children, a dichotomisation of the median value was implemented, resulting in physically fit children having either 2 or 3 as a mark, in comparison to non-physically fit children, who gained the marks 4, 5, or 6. Finally, 31 participants in this study were classified as physically fit, and 18 as physically non-fit. The data showed no significant difference between the different age groups and physical fitness of the main sample \(F(2,44) = 1.32, p = 0.27\).

**Relationship Between IS and Physical Fitness**
In order to examine the relationship between IS and physical fitness, we conducted a linear mixed effects regression analysis (forward stepping) with the covered distance of the 6 min run-performance task as criterion, and BMI, IS and the interaction term of BMI × IS as predictors. The criterion was explained by BMI \((T = -2.07, \beta = -0.28, p = 0.04)\), IS \((T = 2.02, \beta = 0.29, p = 0.04)\) and the interaction between both \((T = 2.14, \beta = 0.32, p = 0.04; F(3,45) = 5.09, p = 0.00, R^2 = 0.25)\). These effects are depicted in Figure 1.

<table>
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<th>TABLE 1</th>
<th>Characteristics of the main and subsample.</th>
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</tr>
<tr>
<td>Female, n (%)</td>
<td>20 (40.8)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.72 (0.56)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.33 (2.57)</td>
</tr>
<tr>
<td>BMIPCT</td>
<td>48.04 (27.58)</td>
</tr>
<tr>
<td>Heartbeat perception score</td>
<td>0.59 (0.18)</td>
</tr>
</tbody>
</table>

All values are mean (SD) unless stated otherwise; \(N^1\), main sample; \(N^2\), sub-sample; BMI, body mass index; BMIPCT, BMI percentiles; SD, standard deviation.
More specifically, a higher IS is associated with a greater covered distance which implies a higher physical fitness. Moreover, a higher physical fitness is positively associated with the interaction between IS and BMI. Therefore, Figure 1 depicts a positive interaction between high IS, covered distance and BMI, but a strong negative interrelation between low IS, covered distance and BMI. In other words, Figure 1 reveals a positive correlation between physical fitness and BMI among good heartbeat perceivers and a negative correlation between physical fitness and BMI among bad heartbeat perceivers.

**Daily Physical Activity**

In total, 21 children, forming the subsample of the study, had valid PA data for five consecutive days with a mean daily wear time of 846 min (corresponding to about 14 h, \(M = 846.2\) min, \(SD = 207.1\); see Table 2).

Boys (\(M = 237.5, SD = 61.02\)) and girls (\(M = 178.2, SD = 63.10\)) differ as far as their light PA in the evening is concerned \([t(19) = 2.18, p = 0.04, d = 0.95]\). Moreover, the data showed a difference regarding sedentary activity \([t(19) = 1.27, p = 0.02, d = 1.1]\), with girls (\(M = 115.04, SD = 88.15\)) being more sedentary in the evening in comparison to boys (\(M = 35.8, SD = 50.7\)). Concerning MVPA there was also a gender-specific difference \([t(19) = 3.9, p = 0.01, d = 1.7]\). MVPA in the morning was higher for boys (\(M = 44.6, SD = 30.2\)) in comparison to girls (\(M = 5.5, SD = 12.6\)). Concerning age, there was no significant difference between the three age groups and the different levels of PA.

**Relationship Between IS and Daily Physical Activity**

Examining the relationship between IS and daily PA, we conducted partial correlations after setting BMI and children's age as control variables. There was a statistically significant correlation between IS and light PA, more specifically in the morning (\(r = 0.39, p = 0.04\)) and in the afternoon (\(r = 0.39, p = 0.04\)), showing that higher IS was positively related to more light PA in the morning and afternoon hours. This interrelation is depicted in Figure 2.

**Discussion**

The present study investigated the interrelation between IS and PA among primary school children. Our results demonstrate, firstly, that IS is a determinable measure in children, indicating that primary school children differ considerably in their ability to perceive ongoing signals stemming from the heart. This is in line with recent data from a large representative sample of about 1350 children (Koch and Pollatos, 2014a). Secondly, further findings of this study highlight that physical fitness and IS are positively associated, showing that higher IS is related to a greater distance covered in the 6 min running performance task. These findings are

![FIGURE 1](image1.png)

**FIGURE 1** | Interaction between IS (low and high), covered distance and body mass index (BMI); Low BMI, normal BMI, high BMI: based on the national reference data for German children (Kromeyer-Hauschild et al., 2001); DV: dependent variable; classification of low and high IS according to the method of median split.

![FIGURE 2](image2.png)

**FIGURE 2** | Partial correlations between interoceptive Sensitivity (IS) and physical activity (PA) in the morning and in the afternoon, after controlling for body mass index (BMI) and age; HBP_Score: heartbeat perception score.

<table>
<thead>
<tr>
<th></th>
<th>Daily total (min/day) (SD)</th>
<th>Morning (min/day) (SD)</th>
<th>Afternoon (min/day) (SD)</th>
<th>Evening (min/day) (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recorded time</td>
<td>846.2 (207.1)</td>
<td>299.5 (75.8)</td>
<td>250.7 (82.8)</td>
<td>296.0 (85.0)</td>
</tr>
<tr>
<td>Sedentary PA</td>
<td>156.1 (70.4)</td>
<td>58.2 (77.6)</td>
<td>20.6 (29.9)</td>
<td>77.3 (81.8)</td>
</tr>
<tr>
<td>Active PA</td>
<td>680.1 (203.9)</td>
<td>241.3 (117.2)</td>
<td>230.1 (116.6)</td>
<td>218.7 (110.2)</td>
</tr>
<tr>
<td>Light PA</td>
<td>636.6 (187.9)</td>
<td>217.2 (87.9)</td>
<td>213 (81.2)</td>
<td>206.4 (67.7)</td>
</tr>
<tr>
<td>MVPA</td>
<td>53.5 (70.6)</td>
<td>24.1 (29.9)</td>
<td>17.1 (33.6)</td>
<td>12.3 (22.4)</td>
</tr>
</tbody>
</table>

All values depicted are in minutes/day; in parentheses: SD, standard deviation; PA, physical activity; Active PA, sum of light PA and MVPA; MVPA, moderate to vigorous physical activity; morning: 6 am–12 pm; afternoon: 12–5 pm; evening: 5–11 pm.
not in line with previous studies regarding IS and physical fitness among adults, for example the study from Herbert et al. (2007b), where good and poor heartbeat perceivers did not differentiate in their fitness level.

Furthermore, results concerning physical fitness and IS revealed also the role of the BMI in this motif. More specifically, these findings indicate that children with a normal BMI and a high physical fitness (according to the 6-min-run) showed a higher IS than those children with a normal BMI but a lower fitness state. Lastly, children with a high BMI and high physical fitness indicated also, surprisingly, a higher IS than those children with a high BMI and a lower physical fitness. Thus, good heartbeat perceivers were these children with a normal to high BMI and with a greater fitness state. These findings could be explained by the fact that BMI could play a role in the degree of IS but the most important factor is one's physical state. In other words, IS does not seem to decline when a child has a high BMI but also at the same time rather good physical fitness. This is in accordance with a few older studies in adults reporting that a higher state of fitness is advantageous for better IS (Borg and Linderholm, 1967; Montgomery et al., 1984). In contrast, children with a lower physical fitness but with higher BMI seemed, in this study, to be bad heartbeat perceivers. In respect to the possible limitations regarding this finding, the use of BMI instead of BMI and BMICPT when referring to children and the absence of use of alternative anthropometric measurements, such as skin-fold thickness or body girth etc. (Chen et al., 2002), should not be neglected.

Moreover, our daily PA related outcomes reveal a positive association between IS and light daily PA in the morning as well as in the afternoon. No significant correlations were observed with the moderate to vigorous activity level, though. This result could be partly due to the fact that our sample was quite small and only 6 (28.6%) participants of the total sample met current PA recommendations of at least 60 min MVPA per day. Referring to former research, there are substantial methodological differences whether daily activity was assessed by self-report or by the use of objective measurements like the Actiheart device in the present study, and which cut-off points were used when determining MVPA (see Borracino et al., 2009; Aznar et al., 2011; Ekelund et al., 2011; Kettner et al., 2013). Being sensitive to one's bodily signals might constitute a positive precondition for effective self-regulation of behavior, as it was suggested for the field of emotion regulation (see Füstös et al., 2013). Taking both obtained results together, we can show that both in a performance task as well as in day to day life, IS interacts positively with PA suggesting that the ability to accurately perceive bodily signals is crucially associated with more fitness and daily activity in young children. Therefore, a link between IS and other health-related outcome variables is to be assumed, such as demonstrated in adults (Herbert and Pollatos, 2014) or in children (Koch and Pollatos, 2014a,b).

The fact that we observed positive correlations between IS, physical fitness and light daily PA generates further questions regarding the regulation of PA. A former study by Herbert et al. (2007b) demonstrated that when participants were instructed to cycle on a bicycle ergometer at a speed they felt comfortable with, good heartbeat perceivers covered a shorter distance as compared to poor heartbeat perceivers. The good heartbeat perceivers indicated a more self-controled physical workload, by perceiving better their internal bodily signals and regulating their fatigue. In contrast to the instruction given by Herbert and co-workers, the 6-min performance task used in this study focused on how fit children were with the clear instruction to run as fast and as far as possible in a certain time. The instruction when undertaking everyday PA was to keep on undertaking normal activity as usual, which implied that the participant was not in a situation where his/her performance was being evaluated. Therefore, we hypothesize that higher PA might favor the development of a better ability to identify internal body signals as assessed by IS. The exact developmental mechanisms of interoception remain yet unclear, due to the lack of prospective studies and in general studies concerning the distribution of cardiac sensitivity in children (Koch and Pollatos, 2014a). Future studies should focus on this research gap and assess PA and IS in a longitudinal fashion.

In accordance to former research, we found some gender differences in daily activity between boys and girls (Riddoch et al., 2004; Jago et al., 2005; Borracino et al., 2009). Moreover, in examining physical fitness, our results suggest that boys are more physically fit than girls. This can be explained by the physiology of the male body and more specifically, by the fact that males have a greater muscle mass than females, which implies a greater ability of achieving high levels of PA. This finding is in the same line with the study of Li et al. (2007), who concluded that males covered a greater 6 min walk distance than females in the performance task. Moving on to age and PA, our results reveal that 9–11-year-old participants undertook the same amount of PA. These results are in line with other studies, which suggest that children under the age of 13 indicate the same levels of PA (Strauss et al., 2001). We did not find any difference in IS according to gender, like other studies with adults (Katkin et al., 1981; Jones et al., 1984; Jones, 1995), while Koch and Pollatos (2014a,b) showed a small but significant difference with higher IS in boys. We assume that the sample size is small to show such an effect.

To sum up, our study demonstrated that IS is not only determinable but also diverse among primary school children, emphasizing the fact that IS is based on individual differences and age. Further studies could shed light on the developmental processes of IS through the life span. Taking into account the lack of studies in this field, in the present study we tried to scrutinize the role of PA and IS in children and our findings demonstrate the first evidence regarding the interaction between physical fitness and IS in young children. Further research is necessary to examine the specific role of BMI as well as the direction of the observed interaction, e.g., by training physical fitness in children and assessing concomitant interoceptive processes, and by using alternative anthropometric measurements apart from BMI (such as skin-fold thickness etc.). In specific, we demonstrated that physical fitness could contribute to a higher IS and in its turn, IS might be trained using PA (Schandry and Weitkunat, 1990). We assume that improving children's perception of their body signals could contribute to a more effective way of regulating health-related behavior, e.g., by a finer ability to tune their physical load in everyday situations and to prevent exhaustion more effectively. Our results suggest that IS constitutes an important factor associated with PA during childhood. This issue
deserves further exploration, by researching a larger sample of children, thanks to the great significance of IS and PA over the life span.

