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On the relationship between interoceptive awareness and the attentional processing of visual stimuli

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ABSTRACT

Mental processes related to visceral activity have gained growing interest during the last few years. The following study is the first to investigate possible interactions between interoceptive awareness and measures of attentional performance. We tested the hypothesis whether interoceptive awareness is positively related to indices of selective and divided attentional performances. Using a heartbeat perception task, 29 healthy female participants were separated into two groups scoring either high or low in an interoceptive awareness task. Attentional performance was assessed by several tests including the 'd2 test of attention' and subtests from the 'TAP: Test Battery for Attentional Performance'. We observed a significantly better performance in selective and divided attention for participants with high interoceptive awareness. Our data suggests that interoceptive awareness is related to a better performance especially in tasks assessing selective and divided attention. We conclude 1) that perception of bodily states might be a crucial determinant for the processing of external, visual stimuli, 2) that the ability to perceive internal signals might be an indicator of self-focused attention, and 3) that bodily signals may use, at least in part, similar processing resources as signals from the attention system.

1. Introduction

Damasio's somatic marker hypothesis (1994, 1998, 2000) is an example of a modern psychological theory incorporating the feedback from the periphery (somatosensory and visceral) to the cortex. Its key idea is that many mental processes are influenced by 'marker' signals arising through bioregulatory processes. Such marker signals are characterized by a state of autonomic arousal or a 'gut feeling' which often precedes and influences decision making (Damasio, 1998, 2000). Following Damasio, perceiving internal signals that occur in e.g. emotional situations should facilitate decision making or performance.

The ability to perceive bodily changes ('interoceptive awareness') is often measured by using the ability to perceive one's heartbeats accurately in a heartbeat detection task (Cameron, 2001; Critchley et al., 2004; Jones, 1994; Pollatos et al., 2005; Schandry and Bestler, 1995). One common observation is the existence of substantial, interindividual differences in heartbeat perception (Jones, 1994; Cameron, 2001). Recent research has highlighted the neural correlates of interoceptive awareness. FMRI and EEG studies revealed that different brain regions including the insula, the anterior cingulate, the somatomotor and the prefrontal cortices were activated when participants were focusing their attention towards sensory signals originating internally (e.g., heartbeats; Critchley et al., 2004; Pollatos et al., 2005). The accuracy of heartbeat perception did furthermore correlate with the BOLD response at the right insula (Critchley et al., 2004; Pollatos et al., 2007a,b) and with the dipole strength at the right insula and the anterior cingulate (Pollatos et al., 2005).

While the neural systems supporting interoceptive awareness have been of interest in recent research, the role that cognitive factors like attention could play in modulating these processes and vice versa is still unclear. First empirical evidence for such a relationship derived from a recent study (Pollatos et al., 2007b) where a positive relationship between interoceptive awareness and a central component of attentive processing of visual stimuli was found when using visual stimuli in an EEG oddball paradigm. Additionally, in an fMRI study Tracy et al. (2007) found that the parietal cortex, known to mediate selective attention to external stimuli in the environment, is also relevant for actively directing attention internally to onus' visceral state and focusing on a specific body signal. In line with these findings Gregory et al. (2003) assumed that cognitive influences, such as heightened attention ('hypervigilance') to the perception of visceral sensations are potential contributors to interoceptive awareness.

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Using fMRI and visual stimulation, Gregory et al. (2003) investigated how selective and divided attention interact with the cortical processing of visceral sensations. They pointed out that attention influences the cerebral processing of visceral sensations which is reflected in the activation of visceral sensory and cognitive networks comprising primary and secondary sensory cortices, prefrontal cortices and anterior cingulate. These structures play an important role not only for interoception but also for attentional processing of external stimuli of any kind as described below.

Attention can be subdivided into two broad domains, one representing the *intensity* aspects of attention, including alertness and vigilance, and the other representing the *selectivity* aspects, including selective and divided attention. The intensity aspects are probably a prerequisite for the more complex and capacity demanding dimensions of attention selectivity (Posner and Boies, 1971; Posner and Petersen, 1990; van Zomeren and Brouwer, 1994; Sturm et al., 1997, 2004).

