



Review Article

Interoception and psychopathology: A developmental neuroscience perspective

Jennifer Murphy^{a,*}, Rebecca Brewer^{a,b}, Caroline Catmur^a, Geoffrey Bird^{a,c,d}^a MRC Social, Genetic and Developmental Psychiatry Centre, Institute of Psychiatry, Psychology, and Neuroscience, King's College London, London, UK^b School of Psychology, The University of East London, London, UK^c Institute of Cognitive Neuroscience, UCL, London, UK^d Dept of Experimental Psychology, University of Oxford, Oxford, UK

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ABSTRACT

Interoception refers to the perception of the physiological condition of the body, including hunger, temperature, and heart rate. There is a growing appreciation that interoception is integral to higher-order cognition. Indeed, existing research indicates an association between low interoceptive sensitivity and alexithymia (a difficulty identifying one's own emotion), underscoring the link between bodily and emotional awareness. Despite this appreciation, the developmental trajectory of interoception across the lifespan remains under-researched, with clear gaps in our understanding. This qualitative review and opinion paper provides a brief overview of interoception, discussing its relevance for developmental psychopathology, and highlighting measurement issues, before surveying the available work on interoception across four stages of development: infancy, childhood, adolescence and late adulthood. Where gaps in the literature addressing the development of interoception exist, we draw upon the association between alexithymia and interoception, using alexithymia as a possible marker of atypical interoception. Evidence indicates that interoceptive ability varies across development, and that this variance correlates with established age-related changes in cognition and with risk periods for the development of psychopathology. We suggest a theory within which atypical interoception underlies the onset of psychopathology and risky behaviour in adolescence, and the decreased socio-emotional competence observed in late adulthood.

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1. Outline

Interoception is described as the perception of the internal state of one's body; as such, signals including those relating to hunger, temperature, heart rate, and blood sugar levels are all interoceptive in nature. These bodily signals are thought to be represented within the insula and anterior cingulate cortex (ACC), leading these

* Corresponding author at: Social, Genetic and Developmental Psychiatry Centre (MRC) Institute of Psychiatry, Psychology and Neuroscience – PO80 De Crespigny Park, Denmark Hill, London SE5 8AF, UK.

E-mail address: Jennifer.Murphy@kcl.ac.uk (J. Murphy).

structures to be collectively referred to as the ‘interoceptive cortex’ (Craig, 2002; but see Damasio et al., 2012; Feinstein et al., 2016, discussed in more detail in Section 2). Accurate perception of internal states is unsurprisingly important for their regulation, with atypical interoceptive sensitivity (Garfinkel et al., 2015a; see Table 1: Glossary) being associated with conditions such as obesity and diabetes (Herbert and Pollatos, 2014; Pauli et al., 1991). In addition to the importance of interoception for physical health, recent research has suggested that interoception may play a role in higher-order cognition, such as in emotional memory (Pollatos and Schandry, 2008), and learning and decision making (Werner et al., 2009). Despite increasing appreciation of the importance of interoception, little is known about how interoceptive ability develops, and its stability across the lifespan. As research directly examining interoception across development is scarce, the current article also draws upon research examining developmental changes in the prevalence of alexithymia. Alexithymia is a sub-clinical condition which has traditionally been defined in terms of difficulties identifying and describing one’s own emotions (Nemiah et al., 1976), but recent evidence suggests that alexithymia may be characterised by atypical interoceptive sensitivity, rather than with specific difficulties in the affective domain (Shah et al., 2016; Gaigg et al., in press; Herbert et al., 2011; Brewer et al., 2016a,b; Longarzo et al., 2015; Näring and Van der Staak, 1995). Accordingly, we interpret increases in the prevalence of alexithymia at certain developmental stages as likely markers of atypical interoception, but of course the association between alexithymia and atypical interoception should be examined across development. While evidence using objective measures of interoception is clearly preferable, research on alexithymia is more common than that on interoception in the developmental literature. Rather than attempting to provide a full review of the adult interoception literature, therefore, the current paper aims to combine developmental research on interoception and alexithymia, in order to present a theory of how interoception may change across development, from infancy to late adulthood, and the possible consequences of this change. Whilst we do not propose that alexithymia and impaired interoception are interchangeable terms, we do propose that where heightened rates of alexithymia are observed within a population then this should be considered a marker of atypical interoception.