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II. Normal interoceptive accuracy in women with bulimia nervosa

Normal interoceptive accuracy in women with bulimia nervosa

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A B S T R A C T

Previous studies suggest that patients suffering from bulimia nervosa (BN) have difficulties in perceiving internal bodily signals, mostly assessed by self-report questionnaires. Whether interoception is, in this case, attenuated or not remains an open question. Therefore, interoceptive processes were examined in twenty-three patients with current BN and were compared to healthy participants. We investigated Interoceptive Accuracy (IAc) assessed by the heartbeat detection task and Interoceptive Awareness (IA) assessed by the Eating Disorder Inventory-2. Patients with BN and healthy participants did not differ in terms of IAc when controlling for BMI, depression and anxiety, whereas IA among BN patients was found to have decreased. Although IAc and IA were not related among controls, we observed an inverse correlation in BN, suggesting that an abnormal overlap between these two levels of interoceptive signal processing is present in BN. The current study introduces a new perspective concerning the role of interoceptive processes in BN and generates further questions regarding the therapeutic utility of methods targeting the interaction between different levels of interoception in the treatment of BN.

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1. Introduction

Bulimia nervosa (BN) is characterized by recurrent episodes of binge eating large amounts of food and self-induced vomiting or other compensatory behaviors for body weight maintenance (American Psychiatric Association, 1994). Different studies (Fassino et al., 2004; Thiels and Patel, 2008) suggest that patients with BN show evidence of difficulties in the perception of bodily signals (interoception), as assessed by a self-report questionnaire. However, it is important to explore different interoceptive axes to quantify such individual differences using experimental approaches alongside questionnaire measures. Having this distinction in mind, there are only a few empirical data that investigate interoceptive processes in BN using not only questionnaires. The focal point of symptomatology of BN lies with the constant preoccupation with bodily sensations, particularly hunger, fullness and lack of control over eating behaviors (Cooper et al., 2004), while less is known about the accuracy of sensing or detecting such bodily signals. Therefore, there is a great need for investigating more levels of interoceptive processes and their interrelation in BN.

Supporting this view, Garfinkel and colleagues (Garfinkel and Critchley, 2013; Garfinkel et al., 2015) emphasize that the terms: “interoceptive awareness” and “interoceptive sensitivity/accuracy” (IAc) have long been treated as synonymous and interchangeable, without taking into account whether the subject of investigation is referred to the objective interoceptive accuracy (IAc; e.g. behavioral tasks such as performance on heartbeat perception tests), metacognitive awareness (e.g. confidence-accuracy correspondence) or subjective interoceptive sensibility/interoceptive awareness. In this study, we chose to use the term “interoceptive awareness (IA)” for the self-assessment of interoception, due to the fact that we made use of the IA subscale of the Eating Disorder Inventory-2 (EDI-2; Garner, 1984; Paul and Thiel, 2005). Various studies have investigated the ability to perceive bodily signals (interoception) and the sensitivity or accuracy in perceiving internal signals (interoceptive accuracy, IAc). Most studies have used tests targeting the cardiovascular system such as heartbeat tracking tasks (Füstös et al., 2013; Herbert and Pollatos, 2014; Pollatos et al., 2015; Georgiou et al., 2015) or heartbeat discrimination tasks (Whitehead and Drescher, 1980; Critchley et al., 2004). Several empirical studies suggest that heartbeat detection correlates with the ability to detect changes in other autonomically innervated organs such as gastrointestinal signals (Whitehead and Drescher, 1980; Herbert et al., 2012). Therefore, this variable should reflect the general accuracy for visceral processes across different modalities.

As far as interoceptive processes in eating disorders are concerned, a previous study by Pollatos et al. (2008) indicated that the perception of bodily signals in patients suffering from anorexia...
nervosa (AN) was affected on different axes, in a way that both IAc assessed by the Mental Tracking method (Schandry, 1981) and subjectively assessed IA were found to be attenuated. Yet, interestingly enough, both aspects were not correlated. This could imply that IA and IAc might describe rather different and presumably independent levels of perceiving own internal bodily signals. Whether this is also the case in BN has, to our knowledge, not yet been investigated. Referring to BN, findings from a recent study showed that the experimentally assessed accuracy for bodily signals (IAc) was altered in women who had recovered from BN (Klabunde et al., 2013). However, this study has two shortcomings. First of all, only ten women with remitted BN were assessed and, secondly, many variables known to interact with IAc – such as depression, anxiety or alexithymia (Van der Does et al., 2000; Dunn et al., 2007; Eley et al., 2007; Pollatos et al., 2009; Herbert et al., 2010) were not addressed. In contrast to the above data, Eshkevari and colleagues (Eshkevari et al., 2014) did not find significant differences concerning IAc in bulimic and anorectic females when using the heartbeat detection task, based on the Whitehead method (Whitehead and Drescher, 1980), even though performance on the heartbeat detection task indicated chance level of performance.

While anorexia nervosa (AN) is characterized by a reduced BMI, weight status is per definition normal or even elevated in bulimic patients, as compared to healthy controls. Herbert and Pollatos (2014) recently demonstrated that individuals who were considered to be obese or overweight were characterized by poorer IAc. This result suggests that IAc might depend on weight status and has to be taken into account when examining interoception in patients with BN. Moreover, the fact that BN patients show deficits in specific emotional face processing (Kühnapst et al., 2012) generates further questions concerning the alexithymic traits of BN patients, which was found to be related to IAc in healthy adults (Herbert et al., 2011). Another study (Montebarocci et al., 2006) showed that BN patients did not indicate higher TAS-20 scores compared to controls, but seemed to share symptoms that are similar to an anxious-depressive condition. On the other hand, BN patients were found to show elevated levels of emotion dysregulation (Lavender et al., 2015), something that could be connected to an impaired IAc, because the perception of bodily changes is a central concept in several theories of emotions (James, 1884; Damasio, 1994; Craig, 2004) and the awareness of one’s emotional state is an essential variable for emotion regulation (Füštös et al., 2013). Furthermore, previous studies (Weiss et al., 2014; Kever et al., 2015) reported a positive relationship between emotion regulation abilities as assessed by questionnaire and IAc.

Bearing these ideas in mind, the aim of the current study is to clarify whether patients with current BN have deficits on various levels of interoceptive processing when controlling for body weight, anxiety and depression. Taking previous research into account, we hypothesized that subjectively assessed IA would be attenuated among patients with current BN. Likewise, IAc would be also low, measured by a heartbeat detection task. Lastly, based on previous literature on interoception and eating disorders (Pollatos et al., 2008), we expect to find no association between IA and IAc.

2. Methods

2.1. Participants

Twenty three women with current BN according to the DSM-IV criteria, as assessed by the Structural Clinical Interview for Axis I Disorders (SCID-I) administered by a trained psychologist, were recruited from counseling units for eating disorders and were reimbursed for their participation. 15 patients were classified as BN purging subtype and eight as non-purging subtype. Participants had been suffering from BN for an average of 5.9 years (SD=3.7 years), with a first episode occurring at a mean age of 17.0 years (SD=3.1 years). Nine patients had a former anorexia nervosa diagnosis (five classified as purging, four non-purging subtype of BN). Moreover, three patients had a current affective disorder (diagnosed as major depression), five patients suffered from an anxiety disorder and two patients fulfilled both of these diagnoses. Lastly, seven patients were in therapeutic treatment. Exclusion criterion was the intake of psychotropic medication, including antidepressants and pain relievers. The mean body mass index (BMI) was in a normal range, with a value of 20.8 kg/m² (SD=3.2 kg/m²).

Patients were compared to 23 healthy women of similar age, levels of education and BMI (see Table 1), who received either course credit or were compensated for their participation. None of them was either taking medication (apart from contraceptives) or had any past or current eating disorder as assessed by the Structural Clinical Interview for Axis I Disorder (SCID-I) or any other psychiatric or severe somatic illness as assessed by screening.

Table 1 Sample characteristics and independent sample t-test comparisons among BN participants and healthy controls.

<table>
<thead>
<tr>
<th></th>
<th>BN1</th>
<th>Controls</th>
<th>t (df=44)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.0 (7.2)</td>
<td>25.1 (3.2)</td>
<td>0.67</td>
<td>0.51</td>
</tr>
<tr>
<td>Educational level1</td>
<td>3.9 (0.4)</td>
<td>4.0 (0.5)</td>
<td>0.86</td>
<td>0.39</td>
</tr>
<tr>
<td>BMI1</td>
<td>20.9 (3.4)</td>
<td>22.0 (2.5)</td>
<td>1.21</td>
<td>0.23</td>
</tr>
<tr>
<td>IAc</td>
<td>5.49 (11.4)</td>
<td>38.5 (8.4)</td>
<td>–5.55 ***</td>
<td></td>
</tr>
<tr>
<td>EDI Interoceptive</td>
<td>51.3 (9.5)</td>
<td>32.7 (9.5)</td>
<td>–8.78 ***</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BDI</td>
<td>18.3 (9.7)</td>
<td>4.2 (3.7)</td>
<td>–6.50 ***</td>
<td></td>
</tr>
<tr>
<td>TAS total</td>
<td>54.1 (8.9)</td>
<td>37.5 (7.4)</td>
<td>–6.89 ***</td>
<td></td>
</tr>
</tbody>
</table>

Note: BN1 = bulimia nervosa; SD2 = standard deviation; Educational level1: assessed by a scoring system for the German school system; 1: without educational qualification; 2: secondary general school certificate; 3: intermediate school certificate; 4: entrance qualification for technical college; 5: entrance qualification for university; p < 0.001 = ***; BMI1 = body mass index.

Participants were asked to complete a series of self-report questionnaires and to answer questions about personal data (age etc.). To quantify anxiety, the Spielberger State Trait Anxiety Inventory (Laux et al., 1981) was used. The Beck Depression Inventory (BDI-II) was administered as a measure to assess the presence of depressive symptomatology (Hautzinger et al., 2006). The Eating Disorder Inventory-2 (EDI-2) (Garner, 1984; Paul and Thiel, 2005) is a diagnostic tool designed to assess the presence of an eating disorder, and consists of 11 subscales. Questions are rated on a 6-point scale. The subscale IA from the EDI-2 was used. The reason that this self-report was chosen, instead of other possible questionnaires that assess interoception such as the MAIA (Mehling et al., 2012), is that it is specifically related to hunger cues and to eating disorders. To assess alexithymia, the Toronto Alexithymia Scale 20 [TAS (Taylor and Doody, 1985)] was used, which consists of three subscales: Factor Scale DIF (TAS 1) evaluates difficulties in identifying feelings, Factor Scale DDF (TAS 2) is concerned with difficulty in
describing feelings, and Factor Scale EOT (TAS 3) reflects concrete externally oriented thinking. The *Structured Clinical Interview for DSM-IV* (SCID) is regarded as a standard method for the detection and characterization of various Axis I disorders (Wittchen et al., 1997). For the assessment of IAc, the Mental Tracking Method suggested by Schandry (1981) was conducted.