According to the classical view of the intensity aspect of attention a distinction between phasic and intrinsic aspects of alertness has to be made (e.g., Posner and Boies, 1971; Posner and Petersen, 1990; van Zomeren and Brouwer, 1994). Intrinsic (non-phasic) alertness refers to the internal control of the level of arousal (in the absence of an external cue) enabling an organism to respond to sensory stimuli — in a sense of a general level of response readiness. A typical task for the assessment of intrinsic alertness is a simple reaction time (RT) task. Some authors have defined even this short period of endogenously maintaining vigilant responding as sustained attention (Robertson et al., 1998). Moreover, it is generally assumed that the level of alertness may be phasically influenced by 'alerting stimuli' that induce a preparatory state of the cognitive system by means of a change in neural state (e.g., Posner and Petersen, 1990). Thus, phasic alertness may be subscribed as the ability to increase response readiness. For example, several studies have shown that stimulus detection and discrimination can be enhanced by 'alerting' or 'warning signals' which inform subjects that a target stimulus is imminent (Posner, 1978). Although alerting signals usually provide no or little information as to where or when a target will occur, the 'alerting effect' confers a behavioral advantage – for example, in terms of RT performance – over conditions without warning signals (Coull, Nobre, and Frith, 2001; Posner, 1978; Posner and Petersen, 1990). Thus, the level of alertness may be hypothesized to enhance visual processing speed which, in turn, is reflected in expedited RT performance and an enhanced ability for detecting and discriminating stimuli. The brain structures that are involved in the *intensity* aspects of attention were examined throughout several imaging studies. Some data exists showing that the noradrenergic locus coeruleus system plays an important role in the regulation of alertness (Aston-Jones, 2005; Aston-Jones et al., 1994; Coull et al., 1997; Posner and Petersen, 1990; Rajkowski et al., 1994; Sturm et al., 2004, 1999). Kinomura et al. (1996) found an involvement of thalamic and brainstem structures in the control of alertness both for visual and somatosensory stimulations. Regions underlying alertness were also investigated in a PET study (Sturm et al., 1999) showing activation in an extended right hemisphere network comprising frontal (anterior cingulate, dorsolateral cortex), thalamic and brainstem structures. Sturm et al. (1999) argued that right-hemisphere frontal brain structures exert top-down control via thalamic nuclei by activating, noradrenergic structures in the ponto-mesencephalic part of the brainstem. Pardo et al. (1991) used PET measurements to identify changes in regional brain activity during simple visual and somatosensory tasks of sustained attention and vigilance. They localized increases in blood flow in the prefrontal and superior parietal cortex, primarily in the right hemisphere.

The *selectivity* aspect of attention involves selective/focused attention as well as divided attention. Focused attention describes the ability to selectively enhance the processing of particular stimuli in relation to less important aspects in a complex environment. The skill to distribute the limited mental resources to different sources of information is denoted as divided attention. In a PET activation study, Corbetta et al. (1991) showed that during selective and divided attention tasks activation was commonly observed in prefrontal cortex, insular cortex, anterior cingulate and thalamus, thus cerebral structures that are also activated during the perception of internal stimuli ('interoceptive awareness'). In accordance with these findings, Nebel et al. (2005) were able to demonstrate in their fMRI study that focused and divided attention rely on largely overlapping neuronal substrates. Conditions of focused and divided attention activated a widespread, mainly right-sided network including dorso- and ventrolateral prefrontal structures, superior and inferior parietal cortex, and anterior cingulate gyrus. Pardo et al. (1991) pointed out that the anterior cingulate is important to recruit high level processing selection systems necessary for the analysis of complex targets and for target selection — confirming the suggested role of the anterior cingulate in complex stimuli processing, Phan et al. (2002) showed that during the processing of emotional stimuli, the anterior cingulate was commonly activated when the task required a higher level of cognitive demand. As can be seen 'attention' to external stimuli in the environment has been well studied both in terms of its cognitive components and its functional microanatomy. In contrast attending to internal states is poorly defined. For example, it is still unclear whether the ability to focus one's attention on internal sensations such as visceral or somatic signals (e.g. heartbeats) is also related to the ability to focus on external objects.

Due to the observed interaction between interoceptive awareness and attention on the level of overlapping neural networks underlying both processes a direct relationship between attentional performance and visceral sensation might be assumed. Following the ideas of Damasio, we hypothesized that interoceptive awareness is directly related to the central processing of external signals. We thus assumed that participants with high interoceptive awareness should have a processing advantage and should therefore show enhanced performance in attentional performance tasks. Moreover, we tested the hypothesis that interoceptive awareness is positively related to indices of attentional performance, especially to measures of selective and divided attention. Therefore, several subtests were accomplished to acquire different components of visual attention while interoceptive awareness was assessed by a heartbeat perception task. To our knowledge, the following study is the first to investigate possible interactions between interoceptive awareness and measures of attentional performance on a behavioural level.

2. Materials and methods

2.1. Participants

29 right-handed, female volunteers participated in the study. All participants had normal or corrected to normal vision and none of them suffered from colour blindness or any psychiatric or neurological impairment. All participants were naïve as to the purpose of the experiment and received either course credits or monetary payment (€ 30) for their participation. Written in-formed consent according to the Declaration of Helsinki II was obtained from all participants.

2.2. Testing of attention

Several subtests of the 'TAP: Test Battery for Attentional Performance' (TAP, version 1.7; Zimmermann and Fimm, 2002) and the 'd2 test of attention' (Brickenkamp, 1994) were accomplished to acquire different components of visual attention (see van Zomeren and Brouwer, 1994). Before the single tests were introduced, there were practice tasks in order to get the participants accustomed to the experimental procedure. The entire experiment took about 1.5 h.

2.2.1. Intensity aspect of attention: alertness and vigilance

2.2.1.1. TAP subtest 'alertness'. The tasks consisted of easily distinguishable stimuli that the participants had to react to as fast as