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Afferent cardiac signals modulate attentional engagement to low spatial frequency fearful faces

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ABSTRACT

Despite the growing consensus that the continuous dynamic cortical representations of internal bodily states shape the subjective experience of emotions, physiological arousal is typically considered only a consequence and rarely a determinant of the emotional experience. Recent experimental approaches study how afferent autonomic signals from the heart modulate the processing of sensory information by focussing on the phasic properties of arterial baroreceptor firing that is active during cardiac systole and quiescent during cardiac diastole. For example, baroreceptor activation has been shown to enhance the processing of threat-signalling stimuli. Here, we investigate the role of cardiac afferent signals in the rapid engagement and disengagement of attention to fear stimuli. In an adapted version of the emotional attentional cueing paradigm, we timed the presentation of cues, either fearful or neutral faces, to coincide with the different phases of the cardiac cycle. Moreover, we presented cues with different spatial frequency ranges to investigate how these interoceptive signals influence the processing of visual information. Results revealed a selective enhancement of attentional engagement to low spatial frequency fearful faces presented during cardiac systole relative to diastole. No cardiac cycle effects were observed to high spatial frequency nor broad spatial frequency cues. These findings expand our mechanistic understanding of how body–brain interactions may impact the visual processing of fearful stimuli and contribute to the increased attentional capture of threat signals.

1. Introduction

Despite the well documented autonomic components of emotion processing, physiological arousal is typically regarded only as a consequence (i.e., efferent responses) of subjective emotional states and rarely as a determinant of the emotional experience. Indeed, the contribution of central representations of bodily arousal to emotion and cognition

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has been largely overlooked in experimental research (Ainley, Apps, Fotopoulou, & Tsakiris, 2016; Allen et al., 2016; Babo-Rebelo, Richter, & Tallon-Baudry, 2016; Critchley & Harrison, 2013). An emerging line of research has set to address this issue by looking at how afferent signals originating in the phasic discharge of arterial baroreceptors set the physiological context through which body-to-brain effects influence the processing of sensory information (Critchley & Harrison, 2013). Arterial baroreceptors are pressure and stretch sensors located in the aortic arch and carotid sinus that detect changes in blood pressure and communicate to the brain the current state of cardiovascular arousal at each heartbeat. Recent experimental approaches capitalize on the phasic properties of baroreceptor firing, i.e., active during cardiac systole and quiescent during cardiac diastole, to study how afferent signals shape the processing of sensory (Edwards, McIntyre, Carroll, Ring & Martin, 2001; Edwards, Ring, McIntyre, Winer & Martin, 2009; Martins, Ring, McIntyre, Edwards, & Martin, 2009; Schulz et al., 2009), cognitive (Fiacconi, Peter, Owais, & Köhler, 2016) and emotional (Azevedo, Garfinkel, Critchley, & Tsakiris, 2017; Garfinkel et al., 2014; Gray et al., 2012) stimuli. Specifically, it has been shown that when certain categories of stimuli are presented during cardiac systole or diastole, stimulus processing is enhanced or attenuated. These cardiac cycle effects seem to be particularly evident in the enhancement of threat signals (Garfinkel and Critchley, 2016). Using an attentional blink paradigm, Garfinkel et al. (2014) found that systole facilitates the breakthrough of fearful stimuli into perceptual awareness. In a separate study, the authors also showed that fearful faces are rated as more intense when presented at systole as compared to diastole. This effect was associated with changes in activity in the amygdala (Garfinkel et al., 2014; see also; Gray, Rylander, Harrison, Wallin, & Critchley, 2009), a key region implicated in fear processing and autonomic regulation (Phelps & LeDoux, 2005). More recently, Azevedo et al. (2017) extended these findings to the social domain by showing enhanced activation of racial threat signals, and subsequent racially biased behaviour, at systole relative to diastole. Together, these studies suggest afferent baroreceptor information as an important mechanism of body-to-brain influences in the processing of fear stimuli.