### 2.3. Procedure

Participants were seated in a comfortable chair in a dimly lit and sound-attenuated chamber, where IAc was assessed using electrocardiography (ECG; comparable to Einthoven lead II configuration by attaching non-polarized Ag-AgCl electrodes to the right mid-clavicle and lower left rib cage) sampled with a DC amplifier (sampling frequency 1000 Hz, bandpass: 0.01–100 Hz; SYNAMPS, Neuroscan, Charlotte, NC, USA).

We used four heartbeat counting phases (25, 35, 45, 60 s) in accordance with the mental tracking method suggested by Schandry (1981). Participants were asked to count their own heartbeats silently and to verbally report the number of counted heartbeats at the end of the counting phase. Interoceptive accuracy (IAc) was estimated as the mean heartbeat perception score according to the following transformation:

\[
\frac{1}{4} \sum \left(1 - \left(\frac{\text{recorded heartbeats} - \text{counted heartbeats}}{\text{recorded heartbeats}}\right)\right)
\]

Then, other experimental tests, not reported here, were performed. Parts of the experimental procedure with substantial overlap concerning the sample used have also been published elsewhere (Mai et al., 2015). At the end of the experiment, weight and height were assessed.

### 2.4. Data analysis

All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, version 21). Group differences in descriptive and questionnaire data were examined using t-tests. Heart rate was examined in the same way. P value was set at < 0.05 as significance level for all analyses. An ANCOVA was run in order to analyse IAc with “Group” as factor and covariates BMI, alexithymia, depression and anxiety. Pearson r correlation analyses between IAc and IA were conducted, as well as partial correlations between IAc and anxiety, with BMI as control variable.

### 3. Results

#### 3.1. Sample characteristics and questionnaire data including interoceptive awareness

Sociodemographic and questionnaire data are depicted in Table 1. There were no significant group differences in age, BMI or educational level. Participants with BN reported significantly more depressive symptoms, higher anxiety, more alexithymia and greater problems in interoceptive awareness.

#### 3.2. Heart rate and interoceptive accuracy

Mean heart rate assessed during the heartbeat counting intervals was 62.5 bpm (SD 9.4) for BN patients and was compared to healthy controls (M = 65.7, SD 11.2). This difference was not significant \(t(df = 44) = 1.07, p = 0.20\), suggesting that both groups did not differ significantly as far as their heart rate is concerned.

Mean and SD of IAc contrasting BN participants and controls are depicted in Fig. 1. We additionally divided the patients' sample according to the BN subtype. In the purging group, IAc was 0.69 (SD 0.20) as compared to 0.68 (SD 0.24) in the non-purging subtype. Therefore, we did not split up the clinical subsample further into two groups, but treated the BN patients as one group.

An ANOVA that examined the effect of BN on IAc was conducted. There was no statistically significant interaction between these variables. An ANCOVA with covariates anxiety (STAI trait), depression (BDI), alexithymia (TAS mean score) and BMI revealed no significant group difference regarding IAc \(F(1,46) = 0.17, p = 0.68\). Focusing on anxiety, partial correlations in both groups were run to determine the relationship between IAc and anxiety, whilst controlling for BMI. We observed a moderate partial correlation in the control group only \((r = 0.50, p < 0.05); \text{BN: } r = -0.16, p = 0.47\) which became non-significant when not controlling for BMI \((r = 0.14, p = 0.36)\).

#### 3.3. Interrelation between interoceptive accuracy and interoceptive awareness

IAc was not correlated to the EDI subscale “interoceptive awareness” \((r = 0.03, p = 0.84)\) in the whole sample. Comparing BN and controls, we found a significant inverse correlation between IAc and IA in patients with BN only \((r = -0.42, p < 0.05)\), while a non-significant correlation was found among controls \((r = 0.28, p = 0.18)\). Participants with BN, who demonstrated increased problems in IA (thus higher EDI scores), exhibited a better IAc and vice versa.

### 4. Discussion

The primary purpose of the current study was to examine different levels of interoceptive signal processing between 23 patients with BN and healthy participants when controlling for possible important co-factors like BMI, depression and anxiety. For this reason, we used an experimental task, the Mental Tracking Method (Schandry, 1981) among patients with current BN to determine IAc, in combination with a self-report questionnaire assessing IA. Despite our expectations, we did not find any significant difference in IAc between healthy participants and patients with BN, while participants with BN reported more problems in IA as assessed by the EDI-2, something that contradicts our hypotheses. Additionally, we found an inverse correlation between IA and IAc in BN only, suggesting that deficit in attention and evaluation of internal signals such as hunger and satiety in BN could not reduce the ability to accurately detect internal signals from the cardiovascular system, something that also contradicts our initial assumptions.

The fact that IAc objectively determined by the mental tracking method (Schandry, 1981) was not reduced in BN is in accordance with data from Eshkevari et al. (2014) who used the heartbeat discrimination task by Whitehead and Drescher (1980). Moreover,
this result was obtained when controlling for possible mediating factors such as anxiety, depression and BMI. Nevertheless, possible other variables might account for the obtained null result. First of all, our sample was rather small and heterogeneous concerning the BN subtypes, comorbidity and etiology. The fact that we excluded patients taking psychotropic medication (including antidepressants) might have led to a bias in the sample. This is of special importance, as moderate depression was found to be associated with reduced IAc (Dunn et al., 2010).

Although IAc and IA were not related in controls, we observed an inverse correlation among patients with BN. Accordingly, Gartinkel et al. (2015) demonstrated that both IAc and IA in a sample consisted of healthy participants were found to be dissociable, something which comes in agreement with our results. However, only within the sub-group of participants with greatest IAc was there significant correspondence between these two variables. It is worth noting that the Porges Body Perception Questionnaire (Chen, 2013) was used to assess IA in this study. On the other hand, taking BN participants into account, we observed alternate patterns between the propensity of being interoceptively focused and sensitive (IA) and being accurate in detecting internal signals (IAc). Hence, a possible explanation is that the sustained attention on bodily processes related to hunger and satiety could decrease the informational relevance of bodily changes in other modalities such as the cardiovascular system. Therefore, other experimental measures like the Waterload paradigm (Herbert et al., 2012) might be useful to assess IAc arising from gastrointestinal signals, in more detail. Moreover, such a partial dissociation between different modalities of internal changes was described by a recent study (Limmer et al., 2015), where patients with Panic Disorder showed increased IAc for cardiac signals alone, whereas IAc for other internal signals like skin conductance changes were perceived inadequately as compared to healthy controls.

We did not observe any difference in IAc between purging and non-purging subtypes of BN, which could be partly due to the fact that our sample was small and not selected in the way that both BN subtypes were equally included. The study of interoception is crucial in order to understand the mechanisms of emotional regulation, which is fundamentally associated to both sensitivity and attention to one’s emotional state and to one’s state of internal bodily arousal. Additionally, IAc could be perceived as a positive predictor for emotion regulation, and more specifically for the downregulation of affect-related arousal (Füstös et al., 2013). One can assume that the accuracy in detecting changes in one’s bodily state facilitates the regulation of emotional responses by enhancing the distinction of different emotional states and permitting earlier countermeasures for controlling emotional arousal (Füstös et al., 2013). From another point of view, the binge eating or purging behavior in BN is known to act as a distraction from thoughts and emotions (Cooper et al., 2004). Previous studies suggest that episodes of binge eating provide a solution to frustration, emotional distress or anxiety, as well as an attempt to control thoughts and behavior, in general. Accordingly, binge eating could provide relief from anxiety, which normally declines during the process of purging (Kaye et al., 1986; Cooper et al., 2004). BN patients, through this binging-purging scheme show a coping mechanism against their frustration and this could be interpreted as an effort to regulate their thoughts and emotions in an efficient way. In contrast to that, anorectic females might use as a coping strategy shutting down bodily sensations.

One of the biggest differences regarding AN and BN patients is their BMI, as AN patients sustain low body weight (Berner et al., 2013; Yilmaz et al., 2014). Further studies indicated the close link between BMI and IAc reporting a reduced IAc in obese and overweight individuals (Herbert and Pollatos, 2014). In this study, average BMI of the healthy and BN participants did not differ significantly. With regards to the interaction between anxiety and IAc, BMI played a moderating effect on IAc in the control group. This does not indicate a direct relationship between a normal BMI and IAc, but it does demonstrate the mediating role of BMI between accurately perceiving bodily signals and low levels of anxiety. Further exploration in this matter is needed.

The fact that we did not detect any differences regarding IAc in healthy participants and participants with BN, but an inverse interrelation in different levels of interceptive processes among BN participants, generates further discussion for the possible clinical implications of interoception. Taking this into account, one should hypothesize that in the therapeutic process of treating BN, the normal levels of IAc could also be seen as “a useful therapeutic mean” and that the pathological phenomenon of being constantly preoccupied with internal bodily sensations, such as hunger and fullness, could be the focus of the therapeutic intervention. Schaefer and colleagues (Schaefer et al., 2014) suggested that the accuracy in perceiving internal bodily signals of patients suffering from somatoform disorders could be improved after receiving a heartbeat perception training. Similarly, other methods such as mindfulness techniques or somatic experiencing that use interoception as a core element in order to reduce symptoms resulting from chronic and traumatic stress (Payne et al., 2015) could be implemented in order to improve certain aspects of interoceptive processes in BN.

Limitations of the current study are referred to both the small and heterogeneous sample of bulimic patients examined and the fact that some healthy controls were not perfectly matched to the BN patients concerning age or BMI. In addition, our BN sample was derived only from counseling units and not from in-hospital settings where the recovery pace and treatment methods are different. Lastly, the lack of control over the therapeutic approach (part of the bulimic patients underwent psychotherapeutic or psychiatric treatment) is a potential shortcoming.

5. Conclusion

On the basis of the evidence currently available, this study demonstrated that BN is characterized by a complex pattern of interoceptive alterations. Using an objectively determined method to assess IAc, patients with BN had a normal IAc, but a reduced IA as compared to healthy participants. While IAc and IA were not correlated among healthy controls, we observed a pathological overlap between IAc and IA in BN participants. This observation can be interpreted as a potential risk configuration for processes related to a higher malleability of interoceptive signal processing and evaluation of these signals.

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III. Describe your feelings: body illusion related to alexithymia in adolescence


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Describe Your Feelings: Body Illusion Related to Alexithymia in Adolescence

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Objective: Having access to bodily signals is known to be crucial for differentiating the self from others and coping with negative feelings. The interplay between bodily and emotional processes develops in adolescence, where vulnerability is high, as negative affect states often occur, that could hamper the integration of bodily input into the self. Aim of the present study in healthy adolescents was to examine, whether a disturbed emotional awareness, described by the alexithymic construct, could trigger a higher malleability in the sense of body-ownership.

Methods: Fifty-four healthy adolescents aged between 12 to 17 years participated in this study. The Strength and Difficulties Questionnaire (SDQ) and the Screening psychischer Störungen im Jugendalter were used to assess emotional distress and conduct problems. Alexithymia was assessed by the TAS-20. The rubber hand illusion was implemented for examining the malleability of body-ownership.