Section 2 of this article briefly defines interoception, outlines methods to measure interoceptive ability, and argues for the importance of understanding the development of interoception with respect to both typical cognition and psychopathology. Section 3 reviews the available literature on the development of interoception across four stages of life: infancy, childhood, adolescence and

late adulthood. It is argued that cross-sectional evidence from both objective interoceptive tests and alexithymia measures indicates that interoceptive ability may decrease in adolescence and late adulthood, and that this change may underlie the emergence of psychiatric disorders and emotion recognition difficulties across these stages, respectively. Section 4 outlines conclusions from this survey of the literature and recommendations for future progress.

2. Interoception: characterisation, measurement, and relevance to health

It is widely agreed that interoception refers to the perception of the internal state of one’s body; such a simple definition, however, hides a great deal of uncertainty. Whilst early definitions included visceral (internal) sensations only (e.g., Craig, 2002; Fowler, 2003), the term interoception has been broadened such that the definition is frequently taken to include certain bodily signals that do not readily meet the criteria to be considered internal (e.g., sensual or affective touch and tickle) but which are all processed using the same neural pathways as interoceptive information. Thus, more recent definitions of interoception include any bodily information that is sent either via 1) small diameter (unmyelinated) C-fibres or (myelinated) A δ -fibres, lamina I, the spinothalamic tract and then onto the insula and anterior cingulate cortex (Craig, 2002), or 2) cranial nerves (vagus and glossopharyngeal) to the nucleus of the solitary tract (Critchley and Harrison, 2013). Whilst the insula and anterior cingulate cortex are thought to be the regions where interoceptive signals converge (e.g., Craig, 2002) and are therefore crucial for interoceptive awareness, a case study of one patient with bilateral insula damage questions this proposal. Despite their insula damage, the patient’s perception of pain, response to tickling, and to some extent taste, remained relatively intact (Damasio et al., 2012). Typical pain perception following damage to both the insular and anterior cingulate cortex was also reported in a separate case study of another patient (Feinstein et al., 2016). While clearly not consistent with the proposal that intact insular and anterior cingulate cortices are necessary for interoception, interpretation of these findings is made difficult by the fact that the patients presumably experienced typical interoceptive abilities for at least 28 years prior to insula or ACC damage. Therefore, while the precise definition of interoception and the neural regions supporting interoception remain a matter of debate, for the purposes of the current article interoception is defined as the perception of any bodily state mediated by the neural pathways described above (Craig, 2002; Critchley and Harrison, 2013).

Table 1
(Glossary) Definitions of the terminology used in this paper are provided below.

Term	Definition
Implicit Interoceptive Perception	A broad term referring to situations in which subconscious processing of interoceptive signals impacts on bodily states, neural activity, and ongoing cognition. This includes homeostatic regulation but also encompasses various effects such as those on perception and memory for stimuli presented at different stages of the cardiac cycle, and at differing levels of physiological arousal (see text).
Explicit Interoceptive Perception	Conscious representation of interoceptive signals. Note that this broad definition would include, at the lowest level, detection of the onset or change of an interoceptive signal, and discrimination of interoceptive signals and knowledge of their intensity at higher levels. Explicit interoceptive perception has been suggested to be a three dimensional construct by Garfinkel and colleagues (see text), including interoceptive sensitivity, sensibility and awareness.
Interoceptive Sensitivity	Accurate detection and discrimination of interoceptive signals on explicit interoception tasks such as the Heartbeat Tracking Task.
Interoceptive Sensibility	An individual’s self-reported interoceptive ability.
Interoceptive Awareness	A metacognitive measure indexing the degree to which an individual’s interoceptive sensibility accurately reflects their interoceptive sensitivity.
Interoceptive Ability	A ‘catch-all’ term encompassing all aspects of explicit and implicit interoception.
Atypical Interoception	Unusually high or low sensitivity, sensibility or awareness. Used to indicate an interoceptive profile that is not typically observed in the general population.

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