The present study aims to look further into the mechanisms underlying the cardiac cycle enhancement of fear processing by investigating its impact on attentional capture processes. The orienting component of attention, or the aligning of attention with a source of sensory input (Posner, Rothbart, Thomas-Thrapp, & Gerardi, 1998, pp. 269–289) is believed to encompass at least three distinct processes, i.e., shift, engagement and disengagement. These can be recruited by two either endogenous or exogenous cues, subserved by interacting, yet distinguishable, neural networks (Posner & Rothbart, 2007). Specifically, attention needs to be: 1) *shifted* from the current object of focus to the new cue; 2) *engaged* with this incoming information; and finally 3) *disengaged* from it. “Exogenous” attentional processes are stimulus-driven, depend on reflexive and bottom-up mechanisms and are sustained by a posterior attention network, encompassing the superior parietal cortex, pulvinar and superior colliculus. Conversely, “endogenous” attentional processes rely on reflective and top-down mechanisms, underpinned by an anterior attention network including the anterior cingulate and prefrontal cortex. These processes can be experimentally assessed using a spatial cueing paradigm (Posner, 1980). In this task, participants are requested to fixate a central point in a computer screen and to detect as fast as possible the location of a target appearing on left or on the right hand side of the screen. Crucially, previous to target presentation, participants' attention is directed to the left or right of the central fixation point via the brief presentation of a task-irrelevant cue. The cue and the target can be presented either on the same (valid trials) or on the opposite (invalid trials) location of the screen. A faster detection of the target is typically observed for valid trials and slower detection on invalid trials. Moreover, the time between the onset of the cue and that of the target, i.e., the stimulus onset asynchrony (SOA), can be shorter (i.e., >150 msec) or longer (i.e., >300 msec) to engage the exogenous or endogenous attentional processes, respectively (Posner & Cohen, 1984). Finally, one version of this task includes both emotional, particularly threat-related, and non-emotional stimuli as cues (Armory & Dolan, 2002; Stormark, Hugdahl, & Posner, 1999). An increased cueing effect when the cue is emotional reflects a bottom-up influence exerted by the affective content of the cue on visual attention. Faster response times (RTs) on valid trials indicate facilitated attentional engagement to the emotional content. Conversely, slower target detection following the presentation of invalid fear cues reflects delayed attentional disengagement from the emotional content.

In the current study, we adapted an emotional spatial cueing task to investigate the role of cardiac afferent signals in the rapid engagement and disengagement of attention to fear stimuli. Specifically, we timed the presentation of cues, either fearful or neutral faces, to coincide with the different phases of the cardiac cycle. Moreover, to investigate how these interoceptive signals interact with visual processing we presented cues at different spatial frequency ranges. We capitalized on the fact that analysis of visual input takes place in distinct neural pathways selectively sensitive to different ranges of spatial frequency information (Garrido et al., 2012; Mendez-Bertolo et al., 2016; Vuilleumier, Armony, Driver, & Dolan, 2003). Broad spatial frequencies (BSF) pictures encompass all the spatial frequency ranges and can be filtered to include only either low spatial frequencies (LSF) or high spatial frequencies (HSF). LSF carry coarse visual information, such as motion and rough configurational cues, and HSF carry fine-grain information, such as colour, texture and contrast. Importantly, research suggests that LSF fearful faces are rapidly processed and conveyed by the magnocellular pathway, through the superior colliculus and the pulvinar to the amygdala (Bar, Neta, & Linz, 2006; Mendez-Bertolo et al., 2016; Vuilleumier et al., 2003; but for a discussion see also: Pessoa & Adolphs, 2010). Conversely, through the parvocellular pathway, engaging ventral visual cortical areas such as the fusiform and inferior temporal-occipital cortex (Vuilleumier et al., 2003). Thus, testing for distinct cardiac cycle effects in emotional attentional capture as a function of stimuli spatial frequency can expand our understanding of how body–brain interactions impact the neural processing of visual fear signals.