Results: A higher body illusion was found to be connected with “difficulties in describing feelings”. Moreover, a higher degree of self-reported conduct and emotional problems as assessed by the SDQ were associated with a more pronounced body illusion. Further findings revealed an association between emotional distress and the emotional alexithymia subscales “difficulties in identifying feelings” and “difficulties in describing feelings”.

Conclusion: Our findings emphasize a close link between the sense of body-ownership and emotional awareness as assessed by emotional facets of the alexithymic trait. We suggest that in adolescents with higher malleability of body-ownership, a vicious circle might occur where affect and integration of different proprioceptive signals regarding the body become more entangled.

Keywords: body illusion, rubber hand, alexithymia, emotions, adolescents

INTRODUCTION

Adolescence is the time where major physical and psychological developmental changes are taking place. It is often known as a transitional stage, where the sense of identity or the establishment of a social role is being formatted/developed and the emotional autonomy or cognitive independence plays a crucial role (Maldonado et al., 2013). Body image and self-esteem are often pertinent in this stage and mass media are influential (Patton et al., 2014). Accordingly, eating disorders or other mental disorders are usually being firstly expressed during adolescence and early adulthood.
(Preti et al., 2009; Benjet et al., 2015). Therefore, the exploration of these changes in this transitional developmental phase is important.

Recent studies investigated the sense of body-ownership (perception of body as mine) using the rubber hand illusion (RHI) experiment, mostly in adults; in this paradigm participants estimate if a rubber hand, which had been synchronously stimulated with one's own unseen hand, feels like their own hand (Tsakiris et al., 2011; Suzuki et al., 2013). Multisensory information, arising from vision, touch and proprioception, is the key for forming the bodily self, where visual-tactile processes are central for the body-ownership and mature during early childhood (Cowie et al., 2013). On the contrary, visual-proprioceptive processes, which are determinable for the visual-tactile integration in adults develop later in childhood (Cowie et al., 2013). Nonetheless, forming the bodily self, having access to bodily signals and differentiating the self from the others is crucial in the developmental processes in order to form more complex social behaviors, such as: social referencing, imitation, empathy, dealing with social exclusion or ostracism (Gallese, 2003; Chaminade et al., 2005; Cascio et al., 2012; Pollatos et al., 2015).

A previous study regarding the RHI in adults and children revealed a dissociation between the sense of body-ownership/ the experience of body as “mine” (Tsakiris, 2010) and the visual perception of hand position in children (Cowie et al., 2013). Moreover, proprioceptive drift responses were influenced by age, suggesting that children 4 to 9 years old indicated greater proprioceptive drifts than adults across synchronous and asynchronous conditions (Cowie et al., 2013). Likewise, another study investigated the role of body-ownership among children with autism spectrum disorders, revealing that autistic children demonstrated a delayed perception of the illusion in comparison to children with normal development. The authors concluded that the integration of visual and tactile information for the formation of body perception is a multidimensional process characterized by distinct differences among healthy and clinical populations (Cascio et al., 2012).

The construct of alexithymia is of great importance in this context: Alexithymia (“no words for feelings”), first described by Sifneos (1976), refers to a personality trait characterized by an inability to describe, express and identify one’s and others’ feelings as well as an externally oriented thinking style (Sifneos, 1976; Herbert and Pollatos, 2012). Alexithymia is related to a wide range of mental disorders (Taylor et al., 1999) including eating disorders (de Zwaan et al., 1996; Taylor et al., 1999; Corcos et al., 2000; Berthoz et al., 2007; Pollatos et al., 2008), depression (Taylor and Bagby, 2004; Foran and O’Leary, 2013; Panayiotou et al., 2015), anxiety disorders (Turk et al., 2005), substance use (Lyvers et al., 2013) and a variety of somatic illnesses such as diabetes mellitus (Chatzi et al., 2009). Self-report measures like the Toronto Alexithymia Scale (Bagby et al., 1994), the most widely used and well-validated assessment tool (Bagby et al., 1994; Parker et al., 2003; Mattila et al., 2007), assess alexithymia and its three main facets; namely difficulties in identifying feelings (TAS 1, DIF), difficulties in describing feelings (TAS2, DDF), and externally oriented thinking or a preoccupation with the details of external events (TAS3, EOT). There is empirical evidence that facets of alexithymia interact with the prevalence of dissociation (Tolmumen et al., 2010) and the risk for developing a psychosis (van’t Wout et al., 2007; van der Velde et al., 2015), suggesting that core elements of alexithymia may support negative affect states that hamper the integration of bodily input into the self and might also affect the sense of body-ownership.

This assumption is in accordance with data of Herbert and colleagues (Herbert et al., 2011) who reported less accurate ability to perceive bodily signals in alexithymia. Tsakiris et al. (2011) could show that participants with less interoceptive accuracy have a higher malleability of body-ownership processes as measured by the RHI paradigm. In spite of these data, empirical research examining a possible relationship between alexithymic trait and body-ownership is to our knowledge sparse. There is one recent study by Grynborg and Pollatos (2015) demonstrating a higher malleability of body-ownership in adults with higher scores of alexithymia. The sense of body-ownership in relation to alexithymia was to our knowledge not examined in adolescents so far, though the prevalence of alexithymia in younger adolescents is relatively high (Säkkinen et al., 2007).

All the above could suggest that the sense of body-ownership and alexithymia could be connected and this could have implications for some mental and somatic symptoms suffered by adolescents. Thus, scope of this study was to investigate the interrelation between alexithymia and its constructs with body-ownership. Based on current literature, we hypothesized that higher degrees of alexithymia would be connected to a more pronounced malleability of body-ownership as measured by a stronger body-illusion in healthy adolescents.

MATERIALS AND METHODS

Participants

In total, our sample consisted of 54 healthy participants fulfilling all required criteria, such as absence of a diagnosed psychological disorder, or other medical condition (e.g.: cardiovascular disease, bronchial asthma, diabetes etc.). More specific 28 girls and 26 boys, aged between 12 to 17, took part in the study, with a mean age of 14.0 years ($SD = 1.55$) and a mean BMI of 19.7 ($SD = 2.8$). Flyers were distributed in sports and chess clubs; advertisements were placed in local newspapers. All experiments were conducted in accordance to the Declaration of Helsinki and were approved by the Ethics Committee of Ulm University.

Experimental Procedure

The participants and their parents gave their written informed consent and filled in online several questionnaires, which are described below. The study took place in the laboratory of the Clinical and Health Psychology Department of Ulm University. The experimental procedure, including the RHI and other tasks not being reported here, lasted about 90 min and all participants received a cinema voucher for their participation.
The psychometric properties of the German sum score SDQ with the Child Behavior Checklist (CBCL) (Klasen et al., 2000). The German SDQ was found to correlate highly specifically the total score, in which the first four subscales are summed up. The German SDQ was found to correlate highly with the Child Behavior Checklist (CBCL) (Klasen et al., 2000). The psychometric properties of the German sum score SDQ demonstrated an internal consistency of $\alpha = 0.82$ (Rothenberger et al., 2008).

Screening Psychischer Störungen im Jugendalter (SPS-J)
The SPS-J is a screening questionnaire for psychological disorders in adolescence, which is the translation of the Reynolds Adolescent Adjustment Screening Inventory (RAASI) and is suitable for assessing emotional and conduct problems. It is comprised of the following subscales: antisocial behavior, anger control problems, emotional distress and negative self. For this study we used only the scale emotional distress in order to evaluate the degree of depression or sadness and anxiety. Internal consistency measured by Cronbach $\alpha$ for this test lies between .75 to .84 and repeatability after six weeks was found to be satisfactory ($r_{tt} = 0.55$ to 0.73) (Hampel and Petermann, 2006).

Alexithymia
Alexithymia was measured by the Toronto Alexithymia Scale (TAS-20). The TAS-20 is the most commonly used self-report questionnaire for the assessment of Alexithymia and it consists of 20 items, divided into three subscales, such as: difficulties in identifying feelings (TAS 1), difficulties in describing feelings (TAS 2) and externally oriented thinking (TAS 3). A 5-point Likert scale is used, and ratings vary from strongly disagree to strongly agree (Herbert et al., 2011). Participants with a TAS total score $\geq 60$ are considered as alexithymic in a clinical manner (Taylor et al., 1991).

RHI Experiment
The RHI experiment assesses the sense of body-ownership, or in other words the multisensory integration of tactile, visual, and proprioceptive information (Grynberg and Pollatos, 2015). The degree of proprioceptive drift, the subjective reports of the illusion and the participant’s hand temperature were taken into account in the current study.

For this reason, each adolescent was seated comfortably in front of a table, facing a two-chambered box [size: 36.5 cm $\times$ 19 cm $\times$ 29 cm (width $\times$ height $\times$ depth)] with open sides, being unaware of the hypothesis of the study. Moreover, the participant placed his/her left hand into the left chamber and a realistic rubber hand, in means of skin color, texture, and shape, was placed in the right chamber of the box. The participant's posture was in this way, that he/she could observe the rubber hand throughout the experiment and participant’s middle finger was lightly fixed to the box with a hook and loop fastener. A hairdressers’ cloth was also used, in order to ensure that the participant's sight was concentrated on the rubber hand. Before each block, participants had to verbally specify the felt location of their left index finger on a ruler placed on the cover of the box, something which is also known as pre-induction proprioceptive location judgment (Tsakiris et al., 2011). Skin temperature was measured at the knuckle of participants’ left index finger with an Infrared Thermometer (Maplin, UK). Furthermore, the synchronous stroking (120 s) of the index finger of the rubber hand and the participant’s hand took place, followed by the assessment of the post-induction temperature and participant’s post-induction proprioceptive location judgment according to a ruler. Meanwhile, the participant was allowed to remove his/her hand from the chamber, and had to fill in the adapted version of the eight items from the RHI Questionnaire for the synchronous condition (Longo et al., 2008). In specific, five items were referred to ownership (items 1 to 5; e.g.: “It seemed like the rubber hand was part of my body”) and three items to location (items 6 to 8; e.g.: “It seemed like the rubber hand was in the location where my hand was”) (Longo et al., 2008). Moreover, the second block was consisted of the same measurement, but in this case the stimulation of the real and fake hand was made in an asynchronous way and the participant had to complete the same questionnaires, but for the asynchronous condition. The proprioceptive drift for the synchronous and asynchronous induction was calculated in the end of each measurement as the difference between the perceived location of the left index finger before and after the stroking (Tsakiris et al., 2011).

Statistical Analyses
All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, version 21). A normality test was performed in order to determine if there was a normal distribution using the Kolmogorov–Smirnov Test. Because of the normal data distribution, parametric tests were conducted, such as Pearson $r$ correlations, in order to assess whether there was an interaction between proprioceptive drift and alexithymia. A $p$-value less than 0.05 was considered significant. Continuous variables were summarized as mean and standard deviation; frequencies were used to analyze nominal and ordinal variables. Continuous variables were compared using the two sample $t$-test and analysis of variance (ANOVA). A repeated-measures ANOVA was performed, in order to determine the effect between conditions. One-sample $t$-tests were run, in order to prove if the RHI paradigm produced illusion among adolescents and to confirm the specificity. Multiple regression analysis was performed using the stepwise method, in order to predict the strength of association between all variables of interest. We did not perform a factor analysis due to the small sample size (Brace et al., 2016).

RESULTS

Sample Characteristics
Our sample ($N = 54$) was consisted of 28 girls; the average age was 14 years ($SD = 1.57$) and the mean...
BMI was 19.72 (SD = 2.79). Table 1 demonstrates sample characteristics and questionnaire data concerning alexithymia, emotional distress, and emotional and conduct problems between the younger-older age group, but also among boys and girls.

**Interrelations between Alexithymia, Emotional Distress, and Emotional and Conduct Problems**

Emotional and conduct problems together with emotional distress significantly predicted TAS 1, $F(2,51) = 12.01$, $p < 0.00$, adjusted $R^2 = 0.32$; TAS 2, $F(2,51) = 6.74$, $p < 0.00$, adjusted $R^2 = 0.21$; TAS 3, $F(4,49) = 7.56$, $p < 0.00$, adjusted $R^2 = 0.38$; but not TAS 3, $F(2,51) = 0.63$, $p > 0.05$. Results of the multiple regression analysis are presented in Table 2.

**Rubber Hand Paradigm**

**Subjective Ratings**

For the statistical analysis of the subjective reports, we recoded the answers (from −3 to 3) into new variables (from 1 to 7), where higher values indicate a higher subjective illusion. Moreover, we conducted a one-way repeated-measures ANOVA, setting condition (synchronous vs. asynchronous) as within-subject factor. The results show that the synchronous condition differentiated significantly from the asynchronous one [$F(1,53) = 19.04$, $p = 0.00$, $\eta^2 = 0.25$] indicating a stronger illusion in the synchronous condition. Both mean scores of the subjective ratings regarding *ownership* [synchronous: ($M = 4.01$, $SD = 1.60$) vs. asynchronous: ($M = 3.08$, $SD = 1.65$)] as well as regarding *location* [synchronous: ($M = 3.70$, $SD = 1.57$) vs. asynchronous: ($M = 3.04$, $SD = 1.59$)] were significantly higher after synchronous stimulation (see Figure 1) and both conditions did differ significantly [location: $F(1,53) = 11.23$, $p = 0.00$, $\eta^2 = 0.17$] [ownership: $F(1,53) = 20.46$, $p = 0.00$, $\eta^2 = 0.27$].

Boys ($M = 3.90$, $SD = 1.53$) and girls ($M = 4.11$, $SD = 1.66$) did not differentiate in *ownership* and in *location* (boys: $M = 3.78$, $SD = 1.60$; girls: $M = 3.56$, $SD = 1.55$). Additionally, age did not seem to influence the subjective assessment of the body illusion [ownership: young ($M = 4.30$, $SD = 1.58$), old ($M = 3.65$, $SD = 1.56$); location: young ($M = 3.95$, $SD = 1.58$), old ($M = 3.30$, $SD = 1.50$)].

**TABLE 1** | Sample characteristics and comparison of means regarding age and gender in all variables of interest.

<table>
<thead>
<tr>
<th></th>
<th>N = 54</th>
<th>Age</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>Younger</td>
<td>M (SD)</td>
</tr>
<tr>
<td>TAS 1</td>
<td>16.20 (4.11)</td>
<td>15.90 (4.25)</td>
<td>16.54 (3.97)</td>
</tr>
<tr>
<td>TAS 2</td>
<td>11.24 (3.50)</td>
<td>11.30 (3.68)</td>
<td>11.17 (3.30)</td>
</tr>
<tr>
<td>TAS 3</td>
<td>22.61 (3.60)</td>
<td>22.30 (3.79)</td>
<td>23.00 (3.36)</td>
</tr>
<tr>
<td>TAS</td>
<td>50.05 (7.40)</td>
<td>49.50 (8.16)</td>
<td>50.71 (6.41)</td>
</tr>
<tr>
<td>EmoDis</td>
<td>0.70 (0.40)</td>
<td>0.63 (0.40)</td>
<td>0.75 (0.40)</td>
</tr>
<tr>
<td>SDQ</td>
<td>11.28 (5.41)</td>
<td>10.00 (4.21)</td>
<td>12.88 (6.35)</td>
</tr>
</tbody>
</table>

All values are mean (SD) unless stated otherwise; SD = Standard Deviation; t = independent t-test; TAS 1: difficulty identifying feelings; TAS 2: difficulty describing feelings; TAS 3: externally oriented thinking; TAS: total score of the TAS-20; EmoDis: emotional distress measured by the SPS-J; emotional and conduct problems assessed by the SDQ; $p < 0.05$ is considered significant; $^*$ trend toward significance. Younger vs. Older: Interaction between younger (12–14) and older (15–17) age group; Boys vs. Girls: Interaction between boys and girls. $^*p < 0.05$.

**TABLE 2** | Multiple linear regression analysis predicting alexithymia (subscases and total score) related to emotional distress and emotional and conduct problems.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Predictor</th>
<th>$B$</th>
<th>SE</th>
<th>$\beta$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAS 1</td>
<td>SDQ</td>
<td>0.32</td>
<td>0.09</td>
<td>0.32**</td>
<td>[0.05, 0.42]</td>
</tr>
<tr>
<td></td>
<td>EmoDis</td>
<td>0.38</td>
<td>1.24</td>
<td>0.38**</td>
<td>[1.38, 6.38]</td>
</tr>
<tr>
<td>TAS 2</td>
<td>SDQ</td>
<td>0.13</td>
<td>0.08</td>
<td>0.20</td>
<td>[-0.04, 0.90]</td>
</tr>
<tr>
<td></td>
<td>EmoDis</td>
<td>3.09</td>
<td>1.14</td>
<td>0.36**</td>
<td>[0.80, 5.38]</td>
</tr>
<tr>
<td>TAS 3</td>
<td>SDQ</td>
<td>0.10</td>
<td>0.10</td>
<td>0.31</td>
<td>[-0.09, 0.29]</td>
</tr>
<tr>
<td></td>
<td>EmoDis</td>
<td>0.16</td>
<td>1.30</td>
<td>0.90</td>
<td>[-2.46, 2.78]</td>
</tr>
<tr>
<td>TAS</td>
<td>SDQ</td>
<td>0.42</td>
<td>0.16</td>
<td>0.31**</td>
<td>[0.08, 0.75]</td>
</tr>
<tr>
<td></td>
<td>EmoDis</td>
<td>6.81</td>
<td>2.21</td>
<td>0.37***</td>
<td>[2.36, 11.26]</td>
</tr>
</tbody>
</table>

TAS 1: difficulty identifying feelings; TAS 2: difficulty describing feelings; TAS 3: externally oriented thinking; TAS: total score of the TAS-20; EmoDis: emotional distress measured by the SPS-J; emotional and conduct problems assessed by the SDQ; $^{**}p < 0.001$; $^{**}p < 0.01$; $^*p < 0.05$.

**FIGURE 1** | Subjective ratings of ownership and location after synchronous and asynchronous stimulation as assessed by the RHI Questionnaire; $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

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TABLE 3 | Pearson r correlation matrix for the RHI (subjective and objective reports) and questionnaire data

<table>
<thead>
<tr>
<th></th>
<th>Drift_S</th>
<th>Temperature_S</th>
<th>Ownership_S</th>
<th>Location_S</th>
<th>EmoDis</th>
<th>SDQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift_S</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp_S</td>
<td>-0.40**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ownership_S</td>
<td>0.35**</td>
<td>-0.19</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location_S</td>
<td>0.27*</td>
<td>-0.01</td>
<td>0.69**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EmoDis</td>
<td>0.10</td>
<td>-0.02</td>
<td>0.14</td>
<td>-0.01</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>SDQ</td>
<td>0.26*</td>
<td>-0.45**</td>
<td>0.21</td>
<td>0.18</td>
<td>0.32*</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Drift_S: proprioceptive drift in the synchronous condition; Temp_S: Temperature drift in the synchronous condition; Ownership_S: subjective report of body ownership in the synchronous condition; Location_S: subjective report of location in the synchronous condition; EmoDis: emotional distress measured by the SPS-J; emotional and conduct problems assessed by the SDQ; ***p < 0.001; **p < 0.01; *p < 0.05.

Proprioceptive and Temperature Drift

First, proprioceptive drift was calculated by subtracting the position of the finger reported by the participant before the stimulation from the position of the finger reported by the participant after the stimulation. Higher values indicate a higher drift toward the rubber hand. The temperature drift is measured by subtracting the temperature of the finger before the stimulation from its temperature after the stimulation. Lower values indicate a higher drift toward the rubber hand (Grynberg and Pollatos, 2015). After conducting a one-way repeated-measures ANOVA, in order to confirm the specificity of the illusion, we found that proprioceptive drift in the synchronous condition (M = 1.14 cm, SD = 4.56) did significantly differ in comparison to the asynchronous condition [(M = 0.02 cm, SD = 2.74); F(1,53) = 4.82, p = 0.03, η² = 0.08], indicating a significantly stronger body illusion after synchronous stimulation. Thus, we solely focus our further analyses on the synchronous condition. There was an effect of condition on the temperature drift, after conducting a paired-sample t-test [t(53) = 2.61, p = 0.01], suggesting that these dimensions were differentially present. Importantly, a higher drift in the synchronous condition was associated with a higher temperature drop (r = −0.30, p = 0.02).

Neither gender [(boys: M = 0.07, SD = 3.66), (girls: M = 2.12, SD = 5.13); t(52) = 1.67, p = 0.10], nor age [(younger: M = 1.76, SD = 5.06), (older: M = 0.35, SD = 3.80); t(52) = 1.13, p = 0.26] influenced the degree of proprioceptive drift in the synchronous condition. Furthermore, Table 3 demonstrates the correlations between proprioceptive drift, temperature, subjective reports and questionnaire data.

Alexithymia and RHI

We calculated firstly Pearson r correlations between all variables of interest. Proprioceptive drift was associated to TAS 2 subscale (r = 0.36, p = 0.01) (Figure 2). Ownership was connected only to TAS 2 (r = 0.27, p = 0.05) (Figure 3). On the contrary, location was not related to the subscales of alexithymia. Finally, temperature drift was not connected to the facets of alexithymia [TAS 1: r = −0.06, p = 0.69; TAS 2: r = −0.16, p = 0.24; TAS 3: r = −0.07, p = 0.59].

We further on conducted a multiple regression using the stepwise method, setting as outcome the different RHI measures (objective and subjective) and as predictors the alexithymia subscales, emotional distress, emotional and conduct problems. Table 4 shows the results of this analysis. As expected, we found significant associations between ownership and TAS 2...
DISCUSSION

Scope of this study was to investigate the malleability of body ownership using the RHI experiment and its interrelation to alexithymia in adolescence. First, findings of this study confirmed the feasibility of the RHI paradigm in adolescents regarding objective and subjective indices of body illusion and further interrelations between these measures were found. The main result was that one emotional facet of alexithymia, namely difficulties in describing feelings (TAS 2; DDF), was associated with a stronger malleability of body-ownership as reflected both in objective markers (proprioceptive drift) as well as in subjective reports (items on body-ownership).

More specifically, the subjective ratings concerning body illusion indicated that the degree of illusion regarding ownership and location was greater in the synchronous condition than in the asynchronous, something that is consistent with previous literature among adults (Tsakiris et al., 2011; Grynb erg and Pollatos, 2015; Riemer et al., 2015). Likewise, the above was confirmed at a behavioral level, in which participants perceived their hand closer to the rubber hand after the synchronous induction in contrast to the asynchronous, and the temperature drop (autonomic measure) after synchronous visuo-tactile stimulation was connected to a larger proprioceptive drift. This is in agreement with previous research (Tsakiris et al., 2011) showing that both objective measures of the body illusion are interconnected. Hence, that could lead us to the conclusion that the integration of visual and tactile information in order to influence proprioception is feasible among adolescents, as measured by the RHI, and that the present results could replicate the original illusion, not only at a behavioral level, but also at a subjective and autonomic level, as has been previously shown in adults (Botvinick and Cohen, 1998; Tsakiris et al., 2011; Grynb erg and Pollatos, 2015) and in children (Cascio et al., 2012).

Surprisingly, gender and age did not influence subjective and objective ratings in the RHI. Body dissatisfaction is known to be more pronounced in females, where girls have a tendency to report more negative body image than boys, something which is consistent with the thin ideal of girls in the European countries (Holubcikova et al., 2015). We did not observe a greater malleability of body representation in girls as assessed by the RHI.

One important point to consider is that our sample consisted of normal-weighted adolescents with presumably no or rather low amount of eating problems, suggesting that alternations in body image might be rather small. As an unhealthy body image is often associated with sedentary lifestyle, obesity and eating disorders (Voelker et al., 2015), additional sample of adolescents with a larger range concerning body weight might change the picture.

Karukivi et al. (2014a,b) suggest that alexithymia is a stable personality trait among adolescents, which can be linked up to lack of social support from friends and to an intrusive and overprotective parenting. From another point of view, alexithymia might also be perceived as a developmental characteristic in young children and not as a pathological phenomenon (Tolmunen et al., 2010). Interestingly, our results revealed that emotional and conduct problems as assessed by the SDQ predicted DIF, whereas emotional distress predicted the emotional aspects of alexithymia (DIF/DDF subscales), highlighting the close link between a possible psychopathology and alexithymic behavior connected to emotion awareness. This finding could highlight problems in affect regulation associated with alexithymia as demonstrated in adults (Taylor et al., 1999; Taylor and Bagby, 2004; Foran and O’Leary, 2013; Panayiotou et al., 2015). Furthermore, the idea that a disturbed body ownership could be related to emotional or conduct problems, was also supported by the fact that SDQ mean scores and proprioceptive drift were associated. Due to the lack of studies in this field, further research is required to establish a conclusion and to determine the specificity of the psychopathologic symptoms in this age.

Main finding of this study in adolescents was that DDF predicted proprioceptive drift and the subjective report of ownership in the RHI. DDF belong to the emotional part of alexithymia and describe a crucial ability for social communication, allowing fine-tuned feedback in emotional situations. There is further evidence that alexithymic individuals face difficulties in differentiating affective symptoms from somatic, which are related to interoceptive experiences (Byrne and Ditto, 2005; Panayiotou et al., 2015). Furthermore, Panayiotou et al. (2015) suggested that alexithymia is linked to the characteristic of experiential avoidance (EA), which is one’s effort to avoid experiencing unpleasant emotions, memories, or aversive bodily sensations. On the other hand, previous evidence has also revealed a connection between deficits in the perception, processing, and interpretation of verbal and nonverbal emotional stimuli in alexithymia (Roedema and Simons, 1999; Lane et al., 2000; Stone and Nelson, 2001; Berthoz et al., 2002; Kano et al., 2003; Luminet et al., 2006; Pollatos et al., 2008; Herbert et al., 2011). In line with these ideas, we suggest that in adolescence, a vicious circle might occur, in which affect and integration of different exteroceptive/proprioceptive bodily signals become more and more entangled. Whether alexithymia leads to an attenuated body ownership among adolescents, or an attenuated body ownership triggers alexithymia, remains yet unclear, as correlational analyses do not allow elucidating the causal chain of our observation.

Nevertheless, possible limitations of this study could be the absence of data regarding personality traits, like introversion or
extraversion, which could provide more individual characteristics of the participants. Accordingly, in this study, we used the TAS 20 in order to assess alexithymia; further studies in this field could be conducted on the basis of experimentally assessing alexithymia. Due to the small sample size, exploratory factor analysis was not possible for the investigation of the underlying structure in the pattern of correlations between RHI alexithymia, something that could also be seen as a shortcoming. Therefore future analyses should include a larger sample and could be conducted in a longitudinal fashion during childhood or adolescence.

To sum up, findings of this study suggest that the measurement of multi-sensory integration regarding body ownership among adolescents, arising from vision and touch can be behaviorally and physiologically estimated. We conclude that our results illustrate for the first time an intriguing link between alexithymic traits and malleability of bodily representations in adolescence, assessed by the RHI. As this is to our knowledge the first study investigating these variables among adolescents, more research on this topic needs to be undertaken to further elucidate the obtained associations and to further observe more closely the developmental characteristics that underlie the interplay between the sense of body-ownership and emotion awareness.

**AUTHOR CONTRIBUTIONS**

EG: study conception, study design, data collection, data analysis, preparation of the MS. SM: data collection, MS editing, MS proof reading. OP: study design, data analysis, MS editing, MS proof reading.

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**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
IV. I see neither your fear nor your sadness-interoception in adolescents

I see neither your Fear, nor your Sadness – Interoception in adolescents

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ABSTRACT

Interoception describes the mapping of the body’s internal landscape and has been connected to greater intensity of emotional experience. The goal of the current study was to explore the relationship between interoception and emotion face recognition in healthy adolescents. The heartbeat perception task was used to assess interoceptive accuracy (IAC) and participants were asked to recognize different facial expressions. EEG activity was recorded, providing data for the P100, the N170 and the P300 ERP components. Results indicated high sensitivity to negative affect, as well as low accuracy in the recognition of fear and sadness among adolescents high in IAC, reflected by amplitude modulations in the N170 and the P300. The interpretation of these results focus on the intensity experienced in negative facial emotions, modified by IAC, as well as on emotional valence and arousal. These findings emphasize the dynamic integration of body and mind for shaping emotion recognition in adolescence.

1. Introduction

Merlaue-Ponty (1962) said that we live in our world through our bodies. But what role do emotions play? Previous research suggests that our bodily changes can affect our emotional experiences (James, 1884; Schachter & Singer, 1962). More specifically, our emotional experiences can be influenced by cognitions and beliefs regarding the causes of our physiological changes (Gendron & Feldman Barrett, 2009; Seth, 2013). These dynamics are important because emotions are essential for forming attitudes and judgments about interpersonal interactions (Forgas, 2003). A common way through which individuals can use emotions to form attitudes and judgments about others is by trying to read facial expressions. Prior research has found that reading facial expressions plays a key role in normative social development (Rodger, Vizioli, Ouyang, & Caldara, 2015) and can be seen as a precondition for socializing (Suzuki, Poon, Kumari, & Cleare, 2015). In the current study, we aim to better understand the role of interoception in emotion processing, specifically emotion processing via reading facial expressions of others.

The dynamic integration of brain and body plays a determining role in emotion processing (Garfinkel & Critchley, 2013). Accordingly, interoception can be described as the perception and processing of our own internal bodily signals (Georgiou et al., 2015; Pollatos, Herbert, Mai, & Kammer, 2016), which are connected to the central nervous system and play an important role in maintaining homeostasis (Geunen, Vlaeyen, & Van Diest, 2016). An individual’s accuracy in perceiving these signals is known as interoceptive accuracy (IAC) and can be assessed by the heartbeat perception task, a task in which participants are asked to estimate their heartbeats in given time intervals (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015; Schandry, 1981). It is worth noting that IAC is separate from the self-perceived tendency to be sensible/sensitive towards own bodily sensations, which is termed interoceptive

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sensibility and can be assessed via self-report (Critchley & Garfinkel, 2017). IAC is related to emotion processing; more specifically, it has been connected to greater intensity of emotional experience (Herbert, Herbert, & Pollatos, 2011) and emotion regulation (Ceunen et al., 2016; Füstös, Gramann, Herbert, & Pollatos, 2013; Terasawa, Moriduchi, Tochizawa, & Umeda, 2014). Previous studies demonstrated that IAC can be determinable and diverse among children (Eley, Gregory, Clark, & Ehlers, 2007; Eley, Stirling, Ehlers, Gregory, & Clark, 2004; Georgiou et al., 2015; Koch & Pollatos, 2014a, 2014b; Murphy, Brewer, Catmur, & Bird, 2017) and adolescents (Mata, Verdejo-Roman, Soriano-Mas, & Verdejo-Garcia, 2015; Murphy et al., 2017; Schauder, Mash, Bryant, & Cascio, 2015). Nevertheless, in this field, there is a lack of studies on how interoception develops and remains stable in childhood and adolescence, as the sense of identity, establishment of a social role (Georgiou, Mai, & Pollatos, 2016), and social skills (Berenschot et al., 2014) are under constant development in these transitional stages.

To our knowledge, no study to date has explored the relationship between IAC and emotion face recognition among adults and adolescents. Terasawa et al. (2014) studied the interaction between IAC and emotional experience in a social context. In that study, participants were asked to judge whether a morphed emotion stimulus elicited an emotion, rather than naming/recognizing this emotion. Results indicated a close link between high IAC and greater sensitivity to happy and sad facial expressions, but not to angry or distorted faces. Prior research also suggests that individuals high in IAC experience emotions more intensely (Wiens, Mezzacappa, & Katkin, 2000), place more emphasis on the dimension of arousal when describing emotion processing (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Cali, Ambrosini, Picconi, Mehling, & Committeri, 2015), and demonstrate more successful cognitive reappraisal of unpleasant images, which is related to better regulation of negative affect (Füstös et al., 2013; Muir, Madill, & Brown, 2017). Overall, studies on IAC and emotional experience in adults suggest that activity in the anterior insula reflects the functional overlap of bodily and emotional experiences, suggesting a close link between bodily and emotion awareness (Craig, 2009; Critchley, Wiens, Rotstein, Ohman, & Dolan, 2004; Harrison, Grey, Gianaros, & Critchley, 2010; Seth, Suzuki, & Critchley, 2011; Zaki, Davis, & Ochsner, 2012). This is also reflected in the predictive coding model proposed by Seth et al. (2011), which describes subjective feeling states as a result of the prediction of the interoceptive state of the body. Taken together, these studies show that experimental psychology has taken the body as a starting point for understanding the self (Tsakiris, 2017) and how we perceive emotions.

Furthermore, the use of electroencephalography (EEG) can provide us with important information concerning cognitive and attentional processing, by examining the event-related-potentials (ERPs) (Mai et al., 2015). Therefore, different ERP components, such as the P100, the N170 and the P300, can give an insight into the underlying neuronal mechanisms occurring when analyzing patterns of emotion recognition (Earls, Curran, & Mittal, 2016). The P100 component is an index of early visual processing and is defined as a positive deflection peaking ~100 ms post-stimulus onset (Neuhuis, Kresse, Faja, Bernier, & Webb, 2016). The N170 refers to a negative deflection at occipitotemporal brain areas between 140 and 220 ms post stimulus-onset and is connected to facial processing (Earls et al., 2016; Mai et al., 2015). Lastly, the P300 is an indicator of attention, detection, and evaluation of relevant information based on cognitive resources and is related to cognitive processing performance. Previous studies have found that the P300 amplitude is associated with arousal and peripheral indices of cardiovascular reactivity in response to emotional stimuli (Pollatos, Herbert, Schandry, & Gramann, 2008), as well as that the P300 is connected to cognitive processing during emotion discrimination tasks (Cavanagh & Geisler, 2006; Sanger & Dorjee, 2015).

Prior EEG studies about visual emotion face processing showed that the N170 amplitude in response to angry and happy faces in children was related to anxiety (O'Toole, DeCicco, Berthod, & Dennis, 2013); however, other findings suggested that the N170 amplitude was found not to be sensitive to emotional faces in preschoolers (Batty & Taylor, 2006) and in primary school children (Dennis, Malone, & Chen, 2009). In general, the modulation of the N170 can depend on the task and on the on-going developmental neural system maturation in emotional processing (O'Toole et al., 2013). In terms of the P300 and IAC, former studies on adults have shown that after rating images with an unpleasant effect, IAC was reflected through modulations of the P300 peak amplitudes, demonstrating a close link between the P300 and the experienced intensity of emotions (Füstös et al., 2013; Pollatos, Herbert, Kaufmann, Auer, & Schandry, 2007). Nonetheless, there is a lack of studies concerning the modulation of ERP components in visual emotion face recognition among children and adolescents.

Bearing these in mind, there are several studies observing the relationship between interoception and emotions in adults, but to our knowledge, no study to date has examined the interaction between interoceptive processing and emotion face recognition in adolescents. In the current study, we sought to elucidate the relationship between IAC and emotion face recognition in adolescents via the use of electrophysiological and behavioural data. Taking into account the fact that interoception can determine how intensely we experience and process emotions (Terasawa et al., 2014), we hypothesize that higher IAC would be associated with better emotion face recognition in adolescents. Taking this into account, we further postulated that the N170 and P300 modulations would be more profound (i.e., indicating better emotion recognition) among good heartbeat perceivers.

2. Materials and methods

2.1. Participants

Our sample consisted of 54 healthy adolescents (28 girls, 26 boys) between 12 and 17 years of age without a diagnosed psychological disorder or other medical condition (e.g., cardiovascular disease, bronchial asthma, diabetes etc.). The average age was 14.00 years (SD = 1.55), and the mean BMI was 19.7 (SD = 2.8). Recruitment occurred via the use of flyers and advertisements placed in local newspapers. All experiments were conducted in accordance with the Declaration of Helsinki and were approved by the ethics committee of Ulm University.
2.2. Experimental procedure

After written informed consent was obtained from the participants and their parents, participants completed a series of online questionnaires. The study took place in a laboratory in the Clinical and Health Psychology Department of Ulm University. Participants received a cinema voucher (worth €15) for their participation. First, electrocardiography (ECG) and EEG electrodes were attached. A baseline measure was introduced 5 min before the heartbeat perception task took place. Participants were seated in a comfortable chair in a dimly lit and sound-attenuated chamber, and a 19-inch computer screen was placed at a viewing distance of approximately 140 cm at the centre of their field of vision. Then, 120 pictures from the KDEF Database (Lundqvist, Flykt & Öhman, 1998) were presented in a randomized order, depicting 20 emotion faces from each of the following categories: neutral, happy, sad, angry, afraid, and surprised. For each trial, a fixation cross appeared for 500 ms followed by a variable stimulus at an interval of 250–500 ms before the facial emotion stimulus was presented for four seconds. At the end of each stimulus, six emotion categories were visible at the bottom of the screen and participants were asked to select the correct category of the depicted emotion. A varying time interval of 1.5–3 s was applied before the next trial. Following this task, another experimental task took place, which is not reported here. The whole experiment lasted 90 min, including electrode placement and preparation; the face recognition task itself took approximately 15 min.

2.3. Self-report instruments

The SDQ (Strength and Difficulties Questionnaire) is a brief behavioural screening instrument for children and adolescents. It consists of five subscales: Conduct Problems, Hyperactivity-Inattention, Emotional Problems, Peer Problems, and Prosocial Behavior (Goodman & Goodman, 2009). In the current study, we administered the German self-report version of the SDQ and used the total score, in which the first four subscales are summed, to exclude participants with possible psychopathology. The SPS-J (Screening psychischer Störungen im Jugendalter), the German version of the Reynolds Adolescent Adjustment Screening Inventory (RAASI) (Hampel & Petermann, 2006), was administered as a screening questionnaire for psychological disorders in adolescence. In the current study, we used the Emotional Distress subscale to evaluate the degree of depression or sadness and anxiety. The German version of the IRI (Interpersonal Reactivity Index) was used to measure empathy and includes the following subscales: Empathic Concern, Personal Distress, Fantasy and Perspective Taking (Davis, 1983; Paulus, 2009). Lastly, the Bar-On Emotional Quotient Inventory (EQ-i) (Bar-On, 2002) was administered to assess trait emotional intelligence. We included the following subscales from the EQ-i: Interpersonal, Intrapersonal, Adaptability, Stress.

2.4. Objective measures: interoception

The heartbeat perception task was used to assess IAC (Schandry, 1981). It is comprised of one training interval of 10 s and four heartbeat-counting phases (intervals lasting for 25, 35, 45, and 60 s), with two 20 s resting phases in between. Participants were instructed to concentrate on their own heart activity and to silently count their heartbeats during this task. The beginning and end of the counting intervals were signaled by the instructor. Participants were asked to verbally report the number of counted heartbeats. Participants were not allowed to take their pulse or to try other manipulations that could facilitate the detection of their heartbeats. IAC was determined via the heartbeat perception score, which represents the mean score across the four intervals, and which is calculated according to the following formula:

\[
\frac{1}{4\sigma} \lfloor 1 - \left( \frac{|\text{recorded heartbeats} - \text{counted heartbeats}|}{\text{recorded heartbeats}} \right) \rfloor
\]

Higher scores indicate higher IAC, with a maximum score of 1 indicating the absolute accuracy of heartbeat perception. We chose the upper bound of the quartile range of IAC (.85) for the differentiation between participants with high IAC (good heartbeat perceivers) and participants with low IAC (poor heartbeat perceivers), respectively. The selected cut-off score of .85 was selected based on previous studies (Herbert, Ulbrich, & Schandry, 2007; Montoya, Schandry, & Müller, 1993; Pollatos, Kirsch, & Schandry, 2005; Schandry, Sparrer, & Weitkunat, 1986). In the current sample, 14 participants were good heartbeat perceivers (mean age: 14.42 years, 3 girls) and 40 participants were poor heartbeat perceivers (mean age: 14 years, 18 girls).

2.5. Psychophysiological recordings

Throughout the experiment, EEG activity was recorded continuously from 62 leads using the Easy-Cap electrode system (Falk Minow Services, Germany) with non-polarized active Ag/AgCl electrodes at equidistant positions. Cz served as a reference and the ground electrode was attached at the electrode position F4. Horizontal and vertical electrooculograms (EOG) were recorded. Impedances were maintained below 5 kΩ. The signals were amplified using an active amplifier system (Brain Products, Germany) and digitized at a sampling rate of 1000 Hz. For the assessment of IAC, ECG was measured by non-polarized Ag/AgCl electrodes placed on the right clavicle and left chest. ECG activity was recorded equivalent to the EEG using an active amplifier system (Brain Products, Germany) and was digitized at a sampling rate of 1000 Hz.

2.6. Data analysis

All ECG and EEG analyses were conducted with Brain Vision Analyzer 2.1 (Brain Products, Germany). ECG R-waves were detected
offline semi-automatically in ECG raw data for the heartbeat perception task. EEG data were visually inspected, filtered (0.05–20 Hz), and examined for ocular, muscular, and other artifact sources. EOG correction for blinks was conducted using the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983). Trials were rejected from the analysis if the voltage exceeded ± 50 µV/ms in any channel. Trials contaminated by artifacts were eliminated. EEG data were segmented relative to the facial pictures (epochs ranging from −200 ms to 1200 ms). RR-interval times were calculated from the ECG during the baseline condition to determine the mean heart rate (HR).

The following components were chosen, in order to detect differences in the electrophysiological responses of the different facial stimuli: the P100 (peak amplitude and latency in the time range of 100–165 ms, analyzed over posterior areas), the N170 (peak amplitude and latency in the time range of 160–215 ms, analyzed over temporal/occipital areas), and the P300 (mean amplitude between 290 and 465 ms, analyzed over medial and posterior areas).

### 2.7. Statistical analyses

All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, version 24). A normality test was performed to determine if there was a normal distribution using the Shapiro-Wilk Test (N = 54) for all variables of interest. Significance across all analyses was determined by a p-value of less than .05 [(p < .001: statistically highly significant), (p < .05: statistically significant)]; values with p > .05 were considered as non-significant. Nominal data were compared using the multi-dimensional chi-square test. For multiple comparisons, we performed ANOVA post hoc analyses to avoid making a Type I error. For the ERP analyses, we created pools of multiple channels and the pooled values where submitted in a mixed-model ANOVA in order to determine the effect between “Laterality” (2 levels: left hemisphere, right hemisphere), “Scalp sector” [4 levels: medial-inferior (CP1, CP3, CP2, C4), medial-superior (TP7, TP9), postero-inferior (PO3, P2, PO4), and postero-superior (O1, O2)], “Emotions” (6 levels: neutral, happy, sad, angry, afraid, surprise) and “Groups” (2 levels: high vs. low IA, indicating good versus poor heartbeat perceivers, respectively) as the between-subjects factors. Accordingly, the design employed for the P100 (electrodes: O1, O2), the N170 (electrodes: PO4, PO3, O2, O1) and the P300 (electrodes: PO4, P2, CP2, C4, CP1, CP3, TP7, TP9) was the following: P100: 2 * 1 = 6, N170: 2 * 2 = 6 and P300: 2 * 4 = 6. Uncorrected F-values are reported together with the Greenhouse-Geisser epsilon values and corrected degrees of freedom. Post-hoc tests were computed using Tukey’s HSD tests.

### 3. Results

#### 3.1. Sample characteristics

Sample descriptive statistics for relevant variables are depicted in Table 1. We did not find any statistically significant differences between good and poor heartbeat perceivers concerning the self-reports. Furthermore, we conducted a multiple regression analysis to explore whether IAC can be predicted by all variables of interest. A non-significant model emerged: F(10,43) = 1.09, p > .05.

#### 3.2. Emotion face recognition performance

The average percentage of correct answers for happy faces was 93.02 (SD = 6.24), the average percentage of correct answers for sad faces was 66.89 (SD = 9.07), and for afraid faces was 67.29 (SD = 17.85). In the categories of sad and fearful faces, participants gave more incorrect answers.

Fig. 1 demonstrates correct answers for all emotions across good and poor heartbeat perceivers. A mixed ANOVA (Emotions × Group) was performed to explore the differences in emotion face recognition between good and poor heartbeat perceivers. There was a statistically significant difference between good and poor heartbeat perceivers regarding sad [F(1, 52) = 5.45, p = .02, η² = .09] and afraid emotions [F(1, 52) = 9.63, p < .001, η² = .09], such that good heartbeat perceivers indicated less correct answers in identifying sad and afraid faces [Sad: M = 62.21, SD = 8.27; Afraid: M = 55.47, SD = 20.74] than poor heartbeat

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sample characteristics and questionnaire data.</th>
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<tr>
<td></td>
<td>N = 54</td>
</tr>
<tr>
<td></td>
<td>M (SD)</td>
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<tr>
<td>Strength and difficulties Questionnaire_total score</td>
<td>11.28 (.542)</td>
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<td>Emotional distress</td>
<td>.68 (.40)</td>
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<td>Fantasy</td>
<td>10.76 (3.30)</td>
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<td>Empathic concern</td>
<td>13.94 (2.36)</td>
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<td>Perspective taking</td>
<td>13.52 (2.88)</td>
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<td>Personal distress</td>
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<td>Emotional Quotient intrapersonal</td>
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<td>Emotional Quotient adaptability</td>
<td>2.77 (.91)</td>
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<td>Emotional Quotient interpersonal</td>
<td>2.50 (.73)</td>
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<tr>
<td>Emotional Quotient stress</td>
<td>1.99 (.79)</td>
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perceivers [Sad: M = 68.53, SD = 8.85; Afraid: M = 71.42, SD = 14.89]. More specifically, 64.3% of good heartbeat perceivers identified a face as sad when the correct answer was afraid. Additionally, 60% of poor heartbeat perceivers identified afraid faces as surprised; this association between good and poor heartbeat perceivers was marginally significant $\chi^2(1, N = 54) = 3.01, p = .08, \phi = .24$. Moreover, 61.5% of good heartbeat perceivers and 62.9% of poor heartbeat perceivers misidentified sad faces as afraid; this interaction was not significant $\chi^2(1, N = 48) = 1.19, p > .05$.

3.3. Electrophysiological responses; Visual evoked potentials to emotion face recognition

To explore possible group differences, we examined amplitude and latency differences for the following time windows corresponding to the P100 (100–165 ms), the N170 (160–215 ms), and the P300 (300–500 ms) (see Figs. 2 and 3). More specifically, we conducted a mixed ANOVA with Laterality * ScalpSector * Emotions * Group (P100: 2 * 1 * 6, N170: 2 * 2 * 6 and P300:2 * 4 * 6).

3.4. P100 peak amplitude

There were no significant differences in the P100 peak amplitudes across Emotions between interoceptive groups. Post-hoc ANOVA analyses were also run to assess the P100 for each emotion separately; there was a statistically significant difference for afraid faces [$F(1, 45) = 5.58, p = .02, \eta^2 = .11$], such that good heartbeat perceivers (mean = 12.93 $\mu$V) indicated smaller P1 amplitudes than poor heartbeat perceivers (mean = 18.71 $\mu$V). No significant main effects regarding the P100 latency were found ($p > .05$).

3.5. N170 peak amplitude

A main effect of emotion was observed [$F(5, 41) = 3.17, p = .01, \eta^2 = .07, \epsilon = .78$], indicating greater N170 amplitudes for afraid faces (mean = −1.21 $\mu$V). Moreover, the main effect of the between-subjects factor was significant [$F(1, 41) = 5.41, p = .02, \eta^2 = .12$], revealing a significant difference between good and poor heartbeat perceivers, such that good heartbeat perceivers indicated greater N170 peak amplitudes (mean = −2.45 $\mu$V) when compared to poor heartbeat perceivers (mean = 1.84 $\mu$V). Post-hoc tests revealed that good heartbeat perceivers indicated greatest N170 amplitudes for afraid faces (mean = −3.23 $\mu$V). Significant main effects regarding the N170 latency were not found ($p > .05$).

3.6. P300 mean amplitude

Regarding the P300, an effect of emotion was observed [$F(5, 28) = 2.92, p = .01, \eta^2 = .09, \epsilon = .78$], where afraid was the emotion with the greatest mean amplitude (mean = 4.00 $\mu$V), followed by neutral (mean = 3.70 $\mu$V) and sad (mean = 3.56 $\mu$V). Moreover, the within-factor interaction of Laterality * Emotions * Group was revealed [$F(5, 28) = 2.31, p = .05, \eta^2 = .08$], in which good heartbeat perceivers indicated lower P300 amplitudes (mean = 3.05 $\mu$V) than poor heartbeat perceivers (mean = 3.94 $\mu$V). Post-hoc tests were run for each emotion separately to explore this relationship. The P300 was lower in good heartbeat perceivers, especially for neutral (good = 4.74 $\mu$V; poor = 5.86 $\mu$V), afraid (good = 4.85 $\mu$V; poor = 5.85 $\mu$V) and sad (good = 4.88 $\mu$V; poor = 5.35 $\mu$V) faces.

Fig. 1. Correct answers of good and poor heartbeat perceivers in various facial emotions; y-axis: depicting percentage of correct answers, x-axis: depicting emotion face categories.
4. Discussion

In the current study, we aimed to explore the interaction between IAC and face emotion recognition ability in adolescents. Contrary to our hypothesis, we observed inverse significant associations between IAC and facial emotion recognition accuracy for the emotions of sadness and fear, such that individuals lower in IAC were better at recognizing sad and afraid faces. The EEG data revealed a characteristic pattern concerning adolescents high in IAC for the processing of facial expressions depicting fear and sadness. Peak amplitudes of the P100 were found to be lower among good heartbeat perceivers for fearful faces. In contrast, the N170 was more pronounced in participants with high IAC regarding fearful faces, whereas the P300 was found to be lower among adolescents with high IAC in response to neutral, fearful and sad faces. Taken together, these results suggest that adolescents high in IAC revealed a characteristic processing pattern of fear and sadness that led to more errors in emotion face recognition.

Interestingly, the majority of the adolescents high in IAC identified a fearful face as sad and a sad face as fearful, indicating that they were able to recognize the negative and unpleasant stimulus content present in both fearful and sad faces, but at the same time they were not able to specifically recognize the type of negative emotion. In other words, it appears as though adolescents high in IAC paid more attention to fearful faces, as evidenced by greater N170, in an effort to encode the threatening stimulus. Previous ERP studies revealed that the N170 component can be modulated regarding the intensity of emotion depicted (Wild-Wall, Dimigen, & Sommer, 2008), as well as it might constitute an effect of arousal of a perceived emotion expression in emotion face recognition.
Taking these findings into account, it is possible that adolescents high in IAC perceived fearful faces and thus threat more intensely than adolescents low in IAC, something which is consistent with prior studies suggesting a relationship between greater emotion experience (Herbert, Pollatos, & Schandry, 2007; Wiens et al., 2000) and emotion sensitivity (Terasawa et al., 2014) in individuals high in IAC.

On the other hand, the speed of attention and the amount of attention resource allocation seemed to decline during the task, as reflected by lower P300, and as a result more errors in recognizing fear and sadness were made. Prior studies on emotion face recognition have shown that, the P300 can be influenced by the stimulus valence (Cavanagh & Geisler, 2006) and can be a sensitive marker for changes to affective orientation (Sanger & Dorjee, 2015) and arousal in response to pleasant and unpleasant stimuli (Hietanen, Kirjavainen, & Nummenmaa, 2014; Keil et al., 2002; Polich & Kok, 1995; Schupp et al., 2007). In the current study, the P300 analyses indicated that adolescents high in IAC demonstrated less attentional resources when recognizing fear and sadness, which could suggest that adolescents high in IAC paid more attention to the general stimulus unpleasantness, rather than to the accurate recognition of the specific unpleasant emotion, thus more errors were made in the emotion face recognition task.

Furthermore, Füstös et al. (2013) explored the relationship between IAC and the neural dynamics of cognitive reappraisal, an emotion regulation strategy in which the meaning of an emotion stimulus is being reframed to lower its affective impact (Goldin et al., 2013; Gross & Thompson, 2007). They found that IAC facilitated the downregulation of negative affect-related arousal, which

Fig. 3. Event-Related potentials for subjects with low versus high IAC. Shown are grand Averages for the emotion face category “Sad” regarding electrodes P2, P1, PO3, PO4. x-axis depicting time window (ms) and y-axis displaying values in μV. Grey line: good heartbeat perceivers; Black line: poor heartbeat perceivers.
was reflected by lower P300 amplitudes. Taking into account the regulatory aspect of IAC, a further possible explanation for the relationship between lower P300 amplitudes and more response errors in fearful and sad faces, could be that adolescents adopt a protective, regulatory approach to these faces to minimize the feelings of frustration, distress, and negativity that these faces may cause (Suzuki et al., 2015). Prior studies have demonstrated that interoception supports homeostatic control and allostatic adaptation, two crucial factors for the stability of an organism in a changing environment that could guide adaptive behaviours (Strigo & Craig, 2016; Tsakiris & Critchley, 2016).

Another possible explanation could derive from the “Circumplex Model of Affect” proposed by Russell (1980), in which valence (pleasure-displeasure continuum) and arousal (alertness) could be seen as two central neurophysiological systems in emotion processing, that interact together with cognition in order to shape emotional experience (Posner, Russell & Peterson, 2005). Accordingly, cognitive representations of the neurophysiological experiences of arousal and valence could contribute to differentiating an emotion from a nearby/similar emotion (Posner et al., 2005). Taking these into account, lower P300 amplitudes in the processing of fear and sadness among adolescents high in IAC could further indicate decreased levels of alertness or arousal, due to the regulatory aspect of IAC, but at the same time could demonstrate increased levels of emotional valence. In this way, fear and sadness are perceived as similarly unpleasant emotions, something that might have led to more errors in emotion face recognition, as individuals high in IAC were more focused during the task on the stimulus averseness, rather than on its arousal dimension.

The current study has several limitations: First, our sample size was relatively small and this did not allow further statistical analyses based on a regression approach that could utilize the sample as a whole, instead of dividing participants into high and low IAC groups. This could also explain why we did not find any significant variables predicting IAC. To this end, future replication of the study utilizing larger samples would be useful. Moreover, all of our data was based on responses to questionnaires made by healthy adolescents, which limits the generalizability of our findings, and as our data was based strictly on self-report of a variety of psychological constructs, the limits associated with self-report (see Stone et al., 2000, for a review) apply to the current study. Moreover, the difficulty of the emotion recognition task used should also be taken into account when interpreting the results, as the participants in general indicated difficulties in recognizing fearful and sad facial expressions. Keeping these limitations in mind, our findings suggest avenues for future research. For example, we encourage a more thorough assessment of the constructs that are thought to impact emotion face recognition and IAC in adolescents, such as loneliness, stress, and culture, to determine any mediating or moderating effects that may be present, as well as replicating this study among adolescents with psychopathology. Moreover, subjective data regarding valence and arousal after observing a facial expression of emotion, or the use of other kinds of emotion face recognition tasks could be of high importance.

4.1. Conclusion

Together these results provide important insights into the underlying mechanisms of emotion face recognition and its relation to IAC in adolescence. Neurophysiological parameters, as well as objectively determined data, revealed a characteristic pattern of emotional and cognitive processing style for fearful and sad facial expressions. Overall, high sensitivity to negative emotions was observed by greater N170 modulation in adolescents high in IAC, whereas low accuracy in the recognition of fear and sadness was connected to lower P300 amplitudes. Interpretations of these findings focus on the intensity experienced in negative affect, on the regulatory effects that IAC could have, as well as on the aspects of emotional valence and arousal. Further research is needed to better understand the mechanisms underlying emotion recognition that takes into consideration the dynamic integration of body and mind throughout the life span.

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References


**ERKLÄRUNG**

Ich versichere hiermit, dass ich die Arbeit selbständig angefertigt habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie die wörtlich oder inhaltlich übernommenen Stellen als solche kenntlich gemacht und die zur Zeit gültige Satzung der Universität Ulm zur Sicherung guter wissenschaftlicher Praxis beachtet habe (§ 8 Abs. 1 Nr. 5 Rahmenpromotionsordnung).

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